Case Study

Improving energy efficiency and seismic resiliency in older housing stock

Completed for
CARBON NEUTRAL CITIES ALLIANCE

Authored by
EARTH ADVANTAGE
on behalf of:
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USE OF THIS DOCUMENT

ABOUT EARTH ADVANTAGE

Earth Advantage is a Portland, Oregon based nonprofit whose mission is to accelerate the creation of better buildings. They provide knowledge to building professionals, and information to consumers through certification, research, education, and product development.

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DISCLAIMER

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Introduction

THE TWIN CHALLENGES: CLIMATE AND SEISMIC

Cities throughout North America and in various regions worldwide grapple with the twin challenge of creating deep carbon reduction to meet climate goals and preparing for seismic events that could prove catastrophic to their existing housing stock.

Building codes for new construction in forward-thinking cities, states, and nations are moving toward net-zero energy buildings, but there are huge stocks of existing buildings that must be upgraded to achieve long-term carbon goals. In Seattle, Washington, Vancouver, British Columbia, and Portland, Oregon, alone, more than 300,000 single-family homes and tens of thousands of smaller wood-frame multifamily buildings lack basic insulation. To date, highlighting potential energy benefits by themselves have proven to be insufficient to drive widespread retrofits. Pairing energy improvements with other motivators provides an opportunity to move the market. The growing recognition of the need to improve seismic resilience (partly resulting from the 2011 earthquake and catastrophic tsunami in Tohoku, Japan) suggests there is great potential in developing a new approach in which improved energy performance and earthquake preparedness are performed in a single retrofit.

Wood-frame construction is by far the most prevalent housing type in cities throughout Canada, the United States, Australia, and New Zealand for single family and low-rise multifamily dwellings. This type of construction is also common in other parts of the world, including Japan. Single-family homes and small multifamily buildings built prior to 1989 are a significant percentage of the housing stock of most metropolitan areas. In the Pacific states region of the United States (California, Oregon, Washington, Alaska, and Hawaii) there are approximately 13 million single-family dwellings built prior to 1989. A majority of the dwellings built prior to the 1980s have very little or no wall insulation. In the Pacific Northwest states of the United States, about a quarter of all homes are without any wall insulation and are also highly vulnerable to seismic events.

What are now considered "high performance" heat pumps, water heaters, lighting, appliances, and windows will all become standard in the near future, therefore creating a need to cost-effectively address the primary remaining element in a deep energy retrofit: the thermal upgrade of walls. This evolution will result in a performance pathway for deep energy retrofits and zero energy-ready levels of performance in older residential buildings. Walls are the weakest thermal element in most older buildings, the most difficult to upgrade to high levels of energy performance, and usually the focal point of seismic failure. The opportunities to add cavity insulation within walls are limited and built up exterior insulation can require expensive levels of detailing. The addition of significant exterior insulation at the same time a siding replacement is planned saves the labor of removing and reinstalling the cladding to accommodate the insulation later. And because the walls contain the largest surface area of a typical residential structure, they provide the building's primary planes for effective additional insulation and air sealing.

Within the last decade, high-performance building envelope assemblies that provide both significant energy efficiency and seismic resiliency benefits are being introduced as a promising emergent practice in the new home construction industry.[1] However, similar assemblies have yet to be tested, analyzed, or documented as an effective strategy to produce scalable energy savings and improved seismic resiliency in the retrofitting of older wood-frame housing. The project seeks to address this knowledge gap.

[1] https://neea.org/docs/default-source/reports/thermal-break-shear-wall-a-case-study-of-rigid-foam-insulation-between-frame-and-sheating.pdf?sfvrsn=4

Retrofitting Walls

PROJECT THESIS

A particular approach, the Thermal Break Shear (TBS) wall assembly, is gaining interest in new construction. Energy-efficiency professionals have begun promoting the TBS wall system to builders as a cost-effective alternative to traditional approaches. Lab testing has determined that the wall system also meets sheer strength requirements and delivers much higher lateral load capacity than conventional new construction wall assemblies[2]. TBS wall systems offer greater resilience in the face of the racking motion typical of seismic events. Like a bamboo tree, the TBS wall exhibits an impressive range of flexibility will retaining strength. It does so while also simultaneously providing a continuous thermal break.

The City of Portland and its partners, Earth Advantage and Owens Corning, identified an opportunity to determine if this same approach to walls could be applied effectively to retrofits of existing residential detached and attached (townhouses, duplex, triplex, 4-plex etc.) housing. The replacement of siding and windows is a regular activity on older wood-frame residential building stock. Siding replacement will be needed with increasing frequency as the useful life of products on many post-1950's homes and buildings comes to an end. That replacement activity represents the opportune time for an energy and seismic intervention, as long as that activity is merely an incremental piece of work within a larger rehabilitation scope of work. If the implementation showed promise, it could be used as an approach to address the dual policy challenges of carbon emissions reduction and seismic resiliency. With the appropriate post-project promotion, market awareness, and new policy mechanisms, TBS wall retrofit activity could then be implemented across the multiple jurisdictions addressing climate action and seismic resiliency.

The City of Portland's project team sought to analyze whether using a TBS wall assembly approach in retrofitting homes and small apartments could address three key market barriers and show opportunity for cost-effective scalability:

Barrier	Project Inquiry
Energy-efficiency retrofits rarely go beyond "low hanging fruit" opportunities.	Could the twin benefits of resilience and greater energy efficiency in the TBS wall assembly address this barrier?
Most ultra-energy efficient and seismic solutions are high cost options.	Could the TBS wall assembly prove a relatively affordable option for wood-frame structures already undergoing a siding and/or window replacement?
Product manufacturers, residential contractors, engineering firms, and government agencies are largely unaware of the TBS wall assembly option.	Could market awareness increase with this project example?

Table 1: Barrier & Project Inquiry

THE TBS WALL ASSEMBLY

The TBS wall assembly is actually a "family of assembly options" in which a continuous layer of rigid foam insulation is sandwiched between the structural sheathing and standard framing to create a "thermal

[2] https://vimeo.com/156026994

break shear" wall for significantly increased energy efficiency and a nailing pattern that creates laboratory-verified seismic resiliency benefits.

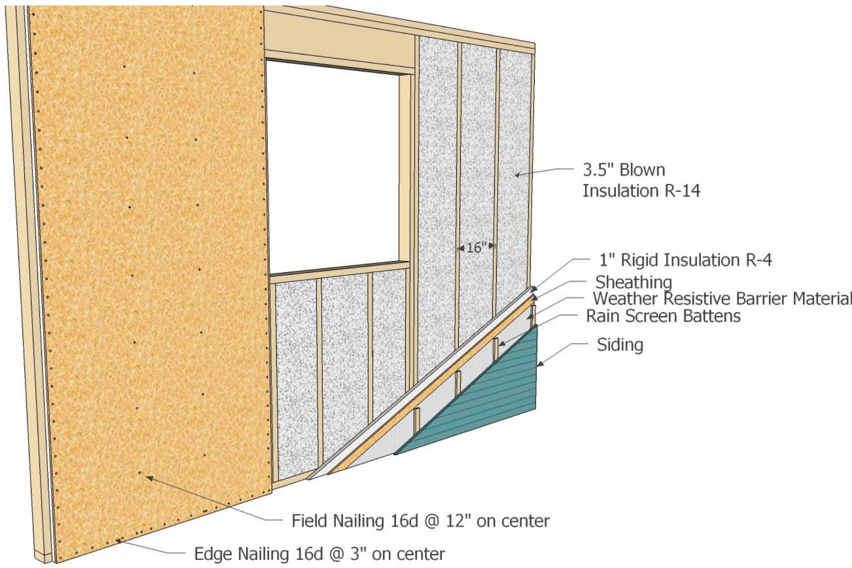


Figure 1: TBS Wall Diagram

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 panel systems. For the purposes of this retrofit project, the project team selected to use field assembly. This was selected for two reasons: 1) appropriate factory assembled panels were not easily or affordably located in Oregon at the time of the project specification 2) field assembly could be undertaken by typical residential contractors possessing diverse skillsets and knowledge levels.

From an energy efficiency perspective, the TBS wall assembly approach contrasts with traditional "drill and fill" wall insulation, which creates marginal increases in energy savings. It also contrasts with typical seismic retrofits that tie foundations to framing in a complex and costly "bolt and epoxy" process. Therefore, only very rarely are both advanced energy-efficient improvements achieved and seismic resiliency addressed in residential attached and detached retrofit projects. By combining seismic and thermal upgrades in one solution, the TBS wall assembly approach has the potential to simplify the process for property owners to more affordably address seismic concerns and achieve maximum efficiency levels.

Initial research evidence in new construction applications suggests that the TBS wall system provides a good return on investment in incremental energy savings as compared to current code minimum wall assemblies of R-21. This type of wall assembly has been shown to supply excellent energy performance, cost-effectively achieving greater than more energy efficiency than standard new construction built to R-33. The TBS wall assembly has also 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 sheer strength requirements and deliver a much higher lateral load capacity than conventional new construction wall assemblies. Given the positive research results produced on TBS wall assemblies for the new homes market, the project team sought to analyze whether a similar approach could potentially work on typical residential retrofits and have transformational impacts on the ageing stock of existing dwelling units.

PILOT SITE DESCRIPTION

The site selected for testing the TBS wall assembly in a retrofit application was the renovation of a 1906 single-family detached house in Portland, Oregon. The house is located in the Lair Hill neighborhood within the South Portland Historic District, offering an opportunity to demonstrate that the wall system can be used in applications requiring that the home remain visually the same as prior to the update. Aside from changing the color of the house, the owner's project team had to adhere to strict historic district requirements that allowed imperceptible changes to the front elevation and no changes to the site plan.

Figure 2: Before and After Retrofit

The site offered an excellent, though somewhat more complicated, prototype of a residential siding replacement project. The project owner sought to perform upgrades to the house to create more livable space in the basement and provide more insulation and air tightness to achieve higher levels of energy efficiency. When offered the opportunity to implement the TBS wall system, the addition of greater seismic resilience became another compelling rationale. In a city where similar homes are frequently replaced with larger new homes, the owner sought to "make the house better so that it will last another 110 years."

While the scope of the entire renovation included multiple other activities, the TBS wall portion of the project called for:

- removal of existing siding
- insulating the exterior walls from the outside in
- adding a layer of rigid foam insulation with plywood sheathing to create a shear wall
- fitting new sills and flashing around the existing efficient windows
- installing new siding and painting it to new specified color

Pre-upgrade energy assessment and modeling results

To evaluate the energy-efficiency benefits of the wall assembly for retrofits, the project team conducted an on-site energy assessment using the U.S. Department of Energy (DOE) Home Energy Score modeling software prior to the TBS wall installation. The energy modeling predicted that given the home's existing attributes, which included a ductless heat pump, the TBS wall system would save 2,037 kWh/yr, or a 27% energy use reduction. If the same home had instead had an electric resistance heating system, the savings from the TBS wall would be 4,860 kWh/yr. The pilot home sought to increase both the insulation levels and the air tightness of the envelope of the house, while also increasing the total square footage of the conditioned space. The assumed change in energy usage is detailed below:

Energy Consumption		
Annual kWh consumption in 12 months preceding start of project:	13447	kWh
Approximate original area of conditioned space (with 2 indoor DHP heads):	1090	sq. ft.
kWh / sf prior to renovation:	12.34	kWh / sq. ft.
New total conditioned square footage:	1586	sq. ft.
Modeled / predicted annual consumption (with blower door test) after TBS installed (including new square footage):	9265	kWh

Table 2: Energy Consumption

Product and Components

The project selected to field assemble the TBS wall system, which included the following components[3]:

- 1" rigid Extruded Polystyrene Board Insulation was specified. Owens Corning provided 1" x 48" x 96" panels of their FOAMULAR™ 150 product. This is a is a closed cell, moisture-resistant rigid foam board
- 7/8" Oriented Strand Board (OSB) was used for sheathing.
- TBS wall components are cut and assembled with standard products, tools, and fasteners. The TBS approach provides sheathing at the exterior of the wall assembly that provides a base layer that is compatible with tested fastener schedules for standard siding materials.
- The nailing pattern included field nailing with 16d nails at 12" on center and edge nailing with 16d nails at 3" on center.
- Additional 2x4 wall studs as needed.
- Window sill and door jamb extensions.

In addition to the TBS wall, the house's new basement perimeter wall was built with double 2x4 framing at 12" OC, with a minimum of 4 studs around each window, further reinforcing the structure of the house.

Requirements

In Portland, a typical siding replacement project does not require a building permit, although "replacing 50% or more of exterior wall area" does trigger a permit. The installation or replacement of insulation can, in some instances, also trigger a building permit. In the case of the TBS wall system, it would therefore also trigger a building permit and inspection by a city building official because it could be

[3] See Appendix A

considered a "seismic upgrade". It appears that a structural engineer would not be required to provide drawings / calculations specifically for TBS wall installs being done in lieu of a standard siding installation. However, a structural engineer may be useful or required when: 1) other foundation/structural work on the house is being pursued, 2) to document for insurance purposes 3) for seismic improvement-related financing. In the case of this TBS wall project demonstration, a structural engineer did provide an analysis and calculations.[4]

The use of the TBS wall assembly did not impact the project schedule adversely. That said, it is worth noting that projects of this type can encounter delays for other reasons. Because the house is in a historic district, a land use application was required to be submitted to the City of Portland's Bureau of Development Services prior to application for the building permit. Any exterior work that might potentially change the look of the house triggers a land use review in a historic district, and the TBS wall retrofit meets these parameters, although it was not the only factor potentially impacting the look of the house in this project. The land use review application was submitted in mid-May 2017, and after iterations in the drawings due to the historic review process, the South Portland Neighborhood Land Use Committee was also required to vote to support the project application. Then a public comment period for the Historical Review followed. The city of Portland's Bureau of Life Safety, Bureau of Environmental Services, and Bureau of Transportation all provided comments that supported the approval of the project application. All told, despite things moving as quickly as possible, the historic and land use review delayed the project start by about two months, but the project concept was ultimately approved in mid-July 2017.

Once comments and notes from the Structural Engineer were added to the primary drawing set, the contractor first attempted to pull the building permit in mid-August. On the first attempt, the contractor and owners were informed of an ordinance that required an additional, unplanned delay in the project start. The Major Residential Alterations and Additions (MRAA) ordinance stipulates that the owners of certain types of projects have to inform their neighbors and Neighborhood Land Use Committee of their project, in addition to a mandatory 35-day delay to permit issuance. The MRAA ordinance, which was enacted in 2015, stipulates that four types of projects qualify:

1. Adding any new story, including a basement or other below-grade structure. Raising a structure to meet the required headroom in a basement is considered the same as creating a basement;
2. Increasing or replacing 50 percent or more of the exterior wall area on any floor. If the subflooring under an exterior wall is removed, it will be treated as if the wall was removed;
3. Adding total new floor area to the existing structure that exceeds 800 square feet; or
4. Adding an area exceeding 100 percent of the existing foundation footprint area of the structure.

It is worth noting that, although this project would have qualified for the MRAA ordinance under the first project type due to its work in the basement anyway, the City of Portland's definition of "replacing 50% or more of the exterior wall area on any floor" means that TBS wall retrofits could also trigger the MRAA ordinance. This may be an area that could be clarified by jurisdictions and where exemptions could be provided in cases where exterior wall enhancements like a TBS wall are being undertaken.

Pilot Site - TBS Implementation

While the project was scheduled for a summer installation, actual installation of the wall system did not begin until the winter months. With respect to weather, there were certain times that were not ideal for working on the exterior, namely when it was raining in the coldest part of winter. During this type of weather, the existing home wall cavity could not be exposed to the elements for any duration of time due to concerns that it would not dry out. In this project, if the walls were open and rain was expected, they

[4] See Appendix C

were tarped until each wall could be worked on. Additionally, TBS wall requires a lot of nails and motor skills tend to deteriorate if they can't be kept dry in cold weather. For this reason, if time is the prevailing issue, then homeowners may not want to undertake a TBS wall retrofit in the middle of winter. This would be true in a typical siding replacement, as well. However, a "drill and fill" insulation job may have an advantage due to the fact that the entire wall cavity is not opened up.

Project work on the TBS wall portion began in earnest in January 2018 with the siding removal. The initial project estimate included salvaging and reusing the existing wood siding. However, when the siding was removed, the lead paint levels on the exterior were deemed too toxic and all the siding needed to be disposed of safely, rather than salvaged. This increased the cost of the siding portion of the project by about 20% and added several days to the TBS wall portion of the construction schedule.

Siding Removal

As noted in the figures below, when the siding was removed the general contractor found that that house lacked sheathing and, in some areas, any wall insulation.

Figure 3: Siding removal

Figure 4: Siding removal 2

Rigid Foam Installation

Approximately 2 weeks later, Owens Corning's FOAMULAR™ Extruded Polystyrene Board Insulation was installed over the existing and new insulation in the wall cavities. Note the new 2x4 wall studs added to the houses framing in Figure 5 and Figure 8.

Figure 5: Rigid foam installation

Sheathing Installation

Approximately one week later, the OSB sheathing was installed.

Figure 6: Sheathing installation

Figure 7: Specific nailing pattern

Figure 8: TBS wall layers on old and new wood studs

The specified nailing pattern was utilized (see Figure 7). This nailing pattern is critical to the seismic resiliency element of the TBS wall assembly.

Weather-resistant barrier (WRB), rainscreen and new siding

Figure 9: Weather-resistant barrier

Finally, the weather resistant barrier, vertical furring strips for the rainscreen, flashing details, and the new siding were installed.

Note that each layer was added sequentially, with a few extra details: "wonderboard" cement board was installed over the pony wall area where the house was raised. (see Figure 11 and Figure 12)

Figure 10: Weather-resistant barrier and rain screen

In most places, trim board only needed to be added – not torn out and replaced – around the existing windows, thus keeping labor costs down. A feature of this historic house is the trim board that encircles the house at a consistent elevation. Flashing was installed behind the trim board above the cement board; then the trim board was installed directly above the cement board; and then more flashing was installed above that, behind where the new siding terminates.

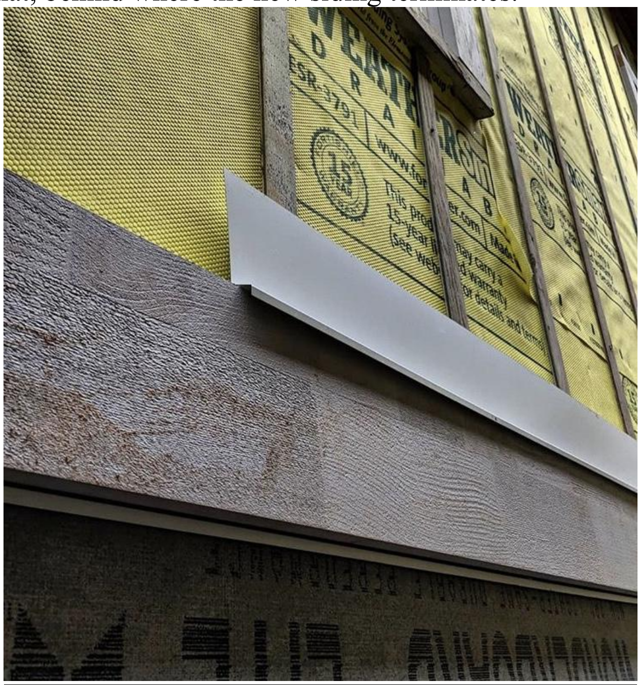


Figure 11: Weather-resistant barrier, rainscreen, and flashing

At the final stage of exterior retrofit, the siding is in place, along with trim boards at the corners of the house and around the windows. Caulking is applied where the new siding hits the trim around doors and windows.

Figure 12: New siding installation

Site constraints and challenges

The pilot site constituted some unique challenges, namely because the property is on such a small piece of land. The primary challenge the general contractor faced when installing the new wall system was the narrow working conditions between the north side of the home and the neighboring house. The contractor noted that the gap between the project house and his own house was so small - roughly 3.5’ - that he and his crew couldn’t even put up their normal scaffolding for the TBS work, and had to actually bring in an alternative scaffolding set up. The contractor also noted that the lack of extra room on the site meant that materials were stored wherever they would fit, and his crew was often working on the sidewalk in front of the house to cut materials.

Figure 13: Narrow working conditions

TBS wall installation timeframe

While planning, engineering, design review, permitting and general construction delays occurred, none were related to the application of the TBS wall system. City permitting site inspections of the TBS wall systems raised no concerns or caused any project delays. The TBS wall portion of the project took approximately 6 weeks to complete. However, this included a pause for inclement weather, other construction priorities, and lead abatement of original siding. Without those issues, the install of the TBS wall took approximately 4 weeks. All told, the contractor estimated that the total amount of time it would take to do a TBS wall retrofit for a typical single family home under “normal” circumstances - i.e. more comfortable site conditions, no lead abatement - would be under 3 weeks from demo of existing siding to new siding installation.

The general contractor's opinion was that if a combined system of pre-fabricated TBS wall components had been used it would not necessarily have reduced time or labor costs. He stated that the rigid foam insulation was easy to work with. Because the shear wall is required to be attached to studs, additional studs needed to be added occasionally. Adding new studs did increase labor time and TBS wall costs.

Table 3: TBS Installation Costs

Activity	Job Type	Line Item	Cost per	Cost Per Sq. Ft.	Total Cost
Baseline 1	Basic siding (cedar lap siding) replacement project with no added insulation or sheathing.	New siding & rainscreen – materials	$6,269.04	$6.73	$13, 469.04 ($14.46 sq. ft.)
		Labor to install siding & rainscreen	$7,200.00	$7.73	
Baseline 2	Typical siding replacement project (above) with addition of standard sheathing and weather resistant barrier.	OSB and WRB-materials	$702.00	$0.75	$17,420.00 ($18.70 sq. ft.)
		Labor to install OSB or plywood	$3,249.00	$3.49	
TBS Wall	Complete TBS wall assembly – additional wall studs, rigid insulation, sheathing, rainscreen, exterior jamb extension, and new siding.	Materials	$779.20	$0.86	$21,448.20 ($23.05 sq. ft.)
		Labor to install rigid foam insulation etc.	$3249.00	$3.49	
				Incremental Cost	$4,028 - $7,979 ($4.35 - $8.59 sq. ft.)

Pilot Site Results and Conclusions

The project team identified key performance indicators to evaluate the relative potential of TBS wall assemblies to reach scalability. These key performance indicators (KPIs) of the TBS wall assembly include:

Table 4: KPIs & Project Results

Project KPI	Project Result
Impact on permit approval	No impact on project permit approval. Would likely require permit in cases were basic siding replacement would not.
Projected energy savings	Energy efficiency estimated to be improved by 31%. (actual energy savings to be analyzed post-occupancy)
Air tightness of construction	There was a 21% reduction in infiltration rates solely from the TBS wall assembly.
Incremental cost	Reasonable incremental cost of $4.35 – $8.59 sq. ft.
Impact on construction timeline	No impact on the original project timeline. Estimated time difference between TBS wall assembly and basic siding replacement project is 7-14 days.

POTENTIAL SCALABILITY IN RETROFITS

Only very rarely are both significant energy-efficiency improvements and seismic resiliency addressed in residential attached and detached retrofit projects. A major barrier to addressing both optimized energy efficiency and seismic performance in older wood-framed housing rests primarily in addressing the framing and wall assemblies. The results of the TBS Wall retrofit project suggests that given the right circumstances, the scalability of this approach is achievable. Although the TBS wall system is somewhat more costly than a typical siding replacement project, it is also appears to be a more cost-effective approach than traditional seismic upgrade options while also providing considerably better energy performance and energy cost savings benefits.

The following factors should be considered as a means to achieving scalability in multiple geographies:

Increased diversity of products

A benefit of the TBS wall approach is that it is generally product agnostic. Because the approach is not tied to one proprietary product or suite of proprietary products, the TBS wall can be undertaken by a wide-range of contractors who have business relationships or allegiances to particular manufacturers. This flexibility also extends to factory assembled "TBS wall-like" products that may be more available and widely known in some markets.

Makers of component materials, especially manufacturers of Extruded Polystyrene Board Insulation, can market their product as an integral part of this fairly simple wall assembly approach that non-specialized contractors can implement. Even a year ago, factory produced sheathing and foam products were difficult to locate and not marketed by manufacturers for energy and seismic benefits. Increasingly, these products are finding greater traction in new construction, especially given requirements included in the most recent update of the International Energy Conservation Code (IECC) for climate zones 6 and above. To our knowledge, these products are not yet being promoted as having potential seismic benefit however and may in some cases not be able to offer these attributes. At least three manufacturers have developed factory-assembled wall systems that could potentially provide TBS wall-like benefits:

- Zip-R panels from Huber Engineered Wood
- Insulfoam ci Panel from Premier SIPs
- ThermalStar LCi-SS from Atlas EPS

In addition to these products, a number of panelized systems designed for roofs are now being marketed for use on walls.

Fannie Mae Financing for TBS Wall retrofits

In early 2018, Fannie Mae announced that its HomeStyle Energy mortgage product will allow borrowers to use the product to make resiliency upgrades that improve the home's ability to withstand environmental hazards, in addition to making their home more energy efficient. Borrowers can finance up to 15% of the "as completed" appraised property value of a home that undertakes energy improvements or resiliency upgrades. This financing can be used when purchasing or refinancing a home. This represents an important pathway for TBS wall projects to be easily financed and amortize the cost over a typical 30-year mortgage.

Local government policy mandates

In Portland, planned commercial building retrofits can sometimes trigger a mandated seismic upgrade. The city is also currently considering a requirement for Unreinforced Masonry Buildings (UMBs) to be seismically enhanced. These UMBs often include residential structures like smaller, 2-3 story early 20th century-era apartment buildings. To meet climate goals and prepare housing stock for future earthquakes, local governments could consider similarly requiring that a TBS-like wall assembly be installed in certain circumstances. For example, pre-1980's vintage homes or residential buildings located in particularly seismically vulnerable sections of the city could be required to undertake a more holistic upgrade using a TBS wall -like approach if a siding replacement or significant renovation is being considered.

Combined local government and utility incentives

As noted above, there appears to be an incremental cost associated with the installation of the TBS wall assembly over standard siding replacement projects and certainly over traditional "drill and fill" wall insulation retrofit approaches. However, the increased energy efficiency and related ancillary seismic benefits are compelling. Therefore, a combination of local government and utility energy efficiency program incentives could potentially help to buy down some of the incremental cost of the installation.

Local government permitting

Local jurisdictions could also assist in easing some permitting requirements related to use of systems like the TBS wall. For example, the city could clarify its stance on exterior envelope retrofits triggering the Major Residential Alterations and Additions (MRAA) ordinance because the additional time and costs of permitting could act as a deterrent to homeowners who are otherwise interested in an energy efficiency and seismic resiliency retrofits.

Contractor engagement

As an industry group, residential contractors are one of the most likely group of professionals to convey the benefits of the TBS wall systems to the market. In the Portland-area, industry associations like the Home Performance Guild of Oregon and non-profits such as Enhabit could provide contractor trainings, program support, and promotional assistance. A city's leadership on the issue would likely be needed in order to fully engage industry groups such as these.

Manufacturer specifications

The participation of Owens Corning in this project demonstration highlights the potential for certain product manufacturers to begin to market their product for use in TBS-like wall assemblies. Manufacturer specification documents are useful to document the potential applications of products or product systems in applications, like seismic retrofits, that differ from the original design intent of the product. Manufacturers obviously also have extensive reach, including networks of loyal contractor clients.

Structural engineers

While perhaps not often involved in a majority of single family detached housing siding replacement projects, structural engineers are likely to be engaged in small multifamily renovation projects. In those projects, structural engineers could be a source of information about the TBS wall approach as an alternative to other structural enhancements.

Affordable housing providers

Although often capital constrained, affordable housing providers do have a longer-term perspective as owner/operators of properties. When considering siding replacement needs of their properties, affordable housing owners are a very likely group to appreciate the cost savings and resident benefits of the TBS wall approach. Those receiving public funding could also be required to undertake upgrades that address their tenant's exposure to seismic events.

Identifying other potential ancillary benefits

Due to project constraints, several analytical tasks were removed from the project scope. Despite this, the project team, including the project owner, is interested in tracking and reporting on several factors that could add to this TBS wall case study. For example, noise mitigation is a promising potential ancillary benefit of the TBS wall system, especially for multifamily complexes located in denser, more urbanized areas. Because the pilot home is located next door to a "sister" home of the same vintage and construction type, a side-by-side comparison of the acoustic impacts of the TBS wall can be done fairly easily.

Conclusion

With greater frequency and increased urgency, municipal governments are recognizing the potential disruptive impacts on their citizens of climate change and seismic events. Preparing to address both of these issues is challenging for any local government and requires foresight, planning, persistence, a strong solution set, and effective communications to its citizens.

The City of Portland began addressing climate change issues in the early 1990's. In 1993, Portland was the first U.S. city to create a local action plan for cutting carbon. Portland's Climate Action Plan (CAP) is a strategy to put Portland on a path to achieve a 40 percent reduction in carbon emissions by 2030 and an 80 percent reduction by 2050 (compared to 1990 levels)[5]. Portland's climate protection planning efforts have emphasized its inextricable link to actions that "create and maintain jobs, improve community livability and public health, address social equity and foster strong, resilient natural systems." Similarly, the city's vulnerability to seismic events was not recognized until fairly recently. It was not until the 1980s that scientists recognized the Cascadia subduction zone as an active fault that poses a major geological hazard to Portland and the region. It was not until the 1990's that the state's building codes were updated to address this newly revealed earthquake threat to the built environment. Since that time, Portland has begun to emphasize seismic resiliency planning and has focused on developing policies that address particularly vulnerable building-types and municipal infrastructure[6].

Portland is particularly interested in supporting solutions that meet multiple goals and address several risk factors simultaneously. The TBS wall approach has the potential to become part of Portland's broad solution set to achieving the goals set out in the Climate Action Plan (i.e. that homes built prior to 2010 becoming 25 percent more energy efficient by 2030) while also helping to make progress in seismic resiliency efforts. However, the TBS wall approach is not currently being used in the marketplace as a means to cost-effectively address deep energy retrofit and seismic resiliency challenges. Implementation of the TBS wall approach for building retrofits is currently non-existent due to a lack of verified real-world examples, lack of energy and cost analyses, lack of building industry awareness to potential seismic benefit, and lack of public sector engagement. The testing and introduction of the TBS wall assembly for residential retrofits undertaken in this project begins to address these gaps in knowledge. The project demonstrates that, in certain circumstances, the TBS wall approach can be a simpler, more cost-effective approach to producing both critical energy efficiency and seismic resiliency results for municipalities and its citizens.

Further work is required to ensure there is increased awareness of the TBS wall assembly approach and that its use is replicated with enough frequency to prove impactful. Motivating homeowners to spend their often-limited resources to prepare for uncertain future events is difficult. It is the project team's contention that the dual benefits of the TBS wall assembly approach make this messaging effort potentially more effective. Cities, community groups, and the private sector will all play an important role in increasing the awareness of the ways homeowners can take action to decrease their susceptibility to seismic events *and* decrease their monthly energy costs. Coordination and collaboration amongst these sectors would be ideal. Without a public-sector emphasis on planning for both climate mitigation and seismic resiliency, residents are unlikely to take action on their own accord. Without cost-effective, market-ready technological or design solutions from the private sector, the municipality is limited on

[5] https://www.portlandoregon.gov/bps/49989
[6] https://www.portlandoregon.gov/cbo/article/563412

what can be promoted or prescribed. And without willing and engaged community groups as partners, residents within that community – especially the most vulnerable – could be left unaware of the risks (and opportunities) or unsupported in their desire to address them. This project was a first step in this kind of collaboration and the project result shows promise. With the appropriate prioritization and collaboration, the TBS wall assembly approach could be one useful tool in addressing the twin challenges of climate mitigation and seismic resiliency at the local level.

Appendix A: Example Manufacturer Specification

Thermal Break Shearwall

GUIDE SPECIFICATION

PROJECT ENGINEER RESPONSIBILITY: This is a general specification guide, intended to be used by experienced construction professionals, in conjunction with good construction practice and professional judgment. This guide is to aid in the creation of a complete building specification that is to be fully reviewed and edited by the engineer. Sections of this guide should be included, edited, or omitted based on the requirements of a specific project. It is the responsibility of both the specifier and the purchaser to determine if a product or system is suitable for its intended use. Neither Owens Corning, Earth Advantage Inc., City of Portland, nor any subsidiaries or affiliated companies, assume any responsibility for the content of this specification guide relative to actual projects and specifically disclaim any and all liability for any errors or omissions in design, detail, structural capability, drawings or other construction related details, whether based upon the information provided by these parties or otherwise.

Thermal Break Shear Wall

1. GENERAL
   - 1.1. SUMMARY
     - a) Section Includes: Provide Thermal Break Shear wall. Extent of Thermal Break Shear wall application is shown on drawings and indicated by provisions of this section.
   - 1.2. REFERENCES
     - a) Materials shall meet the property requirements of one or more of the following specifications as applicable to the specific product or end use:
     - b) American Society for Testing of Materials (ASTM):
       - 1.2.b.1. ASTM C 578: Standard Specification for Rigid Cellular Polystyrene Thermal Insulation.
       - 1.2.b.2. ASTM C 518: Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.
       - 1.2.b.3. ASTM E 84: Standard Test Method for Surface Burning Characteristics of Building Materials.
       - 1.2.b.4. International Code Council Evaluation Service (ICC-ES), Evaluation Report.
   - 1.3. SUBMITTALS
     - a) Product Data: Submit data on the component characteristics, performance criteria, and limitations, including products and installation instructions.
     - b) Sustainable Design: Submit manufacturer's sustainable design certifications as indicated.
     - c) Warranty: Submit documentation for limited product warranty. [___ years or lifetime].
   - 1.4. QUALITY ASSURANCE
     - a) Source Limitations: Obtain exterior building insulation through one source from a single manufacturer.
     - b) Each insulation board must be labeled with manufacturer's name, product brand name, ASTM material specification reference, and identification of the third-party inspection agency used for building code qualification.
   - 1.5. DELIVERY, STORAGE, AND HANDLING

a) Deliver all materials in manufacturer's original packaging.
b) Store and protect products in accordance with manufacturer's instructions. Store in a dry area and protect from water, direct sunlight, flame, and ignition sources. Do not install insulation that has been damaged or wet. In the event the board insulation becomes wet, wipe dry prior to installation.

2. PRODUCTS

2.1. SHEATHING

a) 7/8" Oriented Strand Board (OSB) or Plywood structural sheathing

2.2. FOAM PLASTIC BOARD INSULATION

a) 1" rigid Extruded Polystyrene Board Insulation.
b) Extruded Polystyrene Board Insulation: Comply with ASTM C 578, Type [X, 15 psi minimum compressive strength, 1.30 lb./ ft.3 (21 kg/ m3)] [IV, 25 psi minimum compressive strength, 1.55 lb./ ft.3 (26 kg/ m3)] [VI, 40 psi minimum compressive strength, 1.80 lb./ ft.3 (29 kg/ m3)] [VII, 60 psi minimum compressive strength, 2.20 lb./ ft.3 (35 kg/ m3)] [V, 100 psi compressive strength, 3.00 lb./ ft.3 (48 kg/ m3)].
c) Thermal Resistance: (180-day real-time aging as mandated by ASTM C578, measured per ASTM C 518 at mean temperature of 75°F): [R-5.0] per inch of thickness, with 90% lifetime limited warranty on thermal resistance.
d) Blowing Agent Formulation: Zero ozone depleting.
e) Edge Condition: [Square, Tongue & Groove, Ship-Lap].
f) Surface Burning Characteristics (ASTM E 84): Flame spread less than 25, smoke developed less than 450, certified by independent third party such as Underwriters Laboratories (UL).
g) Indoor Air Quality: Compliance certified by independent third party such as GREENGUARD Indoor Air Quality Certified® and/or GREENGUARD Children and Schools Certified℠.
h) Recycled Content: Minimum 20%, certified by independent third party such as Scientific Certification Systems.
i) Warranty: Limited lifetime warranty covering all ASTM C578 physical properties.
j) Panel Size: Provide 1" x 48" x 96"

2.3. NAILING PATTERNS

a) Field nailing 16d @ 12" on center and edge nailing 16d @3" on center.

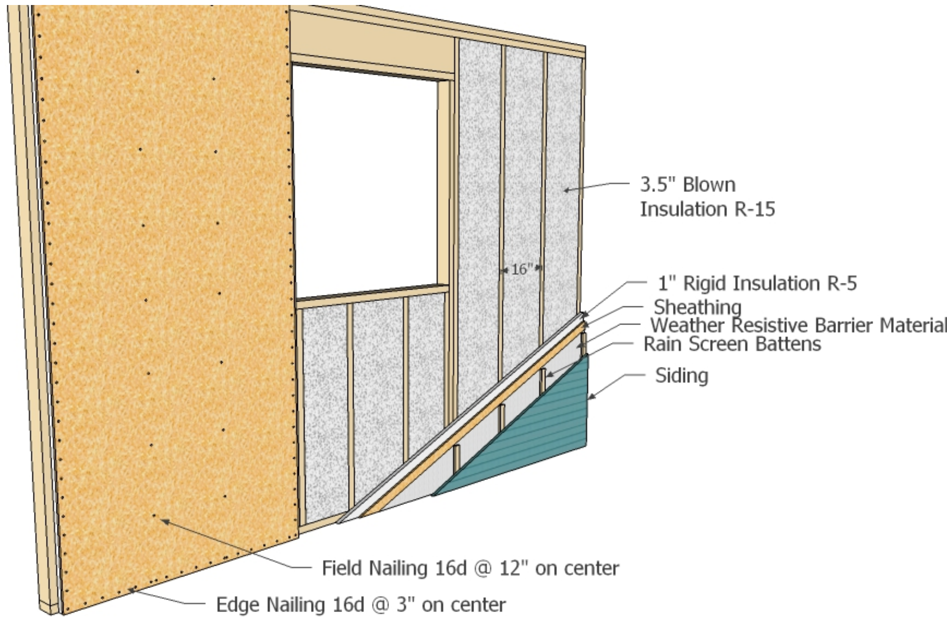
2.4. FRAMING

a) 2X Wood framing, G – 0.42, 24" OC stud spacing max

3. EXECUTION

3.1. INSTALLATION OF THERMAL BREAK SHEARWALL

Figure 8: General Rendering:



A. Siding applied over plastic insulation on studs spaced either 16 or 24 inches on center with gypsum wallboard installed on the interior is an alternate to the construction specified in Item 3 of IBC Section 2308.9.3; or in Method WSP of IRC Section R602.10.2.

END OF SECTION

Appendix B: Post-TBS Wall Energy Analysis

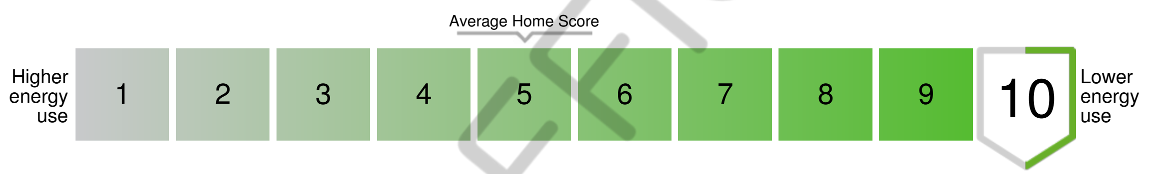
Better Buildings® U.S. Department of Energy

Home Energy Score

3307 SW 1st Ave
Portland OR 97239

SCORE TODAY 10

YEAR BUILT: 1906
CONDITIONED FLOOR AREA: 1,549 FT²



SCORE TODAY

SCORE WITH IMPROVEMENTS

Estimated annual savings $0

The U.S. Department of Energy's Home Energy Score assesses the energy efficiency of a home based on its structure and heating, cooling, and hot water systems. For more information visit HomeEnergyScore.gov.

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ASSESSMENT: Non-Official Score | Mar 26, 2018 | ID# 198358

U.S. DEPARTMENT OF ENERGY

Better Buildings
U.S. DEPARTMENT OF ENERGY

Home Energy Score

3307 SW 1st Ave
Portland OR 97239

SCORE TODAY **10**

Home Facts

The Home Energy Score's Home Facts includes details about the home's current structure, systems, and estimated energy use. For more information about how the score is calculated, visit our website at HomeEnergyScore.gov.

About This Home

ASSESSMENT	
Type	Non-Official Score
Assessor name	OR-PDX-0170
Scoring tool version	v2017
HOME CONSTRUCTION	
Year built	1906
Number of bedrooms	3
Stories above ground level	1
Interior floor-to-ceiling height	9 ft
Conditioned floor area	1,549 ft²
Direction faced by front of house	East
Air leakage rate	3526 CFM50

Estimated Annual Energy Use

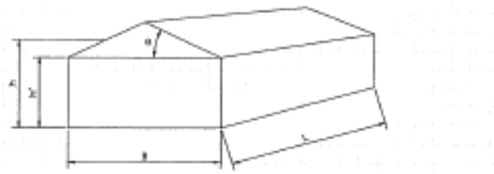
ENERGY BY TYPE	
Total	87 MBtus
Score basis	31 MBtus
Energy use per square foot	20 kBtu / ft²
Electricity	9,265 kWh
ENERGY COST ESTIMATES	
Total annual energy costs	$973
Energy cost per square foot	$0.63 / ft²
Electricity	$0.099 / kWh
DEFINITIONS & CONVERSIONS	
MBtu	Million British thermal units; generic energy unit
kBtu	Thousand British thermal units; generic energy unit
kWh	Kilowatt-hour; electricity unit
Therm	100,000 Btu; heat energy unit
Electricity conversion	1 MBTU = 293 kWh
Heat conversion	1 MBTU = 10 therms

Page 2 of 6 ASSESSMENT: Non-Official Score | Mar 26, 2018 | ID# 198358

U.S. DEPARTMENT OF ENERGY

Appendix C: Engineering calculations

This Spreadsheet calculates the wind load acting on a diaphragm per ASCE 7-10 § 28.4.1 (pg 240); Low-Rise Buildings



V =	120	mph	3-second gust wind speed
h' =	10.33	ft	Eaves height
B =	21	ft	Building width
L =	41	ft	Building length
a =	3	ft	Fig. 28.4-1, pg 242
h =	14.71	ft	Mean roof height
Roof Pitch =	10.00	: 12	
θ =	39.8		

Building is: 0

Exposure is: B

K_d =	0.85	Wind Directional Factor (Table 26.6-1, pg 194)
K_z =	0.70	Exposure Coefficient (Table 28.3-1, pg 241)

Check Criteria For a Low-Rise Building:

Is h<= 60 ft? Yes, O.K.

Is h<= Lesser of L or B? Yes, O.K.

qh = 21.95 psf Sect. 28.3.2, Eq. 28.3-1, pg 239

Topographic Factor (Section 26.8 & Fig. 26.8-1 pgs 195-197)

2-dimensional escarpments

H =	0	ft	Height of hill
L_h =	0	ft	Length of hill
x =	0	ft	Dist. From hill crest to structure

Structure is Downwind of escarpment

z =	0	ft	Elevation from bottom of hill.
K_{zt} =	1.00		

Wind Force Normal to Ridge Building Surface	GCpf	GCpi	P psf (+GCpi)	P psf (-GCpi)	(+GCpi) Horiz. Pressure (PSF)	(-GCpi) Horiz. Pressure (PSF)	(+Gcpi) Vert. Pressure (PSF)	(-Gcpi) Vert. Pressure (PSF)	Area (sq. ft)	(+GCpi) Horiz. Force (LBS)	(-GCpi) Horiz. Force (LBS)	Min. Horiz. Force (LBS)
1	0.56	0.55	0.22	24.37	0.22	24.37	0.00	0.00	181	40	4405	2882
2	0.21	0.55	-7.46	16.68	-4.78	10.68	-5.73	12.82	478	-2286	5109	2450
3	-0.43	0.55	-21.51	2.63	-13.77	1.69	-16.53	2.02	478	-6589	807	0
4	-0.37	0.55	-20.20	3.95	-20.20	3.95	0.00	0.00	181	-3651	714	0
5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1E	0.69	0.55	3.07	27.22	3.07	27.22	0.00	0.00	31	95	844	496
2E	0.27	0.55	-6.15	18.00	-3.94	11.52	-4.72	13.83	82	-323	945	420
3E	-0.53	0.55	-23.71	0.44	-15.18	0.28	-18.21	0.34	82	-1245	23	0
4E	-0.48	0.55	-22.61	1.54	-22.61	1.54	0.00	0.00	31	-701	48	0
									Sum =	9711	9711	6258

ASO x (.6)

(5827#)

Wind Force Parallel to Ridge Building Surface	GCpf	GCpi	P psf (+GCpi)	P psf (-GCpi)	(+GCpi) Horiz. Pressure (PSF)	(-GCpi) Horiz. Pressure (PSF)	(+Gcpi) Vert. Pressure (PSF)	(-Gcpi) Vert. Pressure (PSF)	Area (sq. ft)	(+GCpi) Horiz. Force (LBS)	(-GCpi) Horiz. Force (LBS)	Min. Horiz. Force (LBS)
1	-0.45	0.55	-21.95	2.20	-21.95	2.20	0.00	0.00	N/A	N/A	N/A	N/A
2	-0.69	0.55	-27.22	-3.07	-17.43	-1.97	-20.91	-2.36	N/A	N/A	N/A	N/A
3	-0.37	0.55	-20.20	3.95	-12.93	2.53	-15.52	3.04	N/A	N/A	N/A	N/A
4	-0.45	0.55	-21.95	2.20	-21.95	2.20	0.00	0.00	N/A	N/A	N/A	N/A
5	0.40	0.55	-3.29	20.85	-3.29	20.85	0.00	0.00	181	-596	3777	2898
6	-0.29	0.55	-18.44	5.71	-18.44	5.71	0.00	0.00	181	-3339	1034	0
1E	-0.48	0.55	-22.61	1.54	-22.61	1.54	0.00	0.00	N/A	N/A	N/A	N/A
2E	-1.07	0.55	-35.56	-11.42	-22.77	-7.31	-27.32	-8.77	N/A	N/A	N/A	N/A
3E	-0.53	0.55	-23.71	0.44	-15.18	0.28	-18.21	0.34	N/A	N/A	N/A	N/A
4E	-0.48	0.55	-22.61	1.54	-22.61	1.54	0.00	0.00	N/A	N/A	N/A	N/A
5E	0.61	0.55	1.32	25.47	1.32	25.47	0.00	0.00	19	25	490	308
6E	-0.43	0.55	-21.51	2.63	-21.51	2.63	0.00	0.00	19	-414	51	0
									Sum =	3182	3182	3205

MIN

(1909#) (1923#)

WIND CONTROLS – CHECK SHEAR WORST CASE

$\frac{5827\#}{(2)(20')}$ = 146 PLF ≤ 200 PLF OK.

PER APA TECH NOTE C465E

CAPACITY OF SHEATHING OVER 1" OF FOAM: 200 PLF

$\left(\frac{626 \text{ PLF ULT}}{5} \times 1.6\right)$ = 200 PLF OK.

Δ CHANGE IN FORCE DUE TO LIFT = 87#. ≤ 10% OK

Appendix D: Actual energy costs

Pre-renovation, the primary conditioned space in the home was roughly 890 square feet, although the homeowners regularly used part of the unfinished basement as a living room, and at times heated roughly 200 square feet of this area with space heaters. The house had already undergone several upgrades since it was purchased by the owner in 2013, including new U-.30 (and below) windows installed in the summer of 2014, which replaced existing single-pane windows; a new heat pump water heater installed in April 2015, which replaced an existing gas storage tank water heater; and a new ductless heat pump (DHP) system with two indoor heads in the primary conditioned space, which replaced a central gas furnace system that died in February 2016. The homeowners knew that the DHP system would work inefficiently in their drafty home until such time that they insulated the exterior walls, which was - at the time - a project in the distant future.

Once the house was fully electric in March 2016, the homeowners capped off existing gas lines and canceled gas service from NW Natural. 2016 was a relatively mild year in Portland, however, the impacts of using an all-electric heat pump system to condition the house were evident immediately: while the average daily temperature remained at 46 degrees from February to March 2016, the daily kWh usage jumped from 31.2 to 49.2, an increase of more than 50%. Winter of 2017 yielded some of the lowest average daily temperatures seen in Portland in years, and subsequently the house saw its highest electric bills yet. The table below shows the average daily temperature, kWh consumption, and electric billing history of the house for the two years preceding the start of the project:

Table 5: Average Monthly Costs

Year	Month	Avg. daily temperature	Avg. kWh/day	Total kWh	Avg. cost/day	Total Cost
2015	September	69	18.9	626	$2.39	$83.52
2015	October	63	16.3	475	$2.15	$66.10
2015	November	57	17.9	520	$2.32	$71.27
2015	December	45	18.4	608	$2.33	$81.44
2016	January	40	31.0	1024	$3.70	$128.48
2016	February	46	31.2	906	$3.68	$113.80
Ductless Heat Pump installed late February 2016						
2016	March	46	49.2	1429	$5.86	$176.52
2016	April	51	47.4	1377	$5.64	$170.21
2016	May	59	22.9	665	$2.79	$86.32
2016	June	64	16.8	538	$2.11	$71.84
2016	July	64	14.7	442	$1.91	$60.90
2016	August	68	13.6	397	$1.82	$56.11
2016	September	69	16.4	525	$2.11	$73.03
2016	October	63	17.0	493	$2.21	$69.22
2016	November	56	23.4	681	$2.92	$91.61
2016	December	50	32.7	1081	$3.93	$139.84
2017	January	35	81.9	2541	$10.17	$324.33
2017	February	34	74.8	2321	$9.28	$296.75
2017	March	42	54.2	1628	$6.66	$209.12
2017	April	49	44.0	1277	$5.35	$164.75

2017	May	52	39.2	1099	$4.63	$139.21
2017	June	60	26.1	837	$3.11	$107.65
2017	July	65	17.0	511	$2.14	$69.04
2017	August	71	15.6	453	$2.00	$62.41
TBS Wall Installation						
2018	April	TBD	TBD	TBD	TBD	TBD
2018	May	TBD	TBD	TBD	TBD	TBD
2018	June	TBD	TBD	TBD	TBD	TBD
2018	July	TBD	TBD	TBD	TBD	TBD
2018	August	TBD	TBD	TBD	TBD	TBD
2018	September	TBD	TBD	TBD	TBD	TBD