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BUILDING TECHNOLOGIES OFFICE

Spray Foam Exterior Insulation with Stand-Off Furring

Anastasia Herk, Richard Baker, and Duncan Prahl
IBACOS, Inc.

March 2014

Building America
U.S. Department of Energy

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Prepared for:

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On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

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March 2014

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Unless otherwise noted, all figures and photos were created by IBACOS.

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Definitions

ASD	Allowable strength design
BEopt™	Building Energy Optimization (software)
DER	Deep energy retrofit
GHA	GreenHomes America
HVAC	Heating, ventilation, and air conditioning
NDS	National Design Specification
NYSERDA	New York State Energy Research and Development Authority
SSF	Shell square foot
TREAT	Targeted Retrofit Energy Analysis Tool

Executive Summary

IBACOS and GreenHomes America[1] (GHA) collaborated with the New York State Energy Research and Development Authority (NYSERDA) Advanced Buildings Program to research a variation of a commercial curtain wall assembly for residential construction as part of a comprehensive whole-house deep energy retrofit (DER) package. The advantages of this strategy include minimizing the physical connections to each individual existing wall stud, using closed-cell spray foam to encapsulate existing siding materials including lead paint, and creating a vented rain screen assembly to promote drying. As Moore (2011) states, "Closed-cell foam acts as air-sealing, insulation, and secondary drainage plane..." Field installations on a limited number of houses indicate that the incremental cost when installed as part of a typical siding and window replacement job adds approximately $10/ft^2 of wall area.

2 × 4 framing members were attached to the wall at band joists and top plates using "L" clips, and spray foam was used to insulate the wall after the framing was installed. Windows were installed as the framing was put up, including extension jambs.

Key lessons learned include the following:

- The installed cost of the spray foam system was comparable to the installed cost of the rigid foam and furring strips.
- Spray foam should be applied in such a way that it locks the framing members in place before the remaining foam is installed in the field of the wall. The spray foam has a tendency to move the new wall framing as it expands. Best practice is to "picture frame" the wall framing with spray foam and then apply the spray foam in the field of each bay.
- Variations in the existing siding conditions must be accounted for when attaching the ledger boards and wall framing. A best practice is to uniformly shim the ledger boards off the walls so the new framing is a uniform distance from the ledger boards and the inside surface of the interior framing. This is important primarily for window and door installation and the associated extension jambs and trim.
- From a sequencing perspective, it is advantageous to replace the windows at the same time as the exterior walls are being built. This requires a crew that can perform a number of different tasks (e.g., framing, flashing, window install, trim carpentry) and does not lend itself to subcontracting this approach piecemeal (e.g., framing subcontractor, window installer, drainage plane installer, trim carpenter).
- Application of the brackets and associated fastener screws was more time consuming than anticipated.
- It is important for the spray foam contractor to perform all preparatory work, which in this case included placing plastic over the windows and exposed foundation to minimize or eliminate the possibility of damage due to overspray.

[1] GreenHomes America, Inc., www.greenhomesamerica.com/.

1 Introduction and Background

According to Harvard (2010), "Lower household mobility in the wake of the housing market crash could also mean that homeowners will focus on upgrades with longer paybacks, particularly energy-efficient retrofits." That report also shows that homeowners are investing in new siding ($4.847 billion in 2009) and new windows and doors ($11.448 billion in 2009). The decisions to make these improvements frequently occur without consideration of energy improvement opportunities, and research is needed to determine what additional measures could be taken to improve the energy efficiency of the home and the impact of the various opportunities. Home retrofits have been targeted as an area of great potential for significant energy savings, employment opportunities, and market growth (Osser et al. 2011). Exterior insulation is one strategy for reducing energy use for heating and cooling while reducing potential moisture problems in walls.

The New York State Energy Research and Development Authority (NYSERDA) Advanced Buildings Program has proven the economic need for, and the significant energy-saving benefits of, residential retrofitting strategies based on its deep energy retrofit (DER) pilot project. However, the DER activities are cost prohibitive. When looking into this project, IBACOS researched existing work on exterior insulation and energy smart walls. According to Coldham (2010), "Owners of existing homes can take advantage of energy savings that will result from construction upgrades." Coldham talks about six proven ways to build these energy smart walls.

NYSERDA's Advanced Buildings Program research was conducted to investigate cost-effective DER solutions for improving the building shell exterior while achieving a cost-reduction goal, including reducing labor costs considerably, to reach a balanced, 50/50 split between material and labor. The strategy is designed to integrate with other home improvement projects such as siding or window replacement, with both energy and appraisal value attributes, so DER solutions gain market acceptance.

IBACOS, in collaboration with GreenHomes America (GHA), was contracted by NYSERDA to research exterior wall insulation solutions. IBACOS researched past projects done, including work done by Moore (2011). In addition to the exterior wall insulation, the strategies included energy upgrades where needed in the attic, mechanical and ventilation systems, and basement band joist, walls, and floors.

1.1 Statement of the Problem

One aspect of exterior insulation is creating a new external system for siding attachment that transfers loads back to the structure of the building, meets siding manufacturers' requirements, and complies with the 2012 International Residential Code (International Code Council 2012). This typically means attaching furring strips directly to each vertical stud. Locating and verifying that fasteners are actually in the studs of existing exterior walls can be time consuming and challenging for retrofit crews.

Many existing homes may have exterior surfaces that contain lead paint. Alfano (2010) estimates that lead paint safe work practices can escalate the cost of exterior retrofits by thousands of dollars if significant whole-house containment systems are needed for siding with lead paint. One goal of this research was to develop a strategy that would minimize the disturbance of the siding and lead paint, thereby avoiding triggering the thresholds for the U.S. Environmental Protection Agency's Lead-Based Paint Renovation, Repair, and Painting Rule.[2]

1.1.1 What Is a Deep Energy Retrofit?

A DER is a practice that goes well above and beyond the current common practice of performing energy efficiency work. This involves substantially improving the exterior building envelope with aggressive, emerging insulating practices (e.g., installing polyurethane rigid panel insulation, application of polyurethane spray foam insulation after build-out), installing new windows or relocating existing windows (when applicable), sealing the below-grade foundation to the wall connections, and sealing the roof-to-wall connection with insulation that also provides an air barrier. Typical mechanical systems are then significantly downsized, and performance results yield a reduction in whole-building energy load of at least 50%.

1.2 Key Research Questions

The key research question for this project asks how exterior walls can be retrofitted with exterior insulation that accomplishes all of the following:

- Minimizes the need for attachment to each individual vertical framing member.
- Minimizes or eliminates the need to remove existing siding.
- Maintains the structural and siding attachment requirements of manufacturers and the 2012 International Residential Code (International Code Council 2012).

1.3 Performance Targets

As part of this project, a number of goals were developed, including the following:

- Provide testing measurements, utility impact (before and after), costs (labor and materials), construction time, standard specifications, and analysis for the exterior wall insulation strategy.
- Achieve the following energy-related targets:
  - Whole-house air leakage improvements that can approach or be lower than 0.25 CFM 50/shell square foot (SSF) upon completion.
  - Minimum center of wall R-value of R-25.
- Increase DER awareness among building contractors and homeowners.
- Identify exterior wall insulation retrofit strategies that can be accomplished for less than $10/SSF.
- Share successful solutions with building contractors and homeowners through a wide outreach program.
- Identify barriers to solutions that need to be addressed with future research or externalities under which nonviable solutions would be made viable (e.g., different utility costs, lower material costs).

[2] U.S. Environmental Protection Agency, www2.epa.gov/lead/lead-renovation-repair-and-painting-program-rules.

2 Mathematical and Modeling Methods

The information below shows the modeling that was done prior to the start of construction to verify IBACOS' strategy and the probability of meeting the project goals.

2.1 Modeling

IBACOS used Building Energy Optimization (BEopt™) software Version 2.0.0.4 (BEopt 2013) to model the current conditions of a single-story house located in the area of Syracuse, New York, and an optimization of reasonable retrofit options, including the exterior insulation system with costs as found by the research team. Figure 1 shows the BEopt model with no rebates or financing options, assuming a 7% loan for 5 years to finance the costs. Figure 2 shows BEopt results when the rebates available through NYSERDA (approximately 10% of the cost of qualifying measures, up to $3,000 and ~4% 15-year loan) were included. Note that the actual house as built included a heat recovery ventilation system that significantly increased costs with little savings. In addition, all of the most cost-effective points do not include ventilation, which is not necessarily a recommended practice when working to aggressively air seal a building. The house had an existing sealed combustion furnace, and a power vent was installed on a relatively new gas tank type water heater. No house combinations achieved more than 20% savings without the inclusion of the exterior insulation system.

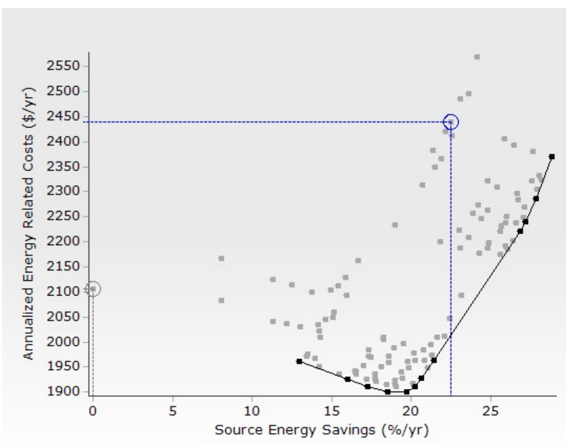


Figure 1. BEopt results without rebates and financing

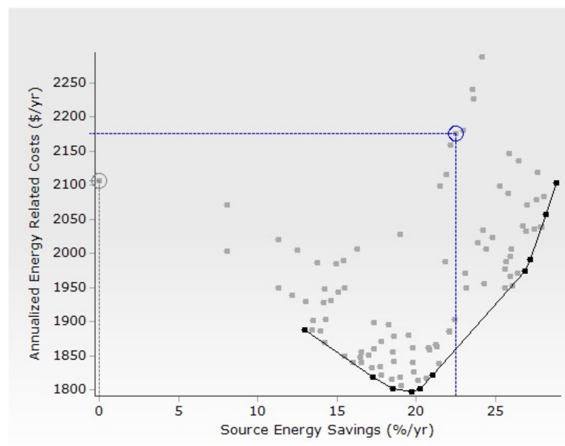


Figure 2. BEopt results with rebates and financing

It is also instructive to look at the impact of rebates and financing of this strategy. BEopt was run with a parametric analysis of financing options and measures, including various interest rates and rebates as shown in Table 1. Figure 3 shows the results of this analysis.

Table 1. Financing Variables Studied

Parameter	Variable
Interest Rate	4%, 5.5%, 7%
Term of Loan	5, 10, 15, and 30 years
Rebates	$2,500, $3000 for entire project

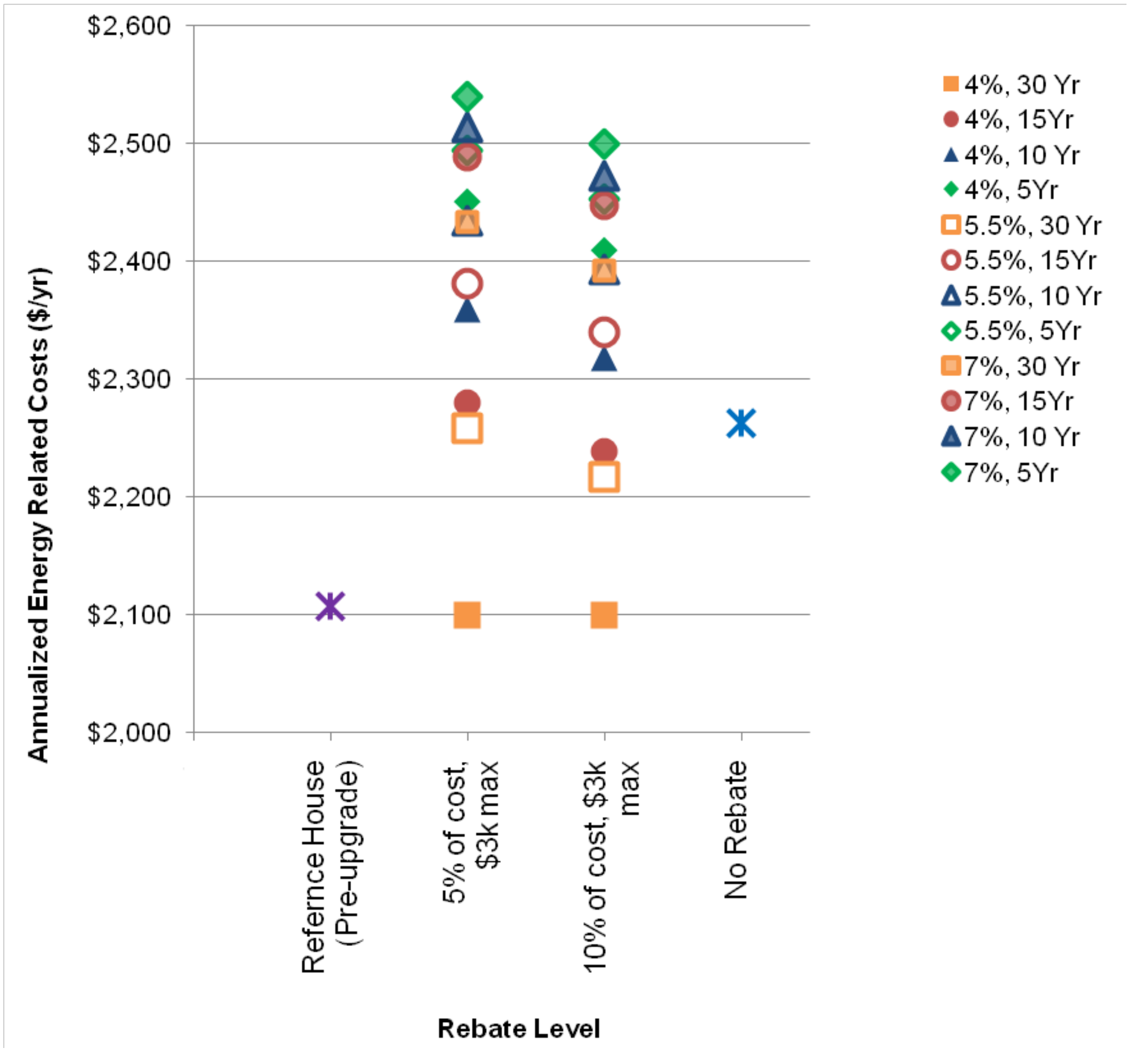


Figure 3. Results of financial analysis

One conclusion is that for major DER investments, it is advisable to evaluate all financing options, including a full-house refinance to a 30-year loan, if a neutral cash flow is the goal. In many cases, this upgrade is made as part of other overall home improvement activities such as re-siding for aesthetic reasons or replacing windows for comfort and functionality. By adding this energy upgrade strategy to a re-siding/window replacement project, the homeowners are further enhancing the value of their home by creating a continuous thermal enclosure, minimizing the risk of condensation on exterior walls, and creating a continuous ventilated rain screen.

2.2 Construction Detail Development

IBACOS created a detailed wall section for a spray foam application DER solution, as shown in Figure 4 and Figure 5. Structural analysis was conducted on these details as described in Section 3.

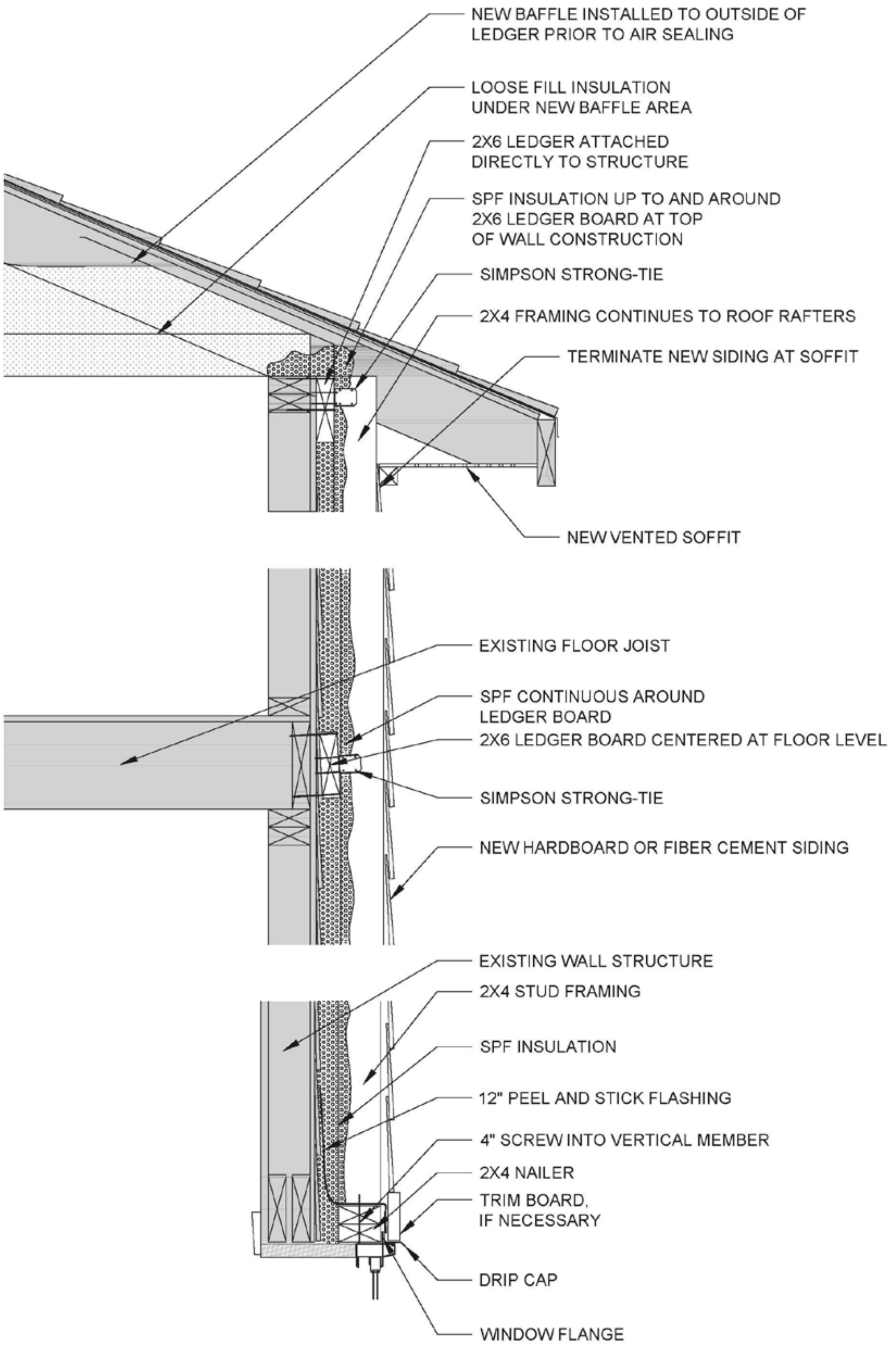


Figure 4. Wall section

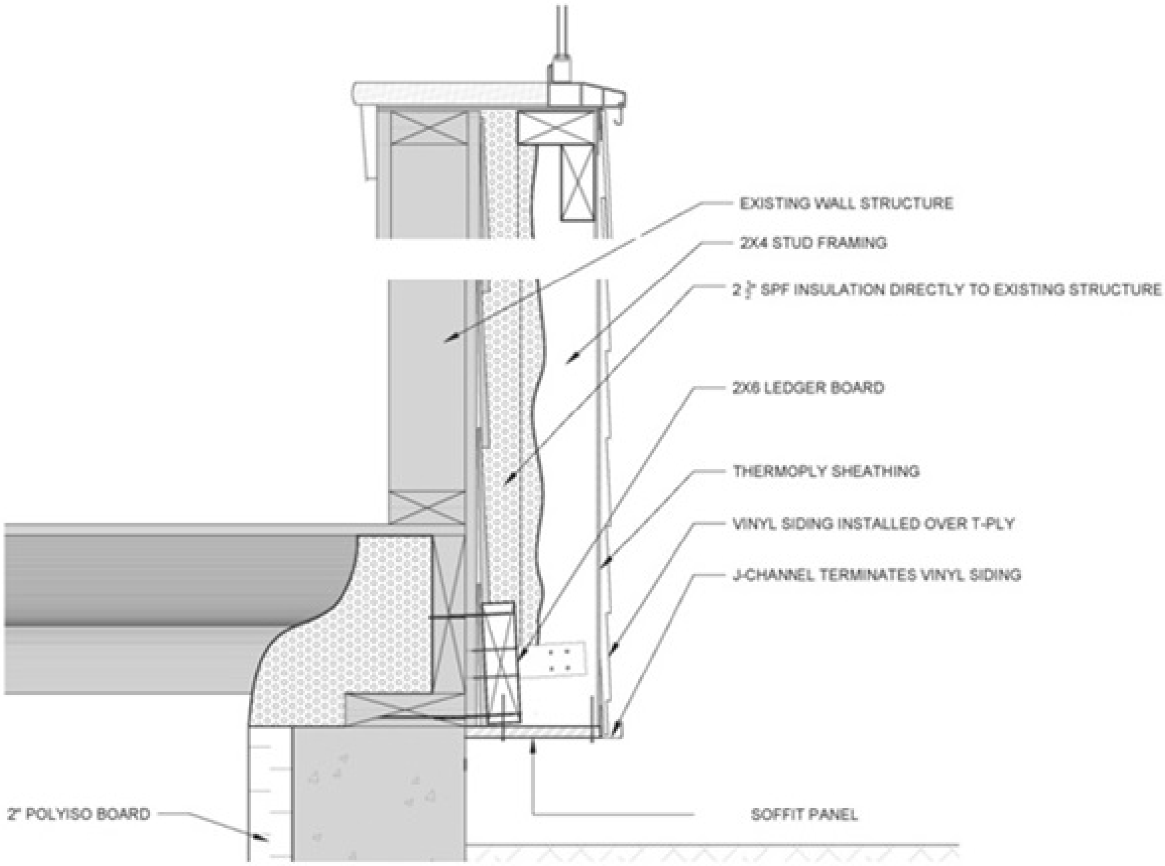


Figure 5. Bottom of wall section

3 Research and Experimental Methods

This research was conducted in conjunction with project partner GHA and a number of manufacturing partners. Methods included a strategic planning meeting, design detailing, structural and energy analyses, mockups, and implementation.

3.1 Planning

At the start of the project, IBACOS gathered various manufacturers that were interested in this project and its outcomes. IBACOS held a strategic planning meeting with all of these manufacturers, NYSERDA representatives, and GHA representatives.

3.2 Design Detailing

IBACOS then took the discussion results from the strategic planning meeting and started to flesh out the details. IBACOS created two- and three-dimensional details of the ideas formed in the strategic planning meeting, working to identify all problem areas.

3.3 Energy and Structural Analyses

Energy analysis was undertaken using BEopt (Version 2.0.0.4) and Targeted Retrofit Energy Analysis Tool (TREAT) software (TREAT 2013). Once the team detailed the solution for this spray foam DER, it was necessary to do some structural analysis of the system. IBACOS planned to have 2 × 4s on edges that were clipped to a ledger board at two locations. After designing that detail, IBACOS worked with one manufacturing partner who specializes in structural metal brackets for residential construction regarding that company's clips and the structural capability of those clips.

3.4 Mockups

IBACOS created SketchUp details (SketchUp 2013) that addressed possible problem areas of a potential home, as identified by the team. These mockup drawings then were built into actual physical mockups at the GHA office by the contractors who would be working on the actual homes. Then GHA was able to test how this work would be done before actually beginning the project in the field.

3.5 Implementation

To implement the spray foam stand-off furring strategy, the team had to find a homeowner who met the criteria. Next, the team had to review the existing conditions of that home and then develop a work scope of what the team would do during construction at that home.

3.5.1 Homeowner Acquisition Strategy

First, GHA developed a market solicitation program to identify and enroll four homeowners for study participation, including meeting cost share requirements. Based on the outcomes of a strategic planning meeting, IBACOS undertook energy and financial modeling to refine project costs and energy benefits in conjunction with laboratory mockups.

3.5.2 Overview of Existing Conditions and Energy Analysis

After a homeowner was chosen for the project, the GHA team assessed the house to ensure that the existing conditions were not too far out of reach for the construction of the DER. This included verifying chimney locations; any protrusions; the heating, ventilation, and air conditioning (HVAC) system; and other initial observations.

3.5.3 Development of Work Scope

Once the team determined that the house was a good candidate for the DER, a work scope was created. This work scope included all work that would be done at the house during construction. The homeowner agreed to this work scope prior to the start of construction.

3.6 Permitting

Before the team could begin construction, it had to obtain permits from the local authorities for the retrofit work on the test house. Some of the permitting officials had never seen an application similar to this one; therefore, they were hesitant to award the permits.

3.7 Construction

Using the best solution sets from the laboratory mockups, GHA implemented the solution set in conjunction with a number of other whole-house retrofit measures. IBACOS and GHA collaborated with other project partners to evaluate in-field applications and modifications that were necessary to reduce costs where possible. GHA collected detailed labor activities and documented the learning curve as the project progressed. IBACOS conducted periodic field visits at key points during construction to identify technical and process barriers that could prevent a solution from meeting the desired results.

4 Results

The following information discusses the results of the strategic planning meeting, design detailing, structural and energy analyses, mockups, and implementation.

4.1 Planning

During the strategic planning meeting, the team identified key issues that could impact the implementation of the solution. These issues included the following:

- Structural analysis and permitting
- Sequencing of the job
- Integration of the wall system to other key assemblies such as the foundation, windows and doors, and roof.

4.2 Design Detailing

During the strategic planning meeting, ideas for detailing also were discussed. The team identified different areas of concern that might be encountered at any given home. Discussion topics covered the roof-to-wall detail, floor-to-wall detail, and basement detail, among others.

After the strategic planning meeting, IBACOS worked with GHA to detail the spray foam solution and created details for construction. Figure 6 shows one of the details. See Appendix A for step-by-step diagrams and Appendix B for computer-aided design details.

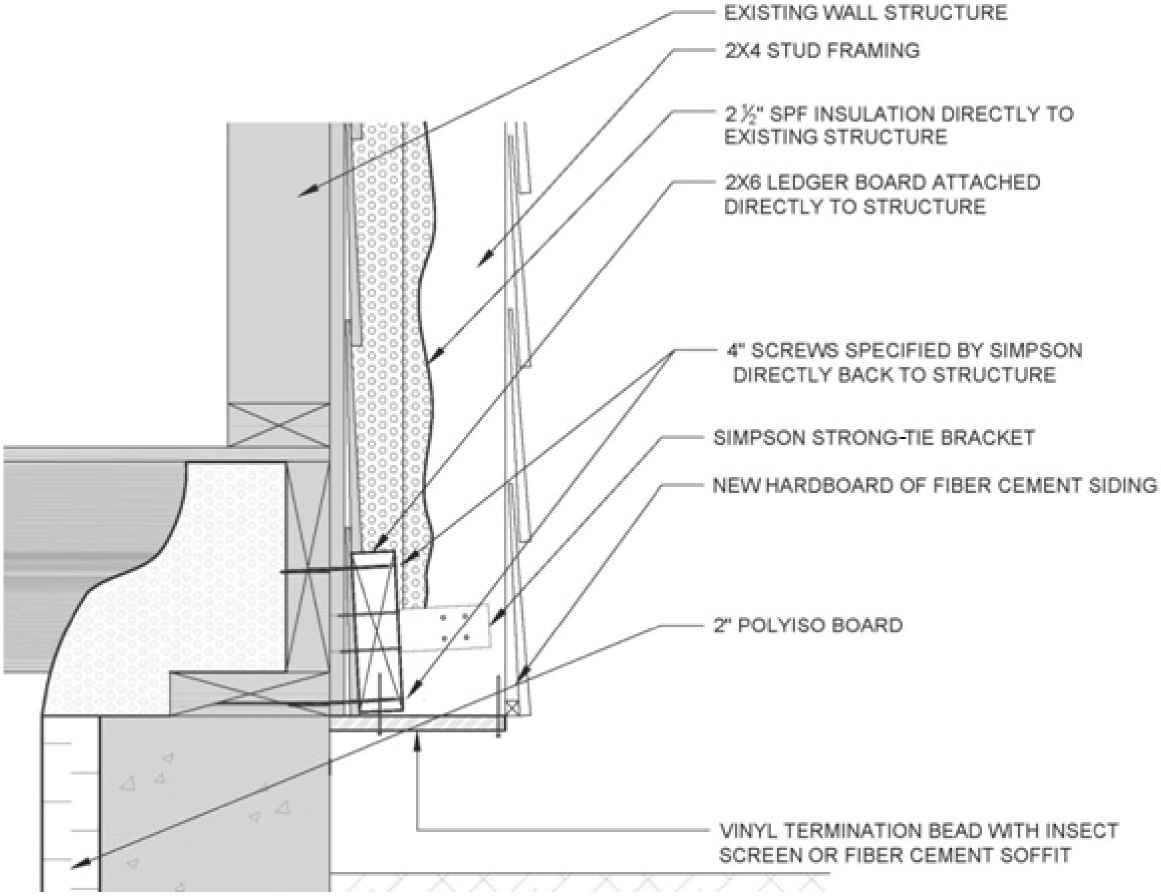


Figure 6. Wall-at-foundation detail

4.3 Structural and Energy Analyses

During the detailing phase, IBACOS discussed using a variety of different brackets for the top and bottom of the 2 × 4 that was installed vertically. To satisfy the building official, an engineer's stamp was needed on the details. For the engineer to stamp the details, technical specifications were needed. Due to the lack of technical information on the structural strength of the adhesion of foam to wood, the clips were needed. The team decided to use a standard "L" bracket product from a national supplier of structural metal clips and hangers. This bracket originally was designed for use on light-commercial, steel-framed curtain wall construction. Figure 7 shows a picture of the Simpson Strong-Tie "L" bracket that was used.

Figure 7. Simpson Strong-Tie "L" bracket

Calculations were done to ensure that the weight of the wall could be carried by the metal brackets. Figure 8 shows the beginning of these calculations. This figure is a moment diagram that shows evenly distributed dead loads on the 2 × 4 framing member. GHA then performed TREAT modeling for NYSERDA purposes.

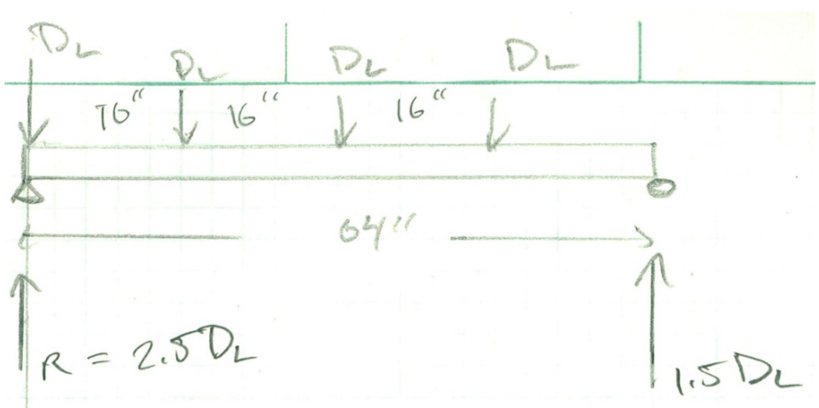


Figure 8. Structural calculation

The analysis of the wall section and other relevant members was done using allowable strength design (ASD) equations from the 2012 National Design Specification (NDS) (American Wood Council 2012a) and the ASD/LRFD Manual for Engineered Wood Construction (American Wood Council 2012b). The following modes of failure were considered:

- Failure of new 2 × 4 wall framing in compression
- Failure of mechanical connection of ledger board to rim joist

- Failure of ledger board in shear
- Failure of ledger board in flexure
- Failure of mechanical connection of ledger board to metal bracket
- Failure of mechanical connection of metal bracket to stud
- Loads for each of the wall section parameters:
    - Vinyl, fiber cement, and stucco siding
    - Windows approximately the same weight as stucco
- Analysis done with new exterior wall studs spaced at 16 in. and 24 in. on center.

4.4 Mockups

IBACOS developed drawings of small-scale mockups for proposed solutions that were tested for constructability, material utilization, and time motion studies. IBACOS worked with GHA and its installers to provide input on the development of the mockups, laboratory testing, and review of results.

The construction of full-scale mockups of key features typical to many existing homes in the area of Syracuse, New York, was the primary mechanism to allow for tests of the constructability of the proposed strategies. These mockups helped in the determination of the amount of materials and labor needed to execute a given strategy. They also provided a venue for those responsible for executing these unconventional practices in the field to refine application methods and sequencing prior to arriving on the job site.

After these full-scale mockups were built, the team was able to troubleshoot specific areas and revise the details before arriving on site at the test house. Figure 9 is representative of the mockup drawings (left) and the corresponding physical mockup (right) built by GHA. Additional mockups are presented in Appendix C.

Figure 9. Detail around exterior door and light fixture

4.5 Implementation

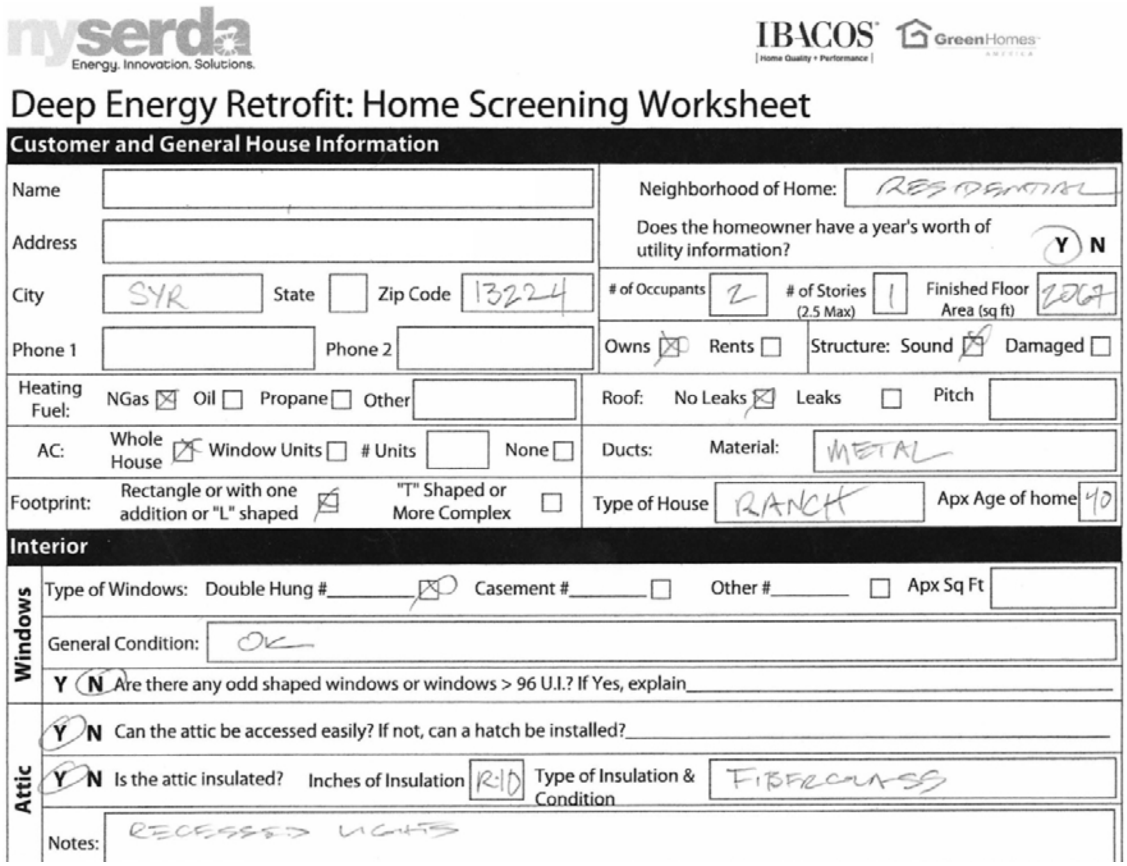
Once the mockups were complete, the team needed to find a homeowner who matched the project criteria and was willing to have their home monitored for a year after completion of the retrofit. The following describes some of the ways the team transitioned to the implementation phase.

4.5.1 Homeowner Acquisition Strategy

The team developed a home screening worksheet that was intended to help assess the suitability and existing situation of the potential home. This home screening worksheet included the following:

- General customer information
- Interior information (e.g., windows, attic, basement)
- Exterior information (e.g., siding, chimney, porch, deck, utilities, exterior lighting, landscape)
- Checklist of photographs to be taken.

Figure 10 shows an excerpt from the home screening worksheet.


nyserda Energy. Innovation. Solutions. IBACOS GreenHomes

Deep Energy Retrofit: Home Screening Worksheet

Customer and General House Information

Name: | Neighborhood of Home: RESIDENTIAL
Address: | Does the homeowner have a year's worth of utility information? (Y) N
City: SYR | State: | Zip Code: 13224 | # of Occupants: 2 | # of Stories (2.5 Max): 1 | Finished Floor Area (sq ft): 2067
Phone 1: | Phone 2: | Owns ☒ | Rents ☐ | Structure: Sound ☒ | Damaged ☐
Heating Fuel: NGas ☒ Oil ☐ Propane ☐ Other | Roof: No Leaks ☒ Leaks ☐ Pitch
AC: Whole House ☒ Window Units ☐ # Units None ☐ | Ducts: Material: METAL
Footprint: Rectangle or with one addition or "L" shaped ☒ "T" Shaped or More Complex ☐ | Type of House: RANCH | Apx Age of home: 40

Interior

Windows
Type of Windows: Double Hung #____ ☒ Casement #____ ☐ Other #____ ☐ Apx Sq Ft
General Condition: OK
Y (N) Are there any odd shaped windows or windows > 96 U.I.? If Yes, explain____

Attic
(Y) N Can the attic be accessed easily? If not, can a hatch be installed?____
(Y) N Is the attic insulated? Inches of Insulation: R-10 Type of Insulation & Condition: FIBERGLASS
Notes: RECESSED LIGHTS

Figure 10. Home screening worksheet excerpt

4.5.2 Overview of Existing Conditions

The test home for this NYSERDA DER project is in a residential neighborhood in Syracuse, New York. Two occupants reside in this single-story, ranch-style home that was built in the 1970s and has a finished floor area of approximately 2,067 ft^2. Figure 11 shows the exterior walls of the test house.

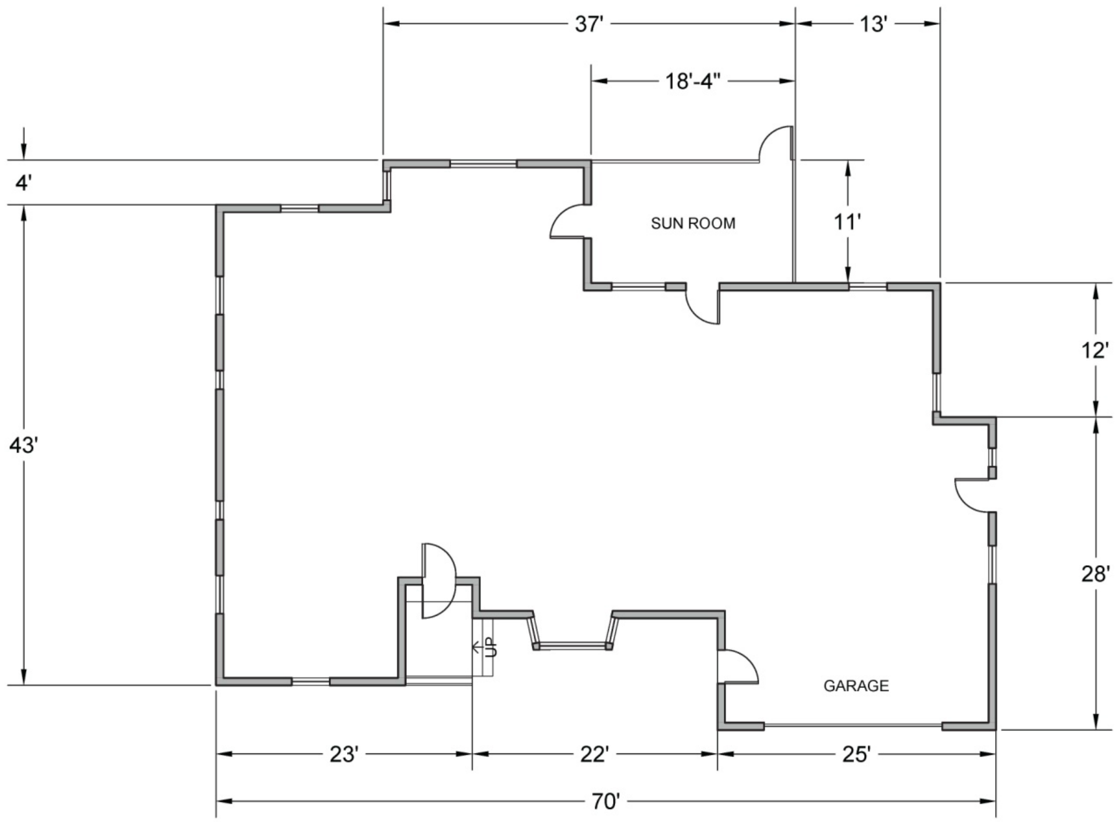


Figure 11. Preliminary sketch of the test house floor plan

Heating and cooling in the existing home were provided by a natural gas furnace with air conditioning, with a metal ductwork distribution system, and the home appeared to have no leaks in the roof. The interior of the home included double-hung windows, R-10 fiberglass insulation in the attic, recessed lighting, and fiberglass wall insulation. Also, a water heater located in the basement was vented improperly and had no direct vent provision. Some existing exterior conditions of the home included wide shingles of the shake variety with about 9 in. of exposure, no chimneys, and a small overhang at the front door, as well as some exterior lighting and a gas meter on the exterior. Figure 12 and Figure 13 show the test house.

Figure 12. Front door of the test house

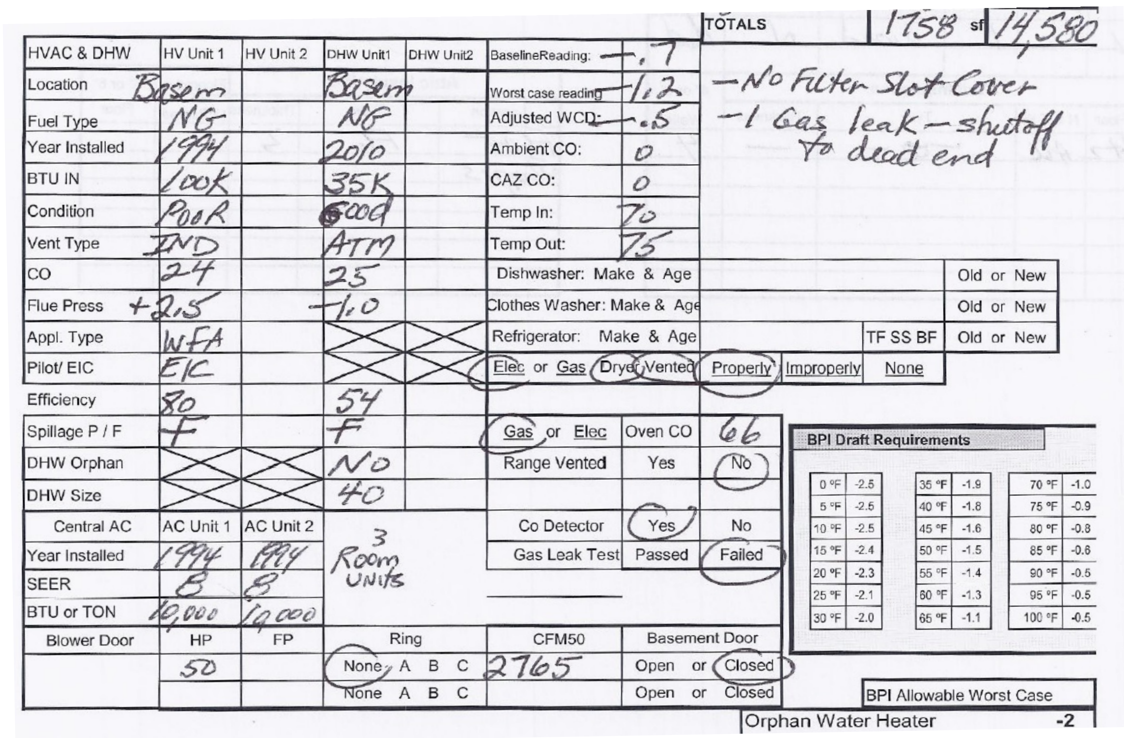
Figure 13. Side view of the test house

4.5.2.1 Initial Home Energy Assessment

GHA conducted an energy assessment of the test house prior to doing any work on the home. This energy assessment included the following:

- HVAC equipment (type, year installed, fuel type, location, and condition)
- Domestic hot water equipment (type, year installed, fuel type, location, and condition)
- Conditioned area and volume calculations
- Number of heated floors in the home
- Fan locations
- Dishwasher, clothes washer, and refrigerator (make and age of each).

Figure 14 shows an example of this energy assessment.



HVAC & DHW	HV Unit 1	HV Unit 2	DHW Unit1	DHW Unit2
Location	Basem		Basem	
Fuel Type	NG		NG	
Year Installed	1994		2010	
BTU IN	100K		35K	
Condition	POOR		Good	
Vent Type	IND		ATM	
CO	24		25	
Flue Press	+2.5		-1.0	
Appl. Type	WFA		X	X
Pilot/ EIC	EIC		X	X
Efficiency	80		54	
Spillage P / F	F		F	
DHW Orphan	X	X	NO	
DHW Size	X	X	40	
Central AC	AC Unit 1	AC Unit 2	3 Room Units	
Year Installed	1994	1994		
SEER	8	8		
BTU or TON	10,000	10,000		

Blower Door	HP	FP	Ring	CFM50	Basement Door
	50		None A B C	2765	Open or Closed
			None A B C		Open or Closed

BaselineReading:	-.7
Worst case reading	-1.2
Adjusted WCD:	-.5
Ambient CO:	0
CAZ CO:	0
Temp In:	70
Temp Out:	75

TOTALS 1758 sf 14,580

-No Filter Slot Cover
-1 Gas leak - shutoff to dead end

Dishwasher: Make & Age			Old or New
Clothes Washer: Make & Age			Old or New
Refrigerator: Make & Age		TF SS BF	Old or New
Elec or Gas Dryer Vented	Properly	Improperly	None

Gas or Elec	Oven CO	66
Range Vented	Yes	No
Co Detector	Yes	No
Gas Leak Test	Passed	Failed

BPI Draft Requirements

0 °F	-2.5	35 °F	-1.9	70 °F	-1.0
5 °F	-2.5	40 °F	-1.8	75 °F	-0.9
10 °F	-2.5	45 °F	-1.6	80 °F	-0.8
15 °F	-2.4	50 °F	-1.5	85 °F	-0.6
20 °F	-2.3	55 °F	-1.4	90 °F	-0.5
25 °F	-2.1	60 °F	-1.3	95 °F	-0.5
30 °F	-2.0	65 °F	-1.1	100 °F	-0.5

BPI Allowable Worst Case	
Orphan Water Heater	-2

Figure 14. Energy assessment example

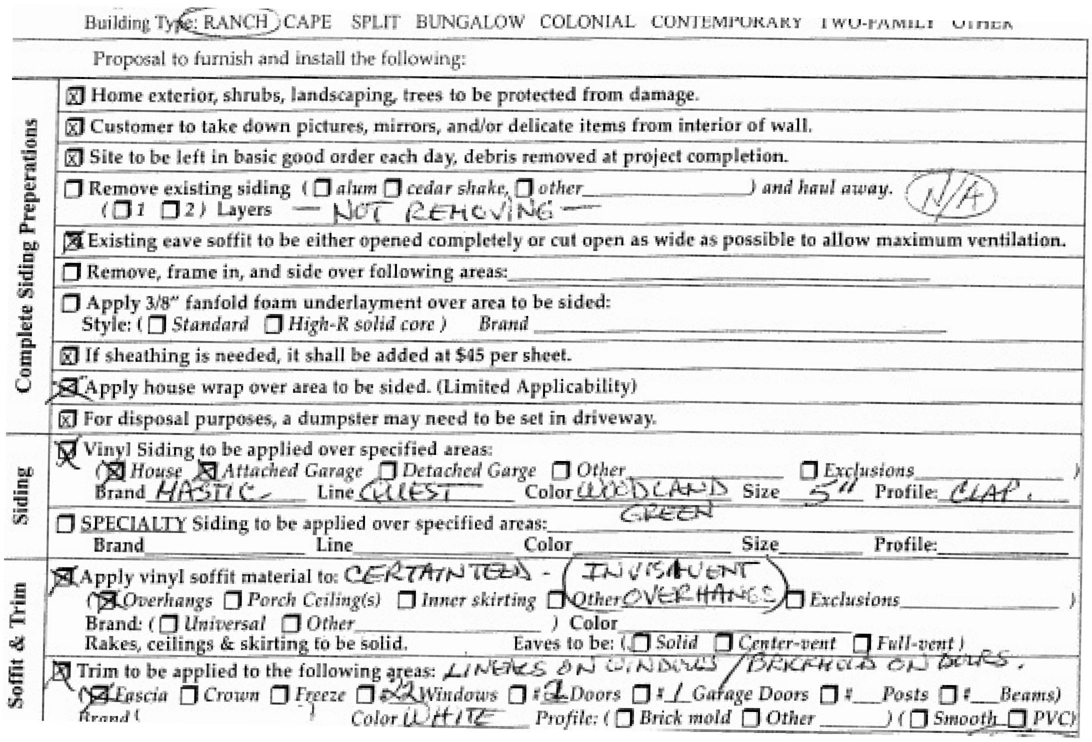
4.5.3 Development of the Work Scope

Once the existing conditions of the test house were assessed, a work scope was created. This work scope described all renovations and updates to be done at this residence. The test house was to receive a spray foam strategy, and the construction included the following:

- Installation of whole-house vinyl siding in the Woodland Green color, 5-in. width
- Installation of vinyl soffit material for overhangs

- Application of white trim to the fascia, 22 windows, two doors, and one garage door
- Addition of a dryer vent in the Woodland Green color
- Installation of ⅜-in. sheathing over insulation for a flat surface under the siding.

Figure 15 shows an example of the work scope for the test house.



Building Type: RANCH CAPE SPLIT BUNGALOW COLONIAL CONTEMPORARY TWO-FAMILY OTHER

Proposal to furnish and install the following:

Complete Siding Preparations

- ☒ Home exterior, shrubs, landscaping, trees to be protected from damage.
- ☒ Customer to take down pictures, mirrors, and/or delicate items from interior of wall.
- ☒ Site to be left in basic good order each day, debris removed at project completion.
- ☐ Remove existing siding (☐ alum ☐ cedar shake, ☐ other ______) and haul away. (N/A) (☐ 1 ☐ 2) Layers — NOT REMOVING —
- ☒ Existing eave soffit to be either opened completely or cut open as wide as possible to allow maximum ventilation.
- ☐ Remove, frame in, and side over following areas: ______
- ☐ Apply 3/8" fanfold foam underlayment over area to be sided: Style: (☐ Standard ☐ High-R solid core) Brand ______
- ☒ If sheathing is needed, it shall be added at $45 per sheet.
- ☒ Apply house wrap over area to be sided. (Limited Applicability)
- ☒ For disposal purposes, a dumpster may need to be set in driveway.

Siding

- ☒ Vinyl Siding to be applied over specified areas: (☒ House ☒ Attached Garage ☐ Detached Garge ☐ Other ______ ☐ Exclusions ______) Brand MASTIC Line QUEST Color WOODLAND GREEN Size 5" Profile: CLAP.
- ☐ SPECIALTY Siding to be applied over specified areas: Brand ______ Line ______ Color ______ Size ______ Profile: ______

Soffit & Trim

- ☒ Apply vinyl soffit material to: CERTAINTEED - (INVISAVENT) (☒ Overhangs ☐ Porch Ceiling(s) ☐ Inner skirting ☐ Other OVERHANGS ☐ Exclusions ______) Brand: (☐ Universal ☐ Other ______) Color ______ Rakes, ceilings & skirting to be solid. Eaves to be: (☐ Solid ☐ Center-vent ☐ Full-vent)
- ☒ Trim to be applied to the following areas: LINEALS ON WINDOWS / BRICKMOLD ON DOORS. (☒ Fascia ☐ Crown ☐ Freeze ☐ #22 Windows ☐ #2 Doors ☐ #1 Garage Doors ☐ #__ Posts ☐ #__ Beams) Brand ( ) Color WHITE Profile: (☐ Brick mold ☐ Other ______) (☐ Smooth ☐ PVC)

Figure 15. Work scope example

4.6 Permitting

The code official in the area in which the test home was located had never seen this type of DER. He wanted to be sure this construction was safe and therefore asked for a professional stamp on the details, structural calculations, and related materials. In response to this request, IBACOS assembled a package that included the construction drawings for the DER, structural calculations, and a summary letter of how the construction would be executed. IBACOS then collaborated with a licensed structural engineer in New York, who agreed to stamp the package. This stamped package was sent to the code official, and construction was approved to commence.

Appendix D discusses some of the questions that might have to be addressed to acquire a permit before construction of a stand-off furring project can begin.

4.7 House Construction

Using the best solution sets from the laboratory mockups, GHA implemented the chosen solution. IBACOS and GHA worked together with other project partners to evaluate in-field applications and modifications that were necessary to reduce costs where possible. GHA worked to collect detailed labor activities and documented the learning curve in actual field practices compared to the mockups. GHA used the same construction crew for the retrofit to document the progression of knowledge and to identify training needs that could speed adoption. IBACOS conducted periodic field visits at key points during construction to identify technical and process barriers that could prevent a solution from meeting the desired results.

4.7.1 Material List

Materials used and unit costs per square foot for the exterior wall system were determined before construction. This helped to inform the overall cost of the system.

4.7.2 Construction Schedule

GHA created the project schedule, as shown in Figure 16, based on its prior knowledge of energy upgrades to homes. During Week 1 of the project, GHA prepared for the construction by ordering materials, obtaining permits, and notifying manufacturers of the timeline. During Week 2, the subcontractors began to install some mechanical equipment and start the energy upgrades to the attic and basement. During Week 3, the exterior framing of the wall system commenced. In Week 4, the subcontractors installed the windows and doors and added the spray foam insulation to the exteiror wall. This was followed in Week 5 by the addition of new siding on top of the wall system.

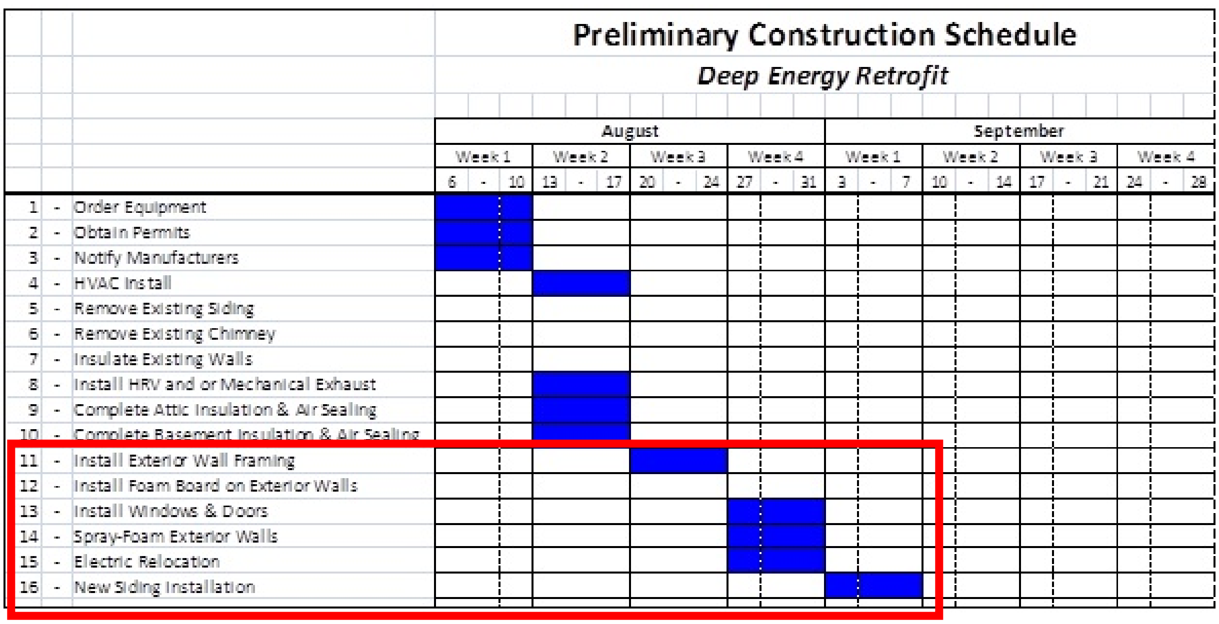


Figure 16. Construction schedule with exterior wall timing highlighted

4.7.3 Construction Process

The following section of photographs provides a visual record of the progress of construction on the test house. Step-by-step details are included in Appendix A.

Figure 17 shows the start of framing being installed over the existing siding for the spray foam DER.

Figure 17. Exterior framing

Figure 18 shows the front elevation of the house, with most of the framework installed.

Figure 18. Exterior front framing

The house then was ready for the application of the spray foam. Figure 19 shows the start of that process.

Figure 19. Installation of spray foam

Figure 20 shows the interior unfinished build-out after the new window was installed.

Figure 20. Window detail at built-out box

Figure 21 shows the interior finished wall trim after the new window was installed.

Figure 21. Window detail

Figure 22 shows the exterior of the test house with the spray foam in place.

Figure 22. Exterior spray overview

Figure 23 shows the wall system at interior and exterior corners.

Figure 23. DER intersection

Because this house was to receive new vinyl siding, a sheathing product was needed over the studs, per the vinyl siding manufacturer's recommendation. The team used a thin profile structural sheathing that was extended to the roof line and was installed after the spray foam insulation. Bulk water was handled by the thin profile sheathing, and it was inferred that incidental water past the sheathing would drain over the spray foam. Figure 24 shows the thin profile sheathing being attached.

Figure 24. Exterior thin profile sheathing

Figure 25 shows the installed thin profile sheathing with the vinyl siding. Note that taping of the windows and seams in the sheathing provides an extra layer of water management in addition to those shown in the step-by-step details described in Appendix A.

Figure 25. Siding Installation

Figure 26 shows the insect screening that was installed at the bottom of the new siding application.

Figure 26. Insect guard and ventilation at the bottom of the wall system

Finally, Figure 27 shows the front elevation of the home after construction was complete.

Figure 27. Final exterior front of the test house

4.8 Costing

One of the main research questions in this DER project was to find a way to install exterior insulation systems for $10/ft^2 or less. Prior to construction, it was estimated that the cost per SSF would be $17, including siding. Table 2 shows a breakdown of the cost for the wall system. The wall work is broken down into the following categories: new framing, removal of existing windows, window trim, spray foam application, installation of thin profile sheathing, and installation of insect screen. The table also shows that, excluding the cost of the siding, the overall cost per square foot is slightly over the $10 target.

Table 2. Wall Cost Estimates Versus Actual Cost

Wall Work	Total Actual	Actual Cost per SSF
New Framing	$5,625	$2.57
Removal of Windows	$671	$0.31
Window Trim	$3,606	$1.65
Spray Foam	$7,198	$3.29
Thin Profile Sheathing	$3,717	$1.70
Insect Screen	$1,167	$0.53
Total Without Siding	**$23,518**	**$10.76**
Install Siding	$18,574	$8.50
Total With Siding	**$42,093**	**$19.26**

4.9 Testing Results

Blower door testing was conducted on the test house prior to construction, throughout construction, and at the completion of construction. Two different blower door tests were performed on the test house: one test that included the basement in the volume of the building, and one that did not.

Table 3 describes the blower door test results without including the basement in the volume of the building. The details used for the test house without including the basement are as follows:

- Volume: 18,208 ft^2
- Square feet of conditioned space: 2,276 ft^2
- Perimeter of the house: 257 ft
- Wall height: 8 ft
- Shell square footage: 6,608 SSF.

Table 3. Test House Airflow Reduction by Stage, Without the Basement

Improvement Stage	CFM50	CFM50 Reduction From Start	% Reduction From Start	ACH50	CFM50/ SSF
Start	2,675	0	0%	8.8	0.40
Air Seal Attic	1,925	750	28%	6.3	0.29
Wall Build-Out (Including Windows and Foam)	1,800	875	33%	5.9	0.27
Spray Foam Band Joist/Energy Recovery Ventilator Installed	1,625	1,050	39%	5.4	0.25

5 Discussion

The following information describes the construction process and how it affected the outcomes of this project.

5.1 Construction Results

Throughout the DER construction of the test house, IBACOS and GHA kept tabs on any unexpected issues that arose. The construction results are as follows:

- The ledger boards installed over the existing siding were different distances from the existing plumb frame walls. This created additional layout work when installing the new studs to ensure the rough openings around windows and doors were a uniform dimension. One solution would be to uniformly shim the ledger boards to be the same distance from the existing face of the wall framing.
- The brackets did not provide the initial rigidity expected for the new wall framing, and the studs moved more than expected when the spray foam was installed. “Picture framing” the studs with spray foam would likely secure them in place and minimize movement of the framing as the spray foam in the field of the wall is applied.
- It had been decided that the windows would be installed after the exterior walls were built; however, it worked better to pull and replace the windows at the same time as the exterior walls were being built.
- The metal brackets required many screws; application of these brackets and screws was more time consuming than anticipated.
- Some siding was removed in areas where the roof line would not accept the new DER.
- Spray foam preparatory work included placing plastic over the windows and exposed foundation to protect them from overspray.

5.2 Construction Issues

The following describes issues that arose when construction began on the test house.

5.2.1 Installation of Ledger Boards

When the ledger boards were installed over existing siding, the inconsistent surface created more layout work. The distance of the ledger boards from the walls varied, depending on where these ledger boards fell. In the case of the test house, the siding was a wide shingle that left significant variation. This led to creating a new wall surface that did not follow the existing wall and rough opening. Figure 28 shows the installers measuring the surface and installing the 2 × 4 boards.

In the future, this issue could be resolved by planning for the inconsistencies from the beginning and measuring out how far the boards need to be placed from the existing wall, or shimming the ledger to a consistent distance from the existing wall framing.

Figure 28. Installation of ledger boards

5.2.2 Brackets and Spray Foam

There was a side-to-side bowing of the vertical studs, so it may be necessary to have a bracket at the midpoint of the wall. This can be a less expensive, nonstructural bracket that would simply provide the rigidity needed while spraying the insulation. This deflection caused additional "detail" work in installing the windows. Some rough openings were moved out of plumb, which affected the trim work and, in turn, affected timing. Figure 29 shows a close-up view of the two brackets at the top and bottom of the ledger boards.

This issue could be resolved by using two or even three brackets from the start and strategically placing them for the greatest stability.

When using spray foam, preparatory work is needed. For the test house, the preparatory work included placing plastic over the windows and exposed foundation to protect them from overspray. However, the subcontractor also built a portable "tent" that propped against the house to minimize overspray onto plantings or other areas adjacent to the house.

Figure 29. Brackets on top and bottom

5.2.3 Window Installation

The decision to change the original plan of installing the windows after the exterior wall construction to doing the two installations simultaneously allowed for sections of wall to be completed; however, this change left a gap between the old and new walls that had to be addressed. Instead of a temporary enclosure with tape or oriented strand board to handle foam expansion, it was decided to install the extension jambs along the way as well. This minimized disruptions on the inside as more work was done all at once in a particular area. Figure 30 shows this process.

It is recommended that contractors plan for pulling and replacing the windows at the same time as the exterior wall framing is being built.

Figure 30. Window installation

5.3 Before and After Details

Figure 31 through Figure 34 show the bottom- and top-of-wall details as the team began to plan them versus what developed into construction.

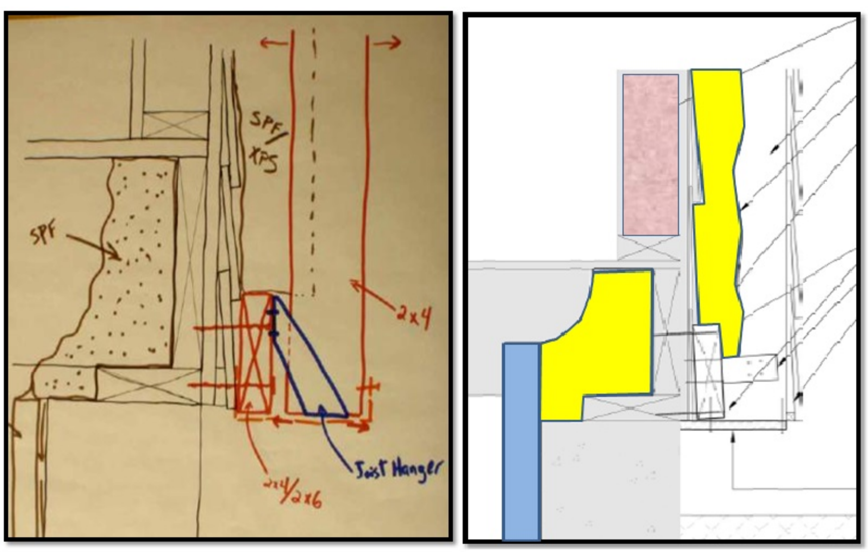


Figure 31. Before—Bottom-of-wall details

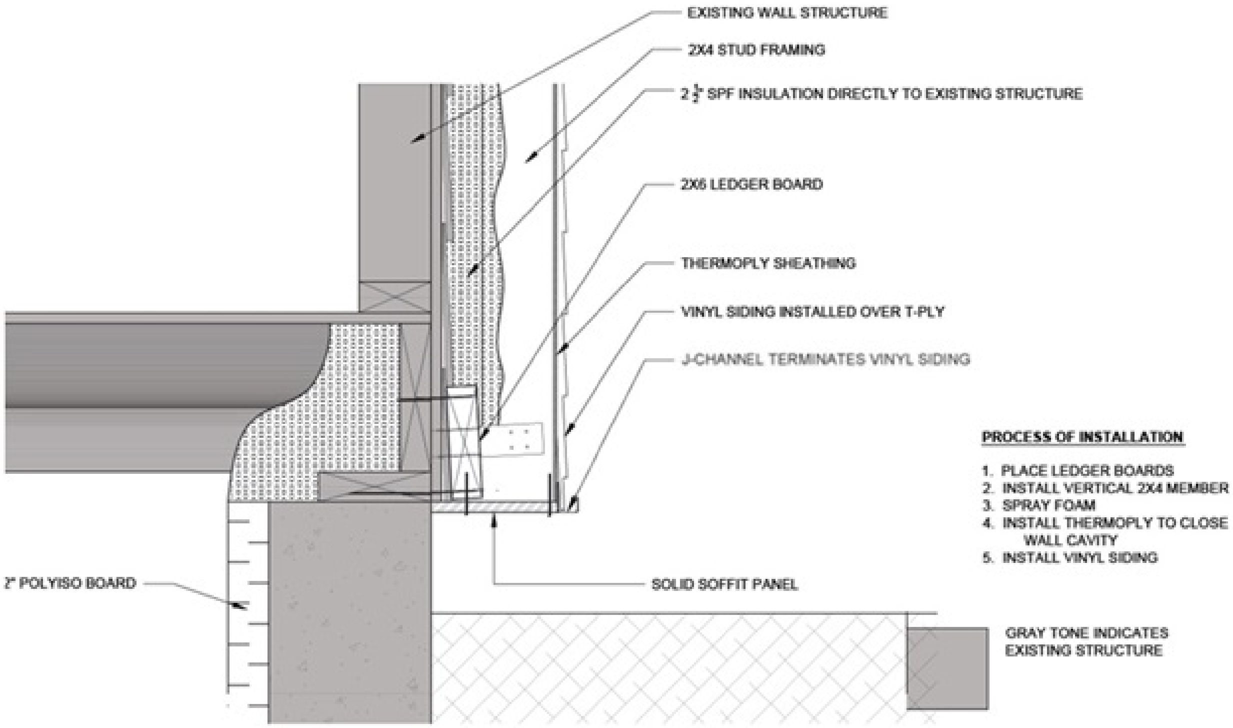


Figure 32. After—Bottom-of-wall details

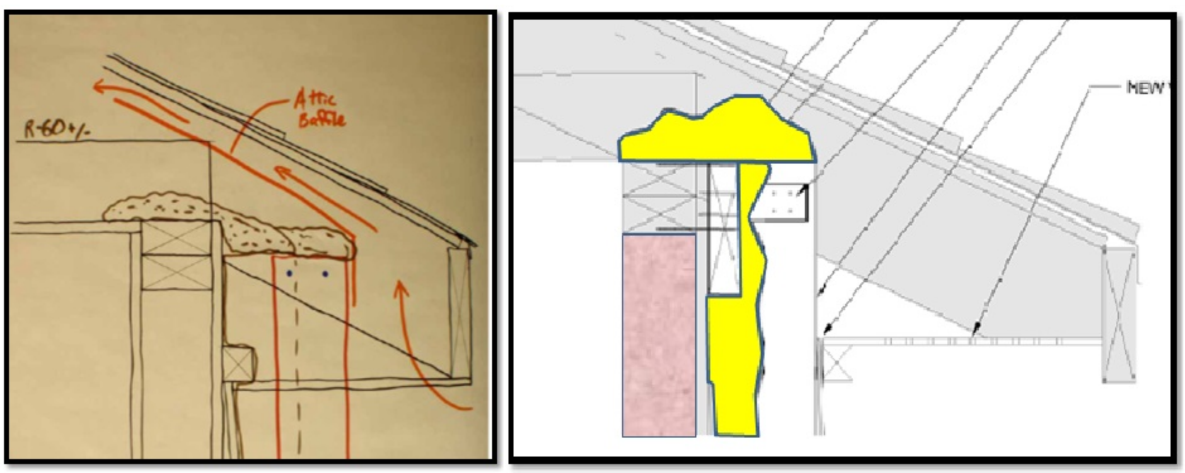


Figure 33. Before—Top-of-wall details

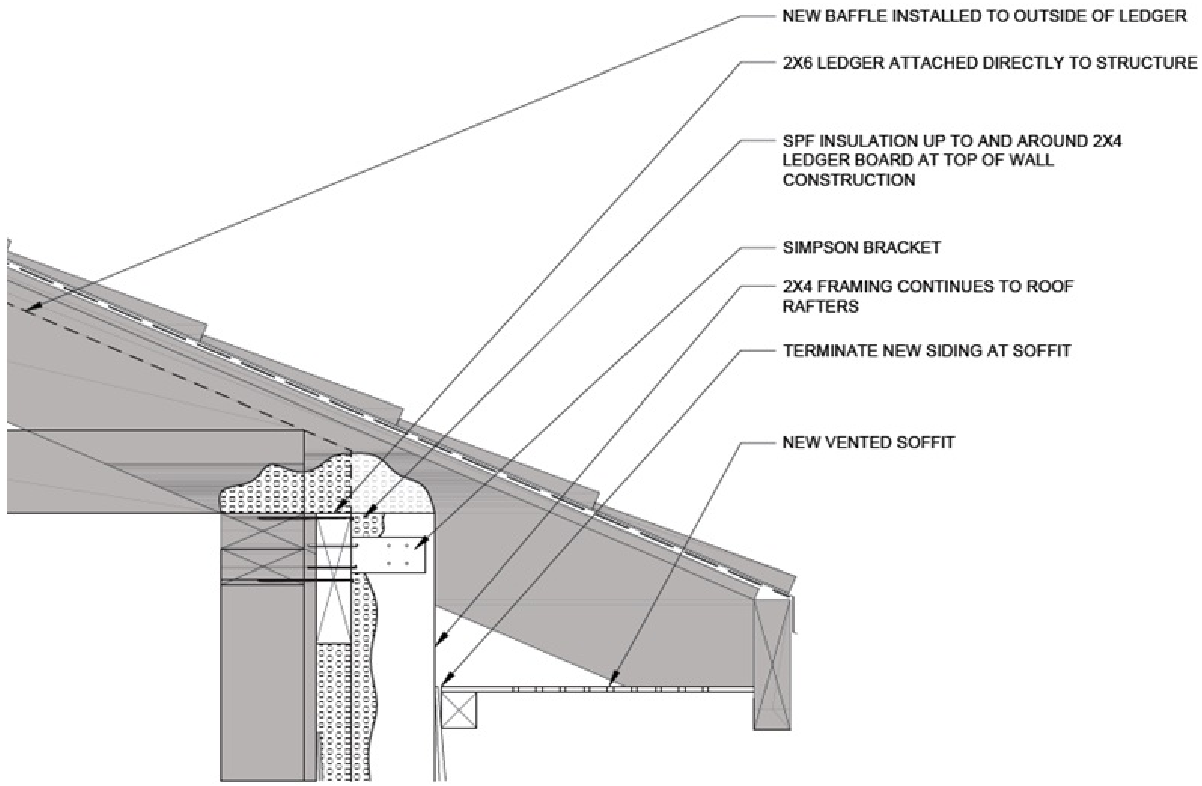


Figure 34. After—Top-of-wall details

All post-construction detail updates can be found in Appendix B.

5.4 House Airtightness Results

In Section 4, Table 3 showed that the wall system did not have a significant contribution to the overall airtightness improvement for the house compared to the attic air sealing. This may be due to the fact that the house was a single story with few possible exterior wall bypasses.

5.5 Monitoring

The research team plans to install this strategy on a few other homes and to compare the use of rigid foam in place of the spray foam. On the house used in this stand-off furring project, monitoring will be done throughout the next year to determine the energy savings resulting from the DER. The monitoring will include indoor and outdoor temperature and relative humidity, run time of the space heating system, blower door tests, and collection of homeowner utility bills.

6 Conclusions

Some lessons that were learned in the DER construction of this test house will help in future building for the contractor and for builders.

Attention to the shimming of the ledger boards can help minimize downstream construction issues associated with the variation in exterior wall siding thicknesses. Additional supporting brackets or the strategic use of spray foam (i.e., "picture framing" the studs) to stabilize wall framing is needed to minimize framing movement due to the expansion of spray foam in the field of the wall.

Planning should include the installation of windows during the framing process.

Prior to construction, it is important to assess the house to discover any potential problem areas. These problem areas could include the following:

- Areas where existing overhangs will not accommodate any added thickness of the wall system
- Services on the exterior of the house, such as plumbing, electrical, utility meters. and service entrances, and attachment to accessory structures such as decks
- Walls that continue from enclosing conditioned space to non-conditioned spaces, such as garages
- Roof-to-wall intersections on two-story to single-story transitions.

The practice of conducting a stakeholder meeting—including all trades, the general contractor, the architect (if used), the homeowners, and any other individual who has influence on the project—should include a planning meeting prior to construction. All details should be discussed and documented, all contractor questions should be answered, and any unforeseen circumstances should be brainstormed at the onset.

Finally, a clear lesson is that the homeowners always have an opinion on what will be installed in their home. Thus, it is best to be clear in the contract and to specify items for which the contractor is or is not responsible, as well as planning for homeowner design aesthetic issues.

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Appendix A: Description

One method to significantly add insulation to an existing wall in residential construction is to use exterior wall spray foam insulation with stand-off furring. The advantages of this strategy include minimizing the physical connections to each individual existing wall stud, using spray foam to encapsulate existing siding materials including lead paint, and creating a vented rain screen assembly to promote drying. Field installation indicates that the incremental cost when installed as part of a typical siding and window replacement job adds approximately $10/ft^2 of wall area.

2 × 4 framing members can be attached to the wall at band joists and top plates using an "L" clip, and closed-cell spray foam can be used to insulate the wall after the framing is installed. Windows can be installed as the framing is being put up, including extension jambs.

Figure 35 through Figure 49 illustrate step-by-step instructions for the process of installing stand-off furring.

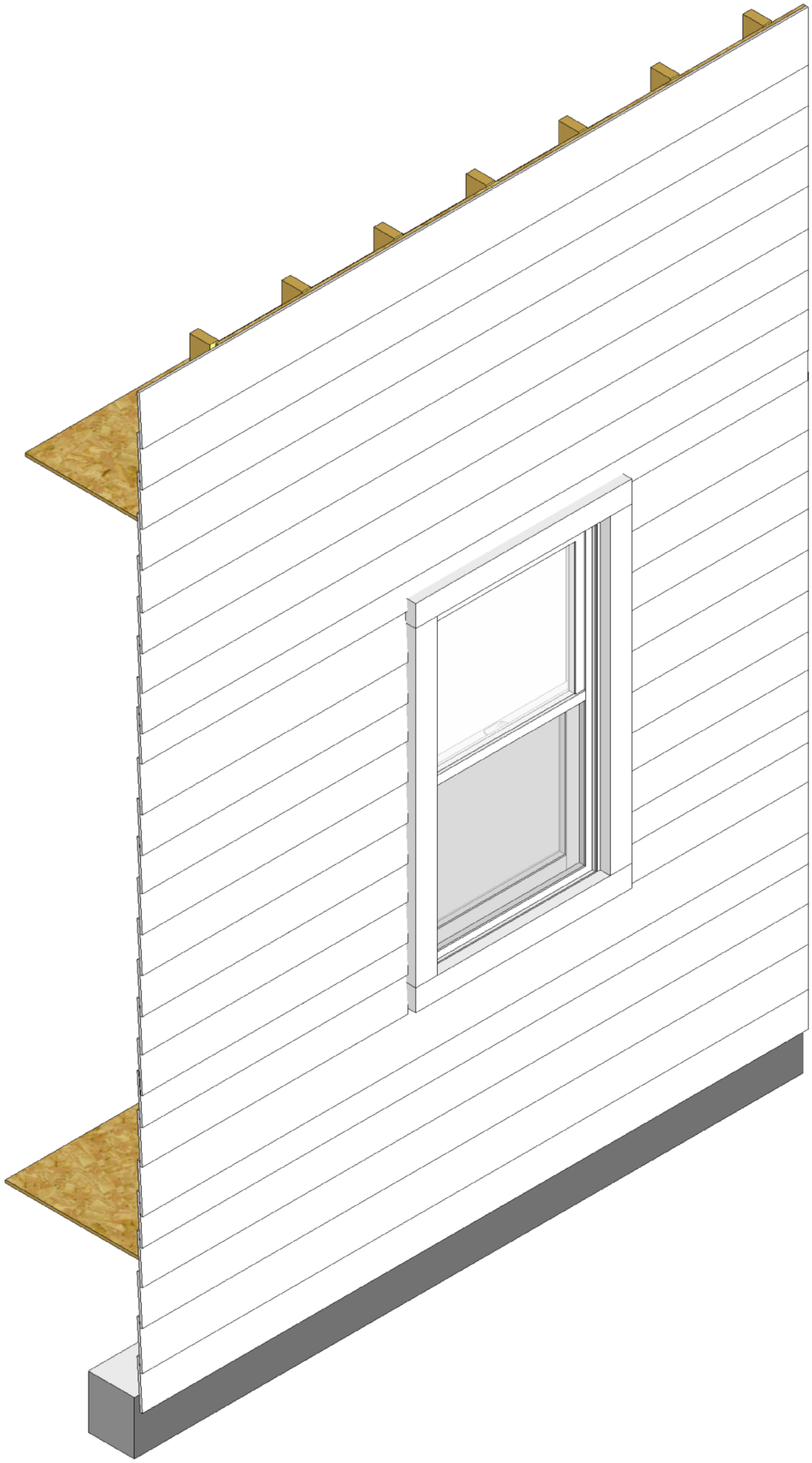

Figure 35. Step 1: Assess the existing condition of the wall.

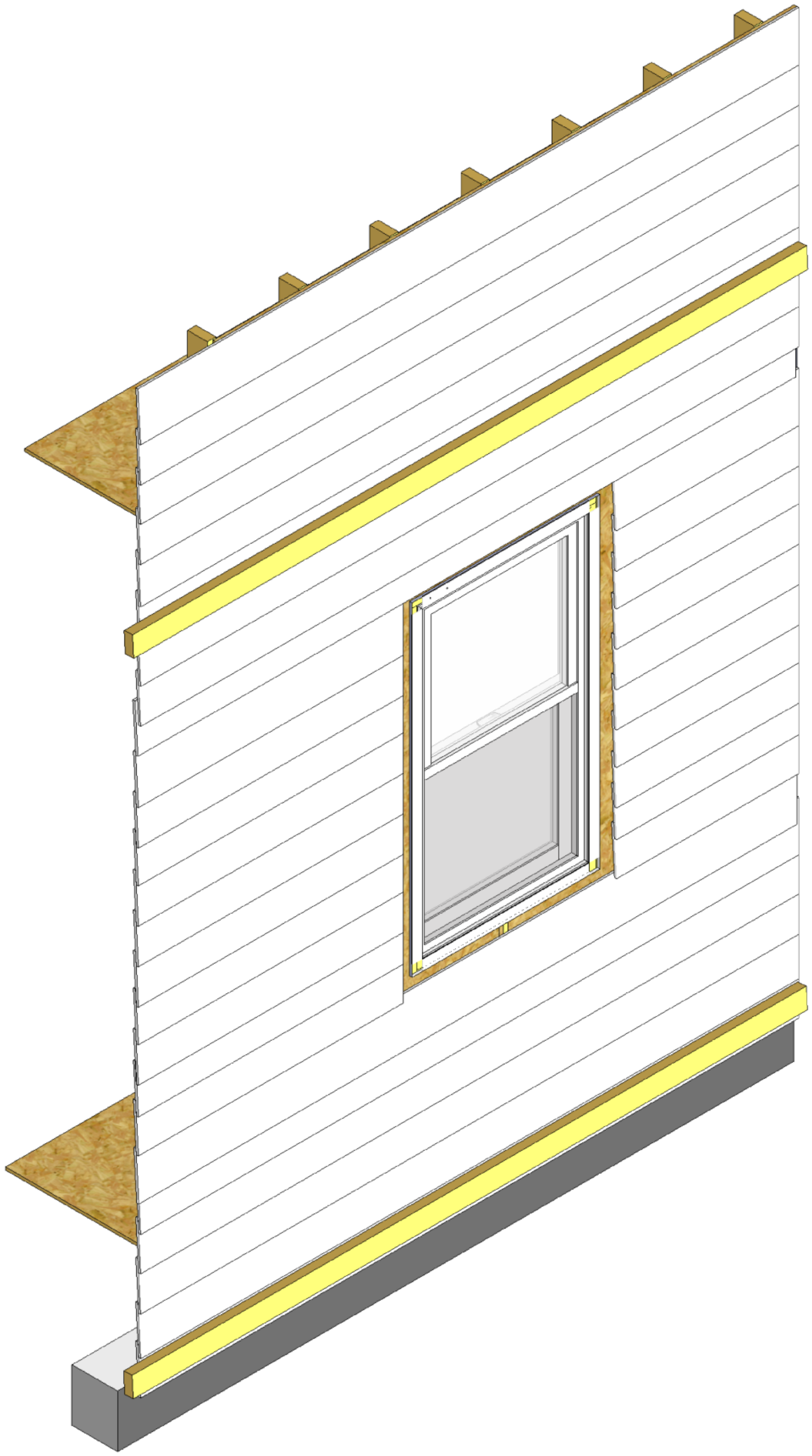

Figure 36. Step 2: Remove the existing window trim, and fasten the ledger boards through the existing exterior cladding and sheathing.

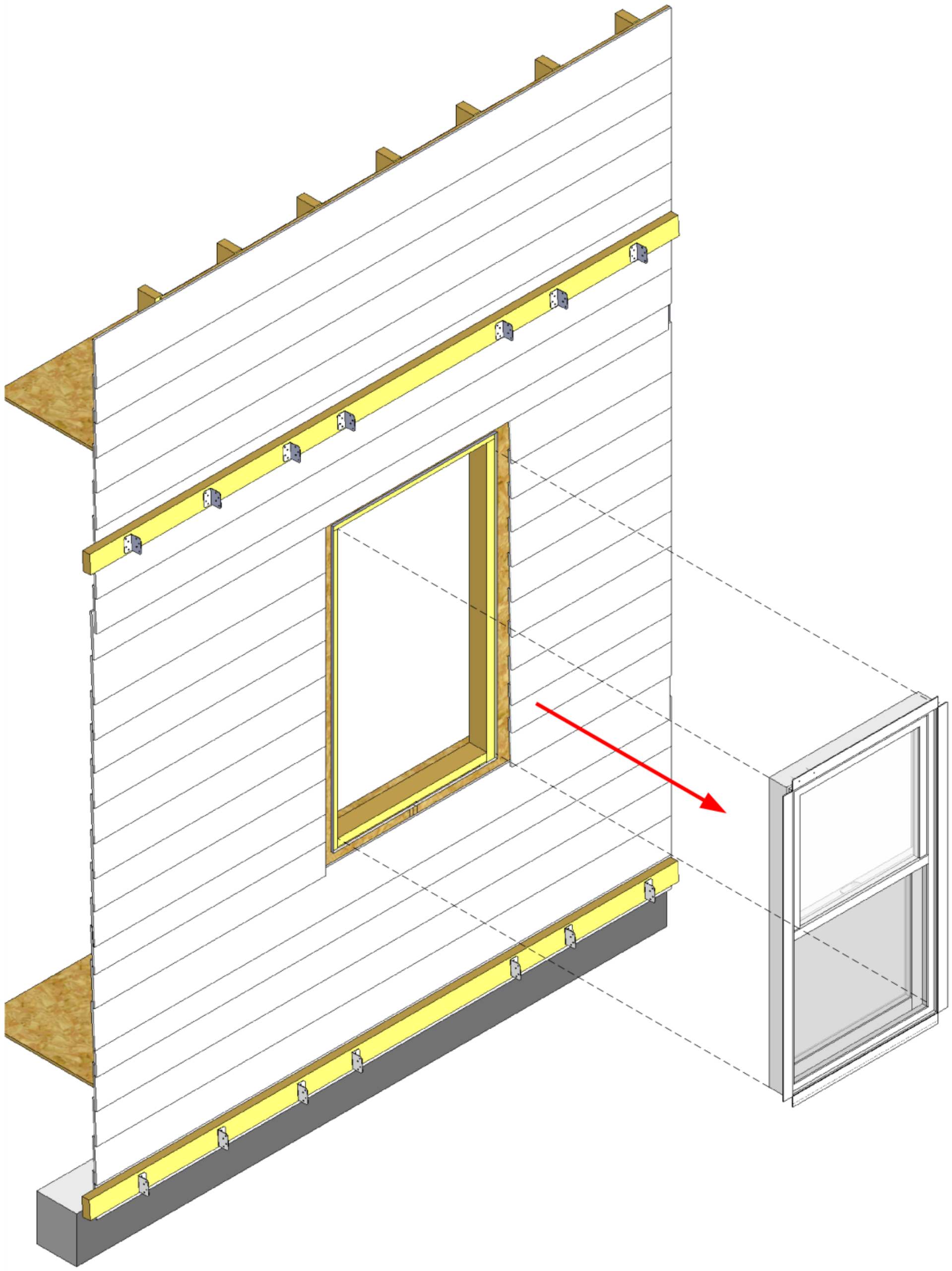

Figure 37. Step 3: Attach the metal “L” clips on the top and bottom ledger board—one on either side of where the new vertical 2 × 4 will be attached. Also in Step 3, remove the existing window, and install new framing for the new window.

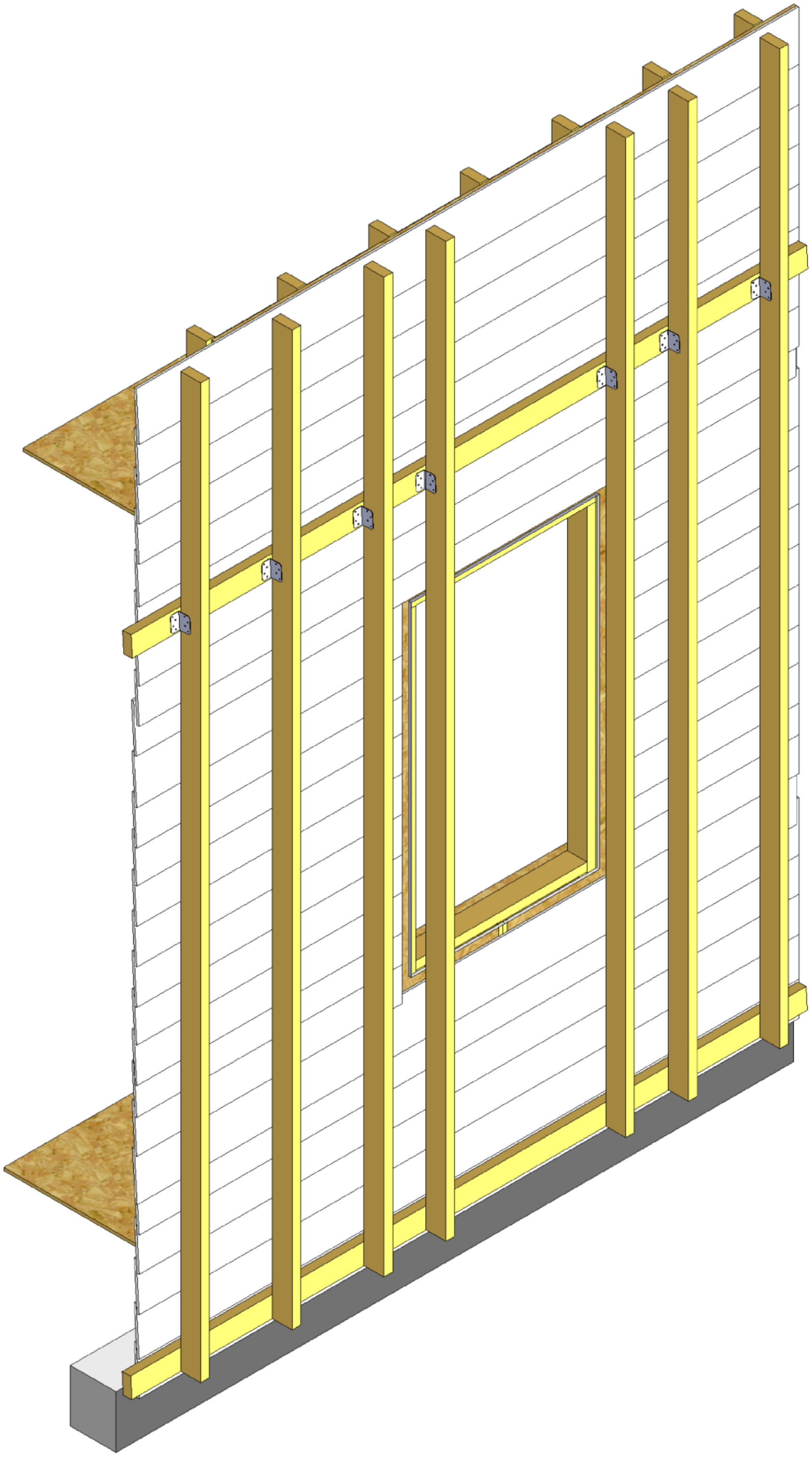

Figure 38. Step 4: Install the vertical 2 × 4s, spaced as needed based on structural calculations and siding manufacturer requirements.

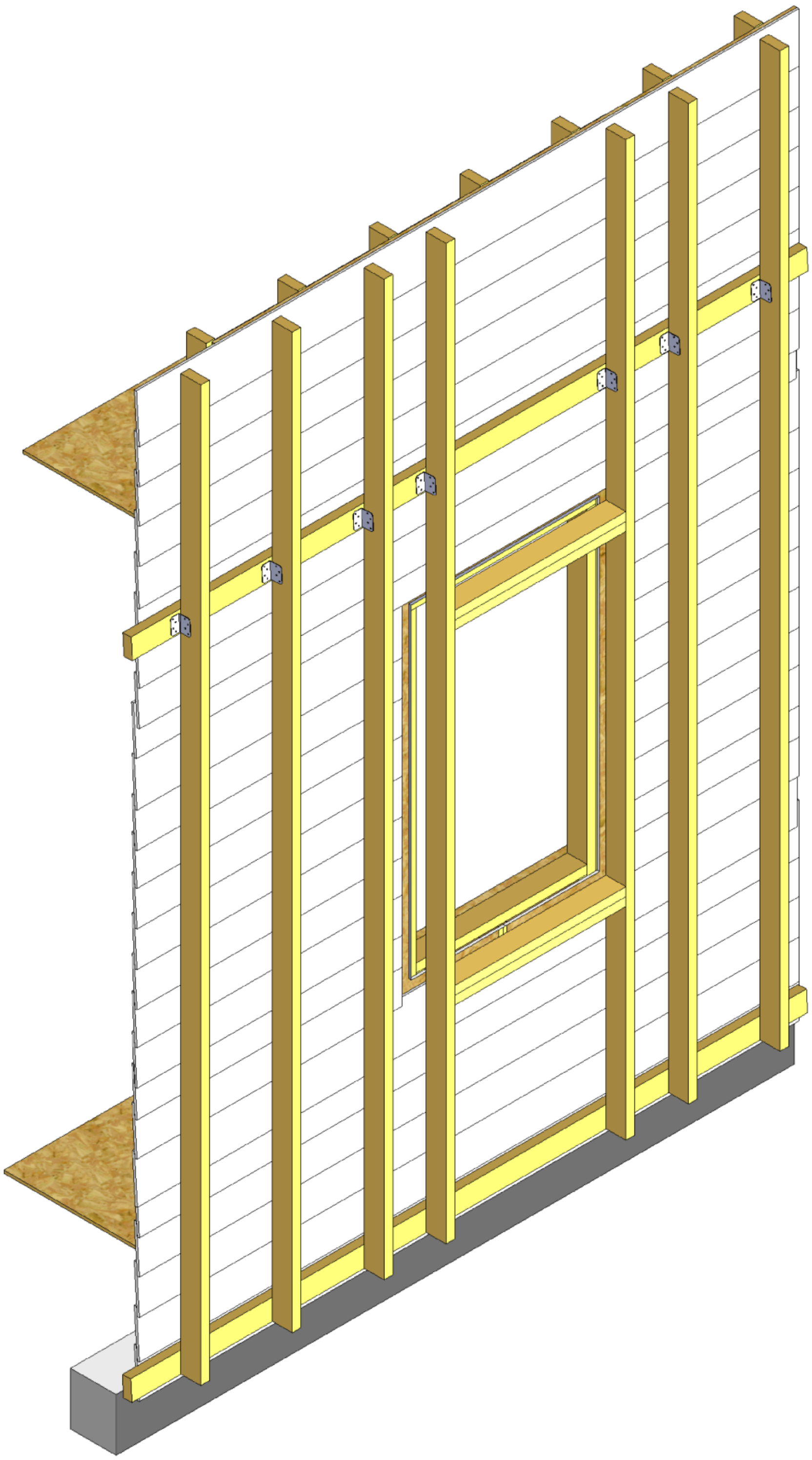

Figure 39. Step 5: Install two horizontal framing members on the top and bottom of the rough opening for the new window. Slightly slope the sill framing to the exterior.

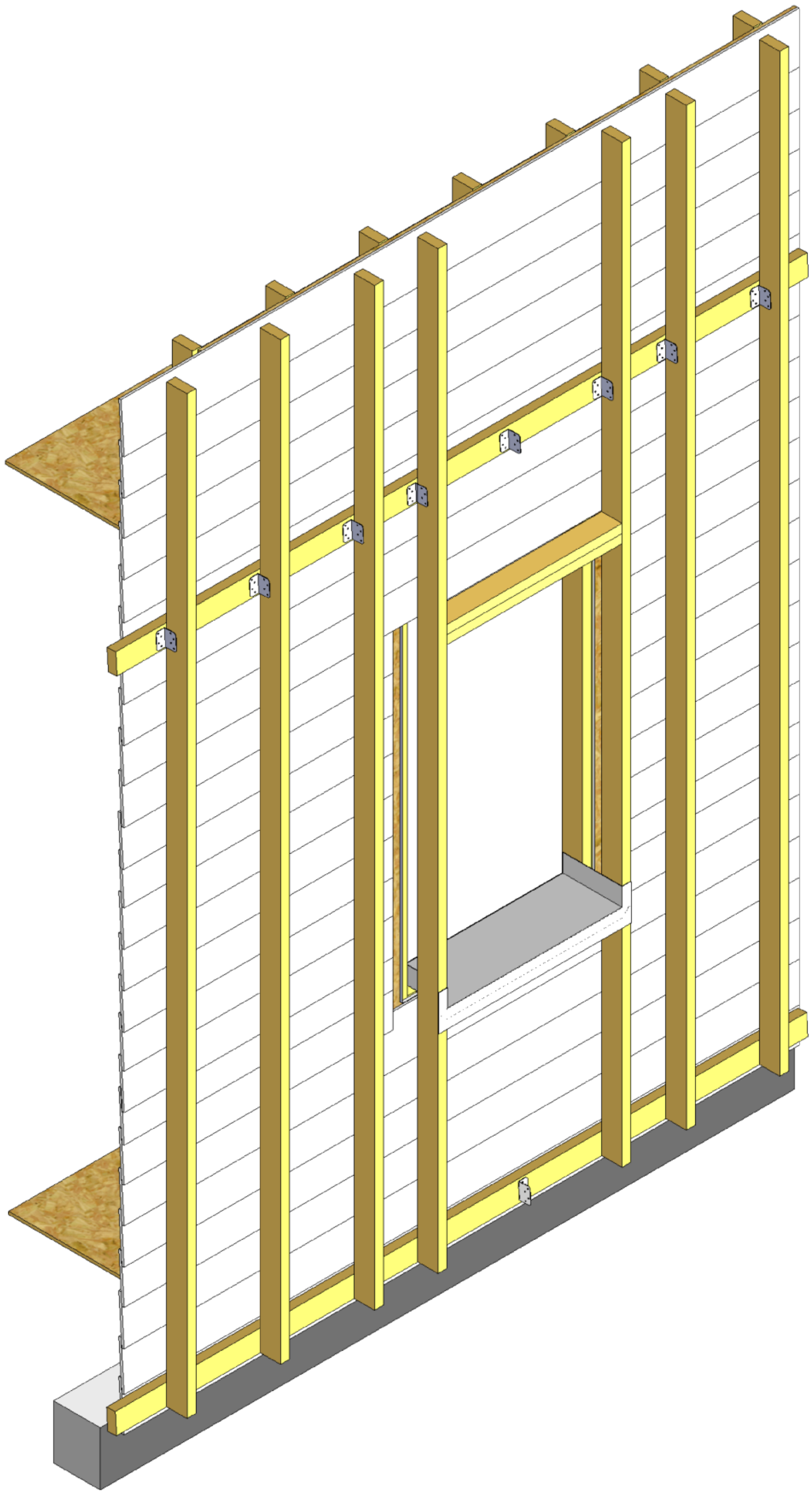

Figure 40. Step 6: Install the sill pan.

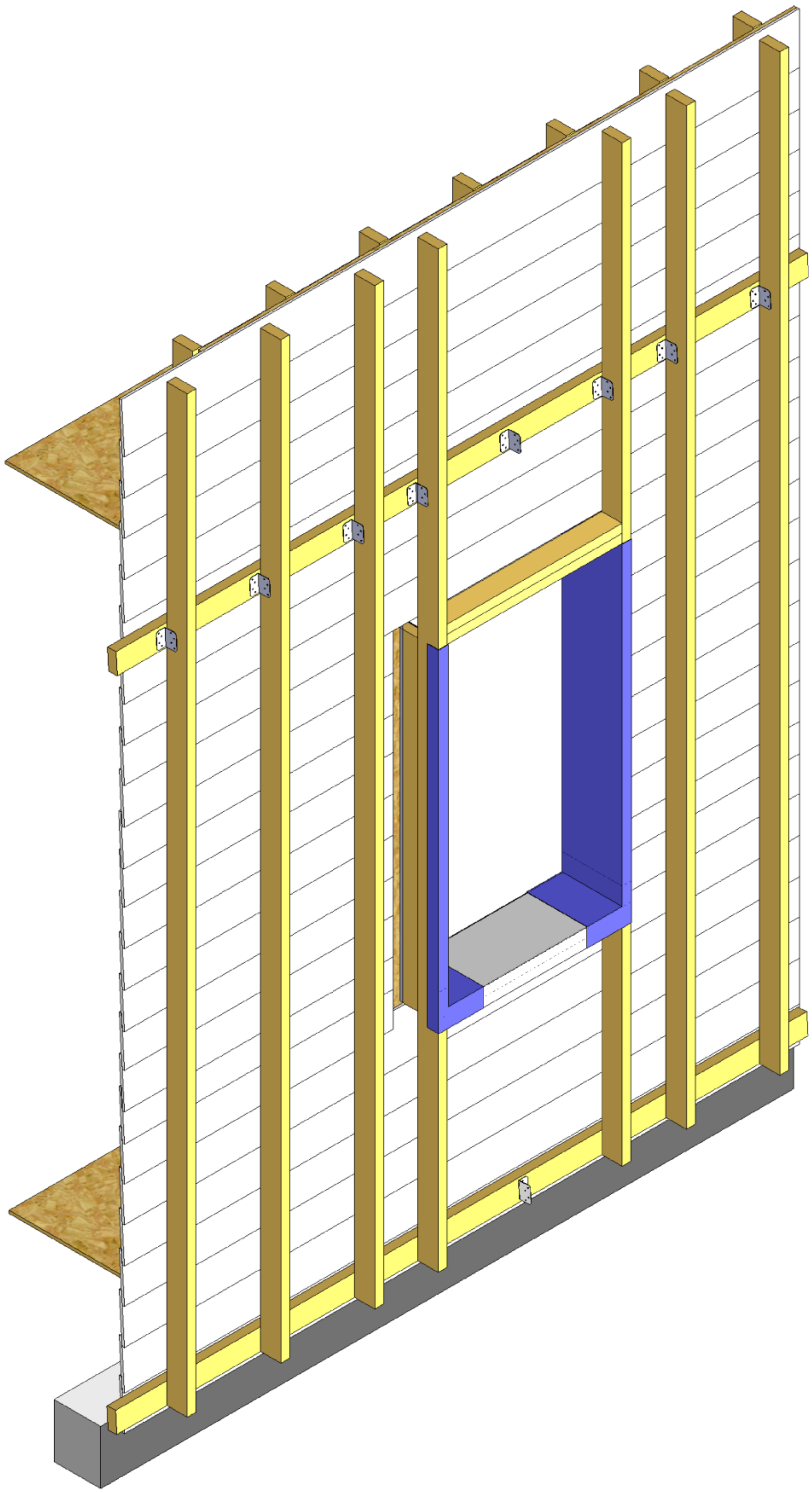

Figure 41. Step 7: Install the flexible flashing on the rough opening and at least 6 in. up the sides of the jamb.

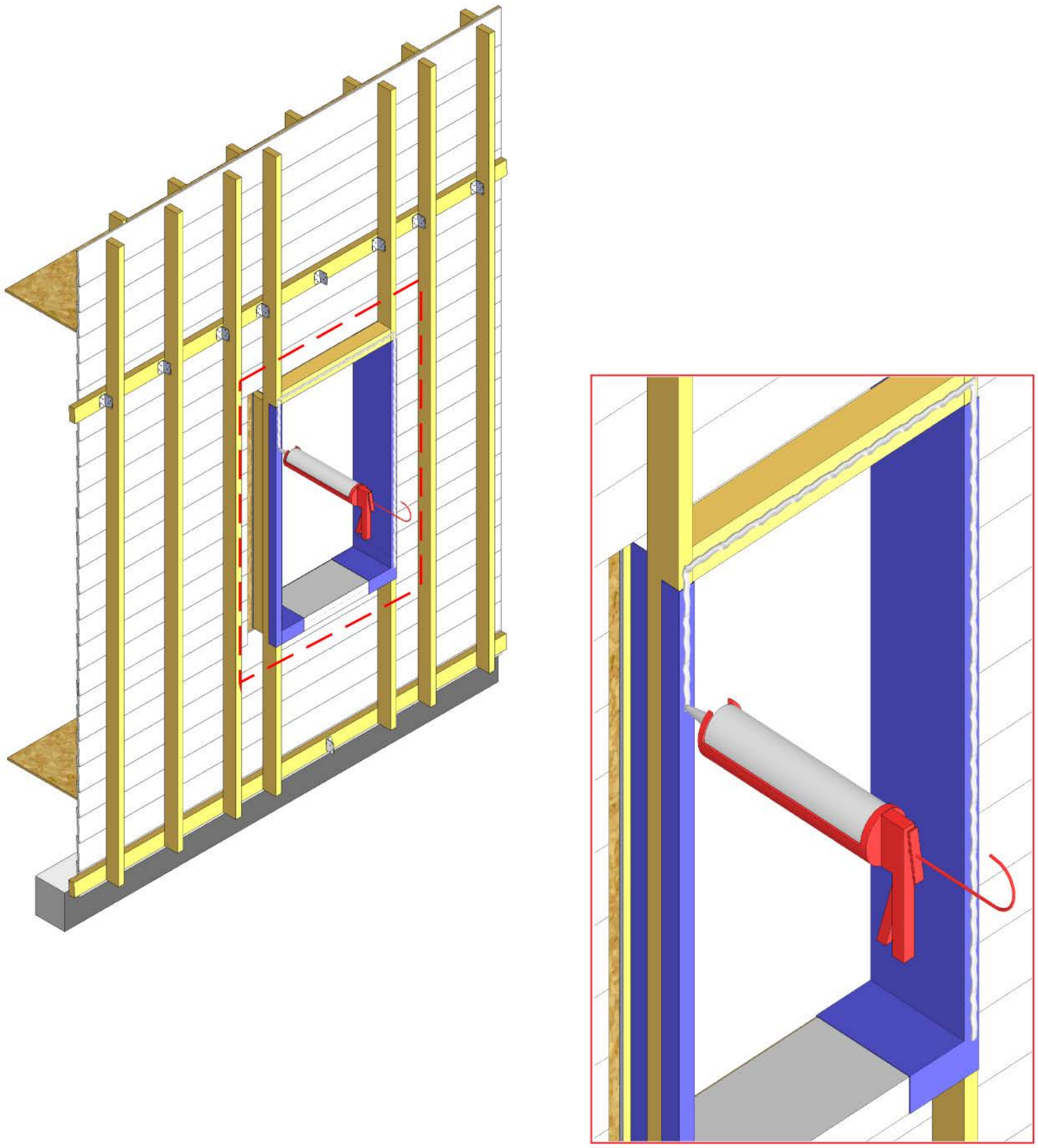

Figure 42. Step 8: Install caulk on the face of the rough opening at the jambs and head. Do not caulk the sill.

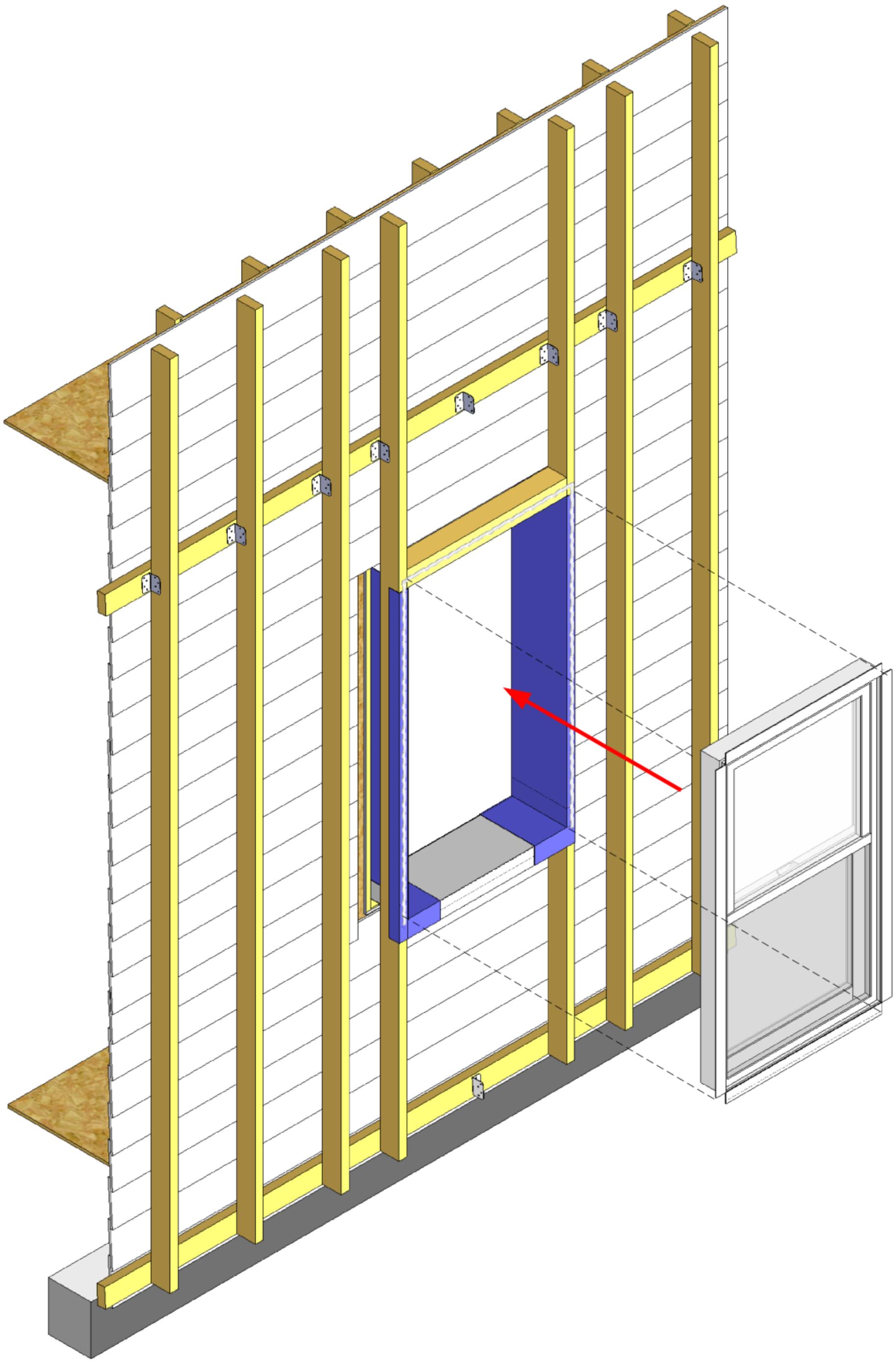

Figure 43. Step 9: Install the new window.

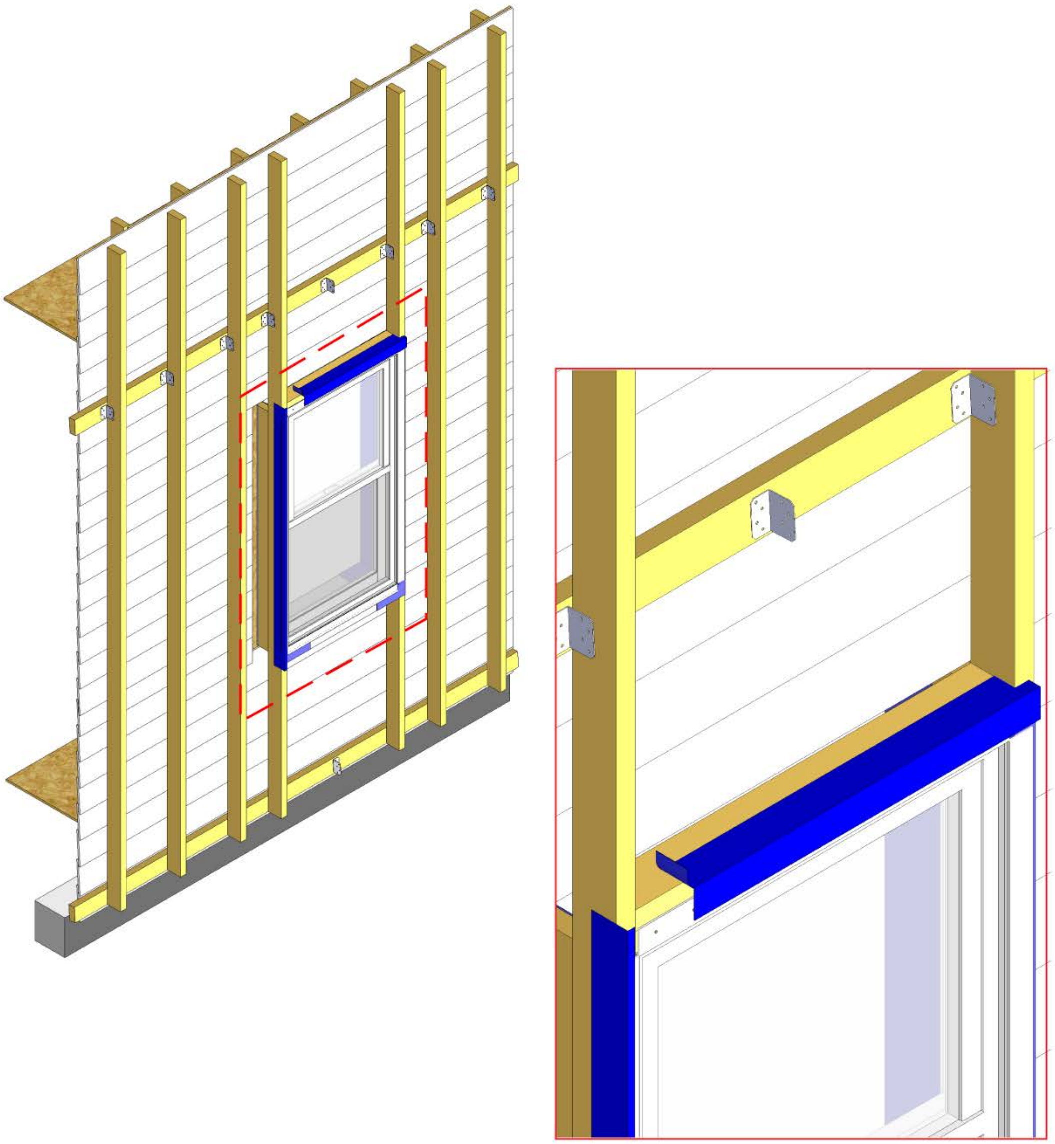

Figure 44. Step 10: Install the jamb flashing (flat on the face of the window flange).

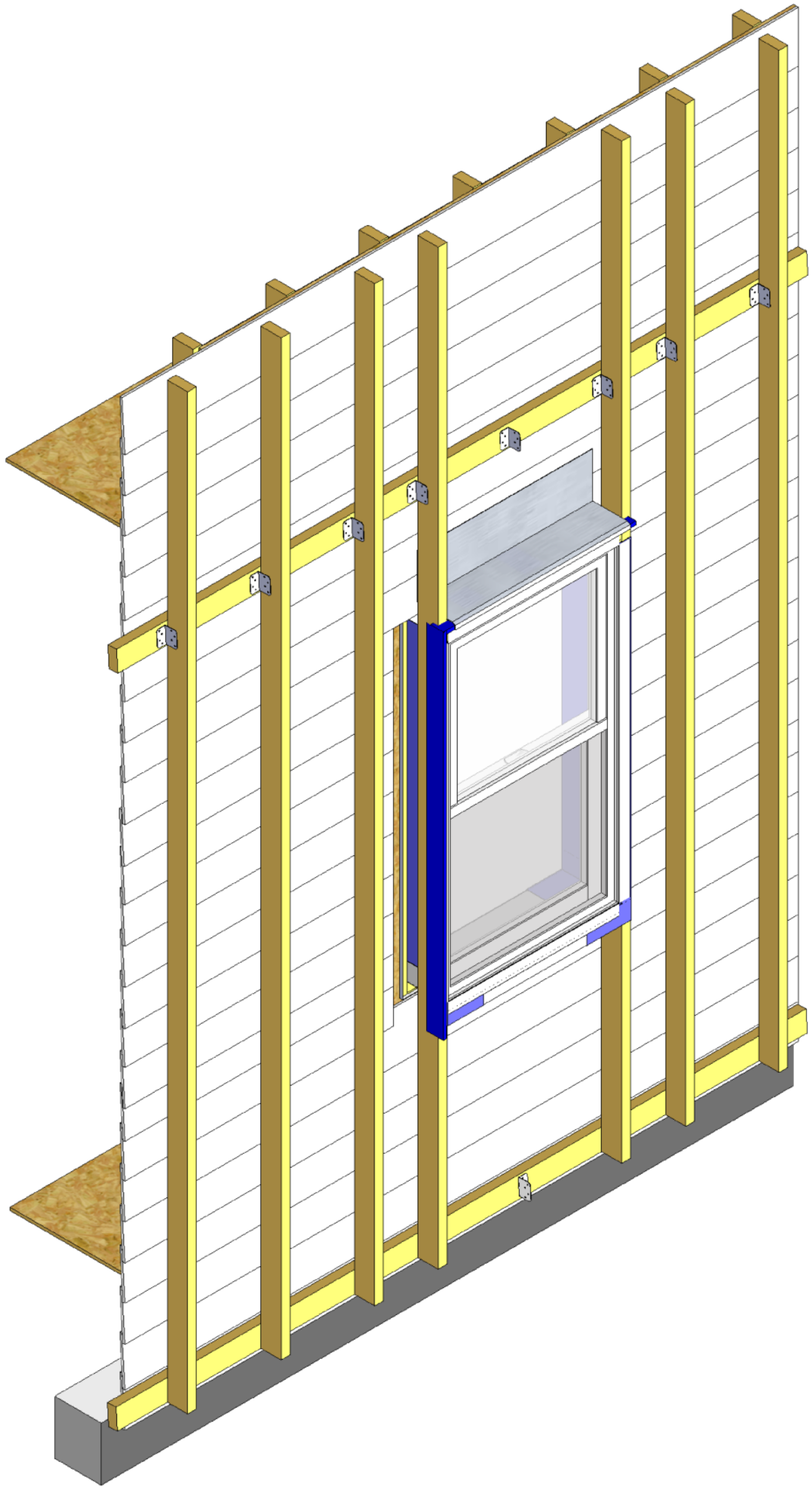

Figure 45. Step 11: Install the head flashing from the face of the existing wall to lap over the head of the new window. Also, tape the flashing at the head using straight flashing tape lapped over the horizontal part of the head framing.

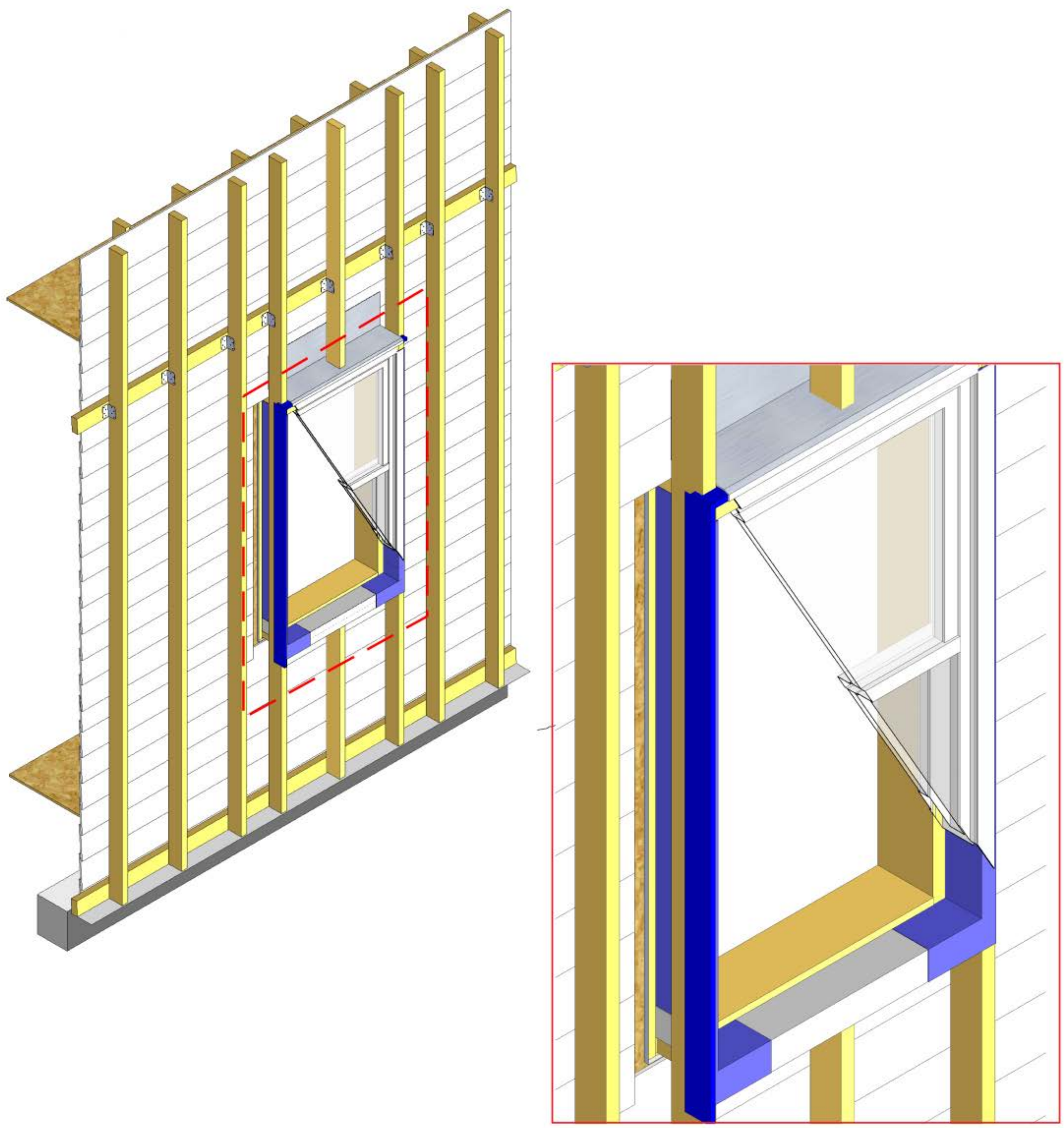

Figure 46. Step 12: Install the vertical framing members above and below the new window, and install the insect screen to the bottom of the new wall. Air seal the window from the interior using non-expanding foam sealant, and install internal jamb extensions to prevent exterior spray foam from getting into the house.

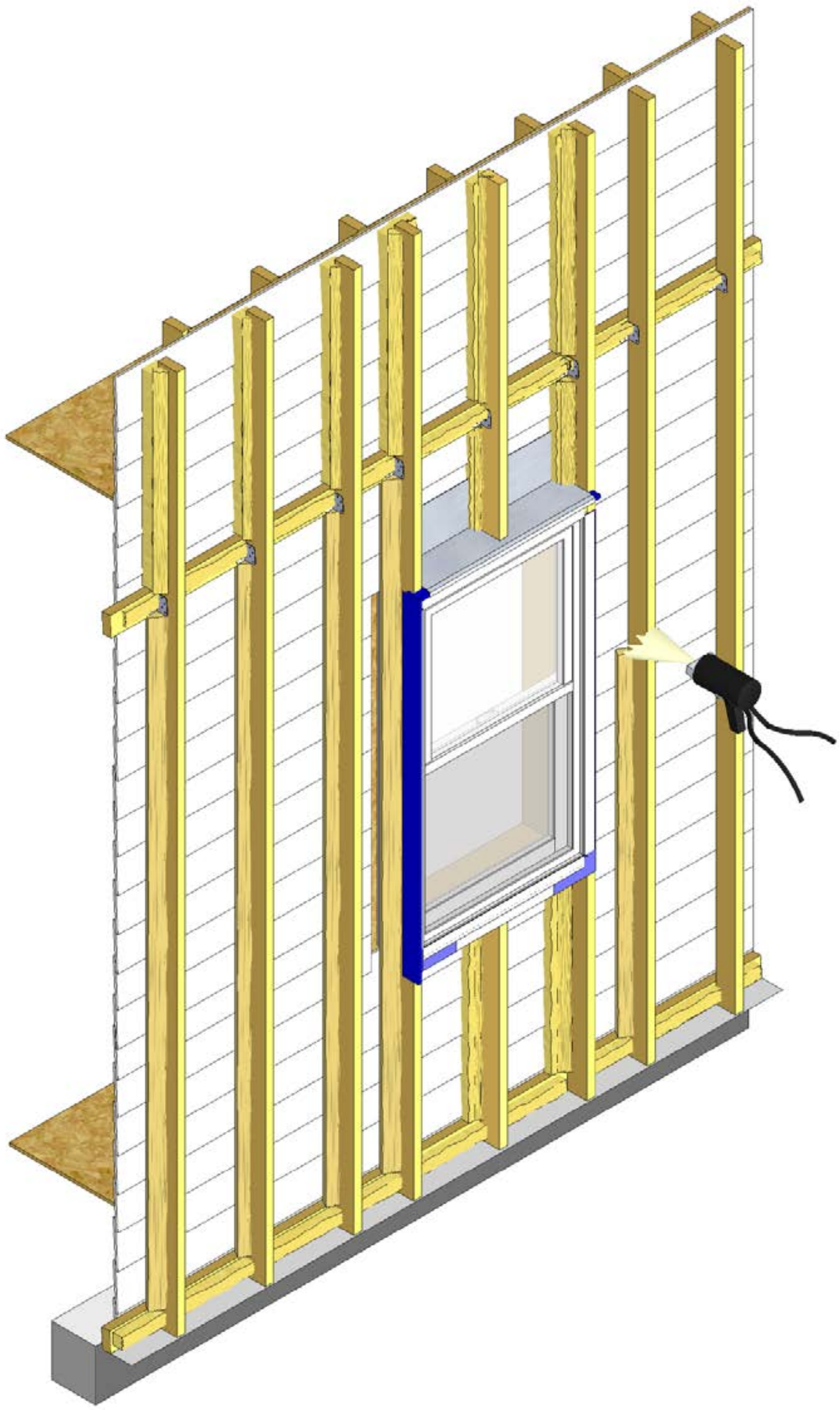

Figure 47. Step 13: Begin the spray foaming by first spraying the foam around the edges of the vertical 2 × 4s to "picture frame" the area. This will also allow the spray foam to extend under the 2 × 4 being held off the existing wall by the clips. Secure the framing in place to minimize movement of the studs.

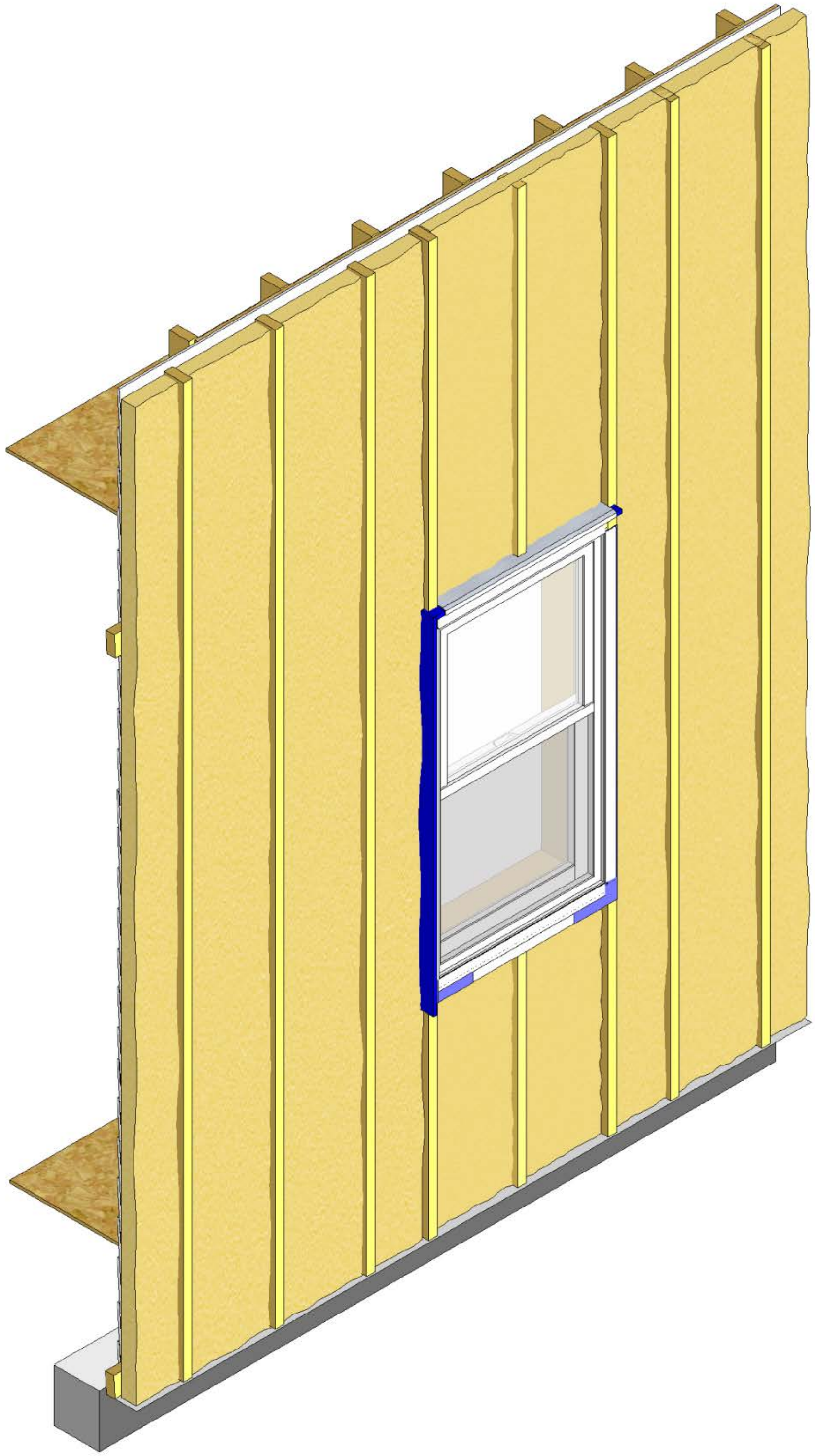

Figure 48. Step 14: Spray insulation within cavities of the new wall.

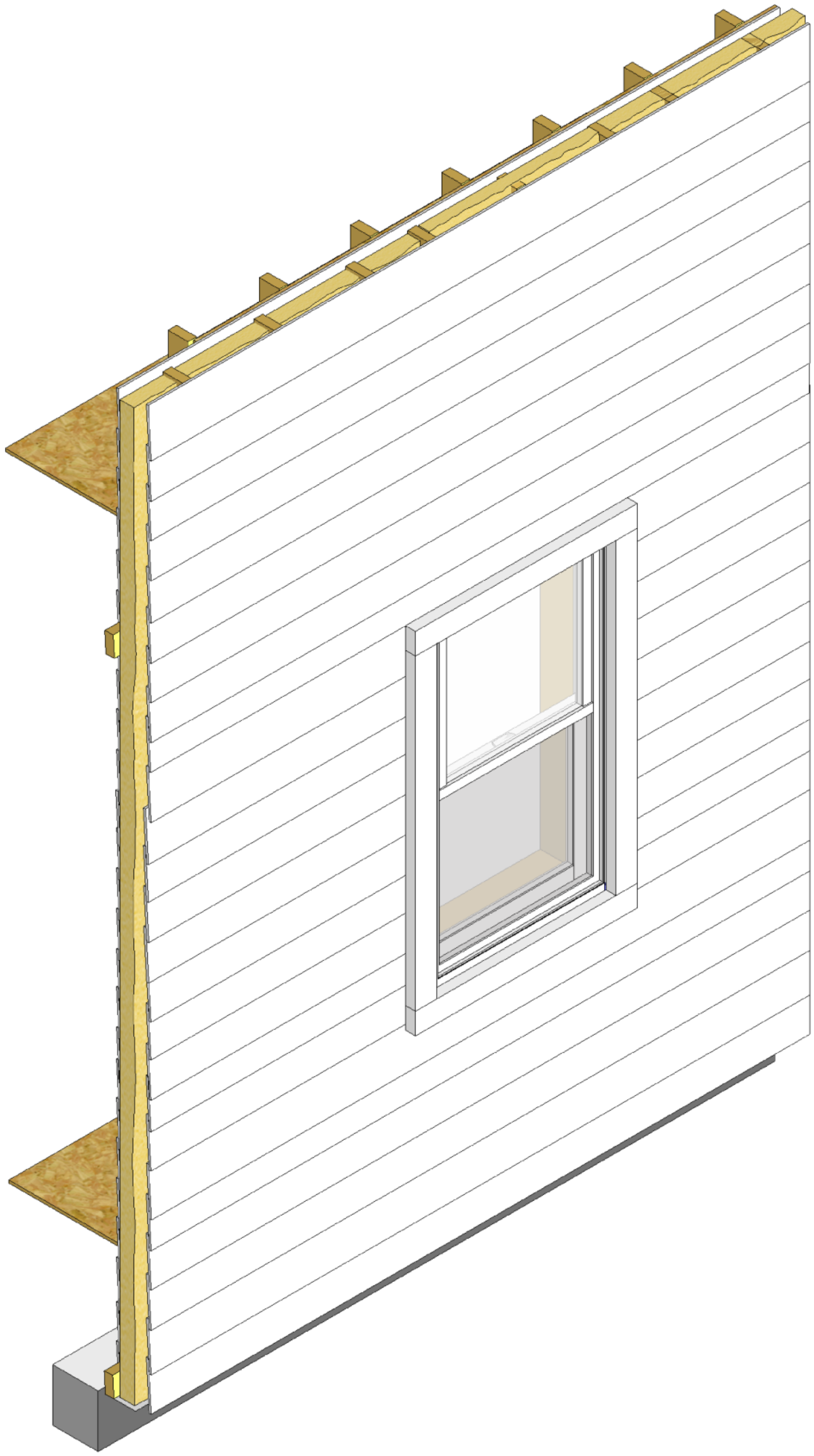

Figure 49. Step 15: Install the new cladding, and install the new window trim.

Appendix B: Computer-Aided Design Details

The computer-aided design details shown in Figure 50 through Figure 56 apply to exterior wall framing with spray foam.

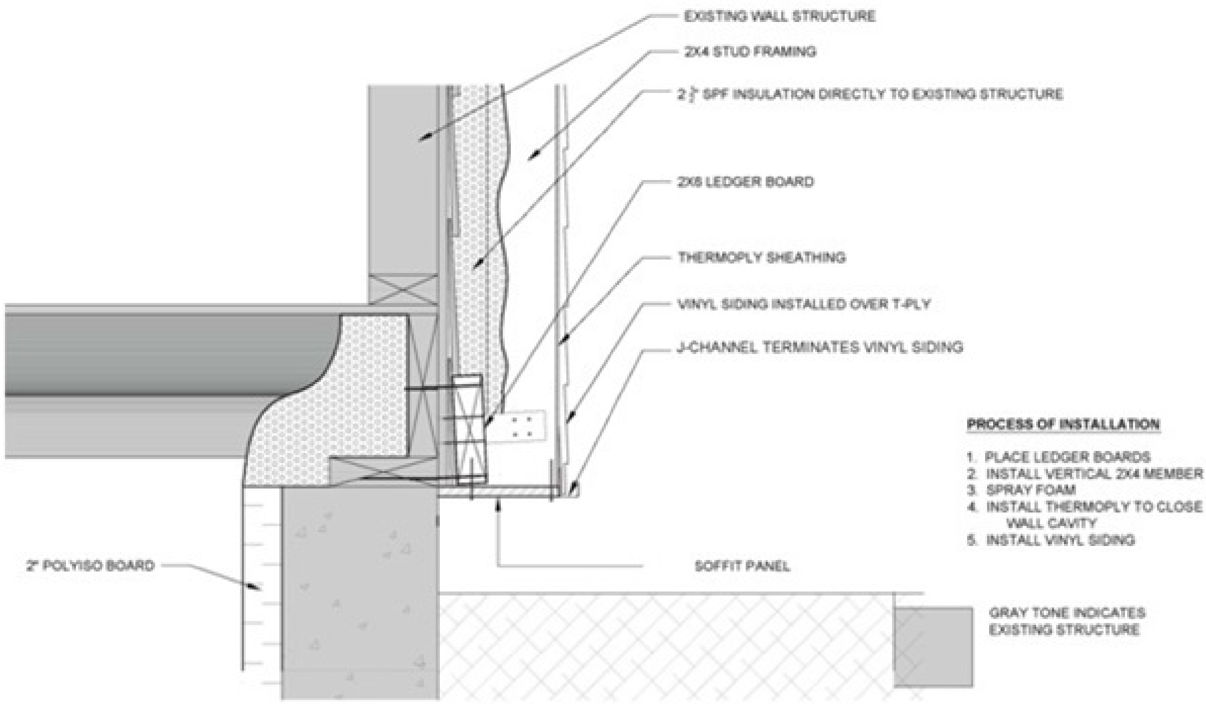

Figure 50. Wall at foundation

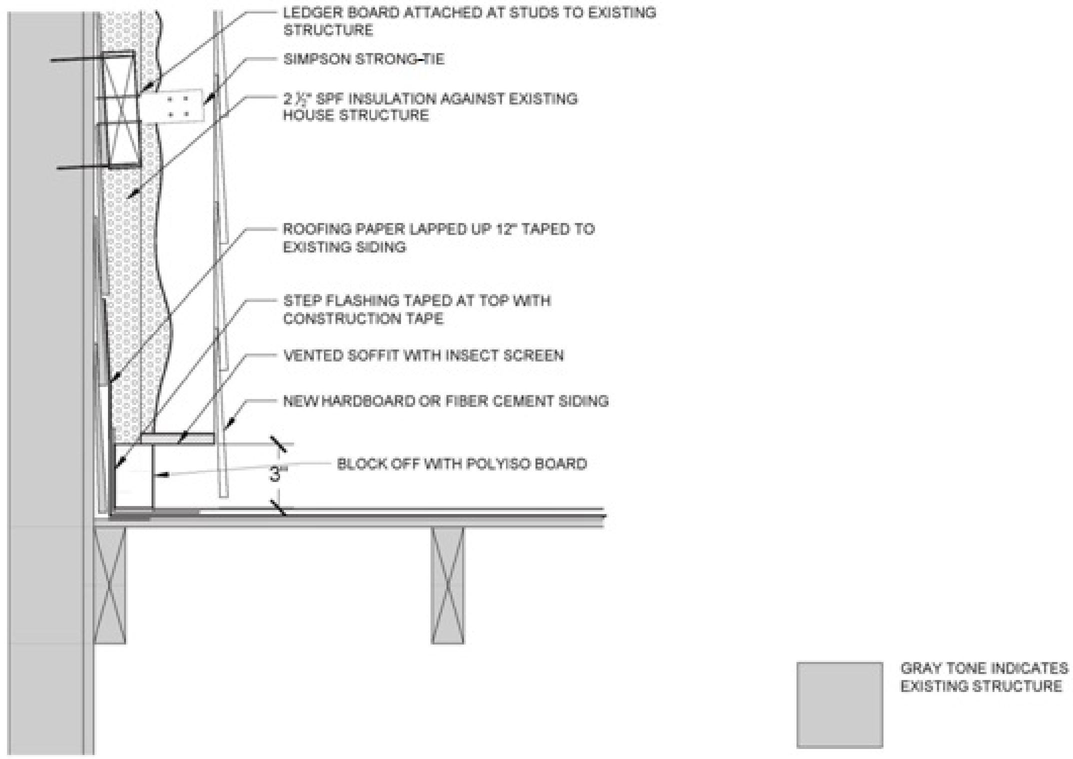

Figure 51. Roof to wall

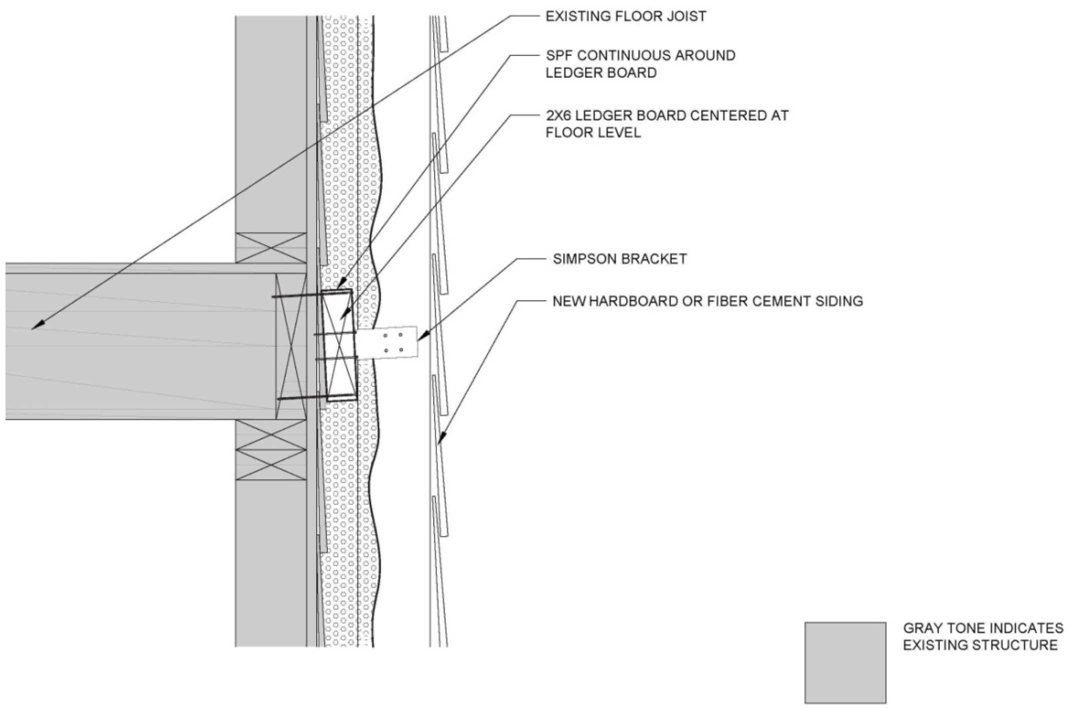

Figure 52. Wall at floor

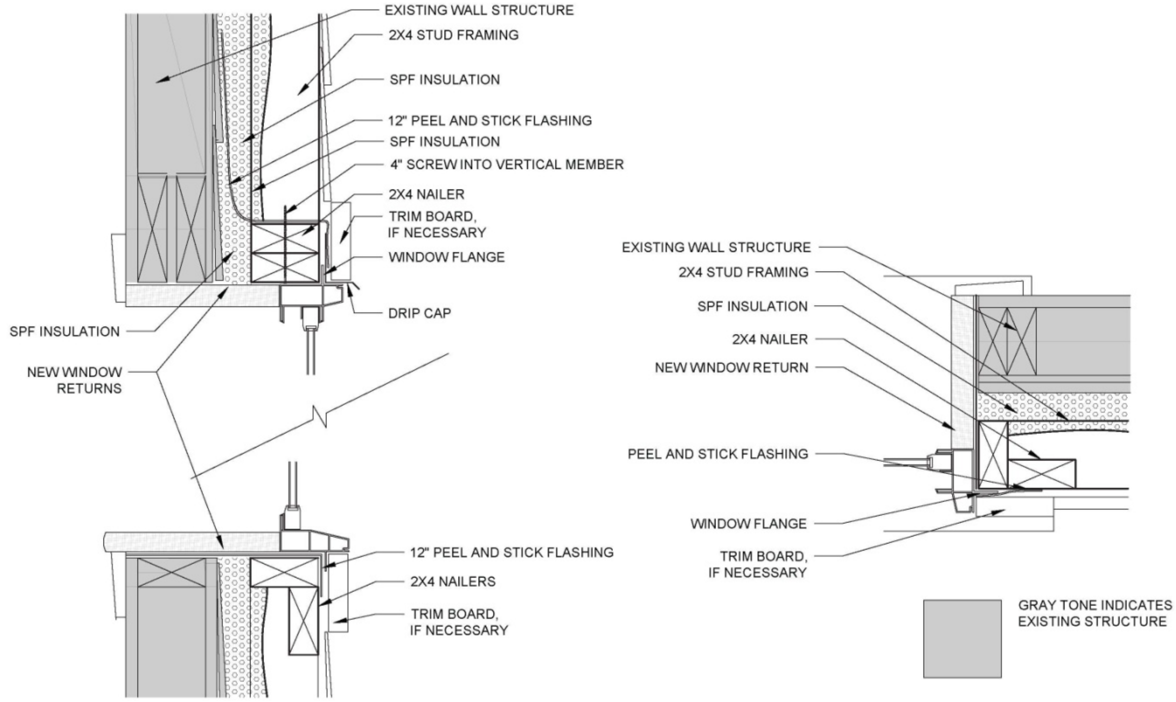

Figure 53. Window details

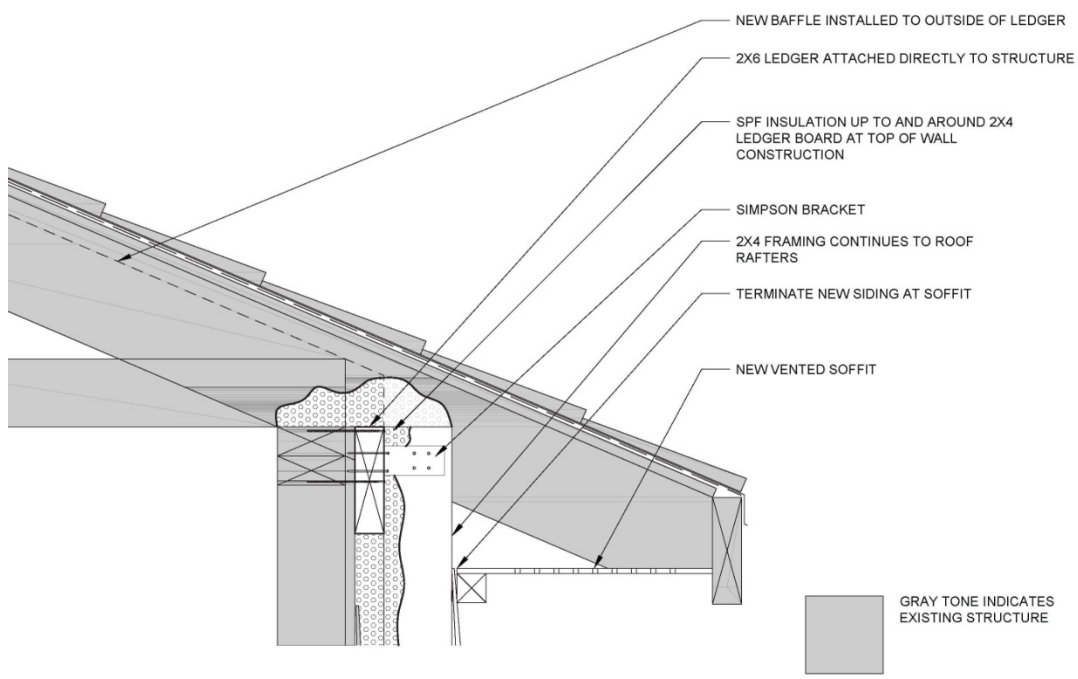

Figure 54. Wall to roof

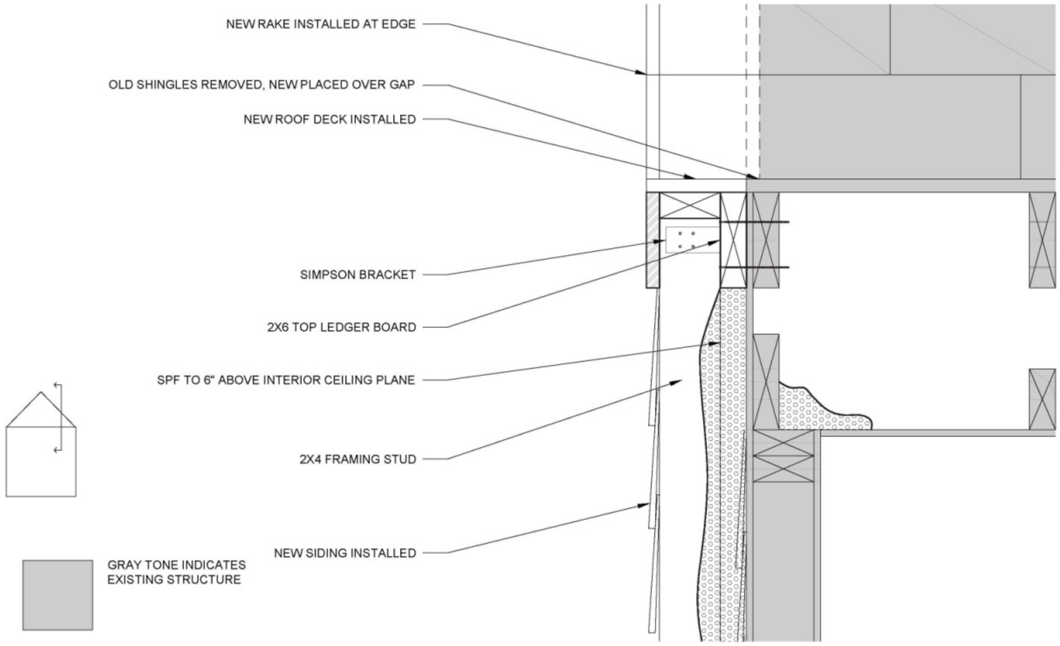

Figure 55. Flush rake

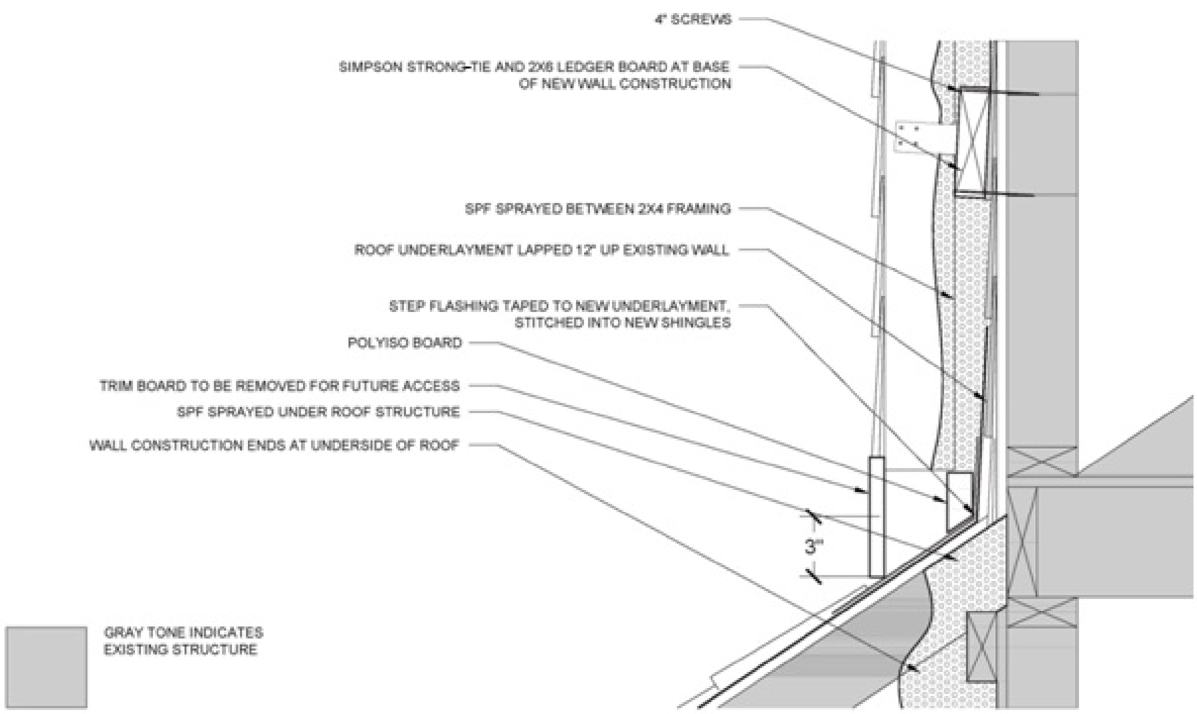

Figure 56. Shed roof

Figure 57 and Figure 58 explain the construction of this wall system.

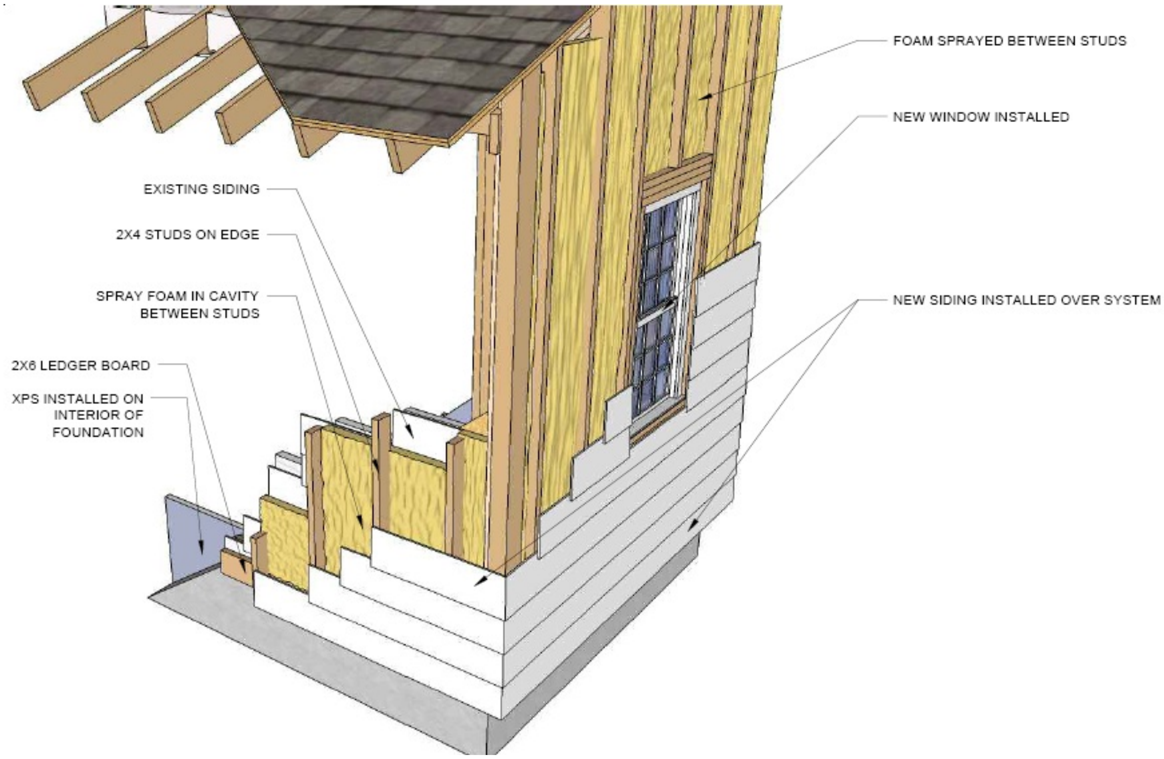

Figure 57. Tear-away view of wall construction

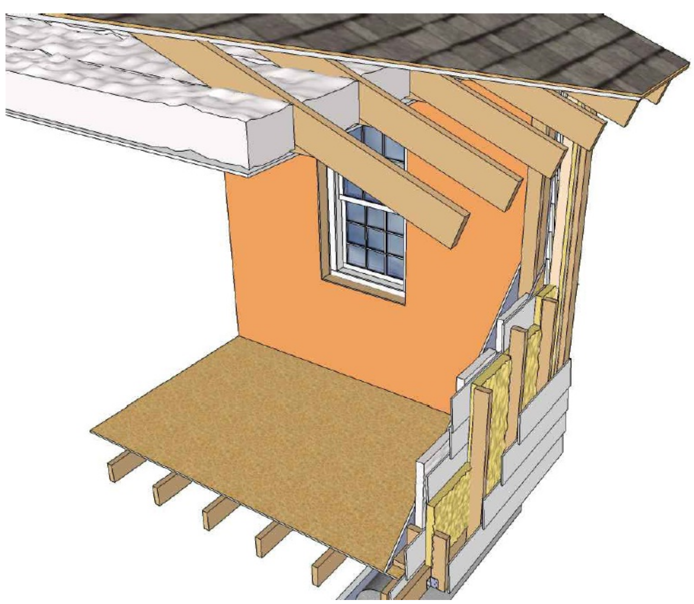

Figure 58. Tear-away view of wall construction from the other side

Appendix C: Additional Mockups

The construction of full-scale mockups of key features typical to many existing homes was the primary mechanism to allow for tests of the constructability of the proposed strategies. These mockups helped in the determination of the amount of materials and labor needed to execute a given strategy. They also provided a venue for those responsible for executing these unconventional practices in the field to refine application methods and sequencing prior to arriving on the job site. Figure 59 through Figure 62 show the design intent (left) and built (right) versions of each mockup to start the DER application. These were areas of a general house that the team thought might be problematic.

Figure 59. Detail around exterior door and light fixture

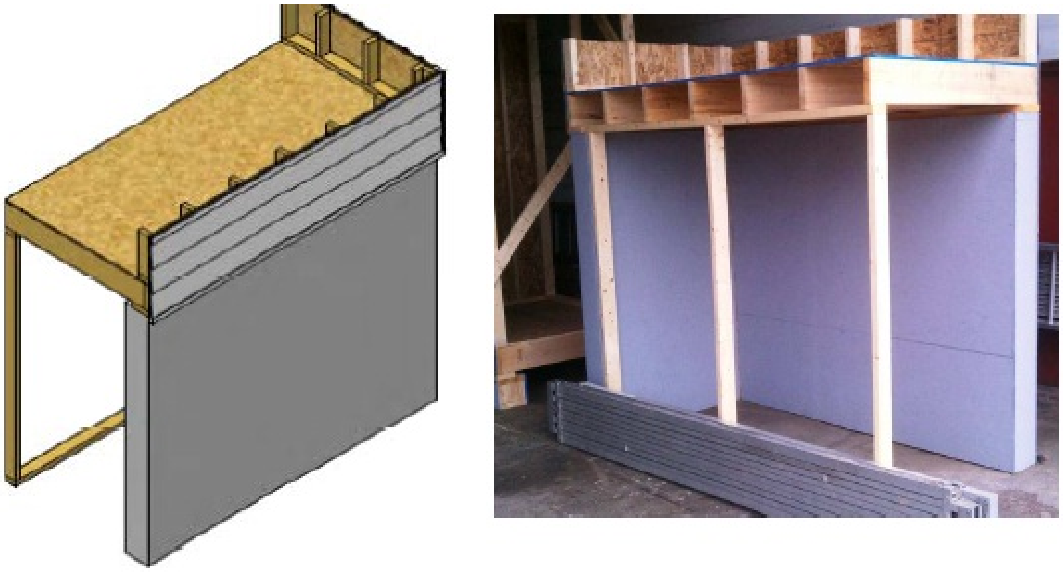

Figure 60. Detail around band joist

Figure 61. Detail at second-floor roof

Figure 62. Detail at inverted corner and light fixture

Appendix D: Compliance

The following discusses some of the permitting questions that might be asked by authorities prior to granting a permit for a stand-off furring type of installation. It may be necessary to obtain the seal of a structural engineer in order to be granted the permit. Consult with the local authorities for permitting requirements.

For a stand-off furring retrofit project, an analysis of the wall section and other relevant members could be done using ASD equations from 2012 NDS (American Wood Council (2012a)) and Manual for Engineered Wood Construction (American Wood Council (2012b)). The following modes of failure could be considered:

- Failure of new 2 × 4 studs in compression
- Failure of mechanical connection of ledger board to rim joist
- Failure of ledger board in shear
- Failure of ledger board in flexure
- Failure of mechanical connection of ledger board to the clip (model number FCB 43.5)
- Failure of mechanical connection of the clip (model number FCB 43.5) to stud.

Regarding loads for each of the wall section parameters, consider the following:

- Vinyl, fiber cement, and stucco siding
- Windows approximately the same weight as stucco
- Studs spaced at 16 in. and 24 in. on center.

The following are the types of questions that might be asked in order to obtain a permit for a stand-off furring retrofit project.

Question: Is 4 in. an adequate screw length? How do we fasten the ledger board?

Response: Four inches is an adequate screw length. All spacing calculations for ledger board are based on a screw length of 4 in.

Based on calculations, walls with stucco and ledger board beneath a window need a minimum spacing of 2 ft between screws. With fiber cement siding or vinyl siding, screws can be spaced 5 to 6 ft apart, with the exception of underneath windows.

Question: Are the clips adequate to hold windows/walls?

Response: The clips must be made to be used in conjunction with steel and, when done so, can produce wall connections that withstand thousands of pounds. For example, Simpson Strong-Tie technical data suggest a minimum allowable load of 550 lb when fastened to wood with four

SD10112 screws. Based on yield limit theory and the International Code Council Evaluation Services measured value of yield bending strength for SD10 screws, a structural lumber to FCB 43.5 connection was estimated to hold up to 680 lb. The largest dead load was estimated to be 172 lb. The clip connected with only two screws can hold 248.4 lb.

Question: How should the studs be spaced?

Response: The studs are much more than adequate in compression when spaced 24 in. apart. Stud spacing is primarily a function of the fastening/spacing requirements of the siding manufacturer.

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