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Thermal Break Shear Wall:

A Case Study of Rigid Foam Insulation between Frame and Sheathing

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Executive Summary

This case study was developed as part of NEEA's interest in advancing the use of energy efficient new homes. It demonstrates the opportunity for significant energy savings in a simple low cost assembly that offers additional benefits (seismic tolerance).

Presented is an innovative wall assembly by a residential developer and general contractor in an entry-level, zero-net-energy subdivision in Washington County, Oregon, between 2008 and 2010. The wall assembly, referred to in this report as a "Thermal Break Shear" (TBS) wall, has a continuous layer of rigid foam insulation board between the standard lumber frame and plywood of a conventional light-frame wall assembly. During the review and approval process, County code officials required destructive testing to demonstrate that the assembly satisfied the requirements of the structural code.

The project team built five houses in the Sage Green subdivision using the subject wall assembly. This report describes the design development and construction challenges the project encountered and analyzes and compares the cost and performance of the assembly with several other conventional and emerging wall assemblies. The project provides an excellent demonstration of the TBS wall system.

The use of a TBS wall assembly at Sage Green demonstrated several benefits, including:

- use of standard framing practices
- improved thermal performance
- conformance with standard construction schedules
- small incremental cost increase

Increased nailing in the wall assembly diminishes the overall energy performance by two percent, an insignificant impact compared to the twenty-five to forty percent improvement from the use of foam as a thermal break.

The destructive cyclic lateral load (ie: earthquake) tests conducted at Oregon State University's Knudsen Wood Engineering Laboratory found that the subject wall assembly meets the shear strength requirements of the code and, further, that it has seismic capacities significantly higher than conventional light-frame wall assemblies.

In addition to the thermal efficiency gains in moving from a standard 2x6 code wall with R16.7 (effective) to the 2x8 TBS wall with R28.1 (effective), the assembly used at Sage Green also helped achieve a continuous air barrier, an average air exchange rate of 2.1 ACH50, and improved seismic resilience . These achievements, combined with triple-glazed low-e windows, produced a twenty-seven percent decrease in the design load of the home. The lower heat loss enabled installation of a smaller-sized mechanical system. The 2x8 TBS wall system had an incremental cost increase of about $2,800 over conventional 2x6 framing. Future homeowners would benefit from improved thermal comfort and approximately $5,000 in heating cost savings over the first thirty years.[1]

[1]With the 2x8 frame assembly, assuming energy costs remained constant, as determined by NEEA staff.

Disclaimer
The authors of this report make no claims of performance or suitability of the assembly for any particular application. The materials and methods employed complied with all applicable building codes and conformed to much of industry standard practice.

Introduction

This report traces the progression of the assembly from concept through deployment.

Background

In response to increasing demand for improved performance, wall assemblies that have reliably delivered structural integrity and occupant safety for decades are changing to make buildings more energy efficient. The construction industry as a whole has been working to develop new standards and practices, but lacks broad consensus beyond the minimum standards of the International Building Code and International Residential Code.[2] Simply put, the design and construction of building envelope assemblies as integrated environmental control systems remains emergent, novel practice for much of the industry.

Many early adopters have been choosing to add rigid foam sheathing to the outside of conventional light-frame wall assemblies as a thermal break. While this has complicated numerous related processes and details, it leaves the prescriptive structural characteristics of the wall unchanged.

The assembly presented in this report departs from that strategy. In hopes of minimizing production costs, it tasks the framers with installing the foam directly over the wall frame prior to application and attachment of the shear ply. Figures 1 shows a cross-section and construction of the wall assembly.

[2] Nb: Modern building codes are the product of more than 4,000 years of historical development. (https://en.wikipedia.org/wiki/Code_of_Hammurabi provides background) Building codes are essentially reactive -- i.e., largely developed in response to catastrophes and technological innovations.

Figures 1 Cross-Section of Wall Assembly

Figure 2. Construction of Wall Assembly

Uncertainty and Fear of Disruption

In early 2008, the Oregon Department of Energy (ODOE) designated two homes at New Columbia in Portland as demonstration models for the Oregon High Performance Home Program.[3] In connection with that project, ODOE staff pointed out the problem of thermal bridging in exterior walls, posed the question of introducing a thermal break into the walls, and suggested the possibility of adding a continuous layer of rigid insulation to the outside of a conventional assembly.

The prospect of adding a layer of foam board to conventional walls raised many questions about construction and material choice like the following:

- How would the trades install the weather-resistant barrier (WRB)/house-wrap, windows, doors, flashings (rigid, flexible, and self-adhesive), trim and cladding, sealants and coatings?
- How much would it cost to answer all those questions?
- How much more would it cost to build?
- Could it promote rot in adjacent structural assemblies?
- Could it create a new fire path?
- Could it adversely affect indoor air quality?
- Could it create some other new long-term failure mode and related liabilities?

In addition to uncertainty of technical and construction practices, there was fear that opposition from any single critical stakeholder (some designer, regulator, supplier, installer, or insurance attorney) could kill the effort. To succeed, the plan would need to be simple and compelling without strong opposition from any critical stakeholder.

Sage Green Project

Green One Construction chose to pursue the TBS wall concept as simple solution to adding a continuous layer of rigid insulation. The TBS wall enabled the desired energy performance goals to be achieved without disruption in construction practices or large incremental costs. Fortunately today, builders no longer face the uncertainty of using a TBS wall system as products and similar projects now exist that confirm the validity the TBS wall.

Methodology

Sage Green Wall Assembly Material and Design

From late 2008 through the spring of 2009, over the course of schematic architectural design, ODOE and Energy Trust of Oregon (ETO) provided energy modeling and related technical support to the development of the zero-net-energy model. That model included a continuous exterior layer of R6 foam board as part of an effective-R33 wall. The project team chose a 1.25 inch layer of 2-pound density, un-faced expanded polystyrene board (EPS) which at the time appeared to be as the most cost-effective,

[3]Ben Walsh was the Project Manager on the construction of these units and was the liaison between the developer and ODOE (represented, at that time, by Christopher Dymond) and Christopher Dymond was the ODOE program manager.

suitable material. Subsequent pricing changes of ridged insulation may have changed this best assembly to use polyisocyanurate foam or other ridged foam board assemblies.

How extra insulation is to be added to the wall is a critical decision. Only three clear options exist: the framer will do it, the sider will do it, or the general contractor will add a line to the budget and schedule for some new provider in between them. Who does the work is an important factor as it affects the cost and schedule the work.

The home-building industry has recently encountered a similar problem with window installation. Framers (rough carpenters) typically installed windows as recently as ten years ago. Now siders (exterior finish carpenters) typically install windows. The integration of the windows with components of exterior cladding systems has become more intricate. Cladding systems have become more complex. The number of different materials and steps in builders' assemblies and details has increased significantly. In between the rough and finish carpentry work that has historically gone into constructing what we now call "building envelopes", many of the new tasks (and the tools, training, and temperament they require) don't look like carpentry. Many of them look much more like an expansion of the painting scope, complete with characteristic coatings industry considerations such as chemical compatibility, weather dependency, and so on.

Trying to Keep it Simple

The fact that construction materials are heavy and bulky, and that houses are big, has ruled the historical development of standards of practice. Particularly in the early phases of building a house, heavy machinery (e.g. excavators, trucks, cranes, all-terrain forklifts) is used for much of the work. In the accompanying rough manual trades, work done flat on a flat surface is safer and more economical than any on-site alternative. Framers build walls flat whenever possible.[4]

Further, the framing trade is well-acquainted with double-sheeting walls. Standard practice for many years has included nailing a layer of gypsum board over shear ply to deliver fire-rated assemblies in attached housing. The going rate for labor to install that extra layer in low-rise construction has for years been $.25-$.50/sf of finished floor area (FFA), or $400-$800 for a 1,600 square foot house. The task of covering a wall with foam board should be simpler and easier than the task of covering a wall with gypsum board. Foam is much lighter than gypsum and can be cut with wood tools.

Moreover, once the framers are done, the exterior trades have to work on a whole building. They use lifts, scaffolding, ladders, jacks, anchors, lanyards, harnesses, and so on to continue their work. Installing insulation when the wall is lying flat on the deck, where framers can easily get at the materials, is clearly easier. For these reasons, the project team sought to get the thermal break from the framer. Working on the walls while they were still lying down became a primary focus of the design of the wall system.

[4]"Tipping" the walls – standing them up after they're framed – is unique in the residential construction process: it sees the single largest group of workers doing the same thing together in the same place at the same time. NB: Framers are injured on the job at a rate more than twice the industry average.

It is not surprising that the integration of insulation into framing materials finds support from R&D investment on the part of a number of major building material manufacturers. Structural Insulated Sheathing (SIS) as a class of products has been growing in residential construction in recent years.

Deciding to give the job to the framer gave a starting point for considering details of the assembly, the process to build it, and its performance characteristics. But many questions followed. First among them is: if there were foam all over the outside of the walls, how would the following exterior trades *attach* anything to it?

The simplest answer is: they wouldn't. As a class of building materials, foam plastic insulation board can't hold common fasteners. The trades would have to figure out how to attach and detail windows, doors, flashings, and cladding system components directly or indirectly through the foam to the structure behind it.

In June 2009, Green One invited prospective framing and siding subcontractors to the Mercer Windows manufacturing plant in Beaverton, Oregon, to build a mock-up wall with 1.25" of foam on the outside and to troubleshoot window installation.

Mercer representatives were eager to see their windows installed directly over foam instead of ply. They had seen failures when vinyl windows were pinched by the wall frame, and wondered if a layer of foam might help protect a window against that kind of damage. But with only 1.5" of vinyl in-board of the nailing flange, only .25" at the inside face of the window would bear on wood structure. Mercer was concerned that the bottom rail of the window might sag, bowing out and down over time. The team wondered if exterior casing could bear some of that load? Mercer asked how much weight such an assembly could bear, what would be the bearing capacity of six (or eight, or ten…) 16-penny nails embedded 1" and cantilevered 2.25" through the foam and casing?

Although answering that question seemed like it should be fairly straightforward, it was not. One after another, leading engineering firms in Portland declined to consider the question. When pushed, one firm explained its reluctance; its engineers were afraid that if they had the only "wet-stamp" on the envelope design, its insurance policy would be first in line on a future defect claim. The engineers said they'd be happy to do the work, though, if they were approached as a subcontractor to a consultant in the context of a comprehensive envelope design contract.

In June 2009 the team met structural engineer Scott Nyseth, who at the time worked for Miyamoto Earthquake and Structural Engineers. Nyseth was willing to address the nail bearing question. The project could move forward again.

The project manager wondered whether the foam could go on first, with the sheathing on the outside, which might address a whole host of problems, not least bearing for the windows. Initially the team could not see how framers would nail the foam in place by itself because it is not strong enough to walk on over the wall frame. But maybe they didn't need to walk on it. Maybe they could just tack the corners, put the ply over the top, then walk out and nail both layers off together, one time. Nyseth's calculations said it would work. Framers would have to nail the sheathing every 3" on the perimeter (instead of the standard 6") Field nailing remained at 12".

Testing and Permitting

The International Residential Code (IRC) grants prescriptive approval to a number of conventional exterior wall assemblies that are known to deliver adequate lateral bracing and load-bearing capacities. Generally speaking, prescriptive light-frame wall assemblies withstand the forces of gravity, wind, earthquakes, and floods by coupling the vertical-load-bearing capacities of a dimensional lumber frame to the lateral-load-bearing capacities of "wood structural panel," ie: by nailing plywood on the outside of the frame. The lumber frame provides vertical load-bearing capacity, and the plywood sheathing provides lateral load-bearing capacity. The two components rely on one another to deliver their respective capacities to the assembly; neither works without the other.

In August 2009, Green One proposed the intermediate foam TBS wall assembly to Dr. Kofi Nelson, Ph.D, Senior Structural Engineer and Supervising Plans Examiner at Washington County, Oregon, the jurisdiction with code enforcement authority over the project. Dr. Nelson asked for proof that the foam layer between the frame and shear panel would not degrade the lateral capacities of the assembly. He required that the proposed assembly be tested and the proposed buildings be engineered based on the test results. It would be ASTM-E72/CUREE-style cyclic lateral load testing commercial code standard, not residential (IBC, not IRC)) with results that demonstrated conformance with applicable sections of ICC Evaluation Service Approval Criterion 130. That meant the project team would have to commission a full-blown seismic test. Nyseth said the team would test a range of assemblies to develop context for the results.

Dr. Rakesh Gupta at Oregon State University's Knudsen Wood Engineering Laboratory in Corvallis would destroy a series of wall panels, including code minimum (no foam) and panels with 1", 1.25", 1.5", 2", and 4" of foam. With continued support from ODOE, Energy Trust of Oregon (ETO), and the rest of the team, testing proceeded the week of September 14, 2009.

Test Results

The cyclic load tests revealed something that prior static load investigations, such as those discussed in APA[5] Tech Bulletin C456E, had not. Putting the foam between the frame and shear ply had shifted the controlling characteristic of the shear nails. Conventional walls, with plywood nailed tight to the frame, fail under the cyclic lateral loading of the test when the shear strength of the nails overpowers the integrity of the plywood. The nails, embedded in the dimensional frame, tear the edges and corners off the plywood sheets and the assembly disintegrates, separating the shear panel from the wall frame.

Putting the foam between the frame and sheathing shifts the controlling characteristic of the nails. Their strength in bending takes the place of their shear strength as the controlling characteristic of the assembly. The bending dissipates energy, increases the flexibility of the assembly, and protects the assembly against destruction of the plywood by the nails. The dynamic cyclic testing revealed improvements so large that the capacity of the wall assembly lies somewhere beyond the bounds of the destructive test protocol underlying the commercial building code. Figure 2 shows the forces applied to both a conventional light frame wall assembly and to the thermal break wall assembly.

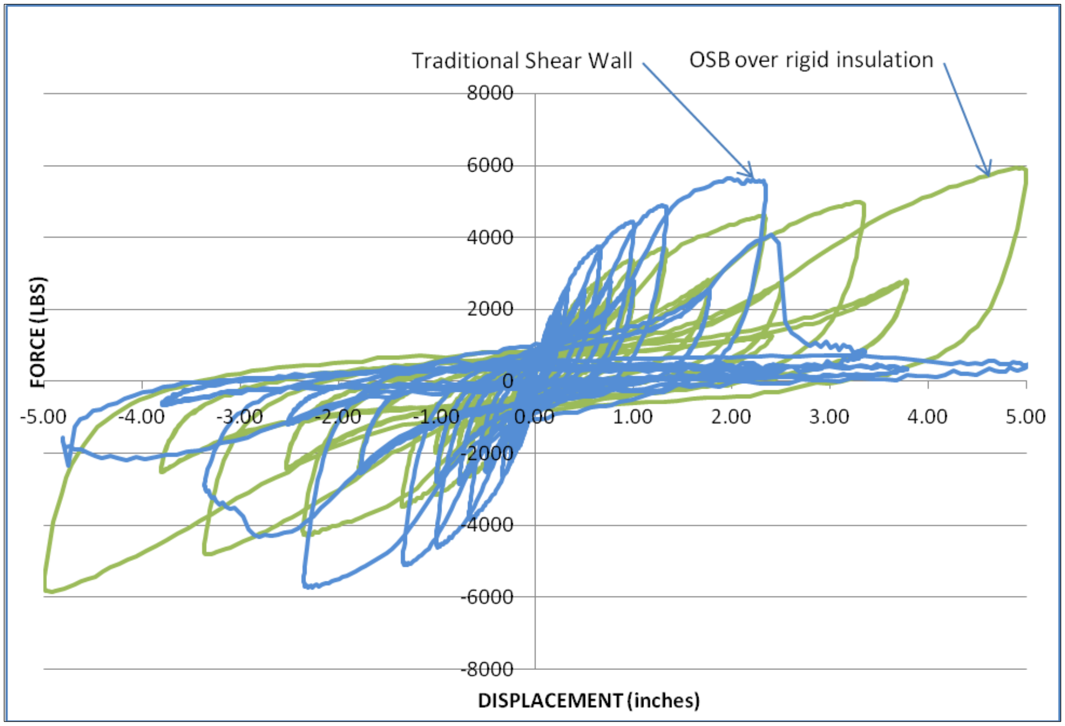
The following quote is taken from the test report summary.

> "The graph below compares hysteresis loops, force curves, from the tests of a conventional wall, and a [TBS] wall. The curves describe wall panels bolted into a test rack, being pushed and pulled increasingly out-of-square by a test cylinder. The blue line shows a conventional assembly reaching its capacity at about 1-3/4" of deflection, under a 5,600-lb load, and suffering catastrophic failure. The green line shows a [TBS] wall continuing to resist deflection with increasing strength as the test reaches its protocol maximum deflection of 5"."

Much to everyone's surprise, The increased flexibility of this wall assembly delivered a higher lateral load capacity than does a conventional wall assembly, and also made the wall much more resilient in the face of the racking motion typical of seismic events.

[5] The full name for APA is *APA – The Engineered Wood Association* (formerly the American Plywood Association)

Figure 3. Comparison of Traditional Shear Wall with TBS Wall



Note: OSB = oriented strand board

Deployment

Dr. Nelson accepted the OSU lab test results and the engineering design based thereon. Washington County issued building permits on January 25, 2010. The general contractor built five houses using the subject assembly, which were completed and approved for occupancy on August 10, 2010. Framing labor to install the foam cost $0.25/ft^2 (FFA). Materials cost another $0.50/ ft^2 (FFA). The deployment of this new wall assembly resulted in a dramatic increase in insulation value for an incremental cost of about $1,500 per home for 2x6 frame construction or about $2,500 per home for a 2x8 frame upgrade.

The only unforeseen complication during construction involved the transference shear strapping commonly used to connect walls to each other across an intervening floor assembly. This transference strapping would not accommodate the foam; as a result, it was moved from the exterior surface of the wall into the cavity, and the conventional flat shear strapping was replaced with hold-downs and bolts. All materials that followed (windows, doors, flashings, cladding system components) were attached by conventional means.

Allowing for cycles of one unit per week, production of each unit took twenty-three weeks – not blazing fast, but not too bad considering the challenges of the project, which included integrating pre-wiring for solar photovoltaics (PV), field design of heat pump water heater isolation and integration with the heat recovery ventilator (HRV), and dragging airtightness down to an average of 2.1 air changes per hour at 50 pascals (ACH50). A total project timeline is presented in Appendix A., which is half of the builders' previous best. Engineering costs, exclusive of testing, ran about $6,000.

Performance

From an energy perspective, The five subject homes at Sage Green appear to be performing according to design. One of the five has provided three years of utility bills that show the house operating consistently as a net generator. (In the absence of any indication to the contrary, it is presumed the other four houses are performing similarly.)

Cost Comparisons

The TBS wall was developed to reduce complexity and cost of improved thermal performance, and straightforwardly prove to subcontractors that this could cause minimal disruptive impact on them. Table 1 shows a comparison of cost and savings ***estimates*** for several different wall assemblies. The following comparisons are based on a 2000 square foot "typical home" design.

Variations in local market supply and demand for labor and materials make it difficult to offer a definitive "most cost-effective" solution; however, the 2x6 TBS wall system consistently offers better "bang for the buck."

TABLE 1. COST COMPARISONS[6]

Wall	Stud Cavity	Batt Type	Insulation ($/ft²)	Materials ($/ft²)	Labor ($/ft²)	Wall Total Cost	Incre-mental Cost	Cost/ft² Floor Area	30-Year Savings	Bang: Buck
Code Minimum	2x6	HD	$0.62	$1.55	$1.85	$7,477	$-	$-	$-	0%
2x6 Standard	2x6	BIB	$0.92	$1.85	$1.85	$8,132	$655	$0.33	$674	103%
2x8 Standard	2x8	HD	$0.82	$1.78	$2.15	$8,638	$1,162	$0.58	$1,700	146%
2x6 TBS	2x6	HD	$1.15	$2.00	$1.95	$8,684	$1,207	$0.60	$2,452	203%
2x8 TBS	2x8	HD	$1.35	$2.35	$2.25	$10,109	$2,633	$1.32	$3,188	121%
2x6 Xrigid	2x6	HD	$1.42	$2.47	$2.55	$11,054	$3,577	$1.79	$2,862	80%

Notes: For Batt Type, HD = high density; BIB = blown-in blanket, XPS rigid refers to an exterior rigid insulation system.

Table 1 does not show a definitive cost analysis (actual costs will vary). The analysis assumes a typical 2,000 ft^2 building built in the Portland, Oregon climate zone. Use of blown-in blanket (BIB) insulation assumed both an increased R-value and a ten percent reduction in infiltration rate. The materials column includes frame, sheathing, fasteners and insulation. The Bang:Buck column is simply 30-Year Savings divided by Incremental Cost; it does not reflect retail price, the time value of money, or the inflation of energy costs over time. The best performance gain for the least cost (currently) is clearly the 2x6 TBS wall with isocyanurate foam. Both the 2x8 and 2x8 TBS walls offer better, and similar bang for the buck options.

Thermal Performance

Table 2 shows a comparison of several different wall assembly systems considered for the project based on 2015 materials cost data.

[6] Table provided by NEEA

Heat loss from a 2x6 TBS wall with 1.25 inches of foam is 2% higher than a wall with 1.25 inches of exterior rigid insulation. The reason is that the exterior rigid insulation of the TBS wall requires a nail pattern 3” on center for the perimeter and 12” on center for the interior, instead of respective 6” and 12” nail patterns. This requirement nearly doubles the number of nails used in a single sheet of plywood, with each nail acting as a small thermal bridge between the exterior and the framing. One additional benefit discovered during construction is that the additional nails also served to slightly compress the foam against the uneven face of the lumber frame, thus reducing air infiltration by sealing gaps caused by variations among studs or by the presence of small debris on the deck when the wall was framed.

TABLE 2. THERMAL PERFORMANCE COMPARISONS[7]

Wall	Stud Spacing	Batt Type	Siding	Rigid Thickness	Rigid Type	No. of nails	Assembly R-value	Cost/ft2 of floor area	U-value	U-value
Code Minimum	16 in O.C	HD	T1-11	0.00	None	54.0	16.7	$-	100%	0.060
2x6 Standard	16 in O.C	BIB	Hardie	0.00	None	54.0	17.4	$0.33	96%	0.057
2x8 Standard	24 in O.C.	HD	Hardie	0.00	None	54.0	22.0	$0.58	76%	0.045
2x6 TBS	24 in O.C.	HD	Hardie	1.25	ISO	104.0	25.7	$0.60	65%	0.039
2x8 TBS	24 in O.C.	HD	Hardie	1.25	ISO	104.0	30.6	$1.32	54%	0.033
2x6 Xrigid	24 in O.C.	HD	Hardie	2.00	XPS	54.0	28.2	$1.79	59%	0.035

Notes: For Batt Type, HD = high density; BIB = blown-in blanket. For Rigid Type, EPS = expanded polystyrene, Xrigid = Exterior XPS rigid insulation

Use of a ventilated rain screen offers benefits. First, it offers better drying potential and durability in the Northwest marine climate. Second, the battens on which the siding is suspended are placed over the tops of the exposed nails, which slightly enhances the thermal properties by reducing heat loss through the heads of the nails.

Based on current pricing for rigid insulation, 1.00-inch-thick polyisocyanurate insulation over a 2x6 stud wall appears to (currently) offer the best blend of cost and performance. A 2x8 advanced frame TBS wall with 1.25 inches of polyisocyanurate offers the best high-performance option. Thicker layers will require a different nail gun that can handle very long shank nails. The extra cost of fasteners and the higher risk of missing the stud dissuaded the team from pursuing thicker thermal breaks. While the use of polyisocyanurate may be appealing, one of the side benefits of the lower-density expanded polystyrene (EPS) insulation is that it more easily forms an air “gasket” that reduces lateral air leakage in the wall assembly and also at the seams of the 4x8 sheets of oriented strand board (OSB). The analysis summarized in Table 2 did not include this added airtightness.

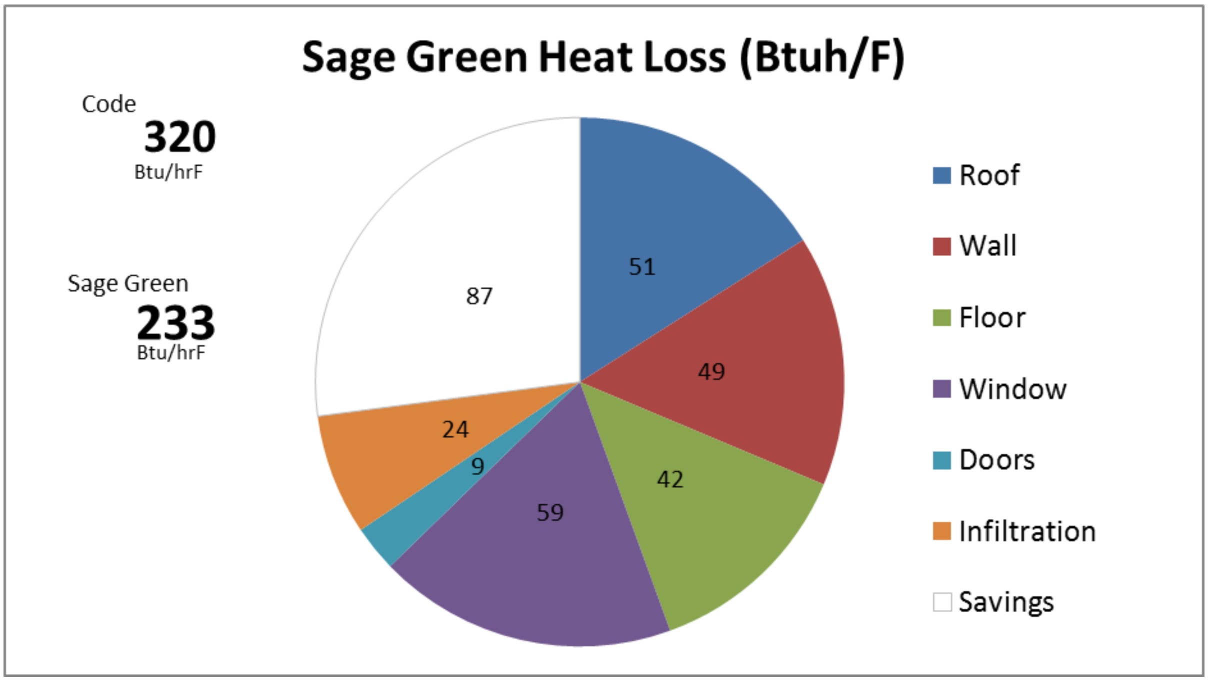
Sage Green Compared to Code

The 1500 square foot Sage Green homes were built with a TBS wall with a 2x8 frame with 1.25 inches of exterior medium density expanded polystyrene. Compared to the standard 2x6 code wall with an

[7] Analysis of thermal performance provided by NEEA

effective R16.7 value, this wall system has an effective R28.1 value (effective). Sage Green project also facilitated achievements of a continuous air barrier and an air exchange rate of 2.1 ACH50. These achievements, combined with triple-glazed low-e windows upgraded from the code minimum of 0.35 Btu/hr-ft^2-^{0}F to 0.26 Btu/hr-ft^2-^{0}F, would result in a twenty-seven percent decrease in the annual design load of one of the Sage Green homes (see Figure 3). This improves comfort and enables a smaller-sized mechanical system for an incremental cost of about $2,000. The occupants of such a home would save roughly $5,000 in heating costs over the first thirty years, assuming energy costs remained constant.

FIGURE 4. DESIGN HEAT LOSS SAGE GREEN HOMES



Conclusions

The Sage Green project successfully delivered a thermal break wall with minimal increase in labor costs or impacts on the construction schedule.

The intervening years have seen a number of products enter the market (such as the OX SIS-brand structural insulated sheathing and the Premier Insulfoam ci Panel; see Appendix B) that offer pre-assembled sheathing on foam (a thermal-break shear panel). As the practice becomes more common in both the manufacturing and building sectors, the efficiency of factory assembly of the two components will beat field assembly by an increasing margin.

The intervening years have also seen the publication of ICC Evaluation Service's (ICC-ES') evaluation report ESR-2586. While ESR-2586 is both obscure and arcane APA, the Oregon Building Codes Division, and the City of Portland's Bureau of Development Services all acknowledge that the document confers prescriptive path approval for lateral bracing under International Residential Code (IRC) Table 602.10.2, Method WSP,[8] on an assembly with up to 1" of rigid foam plastic insulation installed between the wall frame and the shear ply.The City of Portland has approved a permit for a home using an ESR2586 TBS wall for lateral bracing: 5467 NE 64th Avenue).

As a matter of trade practice, the assembly presented in this report proved to be a very effective means for adding a thermal break. It significantly simplified the foam installation process and minimized disruption to other established trade practices. Moreover, under testing, the assembly exhibited significantly different seismic characteristics and significantly higher capacities than its conventional cousins (see Section 2.3).

The success of this project would not have been possible but for the dedicated involvement of the Oregon Department of Energy, Energy Trust of Oregon, Oregon State University, and numerous, similarly bold, private providers.

[8]WSP = wood structural panel

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Appendix A – Timeline of Project

Fall 2007	Initial contact with ODOE re: demonstration/pilot OHPH details and related E* and Federal EENH tax credit matters. ODOE poses question of "thermal break." Sage Green site is acquired in October.
2008 through Spring 2009	Conversations with various project teams and industry advocates about continuous rigid sheet insulation fail in the face of cost concerns/ poor presentation of value proposition. No deployment opportunities emerge. Sage Green entitlements are secured, site development/subdivision improvements begin, development of preliminary construction details.
June 7, 2009	Extended search for structural engineer willing to participate in designing advanced wall assemblies brings Scott Nyseth of Miyamoto International to the project team.
June 24, 2009	Wall mock-up workshop at Mercer Windows, Beaverton, Oregon. With various material and trade providers in attendance, we build a wall with continuous rigid insulation over a conventional light frame assembly, with WRB, penetration flashings, and window installed directly over the foam.
Summer 2009	Miyamoto engineers brace walls constructed with rigid insulation (thermal break) between wall frame and shear ply.
September 2009	Foam walls are tested at OSU.
January 2010	Building permits are issued.
August 2010	Buildings are completed.
July 2011	Sage Green is foreclosed, units are sold for $199,000.
November 2014	Three years of utility meter data demonstrate net-positive operation.

Appendix B – Relevant New Products

Composite Panel Building Systems CPBS C-SIS:
http://compositepanelbuildingsystems.com/products/composite-structural-insulated-sheathing/

OX Engineered Products Styrofoam SIS:
http://oxengineeredproducts.com/building-products/styrofoam-sis-insulated-sheathing/

Premier Insulfoam ci Panel:
http://198.1.103.52/~premigk1/wp-content/uploads/2014/05/Premier-ci-panel_lo.pdf

Appendix C – Supplemental Materials

Supplemental Materials are available from NEEA.

Engineering Test Report
Miyamoto International, approved Sage Green Engineering package and OSU test report
NOTE – Not all videos taken are provided

Engineering Structural Calculations
Document of calculations used in permit application
*NOTE – document on NEEA site only includes calculations relevant to wall system (**not** a complete set of calculations for the entire home)*

Permit Drawings
Sage Green permit drawings for one of the homes
*NOTE – document on NEEA site does **NOT** include all pages of permit drawings. Scanned set includes those pages relevant to wall system design.*

OSU Lab Destructive Test Videos
Videos taken of the destructive testing at OSU Lab demonstrate the difference between TBS walls and conventional OSB on frame walls. Three sample videos are available on Vimeo that shows how the tests were conducted and how the TBS wall remained intact to maximum point of deflection without the nails destroying the OSB shear panel.
NOTE - there is no audio with videos

OSU TBS Wall Test Video 1
0:00 Minutes Test Wall #2 – OSB on standard frame wall (OSB damaged)
5:32 Minutes Test Wall #3 – TBS wall
10:58 Minutes Test Wall # 4 – TBS wall

OSB TBS Wall Test Video 2
18:34 Minutes Test Wall # 4 – TBS wall (end of test)
25:00 Minutes Test Wall # 6 – TBS wall (good close up shots of nails during deflection)

OSU TBS Wall Test Video 3
0:00 Minutes Test Wall #7 – TBS Wall with sheetrock
4:26 Minutes Test Wall #8 – TBS Wall with sheetrock (good images of sheetrock impact)
9:35 Minutes Test Wall #9 – TBS Wall with sheetrock (good images of OSB impact)