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Market-Ready High-Performance Walls: Phase 1 Report

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Executive Summary

The construction of high-performance or “advanced” walls represents a significant energy efficiency opportunity for the regional new home construction sector. While several of the Northwest’s leading high-performance custom and small-volume speculative builders are currently using these types of wall systems, they currently have limited exposure and acceptance by the broader regional new construction market.

The three highly energy efficient wall systems reviewed in this report have been selected by several leading high-performance builders based on their assessments that the walls provided greater energy performance and were an important part of the overall quality of construction. The three wall types are:

1) Thermal Break Shear Wall (TBS);
2) 2x6 intermediate frame with exterior rigid insulation; and
3) 2x4 double stud with blown-in fibrous insulation.

Each of these wall systems have heat loss 25-40% lower than conventional 2x6 R21 walls and a well-established presence in the super-efficient home market. If constructed at scale (production building) the incremental cost of these walls over conventional 2x6 R21 was estimated to be $0.48/square foot for the TBS wall, $1.03/square foot for exterior rigid insulation wall, and $0.79/square foot for the double stud wall.

Builders who chose to use one of the three wall systems did so largely because they perceived it to be “the better way to build.” These builders are generally looking for ways to improve the performance of their homes, especially their energy performance.

The objectives of this report—the first of three intended phases of a project on advanced wall systems—is to provide the Northwest Energy Efficiency Alliance (NEEA) with insights into the best and lowest-cost wall assembly solutions for advanced residential wall construction, with increased energy performance a key consideration. In addition, this report is intended to identify the benefits and challenges associated with each of the three wall systems, as well as recommendations for additional steps to address the challenges.

Risk aversion—in addition to cost—constitutes another key consideration for production-scale builders of higher-performing homes. Encouraging these builders to shift to one of these more advanced wall assemblies will necessitate documented evidence of the walls’ added non-energy benefits, as well as descriptions of ways to mitigate perceived deficiencies in the wall assemblies.

Most builders learned of the wall assembly approach from industry sources. A credible messenger—as much as the information being delivered—was clearly an important factor in motivating several of the builders to switch to one of the three high-performance wall systems. Training courses delivered by reputable and successful builders have proven to be a strong driver in getting these builders to accept the risk of a new construction approach.

The Earth Advantage Team has identified several topics related to one or more of these wall systems for additional research and documentation, particularly with regard to code acceptance, embodied carbon, moisture management, and noise attenuation.

Introduction

The construction of high-performance or “advanced” walls represents a significant energy efficiency opportunity for the regional new home construction sector. This report documents the detailed process, components, and estimated costs[1] of three highly energy efficient wall system archetypes:

1) Thermal Break Shear Wall (TBS);
2) 2x6 intermediate frame with exterior rigid insulation; and
3) 2x4 double stud with blown-in fibrous insulation.

These three wall systems are currently used by a number of the Northwest’s leading high-performance custom and small-volume speculative builders. However, the wall systems currently have limited exposure and acceptance by the broader regional new construction market. The project team estimates that these wall assemblies are currently used in approximately 2%–3% of all new homes that are being built to performance standards greater than required by local energy code.[2]

This report uses illustrations from various sources. It is not intended to provide detailed construction details, but simply to sufficiently describe each wall system. The purpose is to provide the Northwest Energy Efficiency Alliance (NEEA) with adequate evaluation of the best and lowest-cost solutions for advanced residential wall constructions.

This report represents the first of three phases. Phase 2 provides additional clarity of market barriers and strategies to increase market adoption of these wall systems. Phase 3 will be the implementation these strategies through NEEA’s Residential New Construction program.

[1] When providing cost estimates, builders do not commonly separate out exterior wall material costs and incremental labor costs when budgeting. Additionally, labor prices are volatile and vary considerably by location.
[2] A review of Energy Trust of Oregon EPS (an energy performance scoring tool) program data shows that 8,991 EPS homes have been constructed since 2015. These homes were built at least 10% more energy efficiently than Oregon state energy code required. Of those, 185 had upgraded wall packages. The number of these homes using upgraded wall assemblies has increased each year since 2015. Of those 185 homes with upgraded wall assemblies, 103 used either TBS or exterior rigid foam, while 82 used a double stud (or staggered stud) wall. EPS homes represent approximately 35% of Oregon’s new construction market, meaning that upgraded walls were likely used in <1% of all new homes built since 2015.

Three Market-Ready High-Performance Wall Systems

Each of the descriptions of the three wall systems includes the following information:

- A narrative and visual description of the system
- Thermal performance of the wall system
- Non-energy benefits of the system
- Trades information (changes to standard practice, impacts, etc.)
- Challenges
- Construction costs (both current and at scale/market maturity)

Wall Assembly #1: Thermal Break Shear Wall (TBS)

Description

The TBS wall is an assembly in which a continuous layer of rigid foam insulation is sandwiched between the structural sheathing and standard framing to create a "thermal break shear" wall for significantly increased energy efficiency and a nailing pattern that creates laboratory-verified seismic resiliency benefits.

Photo from Green One Construction

Figure 1. Thermal Break Shear Wall

The TBS wall can be either field assembled with standard construction materials, such as plywood or oriented strand board (OSB) and rigid foam insulation panels, or use factory assembled insulated sheathing panel systems. The exterior flashing details are the same as for standard stud-framed construction practice. An optional best practice is to install a ventilated rainscreen behind the cladding to provide added protection from bulk water intrusion and to increase the drying potential to the exterior.

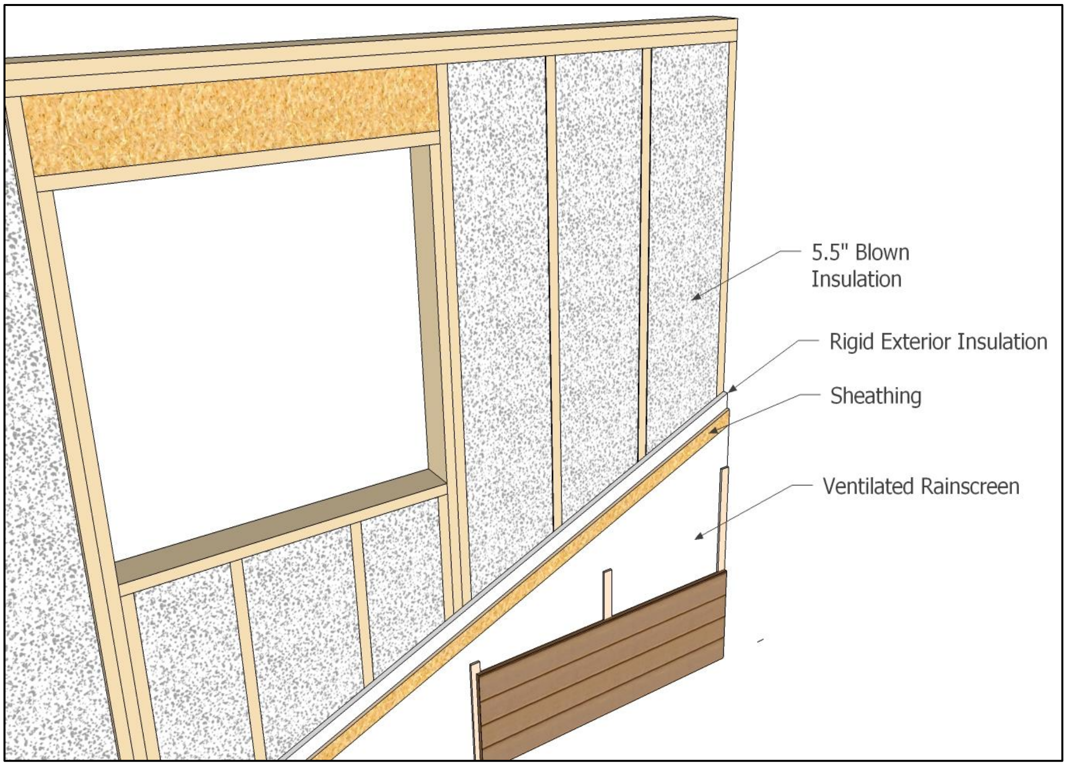

Figure 2. Thermal Break Shear Wall Assembly

Additional Materials Required

Compared to standard wall construction the additional materials required for a TBS wall include a layer of rigid insulation typically 1” thick. Alternatively, sheathing products exist that are manufactured with a layer of foam insulation glued to the interior side of the wooden structural sheathing. An increased quantity of nails is required with a nailing schedule of 3” at the edge (vs. standard 6”) for the field assembled TBS wall.

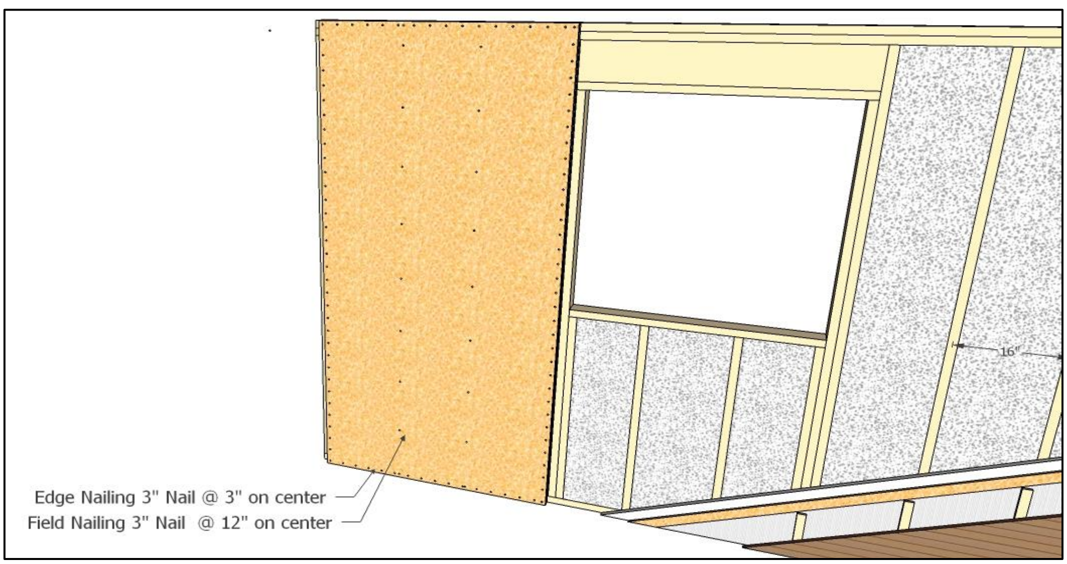

Figure 3. TBS Wall Nailing Pattern

Thermal Performance

Typical U values are U=0.035–0.038 Btuh/ft2-F depending on the type of rigid exterior and cavity insulation installed.

- U=0.038 R21 batts + R5 exterior extruded polystyrene (XPS)[3]
- U=0.037 R23 blown + R5 exterior expanded polystyrene (EPS)
- U=0.036 R23 blown + R5 exterior XPS
- U=0.035 R23 blown + R6 exterior polyisocyanurate (ISO)

Non-Energy-Related Additional Benefits

Greater Shear Strength

The TBS wall assembly has demonstrated significant seismic resiliency benefits. Earthquake testing conducted at Oregon State University's Knudson Wood Engineering Laboratory has documented that TBS assemblies used in new construction meet shear strength requirements and deliver a much higher lateral load capacity than conventional new construction wall assemblies.

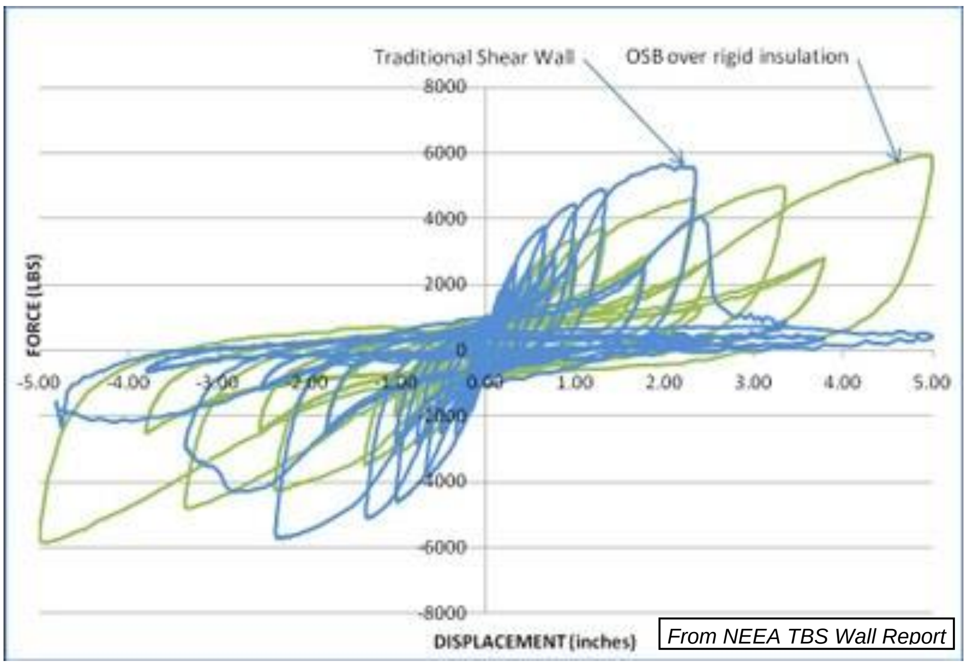

Figure 4. Wall Displacement—Standard Wall vs. TBS

Durability

Continuous exterior insulation protects the wooden structural elements by helping to maintain the internal wall temperature above the dew point to avoid condensation and wetting of the framing.

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3 The embodied carbon inherent in most XPS products currently available in the United States market makes this an unattractive choice. Analysis shows that the carbon emissions reduction benefits from the improved energy efficiency of XPS do not outweigh the embodied carbon of this product.

Ease of Construction
The weather-resistive barrier, exterior flashing, window/door installation, and siding installation can follow standard construction practices. This is because the wall can be framed laying flat, with the layer applied atop the frame and secured with just a few corner nails. Then the shear panel (OSB or plywood) is added and secured with additional perimeter nails. Windows and other openings can be cut out with a router or skill saw just as in typical framing. Once these steps are completed the wall is tilted in place as shown in Figure 5.

Sound Attenuation
Continuous exterior insulation provides not only a thermal break but also potentially reduces noise transfer from the outside environment.

Trades Information

Framers
Framers are the only trade workers significantly impacted by the construction of a thermal break shear wall. After typical wall framing on the ground, the foam board is tacked at the corners to keep it in place. Next, the sheathing is placed on top of the foam and attached to the studs following a nailing schedule of 3” at the edge (vs. standard 6”) and every 12” in the field. TBS wall framing challenges increase with more intricate geometries and varying ceiling heights. Use of pre-assembled foam and sheathing panels reduces complexity, but can increase challenges of cut-offs and waste at the job site. Additionally, roofing trusses frequently require doubling up at the gables (or rakes) to get bearing on the top plate and to keep the cladding plumb without installing rigid insulation on the exterior wall of an unconditioned attic space.

Photo from Green One Construction

Figure 5. Framers Assembling TBS Wall

Insulation
No major changes to conventional practices are necessary.

Electricians
No major changes to conventional practices are necessary.

Plumbing
No major changes to conventional practices are necessary.

Exterior Finishing and Siding
As discussed above, exterior siding and finishing of these wall systems is very similar to that of conventional framed wall systems. To ensure siding nails penetrate at least 1¼” into the studs, longer nails may be needed. Longer fasteners for windows are needed.

Drywall
Due to the added foam insulation, window returns (often drywall) and window sills (often wood) are larger. Other than this size factor, however, window finishing is no different than that for a 2x6 framed wall.

Challenges

Code Acceptance
Challenges to greater market adoption of the TBS wall assembly include the lack of specifications in the structural building codes and a potential lack of awareness with building code officials about the research supporting the increased seismic resiliency of the TBS assembly. Builders who confront these issues can refer to the 2013 International Code Council Evaluation Services (ICC-ES) Evaluation Services Report 2586. Beginning in 2015, building regulators at the City of Portland have acknowledged that ICC-ESR 2586 establishes that a TBS wall assembly with up to 1” of foam meets requirements for lateral bracing under International Residential Code (IRC) Table 602.10.2, Method WSP (ICC 2018), and confers prescriptive approval on such an assembly with no engineering required.

Moisture Management
Due to the continuous layer of low-permeable foam (such as ISO foam), a perceived disadvantage of the TBS wall is the potential to trap moisture in the wall cavity. This issue can be alleviated by using a vapor semi-permeable rigid insulation such as XPS, unfaced EPS and GPS, or a vapor semi-impermeable fiberglass faced polyiso product. By foregoing a polyvinyl acetate (PVA) primer to seal the drywall, instead using a primer with a higher perm rating, the wall cavity has increased potential to dry out toward the interior. The applicable Washington state building code (WSEC 2009) exemption for required perm rating of the warm side of the wall is as follows:

> 502.1.6.6 All walls separating heated from unheated spaces must have a vapor retarder. Vapor retarders need to be installed on the inside of the wall, or the warm side in the winter. Wood framed walls with insulated sheathing installed outside of the framing and structural sheathing do not need a vapor barrier. R-5 insulated sheathing must be used in climate zone 1 and R-7.5 must be used in climate zone 2. The interior cavity insulation for this exception must be a maximum of R-21.

Construction Costs

Current estimated incremental cost vs. standard 2x6 wall
- Incremental material costs: $1.12/sq foot
- Incremental labor costs: $0.25–$0.30/sq foot
- Total incremental material and labor costs: $1.37–$1.42/sq foot

Estimated incremental cost at Scale
- Total incremental material and labor costs: $0.48 /sq foot (12%)

Wall Assembly #2: 2x6 Intermediate Frame with Exterior Rigid Insulation

Description

The 2x6 intermediate frame with exterior rigid insulation wall is an assembly in which a standard code compliant wall has continuous exterior rigid insulation to help reduce thermal bridging through wood structural members. Continuous rigid insulation is a construction solution that provides a thermally efficient building enclosure. Rigid insulation boards are available in several thicknesses and R-values; 1-inch and 2-inch thicknesses are common. In addition to providing thermal protection, rigid insulation can also serve as an additional air and moisture barrier.

For foam-based products with thicknesses over 1”, the perm ratings decrease. Drying potential to the inside must be addressed in the design and construction of walls with thicker exterior foam insulation due to the decreased drying potential to the outside.

When utilizing foil faced foam insulation (typically polyisocyanurate foam, specifying perforated foil faced foam is highly recommended because the unperforated foil faced foam is vapor-impermeable (perm rating of 0.03), which eliminates drying potential to the outside. Fiberglass faced foam could also be used.

Detailed below are options for an exterior rigid install in climate zone 4 Marine (West of the Cascades) and climate zone 5 (Eastern Oregon, majority of Eastern Washington). Further research is needed on embodied carbon impacts to explore the practicality of an install with more than 2” of rigid foam, which is needed in climate zone 6 (Montana).

<u>Option 1: 1” of EPS</u>

For climate zone 4 Marine, 1” of exterior rigid insulation is installed on top of the WRB using cap nails. For window installation, 1”x4” or 1”x3” wood furring strips are used to wrap the perimeter of the window. Extended window wrap is used to flash the rough opening and to tie it to the WRB. Window installation proceeds as usual and siding is nailed directly through the foam.

Best Practice: Install a ventilated rainscreen behind the cladding to provide added protection from bulk water intrusion and increase the drying potential to the exterior. The battens of the rainscreen also act as nailers for the siding. Use 2”x4” lumber to wrap the windows and secure 1”x2” or 1”x3” wood furring strips on top of the rigid foam at the studs. An insect barrier such as Cor-A-Vent is installed at the top and bottom of the rainscreen. Most major cement board cladding manufacturers (e.g., Hardie) require this nailer when the rigid foam exceeds 1”.

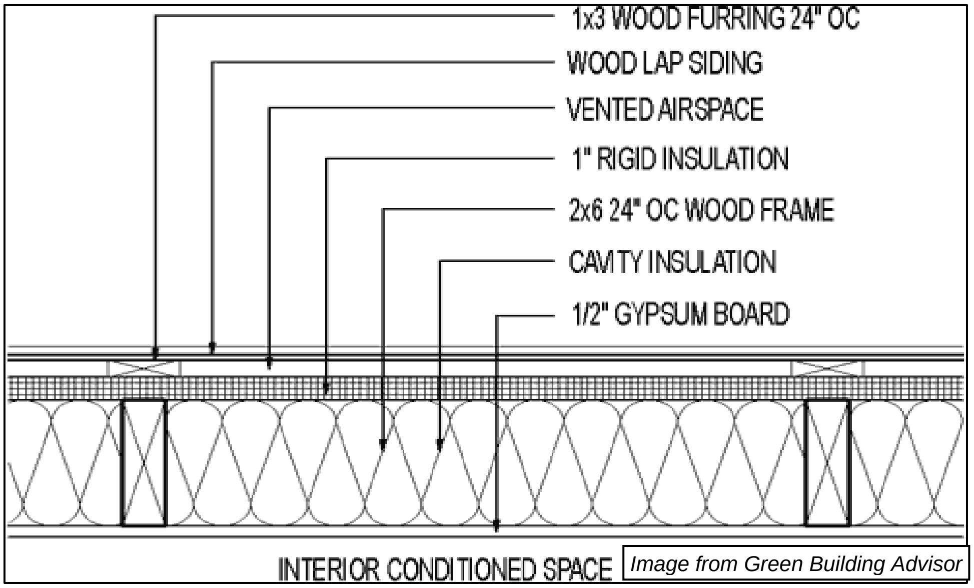

Figure 6. Option 1, 2x6 Intermediate Frame with Exterior Rigid Insulation: 1" Rigid Insulation with Optional Furring Strips for a Rainscreen

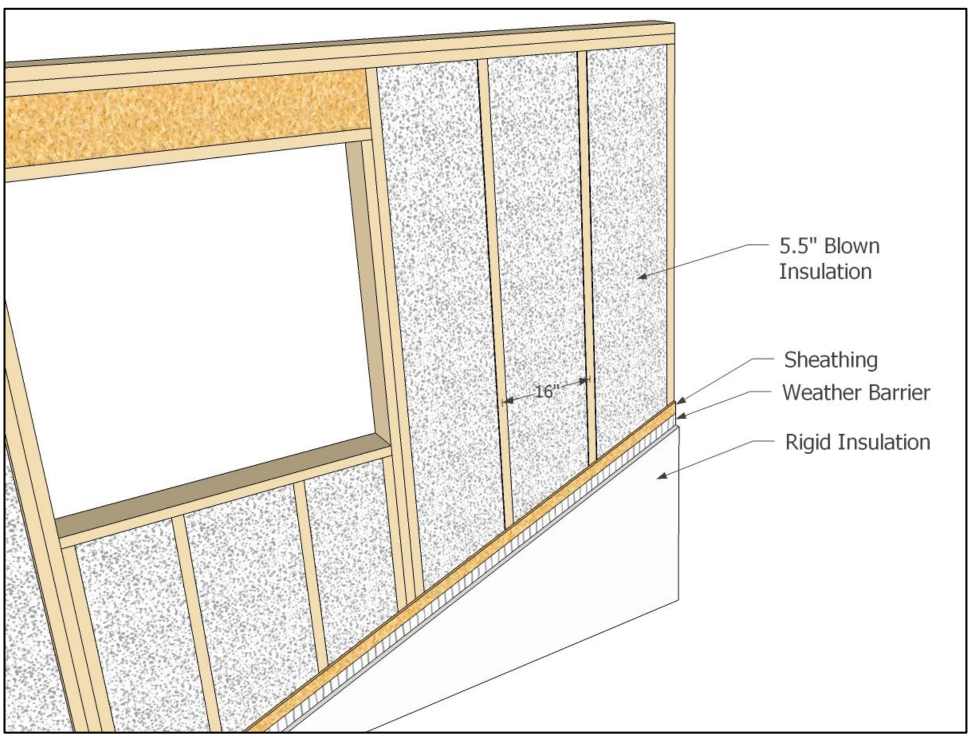

Figure 7. Option 1, 2x6 Intermediate Frame with Exterior Rigid Insulation: Rigid insulation is applied outside the weather resistive barrier (see figure 9 for example).

<u>Option 2: Two Layers of 1" EPS</u>

For climate zone 5, the WRB is also installed directly on the sheathing. Two layers of 1" EPS foam are attached on the outside with offset seams. The first layer is secured with long staples. The second layer is installed with seams offset from the first layer and secured with a screw and Wind-lock plastic washer to the stud. The offset seams reduces infiltration and air transport. 1"x4" furring strips are secured on top of the foam in the field at the studs to act as siding nailers. 1"x6" strips are used at the corners. 6" structural lags secure the furring strips every 18–24 vertical inches. An insect barrier such as Cor-A-Vent is installed at the top and bottom of the rainscreen. ThermalBucks are installed in the window rough openings to allow window attachment without thermal bridging through a typical plywood buck box.

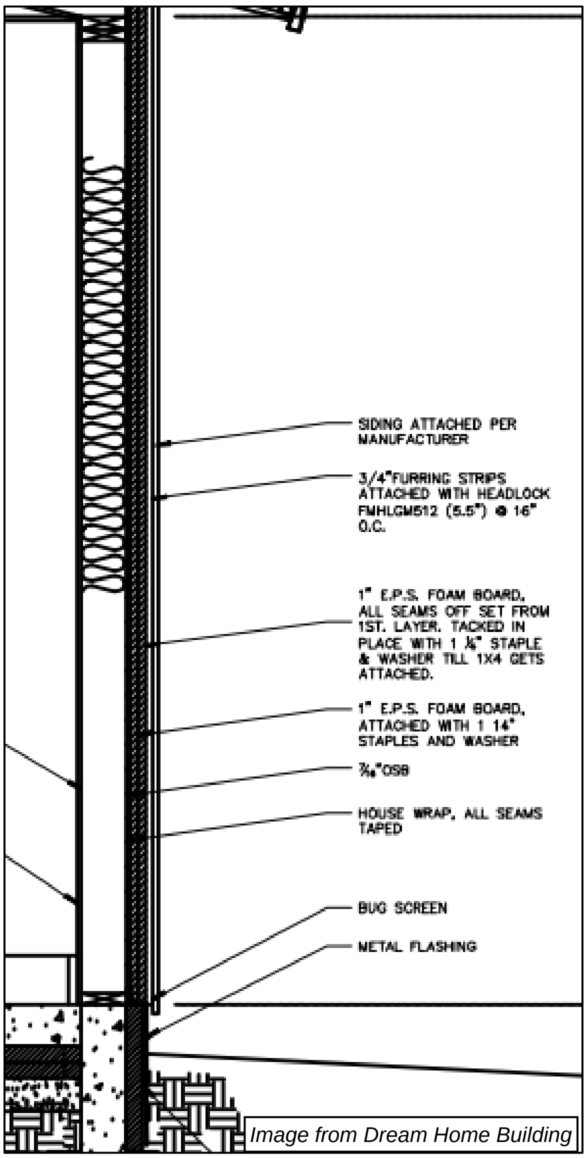

Figure 8. Option 2, 2x6 Intermediate Frame with Exterior Rigid Insulation: Two Layers of 1" EPS Foam. Wall Diagram and Material Specs.

Photo from Dream Home Building

Figure 9. Design Wall Mock-Up Demonstrating Option 2 for 2x6 Intermediate Frame with Exterior Rigid Insulation

Thermal Performance

As with the TBS wall, the continuous insulation over the exterior of the framing renders the thermal bridging from the framing negligible; therefore, the framing factor becomes much less important where the overall wall R-value is concerned. Advanced framing benefits focus more on cost savings and material conservation as opposed to overall R-value.

Typical U values are U=0.028–0.038 depending on the type of rigid exterior and cavity insulation installed.

- U=0.038 R21 batts + R5 exterior XPS[4]
- U=0.037 R23 blown + R4 exterior 1” EPS
- U=0.032 R23 blown + R8 exterior 2” EPS
- U=0.028 R23 blown + R12 exterior 2” ISO

Non-Energy-Related Additional Benefits

Durability

Continuous exterior insulation protects the wooden structural elements by helping to maintain the internal wall temperature above the dew point to avoid condensation and wetting of the framing or sheathing. Inward vapor drive, which is typically caused when the sun heats up a wet surface forcing the moisture through the wall to the inside, is less likely with low permeable

[4] The embodied carbon inherent in the XPS products available in the United States market makes this an unattractive choice. Analysis shows that the carbon emissions reduction benefits from the improved energy efficiency of XPS do not outweigh the embodied carbon of this product.

exterior insulation. For situations in which a rainscreen is not installed, this can be a significant benefit.

Ease of Construction/Cost Savings
Exterior rigid insulation rated for water resistance can be used as the WRB when it is installed with manufacturer-recommended tapes applied to clean, dry surfaces. Although elimination of the WRB would result in initial cost savings, doing so could result in more drainage plane details and training for subcontractors, thus resulting in higher labor costs.

Variations to This Wall Assembly

Primarily Material-Based Variations
- Type of exterior rigid insulation used (foam, mineral wool board)
- Thickness of exterior rigid insulation
- WRB type and location (inboard or outboard of exterior rigid insulation)

Trades Information

Framers
No major changes to conventional practices are necessary.

Windows and Doors
One of the biggest changes from conventional frame wall construction for this wall assembly is the framing and finishing of the window and door openings. Doors are set to the inside of the home and extension jambs are required to finish the opening to the exterior, tying them into the exterior trim and siding. This wall assembly requires detailed design specifications and subcontractor training to integrate the rigid foam and WRB with flashings around doors, windows, and other penetrations.

Option 1: 1” EPS
With 1” rigid installation, 9” window flashing is substituted for 4” or 6”. Without installing a rainscreen, 1”x4” or 1”x3” nailers are used to wrap the perimeter of windows. The WRB is installed onto the sheathing, just to the edge of the nailer around the window perimeter. The 9” flashing is then pulled over the nailer to tie it into the WRB. The siding can be installed directly into the foam using the correct nails.

If pursuing the rainscreen best practice with Option 1, the same window flashing process is used over 2”x4” window perimeter nailers. This ½” larger nailer provides a flush siding surface with the rest of the wall using 1” of rigid insulation and ½” battens.

Option 2: Two Layers of 1” EPS
In installations with more than 1.5” of exterior foam, ThermalBucks[5] extend the mounting point for windows and doors to create a flush plane for cladding, and allow for structural attachment of the window. They insulate the mounting points with an R-value of 4.4–17.6, and act as an air and water barrier when installed with recommended sealants, preventing moisture around windows and doors.

[5] The ThermalBuck website provides details, photos, and videos of a variety of installations with different WRB strategies. The installation of the WRB interior to the continuous insulation is recommended.

Steps: Install the WRB, then tape back the head flap and jambs. Cut the WRB flush with rough opening at sill, and seal the WRB to sheathing at sill. This is the only place where the WRB will go between the ThermalBuck and the sheathing. Next, install ThermalBuck, then let cure for 24 hours. Install the window according to the manufacturer's instructions. Seal the transition of ThermalBuck to the sheathing at the jambs and head with DAP Dynaflex 800 or Dow Corning 758, then press WRB into the wet sealant. To complete flashing, tape across the jambs and head of WRB across nail flange of window. Install continuous insulation according to manufacturer's instructions.

Additional materials include:[6]

- DAP Dynaflex 800* or recommended sealant and sealant gun
- 2″ galvanized roofing nails for ThermalBucks
- #10 nails or screws for flange (penetrate 1¼″ into structure)
- Flashing tape to cover window nail flange and J-roller
- Miter saw

[6] A full instruction document can be found here: https://thermalbuck.com/wp-content/uploads/2018/04/WRB-Interior-of-Continuous-Insulation-April-2018.mid.-5pg.pdf

Figure 10 (left). Traditional On-Site Constructed Plywood Buck Boxes
Figure 11 (right). ThermalBuck Image. "Improve Ease of Window Install & Reduce Thermal Bridging."

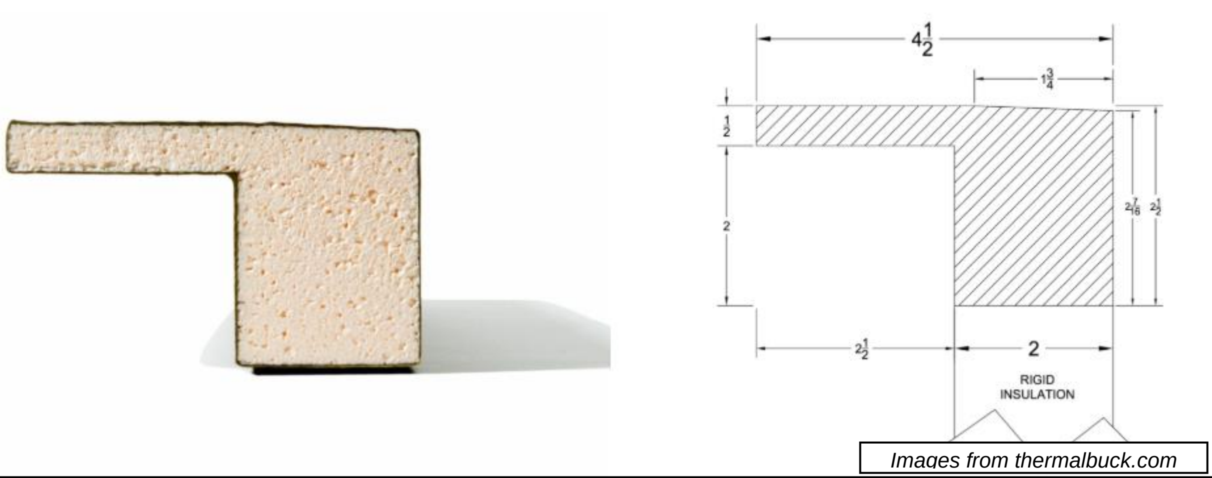

Figure 12. ThermalBuck Image and Diagram of Size Specified for Option 2 for 2x6 Intermediate Frame with Exterior Rigid Insulation: Two Layers of 1" EPS Foam

Roof Details
The roof-wall connection is another exterior finish detail affected by the addition of the rigid insulation. Two effective installation options exist. The first entails stopping the rigid insulation at the soffit and extending the attic insulation over the wall to the outside edge of the rigid. Another viable option involves extending the rigid insulation up past the top plate. This method may involve notching the rigid insulation around the rafter tails, depending on the type of roof framing employed.

Insulation
No major changes to conventional practices are necessary.

Electricians
Exterior lighting and electrical outlets should be properly blocked for stable attachment (see photo in Figure 14). No major changes to conventional practices are necessary; however, issues may arise with siders drilling rainscreen batten screws into wiring in the cavities. To address this, builders can specify a range of height for the electrician to run wiring to avoid the lag screws.

Figure 13 (left). XPS Insulation with Rainscreen
Figure 14 (right). Blocking for Electrical Outlets

Plumbing
No major changes to conventional practices are necessary, but extra blocking may be necessary for stable attachment of exterior plumbing fixtures such as hose bibs, vents, etc.

Exterior Finishing and Siding

Option 1: 1” EPS

When installing 1” or less of exterior rigid foam, the siding can be installed directly onto the foam as long as the nail size is long enough to sink at least 1¼” into the studs. Secure the 1” of exterior rigid foam on top of the WRB using cap nails.

If pursuing the rainscreen best practice with Option 1, secure 1”x2” wood furring strips on top of the rigid foam at the studs to use as siding nailers. An insect barrier such as Cor-A-Vent is installed at the top and bottom of the rainscreen. Note that when installing these furring strips, the rigid insulation beneath can get compressed, leading to a wavy appearance of the finish cladding. To get a plumb finish, holes can be pre-drilled, allowing the furring strips to be screwed in to a consistent depth.

Option 2: Two Layers of 1” EPS

Two, 1” layers of EPS foam are attached on the outside with offset seams. The first layer is secured with long staples, then a screw with a Wind-lock plastic washer is used to secure the second layer. 1”x4” furring strips are secured on top of the foam in the field at the studs to act as siding nailers. 1”x6” strips are used at the corners. 6” structural lags secure the furring strips every 18–24 vertical inches. An insect barrier such as Cor-A-Vent is installed at the top and bottom of the rainscreen.

Drywall

Larger drywall returns may be needed if windows are exterior set. Otherwise, this method presents no significant differences from conventional frame construction.

Challenges

Moisture Management

In general, the goal of moisture management is to prevent moisture from entering into the assembly while allowing maximum drying should water penetrate or condensation form. In climate zones 5,6,7,8 and zone 4 Marine, code requires a Class I or Class II vapor retarder on the warm-in-winter side of the wall assembly (ICC 2018). Should water enter the cavity, any necessary drying would be assumed to occur on the outside.

Because of its low vapor permeance for certain foams, exterior rigid insulation could prevent this from happening and could cause moisture to be trapped in the wall cavity. To ensure that drying can occur, the interior vapor retarder should be eliminated to allow drying to the interior of the home. Table 702.7.2 in the 2018 International Residential Code (IRC) has vapor barrier exemptions if continuous exterior insulation requirements are met. Class III vapor retarders (latex paint) can now be used instead of Class I or II vapor retarders in zone 4 Marine with continuous rigid exterior insulation of R-2.5 for 2×4 walls and R-3.75 for 2×6 walls; in zone 5: R-5 for 2×4 walls and R-7.5 for 2×6 walls; and in zone 6: R-7.5 for 2×4 walls and R-11.25 for 2×6 walls.

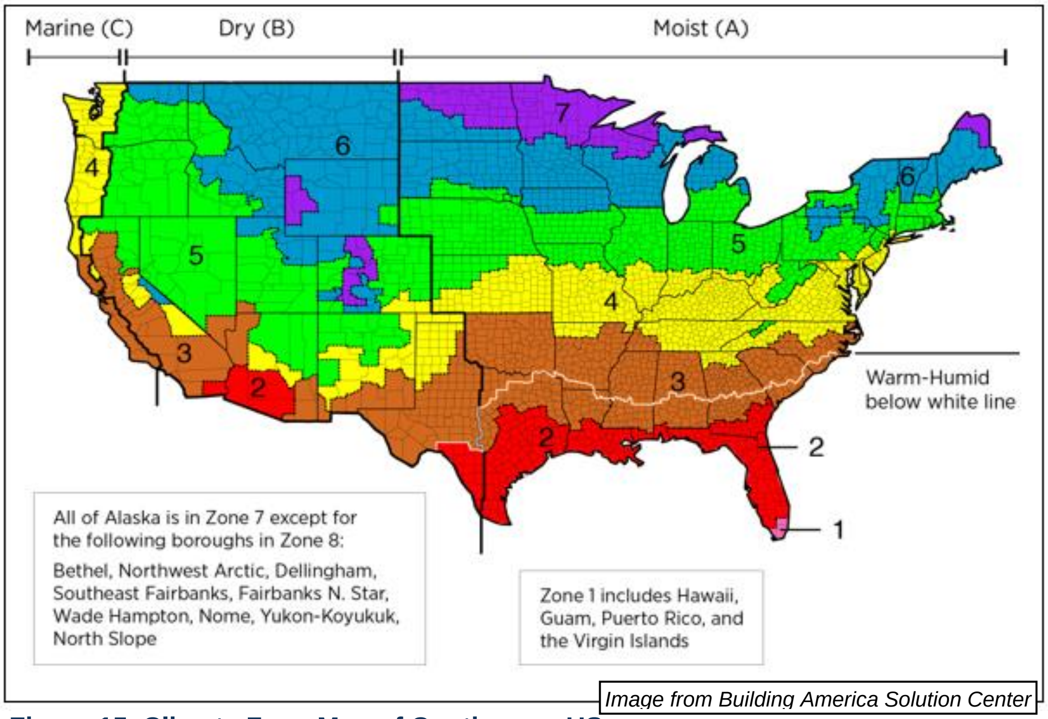

Figure 15. Climate Zone Map of Contiguous US

Inspection Timing
In some areas, codes require nailing pattern inspections for the structural sheathing. When installing rigid insulation, this requires postponing the installation until after the shear inspection.

However, some code inspectors require only a portion of the wall to be accessible for this inspection. If so, builders can minimize the impact to their construction schedule by installing the WRB (only nailed at the top, with the bottom folded and tacked up so the nailing pattern is visible) and rigid foam insulation on the top third of the wall before standing it up, and leaving the bottom two-thirds of the wall exposed for inspection.

Handling and Storing Rigid Insulation
On-site storage and protection of rigid insulation is very important. Both expanded and extruded polystyrene and unfaced polyiso should be protected from UV radiation. EPS breaks easily, especially around the edges, and must be handled with care. Foil faced polyiso needs to be protected from moisture exposure as it can warp and cup. All boards should be stored in a protected, covered location, and exposure to the elements should be minimized before the siding is installed.

Construction Costs

Current estimated incremental cost vs. standard 2x6 wall
Option 1: Total incremental labor and material costs: $2.50/sq foot
Option 2: Total incremental labor and material costs: $4.50/sq foot

Estimated incremental cost at scale
Option 1: Total incremental labor and material costs: $1.03/sq foot (23%)
Option 2: Total incremental labor and material costs: $2.34/sq foot (41%)

Wall Assembly #3: 2x4 Double Stud with Blown-In Fibrous Insulation

Description

Double-stud wall construction consists of an exterior 2x4 stud-framed structural wall and a second 2x4 non-structural wall built to the inside with a gap in between. This second wall can be constructed when interior framing begins with 2x4 or 2x3 framing at 16” or 24” on center. Framed openings for windows and doors are usually aligned square with the openings in the exterior walls for simplicity and best thermal performance, although 45° side and top returns are also possible for aesthetic purposes. The studs in each wall can be aligned or staggered, although research has shown only minor improvement (<R-1) when staggering the studs.[7]

Best practice includes an air gap of 1”–3” between the 2x4 walls to eliminate thermal bridging between the studs, with sheathing above the double top plates to span the gap of the 8”–10” double wall.

A common variation is a staggered stud wall consisting of 2x8 top and bottom plates with staggered 2x4 studs that are used to create a 7.5” wall cavity. The assembly is insulated with blown-in fiberglass or cellulose.

The exterior wall studs and sheathing will experience colder temperatures in the winter; therefore, a ventilated rainscreen is highly recommended to provide robust drying potential to the exterior to help prevent any moisture vapor intrusion from accumulating within the assembly.

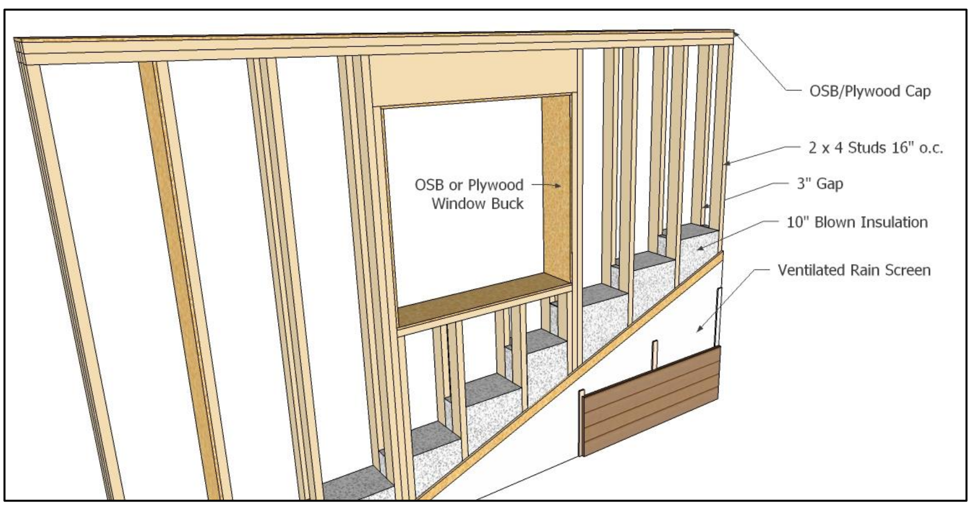

Figure 16. Assembly for 2x4 Double Stud Wall with Blown-In Fibrous Insulation

Additional Materials Required

Compared to standard wall construction, the double stud wall requires more wood studs. Plywood or OSB buck boxes are constructed for door and window framing to span across the assembly. Sheathing is also used above the double top plates to further connect the 2x4 walls. Additional blown-in insulation is required to fill the entire assembly.

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7 See California Air Regulatory Board, 2009.

In some jurisdictions, the code officials may require a vertical fire block every 10 feet. The fire block can be constructed with plywood, OSB or 2x lumber that spans the gap between studs. Some jurisdictions simply allow blown-in fibrous insulation to meet this requirement.

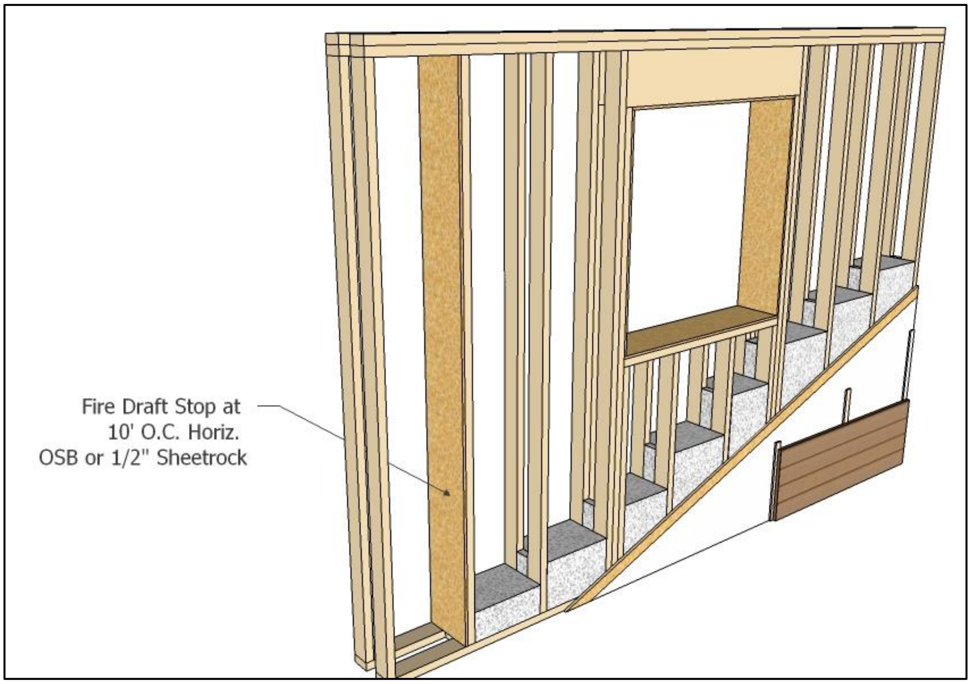

Figure 17. Fire Draft Stop for 2x4 Double Stud Wall with Blown-In Fibrous Insulation

Additional materials for the ventilated rainscreen include 1”x4” wood battens, fastener screws, and insect protection screens for the top and bottom vents.

Thermal Performance

Typical U values are U=0.026–0.038 depending on the type of cavity insulation and wall depth.

- 8” wall, blown fiberglass U=0.030
- 8” wall, blown cellulose U=0.035
- 10” wall, blown fiberglass U=0.024
- 10” wall, blown cellulose U=0.028

Non-Energy-Related Additional Benefits

Ease of Construction

Weather-resistive barrier, exterior flashing, window/door installation, and siding installation can follow standard construction practices. Training for framing crews is minimal.

Aesthetics

The deep window sills that result from the use of this wall system provide an opportunity to use drywall returns instead of jamb extensions and trim around windows. This both saves builder costs and enhances aesthetics. Additionally, the thicker wall acts as a visible reminder to better demonstrate the increased thermal performance to the homeowner.

Embodied carbon
The embodied carbon of a home can be measured by analyzing how effectively a home is sequestering carbon and how its manufacture is avoiding the generation of carbon emissions. Analyzing the sequestration requires a look at differences in construction. Double stud walls using 2x4 studs use slightly more wood than a 2x6 wall, approximately 44 more cubic feet for a 2,000 square foot home. This additional wood will have the effect of sequestering the carbon bound up in the lumber for the life of the home, in this case 709 lbs of carbon.

On the manufacturing side, a double stud wall insulated with dense packed fiberglass will have less embodied energy than a wall that utilizes foam board insulation, because current foam board manufacture utilizes reactive blowing agents. Different foam boards are manufactured with different processes that have different global warming potential (GWP). In a typical 2,000 square foot home, using dense packed fiberglass results in a reduction in embodied carbon of about 2,000 compared to a home with 1" of EPS or polyisocyanurate foam about 6,700 than a wall with to 1" of XPS foam. This embedded energy is significant as it is on the same order of magnitude as the carbon emissions generated during a typical year if the home were heated using a gas furnace.

Variations to This Wall Assembly

- Staggered Stud Wall

Trades Information

Framers
Outer 2x4 wall: constructed as normal except with 2x4 rather than 2x6 lumber.

Inner 2x4 wall: Because window and door openings in the inner frame wall must be carefully aligned with windows and doors, framing the interior wall can sometimes take more time than the exterior framing. As the inner wall is not load-bearing, framing spacing can be increased to 24" on center to save on time and materials. On the inner wall, double top plates and jack studs are often not necessary (though jack studs may still be used for more consistent alignment of window openings). Two-stud corners are quite simple to implement on both the outer and inner framed wall, as no drywall is attached to the outer wall and no exterior sheathing is attached to the inner wall.

Fire blocking is required every 10 ft horizontally in some jurisdictions. Others allow blown-in fibrous insulation to meet the requirement.

Windows and Doors
Window and door installations are typical, except all exterior doors require jamb extensions. Window sills must be wider, and if using window trim instead of a drywall wrap, then trim must also be wider.

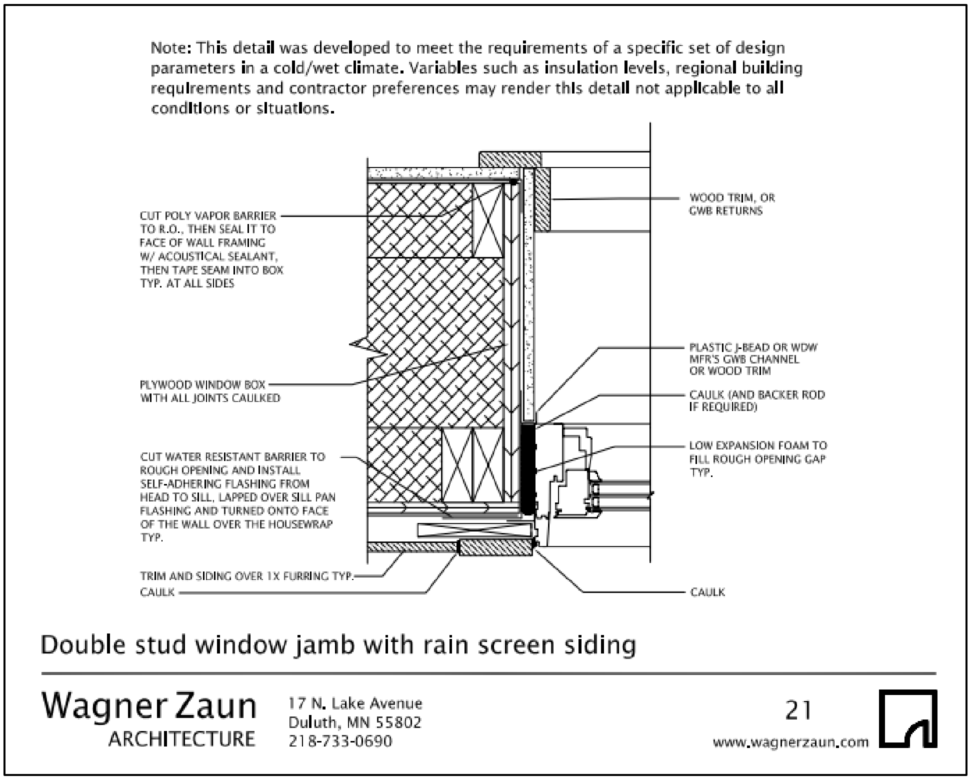

Figure 18. Double Stud Window Jamb with Rainscreen Siding

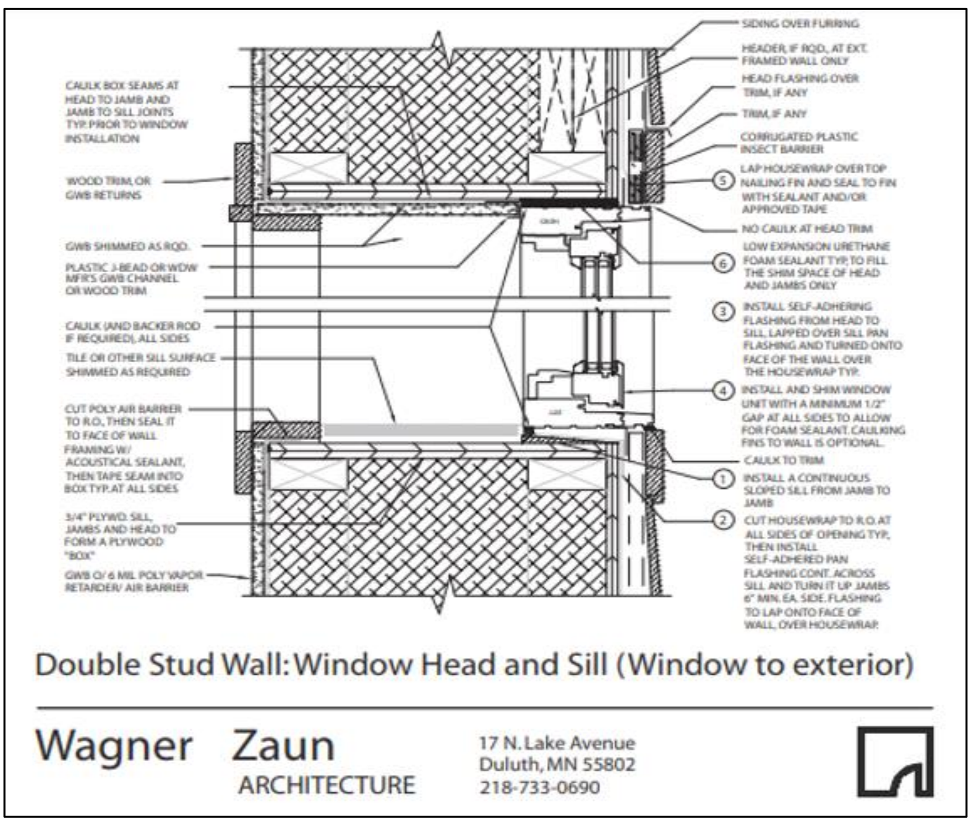

Figure 19. Double Stud Wall–Window Head & Sill (Window to Exterior)

Insulation
The method of blowing insulation for this 2x4 double stud wall is somewhat different than in single frame construction. Because the wall is not divided into discrete stud bays, the exterior walls for each story basically include one large insulation cavity. When using dry, dense-blown insulation, insulators typically fill this cavity by moving around the home in a circular pattern; each section of the wall is partially filled. After the walls are nearly completely filled, the insulator makes one more circuit around the home blowing through each interior stud bay until the insulation reaches the desired density.

In cases of the single insulation cavity mentioned above (i.e., no discrete stud bays filled with insulation), some builders have chosen to install insulation netting around critical wall penetrations. In this way, if a vent pipe must be accessed or repaired, insulation in the entire wall is not compromised; only insulation around the penetration must be replaced.

Electricians
Electrical rough-in in double walls can be slightly simplified as wires can be run between the two framed walls; drilling is not necessary except through fire blocking. Electrical boxes are installed normally on the interior wall.

Plumbing
Aside from careful coordination of wall penetrations mentioned earlier, few—if any—changes are required for plumbing in double-wall home construction.

Exterior Finishing and Siding
As discussed above, exterior siding and finishing of these wall systems is very similar to that of conventional framed wall systems.

Drywall
When window openings in the interior framed wall are square with windows, window returns (often drywall) are larger. Other than this size factor, however, window finishing is no different than that for a 2x6 framed wall.

Challenges

Design constraints
Issues can arise due to the width of the wall. For example, costly door jamb extensions are required for exterior doors, and finding wider ADA compliant thresholds can be a challenge. The thickness of the wall also results in a loss of usable square footage.

Moisture Management
Thicker walls prevent heat transfer between the interior building temperature and the exterior sheathing. Colder temperatures of the exterior sheathing can lead to increased likelihood of condensation from air exfiltration.

Construction Costs

Current estimated incremental cost vs. standard 2x6 wall

- Incremental material and labor costs: $1.00 sq foot
- Incremental insulation costs: $0.90 sq foot
- Incremental framing material costs: $0.10 sq foot
- Incremental framing labor costs – negligible

Total Incremental labor and material costs: $2.00 sq foot

Estimated incremental cost at scale

Total incremental labor and material costs: $0.79 sq foot (19%)

Key Considerations for Each Wall System

Table 1 below summarizes key considerations for each wall system. The project team has identified areas that require further research or analysis to fill in gaps in knowledge or awareness among the building industry of the attributes of these three wall systems. This table can be used to identify necessary future primary research and/or to direct further review of existing research that could be "repackaged" and repurposed for the regional builder audience.

Table 1. Key Considerations for Each Wall System: Benefits and Challenges

	Benefits					
Wall Type	**Ease**	**Aesthetic benefits (deeper sills)**	**Less thermal bridging**	**Seismic**	**Noise**	**Moisture management**
TBS	Y		Y	Y	R	R
Exterior Rigid			Y		R	Y
Double Stud	Y	Y	Y		R	
,						
	Challenges					
Wall Type	**Framer issues**	**Design detail issues**	**Moisture management**	**Siding installation**	**Code acceptance**	**Carbon impact**
TBS	T		R/T		R/T	R
Exterior Rigid		Y	T	T	R/T	R
Double Stud	T	Y	R/T			

Y= Wall system has been shown to have benefit or challenge
R= Research/analysis needed
T= Training needed

Summary

The wall systems reviewed in this report have been selected by several leading high-performance builders based on their assessments that the walls provided greater energy performance and were an important part of the overall quality of construction. Small-scale builders, especially those using approaches unfamiliar to most subcontractors, historically pay a price premium compared to their production-scale competitors. Production-scale construction practices and purchasing power could likely decrease the costs associated with each of the three wall systems sufficiently to be within the typical range of wall construction costs. while offering them the potential for both greater energy and non-energy benefits.

As this report shows, the three documented wall assemblies provide an opportunity to increase energy performance across the new homes market. However, full embrace by production-scale high-performance builders of the viability of each wall system will likely require proof of the benefits of the systems and refutation of their perceived challenges.

Although cost is a huge factor in decision-making for production-scale builders of higher-performing homes, risk aversion is also a key consideration. Production-scale builders make changes to their standard operating procedures only after they have determined that the new course of action offers less risk than staying with the “tried and true” approach. Before a case can be built to transition regional builders from traditional, less efficient wall systems to one of these three more advanced wall assemblies, existing information gaps must be filled. Documented evidence that demonstrates additional non-energy benefits or addresses builder concerns about perceived deficiencies with the wall assemblies will greatly influence builder decision-making about transitioning to a new wall approach.

Discussion

Builders chose to build with one of the three subject wall systems largely because they perceived it to be “the better way to build.” These builders are generally looking for ways to improve the performance of their homes, especially their energy performance. While one or two builders innovated on their own, most builders learned of the wall assembly approach from other industry sources. From discussions with these builders, a credible messenger—as much as the information being delivered—was clearly an important factor in motivating several of them to switch to one of the three high-performance wall systems. Training courses delivered by reputable and successful builders have proven to be a strong driver in getting these other builders to accept the risk of a new construction approach.

Because some of the builders using these wall systems are building for a higher-end market, they consider the incremental costs associated with the walls as negligible. Most also see the benefit of including these incremental costs, along with the costs of other energy investments, in an appraisal addendum to ensure that appraisers are aware of, and accurately value, the additional costs and residual performance benefits. This step is especially important for elements of the home that are invisible to the appraiser, such as high-performance wall assemblies.

As the earlier-presented Table 1 indicates, several topics related to one or more of these wall systems require additional research and documentation. The project team recommends that Phase 2 address the information gaps related to code acceptance, embodied carbon, moisture management, and noise attenuation.

1. **Code acceptance:** State building codes, local interpretation of those codes, and building code official awareness of the viability and benefits of the three wall systems likely remain barriers to their full acceptance. The project team recommends undertaking an analysis of regional building codes to identify potential language alterations that would support greater acceptance of each of the wall options, especially in the case of the TBS and exterior rigid insulation walls. Where applicable, the project team suggests NEEA and partners engage in code update processes to support the inclusion of updated code language related to high-performance wall performance levels. For example, an opportunity exists to demonstrate that high-performance walls should be included in the options table as part of future Oregon Residential Specialty Code updates. This option would prompt builders to consider using high-performance walls as a means to achieve the requirements of Oregon’s Executive Order 17-20.[8]
2. **Embodied carbon:** The next cohort of builders likely to consider using one of the three market-ready high-performance walls will be motivated by the concept of “climate friendly” building practices; at the very least, they will be concerned with adopting practices that could be considered “climate unfriendly.” Providing clear guidance to these builders on the relative embodied carbon of insulation materials, especially rigid insulation options, will help them feel comfortable selecting a new product and/or process that is climate positive. Existing tools are available to evaluate the relative carbon intensity of various materials. The project team recommends the development of a summary document that calculates and organizes these findings in a clear, concise format that is accessible to builders.

[8] https://www.oregon.gov/gov/documents/executive_orders/eo_17-20.pdf

3. **Moisture management:** A common concern—real or perceived—with each of the wall systems is how they address moisture issues in wet climates. While the project team is aware of the field and lab research conducted on this topic, it has identified a need to coalesce relevant research addressing these particular wall systems into a single regionally-specific document that could be accessed by builders.
4. **Noise attenuation:** Several builders using one of the three market-ready high-performance walls stated that they convey the noise reduction benefits of the wall system to their clients. While anecdotally these builders find the walls provide noise attenuation, the availability of actual field research that conclusively documents this perceived benefit is unclear. Documented noise reduction benefits could become a motivator for builders to select these wall systems, especially for builders focusing on urban infill construction or home building occurring adjacent to main arterials, freeways, or other high-noise areas. The project team recommends further investigation into available field or lab research findings.

References

Earth Advantage. 2018. *Improving Energy Efficiency and Seismic Resiliency in Older Housing Stock.* Accessed from https://www.earthadvantage.org/assets/documents/Publications/TBS%20Wall%20Case%20Study%20180515%20FNL.pdf

Earth Advantage, Builder Interviews. [2019]. https://docs.google.com/document/d/1uksPJaMv20z2wfc0E6RP6a6JqLcz0f4YFr_ZKvkkADI/edit?usp=sharing

International Code Council (ICC). 2018. *International Residential Code (IRC).* Accessed May 7, 2020 from https://codes.iccsafe.org/content/IRC2018.

Northwest Energy Efficiency Alliance (NEEA). February 2016. *Thermal Break Shear Wall: A Case Study of Rigid Foam Insulation between Frame and Sheathing.* Accessed from https://neea.org/img/uploads/thermal-break-shear-wall-a-case-study-of-rigid-foam-insulation-between-frame-and-sheating.pdf

Smegal, Jonathan, and John Straube. June 2010. RR-1014: *High-R Walls for the Pacific Northwest—A Hygrothermal Analysis of Various Exterior Wall Systems.* Accessed from https://www.buildingscience.com/sites/default/files/migrate/pdf/RR-1014_High-R_Walls_Pacific_Northwest.pdf

Straube, John. January 2011. BSD-163: *Controlling Cold-Weather Condensation Using Insulation.* Accessed from https://www.buildingscience.com/documents/digests/bsd-controlling-cold-weather-condensation-using-insulation

US Department of Energy (DOE) Building America Solution Center. March 2016. *Continuous Rigid Insulation Sheathing/Siding.* Accessed from https://basc.pnnl.gov/resource-guides/continuous-rigid-insulation-sheathingsiding#quicktabs-guides=0

Washington State Energy Code (WSEC). 2009. *Builder's Field Guide*, 8th Edition. http://www.energy.wsu.edu/Documents/BFG%20Chapter%205-Jan2011.pdf