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Measure Guideline: Three High Performance Mineral Fiber Insulation Board Retrofit Solutions

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Ken Neuhauser

Abstract:

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K. Neuhauser
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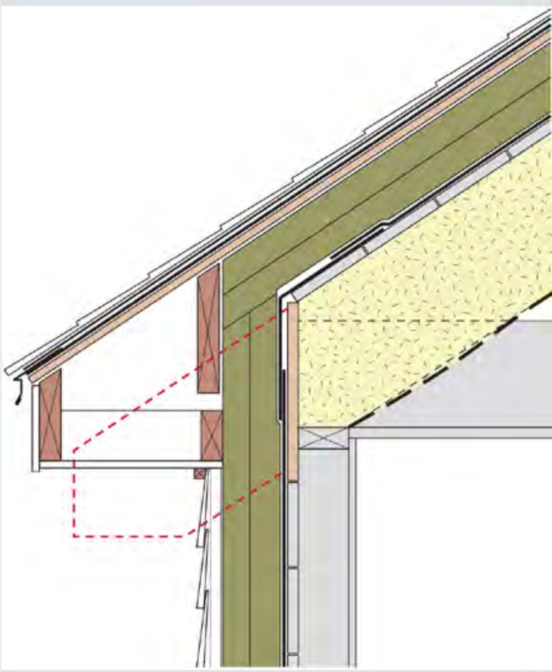

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Measure Guideline: Three High Performance Mineral Fiber Retrofit Solutions

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Office of Energy Efficiency and Renewable Energy

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Definitions

bf	Board foot or board feet, used to refer to a volume of material 12 in. × 12 in. × 1 in. or 144 $in.^3$
DER	Deep Energy Retrofit
ft^2	Square Foot
IBC	International Building Code
IECC	International Energy Conservation Code
IRC	International Residential Code
NREMD	National Residential Efficiency Measures Database
OSB	Oriented Strand Board
PIC	Polyisocyanurate
SPF	Spray-Applied Polyurethane Foam
XPS	Extruded Polystyrene

Executive Summary

This Measure Guideline describes a high performance enclosure retrofit package that uses mineral fiber insulating sheathing. The Measure Guideline describes retrofit assembly and details for wood frame roof and walls and for cast concrete foundations.

This Measure Guideline is intended to serve contractors and designers seeking guidance for non-foam exterior insulation retrofit and is best suited to contractors who are either familiar with exterior insulation and flashing installation or who can learn these techniques.

Exterior insulation retrofit is important to the goal of net zero energy ready homes. Mineral fiber insulating sheathing can provide enhanced moisture durability for the exterior enclosure. Mineral fiber also represents a viable solution for high performance home builders, designers, and clients who wish to use an alternative to foam plastic insulation.

Progression Summary:
High Performance Mineral Fiber Roof Retrofit

INSPECT AND ASSESS THE HOME

Inspect and Assess the Home: Identify and address risks to occupants or to the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed.

Do Not Proceed If:

- The house is not structurally sound.
- The house includes atmospherically vented combustion appliances (except cooking appliances).
- The house has knob-and-tube wiring in cavities that will be insulated.
- The house contains hazardous materials that pose a risk to occupants or workers.
- The house has active water leaks that will not be resolved by the retrofit projects.
- Kitchen and/or bath fans are not vented to the exterior.
- The home is not equipped with a whole-house ventilation system.
- The existing roof and/or insulation materials exhibit rot, insect damage, or contamination.

REMOVE CLADDING

1 **Remove Roof Cladding.** Remove roofing to expose the roof sheathing and prepare the roof sheathing for the air and water control membrane.

Optional Step: "Chainsaw" Retrofit. If roof framing allows, remove roof sheathing, rafter tails, and gable rake framing to be flush with the exterior wall sheathing. Provide infill as needed to allow wall sheathing plane to meet roof sheathing plane.

AIR AND WATER CONTROL MEMBRANE

2 **Install Air and Water Control Membrane.** Air and water control membrane must also provide the necessary vapor retarder performance. Install the air and water control membrane continuously across the roof sheathing surface and connect it in an airtight and durable manner with the air control layer of adjacent assemblies. Seal all penetrations against air and water leaks.

MINERAL FIBER INSULATION BOARD

3 **Install Insulation Board**. Install over the air and water control membrane. Butt joints tight. When installing multiple layers, offset seams in two directions.

Optional Step: "Chainsaw" Retrofit. Install framing for new roof overhangs over continuous insulation board.

Optional Step: Vented Roof. For vented roof, install 2 × 4 on the flat purlins over insulation board and fastened through insulation sheathing to roof structure.

ROOF SHEATHING

4 **Install Roof Sheathing.** Install roof sheathing to serve as a nailbase for roof cladding (e.g., shingles). Attach sheathing to roof structure through insulating sheathing. For a vented roof, attach roof sheathing to purlins.

ROOF CLADDING AND FLASHING

5 **Install Underlayment, Flashing, and Roofing.** Install underlayment, ice and water membrane, flashings, and roofing as per new construction best practices.

Progression Summary:
High Performance Mineral Fiber Wall Retrofit

INSPECT AND ASSESS THE HOME

Inspect and Assess the Home: Identify and address risks to occupants or to the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed.

Do Not Proceed If:

- The house is not structurally sound.
- The house includes atmospherically vented combustion appliances (except cooking appliances).
- The house has knob-and-tube wiring or other electrical hazards.
- The house contains hazardous materials that pose a risk to occupants or workers.
- The house has active water leaks that will not be resolved by the retrofit project.
- Kitchen and/or bath fans are not vented to the exterior.
- The home is not equipped with a whole-house ventilation system.
- The existing roof and/or insulation materials exhibit rot or insect damage or contamination.

REMOVE CLADDING

1 **Remove Wall Cladding and Trim.** Remove cladding attachment, trim, and decking adjacent to the wall to allow for continuous exterior insulation. Prepare the wall sheathing to receive the water and air control membrane.

WINDOWS AND DOORS

2 **Remove Windows and Doors To Allow Flashing and Air Control Transitions.** Remove the windows to allow installation of air control transition membranes and flashings in the window and door openings.

WATER AND AIR CONTROL MEMBRANE

3 **Install Water and Air Control Membrane.** Install a continuous water and air control membrane to the existing sheathing. Water and air control membrane must also provide the necessary vapor retarder performance.

FLASHINGS AND AIR CONTROL TRANSITIONS

4 **Install Flashings and Air Control Transitions:** Install adhered membranes to transition the air control into window and door rough openings and air seal all penetrations through the wall. Flash window and door rough openings as well as all wall penetrations.

INSTALL WINDOWS AND DOORS

5 **Install Windows and Doors.** Reinstall windows and doors or install new windows and doors in properly flashed openings. Air seal window and door units to the air control transition membranes at interior perimeter of window and door units.

MINERAL FIBER INSULATION BOARD

6 **Install Insulation Board.** Install over the water and air control membrane. Butt joints tight. When installing multiple layers, offset seams in two directions.

FURRING STRIPS

7 **Install Furring Strips.** Install over insulation board and attach to structure through the insulation board. Install furring strips in a *vertical orientation only*.

CLADDING AND TRIM

8 **Install Cladding and Trim.** Attach wall cladding and trim to furring strip.

Progression Summary:
High Performance Mineral Fiber Foundation Wall Retrofit

INSPECT AND ASSESS THE HOME

Inspect and Assess the Home: Identify and address risks to occupants or to the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed.

Do Not Proceed If:

- The house is not structurally sound.
- Framing exhibits rot or insect damage.
- Underground electric and gas service to the building or passing near the foundation has not been located.
- Soil around the foundation is contaminated (e.g., with lead, pesticides).
- The house includes atmospherically vented combustion appliances (except cooking appliances).
- The house has knob-and-tube wiring or other electrical hazards.
- The house contains hazardous materials that pose a risk to occupants or workers.
- The house has active water leaks that will not be resolved by the retrofit project.
- Kitchen and/or bath fans are not vented to the exterior.
- The home is not equipped with a whole-house ventilation system.

UNDERGROUND UTILITIES

Locate Underground Utilities. Locate utilities serving the building or passing near the foundation. Implement measures to ensure the protection of these through the project.

EXCAVATE PERIMETER

1 **Excavate Perimeter.** Excavate to a depth of at least 2 ft below grade and 4 ft from foundation wall. Bottom of excavation to slope at least 5% away from foundation.

METAL CLOSURE/ TRANSITION FLASHING

2 **Install a Continuous Metal Closure and Transition Flashing at Top of Foundation Wall.** Seal to foundation wall with bituminous flashing and sealant. Seal lapped seams with bituminous membrane flashing or bituminous sealant.

Optional Step: Install Insulated Foundation Skirt. Line bottom of excavation with 4 in. clean aggregate. Install at least 3 ft wide non-moisture-sensitive rigid insulation (e.g., XPS or foam glass).

GROUND ROOF/ FOUNDATION SKIRT

3 **Install Ground Roof/Foundation Skirt.** Lay rubber roofing or similar across bottom of excavation (or over insulation) and attach to foundation with retaining bar.

DRAINPIPE

4 **Install Perforated Drainpipe at Low End of Ground Roof/Foundation Skirt.** Wrap drainpipe in clean aggregate and filter fabric. Slope drainpipe to storm water collection or to daylight outlet. DO NOT connect drainpipe to foundation drain.

MINERAL FIBER INSULATING SHEATHING

5 **Install Insulation Board to Exterior of Foundation Wall.** Butt insulation tight to underside of metal closure and extend to top of ground roof/foundation skirt.

PROTECTIVE FINISH

6 **Install a Protective Finish Over Mineral Fiber Insulation Board.** Install a non-moisture-sensitive, non-UV-sensitive, impact-resistant protective finish over the insulation from the top of insulation to the level of finished grade.

Introduction

This Measure Guideline provides details and procedures for high performance retrofit using insulation board composed of mineral fiber material. Specifically, the guide demonstrates techniques for retrofitting three major enclosure components: roofs, walls, and foundation walls. The strategies and procedures developed in this guide are directed to wood-framed residential buildings with sloped roofs and cast concrete, block, or brick masonry foundation walls. The approach supported in this guide could also be adapted for use over masonry-clad or bearing masonry structures.

Table 1 shows the minimum assembly R-value that would constitute a high R-value enclosure for the various International Building Code (IBC)/International Energy Conservation Code (IECC) climate zones and pertinent enclosure components. These values are based on work by Straube (2010). A high performance retrofit, sometimes referred to as a deep energy retrofit (DER), results in enclosure components that meet these high R-value targets.

Table 1. Recommended Minimum R-Value for High R-Value Enclosures

Climate Zone	Building Enclosure Component			
	Wall	Compact Roof	Basement Wall	Slab Edge
1	10	35	5	None
2	15	40	10	5
3	20	45	10	7.5
4	25	45	15	7.5
5	30	50	15	10
6	35	60	20	10
7	40	65	25	15
8	50	75	35	20

DER has been shown to provide a path to net zero energy ready homes for existing homes (Gates and Neuhauser 2013, 2014). High performance enclosure retrofit can position an existing building to perform at the level of best-in-class new construction. Retrofitting a wood-framed enclosure with thick layers of foam plastic insulation board is a proven high performance retrofit technique.

An exterior retrofit is generally more favorable than an interior retrofit because it is less disruptive to the living space and typically allows a structure to remain occupied during the project. Exterior retrofit also offers significant advantages for building durability by reducing the likelihood of cold weather condensation within the structure.

However, Ueno (2010) observed that although thick insulation board virtually eliminates the risk of condensation from outward vapor drive (cold weather condensation), vapor-impermeable insulation board can make a wall more vulnerable to water leaks than walls without insulation board. Homes built more recently often incorporate engineered wood sheathing (oriented strand board, OSB) and rim boards. When these elements are insulated to the interior with closed-cell spray-applied polyurethane foam (SPF) insulation, drying to the exterior becomes critical and foam plastic insulation board applied directly over the wall could present a problem (Lstiburek 2013b). Mineral fiber provides a vapor open insulation board that is key to making these assemblies both high R-value and moisture safe.

This Measure Guideline is important to the high performance retrofit industry because it demonstrates techniques for using vapor-open, noncombustible, mineral fiber insulation board in a high performance enclosure retrofit.

This Measure Guideline includes a review of decision criteria pertinent to the selection of a mineral fiber-based retrofit strategy. These criteria include relative cost, combustibility, moisture performance, cladding attachment, trade resources, as well as other considerations associated with the insulation material.

Risks that must be addressed with a high performance enclosure retrofit generally, and with a mineral fiber-based enclosure retrofit specifically, are outlined. Proper techniques for moisture management as well as climate-specific considerations are reviewed. Cladding attachment considerations are also discussed.

Although the Measure Guideline does not include any recognized fire resistance rated details or assemblies, it does present methods to improve the fire resistance of the retrofit assembly.

This Measure Guideline is intended to support contractors implementing a mineral fiber-based high performance enclosure retrofit as well as designers looking to design a high performance enclosure retrofit using an alternative to foam plastic insulation. The Measure Guideline may also be helpful to building owners wishing to learn more about strategies available for high performance retrofit of wood-framed residential buildings.

1 Assess the Home

1.1 Risk Identification

1.1.1 Identify Site Risks

Before a significant retrofit project is conducted, the home must be assessed to determine whether significant, if hidden, problems should be addressed as higher priorities than an enclosure performance upgrade. Also, changes to the building enclosure will have a significant impact on the dynamics of water, air, vapor, and heat flow within the home. Certain measures should be implemented prior to, or as part of, any significant enclosure retrofit project to ensure that these changing dynamics do not have negative ramifications for health and safety or for building durability. Measures to be implemented prior to or as part of the enclosure retrofit outlined in this Guide relate to:

- Remediation of existing hazardous conditions
- Combustion safety
- Indoor air quality.

The measures described to address indoor air quality include mechanical ventilation and soil gas control. These are not the only means to ensure good indoor air quality. However, effective mechanical ventilation and soil gas control are essential aspects of the building (as contrasted to furnishings, equipment, materials, etc. that people might bring into a building) that provide the occupants a means to control contaminants and respond to indoor air conditions.

1. Remediate hazardous conditions.

Before a DER project begins, any hazardous conditions must be remediated that will be affected (e.g., exposed or aggravated) by the planned work. Also, it is wise to ensure that more serious problems are not lurking. A high performance enclosure retrofit—however worthy the goals may be—should not divert resources from where they are more urgently needed.

Before embarking on a project as outlined in this Guide, inspect and assess the building for:

- Structural integrity of the frame and foundation
- Safety and serviceability of the electrical system
- Hazardous materials (e.g., lead, radon, asbestos)
- Rainwater, groundwater, or plumbing water leaks
- Rot or decay in framing
- Insect and other pest damage and activity.

The structural system must be sound before high performance retrofit work can begin. Similarly, the electrical system must provide basic electrical safety. Knob-and-tube wiring may preclude retrofit of the enclosure; a licensed electrician should be consulted to discuss the nature of the retrofit and determine whether knob-and-tube wiring should be replaced. Ideally, the electrical system would be brought up to date with current code and brought into alignment with current and projected building needs.

Hazardous materials that will be affected by the planned work or that may impact the indoor air quality must be remediated and/or removed to avoid exposure to occupants or workers.

Any bulk water issues, whether these relate to rainwater leaks, groundwater infiltration, or plumbing system leaks, must be repaired before the enclosure retrofit project proceeds, unless the planned work will remove the source of the bulk water issue (e.g., if the roof surface or leaking section of plumbing is to be replaced as part of the project).

Any framing that shows signs of rot or decay should be replaced. This frequently applies to the framing sill in older buildings. Also, any framing that exhibits preconditions for rot or decay—i.e., damp wood—will require remediation.

Past insect and pest damage must be evaluated for impact on the building. Ongoing insect and pest activity must be remediated.

Follow applicable laws and industry procedures for mitigation of hazardous materials. Engage the services of a qualified professional when needed.

2. Ensure combustion safety.

Atmospherically vented (or naturally aspirated) combustion appliances are not appropriate for high performance homes. With the exception of gas cooktops, ranges, and wall ovens, combustion appliances should be direct-vented or direct exhaust-vented equipment. These types of appliances are significantly more energy efficient than natural draft appliances. If replacing equipment is not feasible, draft inducer retrofit kits can provide fail-safe forced-draft performance for some types of combustion appliances. This can address the combustion safety issue; however, adding forced-draft operation alone is unlikely to have a significant impact on energy performance.

Gas cooktops, ranges, and wall ovens must be equipped with a range hood that is ducted to the outside.

Solid fuel-burning stoves (e.g., wood stoves and pellet stoves) if not equipped with a fail-safe draft inducer, must have a tight-fitting loading door (and no permanent openings or leaks into the firebox or flue) and outdoor combustion air ducted to the firebox. If any combustion appliance vents through a chimney, the flue should be inspected to ensure that it is in good condition. The flue must be repaired if it exhibits any deficiencies.

Attached garages present a potential source of carbon monoxide and other contaminants that could infiltrate into the home. Consult the Indoor airPlus guides for specific guidance on treatment of attached garages.

If the house has combustion appliances of any kind or an attached garage, carbon monoxide alarms complying with Underwriters Laboratories 2034 should be placed in reasonable proximity to the combustion appliances, in any regularly occupied space adjoining an attached garage, and outside each separate sleeping area in the immediate vicinity of the bedrooms.

3. Ensure adequate ventilation

Mechanical ventilation is an essential feature of high performance homes. Ventilation is needed for source control at the location of contaminant sources (e.g., kitchens, bathrooms, craft areas) as well as for distribution of fresh air and dilution of general contaminants. The distribution of fresh air and dilution of general contaminant is referred to as *background* or *whole-house* ventilation.

The 2012 International Residential Code (2012 IRC) provides code minimum requirements for ventilation systems, including the ventilation rate capacity for background/whole-house ventilation and source control ventilation. This Guide aims to provide additional guidance toward meeting the high performance objectives of DER projects.

4. Control soil gas.

Before any enclosure retrofit project begins, measures must be taken to prevent entry of soil gases into the home. Radon is a soil gas with significant and well-documented health risks. Air moving through soil also carries significant moisture and may carry other contaminants such as mold spores, herbicides, pesticides, and methane.

As a minimum soil gas control measure, cracks and holes in the foundation walls and basement slab must be sealed. Because of the need for soil gas control, it is important that any penetrations made through ground-contact assemblies (slabs and foundation walls) are sealed. Sump pits must have airtight and gasketted covers.

Implementation of a soil gas venting system is strongly recommended. Any significant work to the roof or basement/crawlspace provides an opportunity to establish such a system.

A soil gas venting system essentially provides the soil gas a direct pathway from below the house to the outdoors so that it does not move through the indoor living space. If needed, a fan can be added to the vent pipe to actively move soil gases from beneath the basement floor to the outside.

For additional information on soil gas control, see Radon Fan and Vertical Radon Ventilation Pipe on the Building America Solution Center website.

1.1.2 Identify Work Risks

In addition to the hazardous material risks indicated above, other risks to worker and building safety must be addressed before work commences.

1. Locate gas and electric utilities.

The foundation retrofit measures described in this guide require excavation adjacent to the foundation. Before foundation retrofit work begins, any underground gas or electric utilities in the vicinity of the excavation must be located.

Overhead wires could present a safety hazard for wall and roof retrofit measures. Work and staging in the vicinity of overhead wires must be carefully planned to provide safe working conditions.

2. Assess staging needs.

The wall and roof retrofit measures described in this guide require ladders, staging, or mechanical lifts. Carefully review the area around the building to assess the suitability of the ground to support ladders, staging, or mechanical lifts.

1.2 Assess the Home To Determine Suitability of Options and the Need for Additional Control Measures

1.2.1 Roof Measure

Investigate the roof assembly to determine whether it has vapor retarders, and if so, what type. Examples of vapor retarders of concern could be class I and class II types such as OSB sheathing, closed-cell SPF insulation to the underside of the roof sheathing, kraft or foil facings on fibrous insulation, a polyethylene vapor retarder, and plaster finish with oil-based paint.

Assess the roof and wall structural systems to determine whether they can support a “chainsaw” approach. If the roof overhang framing is part the roof truss or if roof rafters are supported beyond the top of the wall on cantilevered framing, a “chainsaw” approach is not recommended.

1.2.2 Foundation Measure

The exterior foundation retrofit described in this Guide requires that the foundation wall surface be relatively flat. If the foundation wall is constructed of field stone or fractured block, other retrofit strategies should be pursued.

The exterior foundation retrofit described in this Guide also requires excavation around the perimeter of the building. Assess whether there are impediments to excavation. Excavation necessitates locating underground utilities in the vicinity of the planned excavation.

It will also be important to assess how surface water and roof runoff can be drained. Does the site allow a drain to daylight? Will a storm water collection or drywell be required?

2 Decision-Making Criteria

2.1 Cost and Performance

Cost and performance are intricately linked and have to be studied in conjunction to determine the best choice per the decision-maker's goals and objectives. Installation costs for the retrofit solutions described in this Measure Guideline can be expected to vary widely from estimates in the referred sources to field experience depending on such factors as contractor experience, prevalent region practices, material costs, and the particular circumstances of the project. It is worth noting that the range is sometimes a factor of 5 to 10.

2.1.1 Roof Retrofit

As with the walls, the National Residential Efficiency Measures Database (NREMD) does not directly provide a cost estimate for retrofitting insulating board to wood-framed roof assemblies. The retrofit measures provided that are relevant to a conditioned attic include both cavity insulation and insulation board. For a retrofit situation, it may reasonably be the mode that pre-retrofit case involves an insulated attic space; therefore, insulating within rafter cavities would be a necessary part of the measure. The NREMD does not provide costs for removal of roofing but does provide cost estimates for replacing an asphalt roof with a unit cost range of $1.90/ft^2 to $4.30/ft^2 (see Table 2).

Table 2. NREMD Unit Costs for Insulation Board and Cavity Insulation Roof Retrofit ($/ft^2)

Retrofit Description (Cavity Insulation, Insulation Board)	Nominal R-Value	Cost Range ($/ft^2)
R-19 Fiberglass, 3 in. XPS*	34	2.10–3.60
R-19 Fiberglass, 4 in. XPS	39	2.50–4.20
R-30 Fiberglass, 3 in. XPS	45	2.40–4.10
R-30 Fiberglass, 4 in. XPS	50	2.80–4.70
R-38 Fiberglass, 3 in. XPS	53	2.60–4.50
R-38 Fiberglass, 4 in. XPS	58	3.00–5.10
R-38 Fiberglass, 5 in. XPS	63	3.40–5.80

* Extruded polystyrene

The National Grid DER pilot projects that Gates and Neuhauser (2014) evaluated pursued a roof/attic insulation target of R-60. The projects that met this target with a strategy including both insulation board and framing cavity insulation, all used either 4 in. or 6 in. of polyisocyanurate (PIC) insulation board. The reported unit costs for this strategy (excluding outliers) ranged from $10.05/ft^2 to $21.84/ft^2.

The target thermal performance in the National Grid DER pilot might correspond to the nominal values of the NREMD for R-38 fiberglass plus 4–5 in. of XPS insulting sheathing; however, the costs reported for the National Grid DER pilot projects would reflect elements beyond the insulation. For example, the reported pilot project costs would include removal of existing roofing, installation of an air and water control membrane over the existing sheathing, installation of a second layer of roof sheathing above the insulation board, and, in many cases removal and subsequent reconstruction of roof overhangs. Actual costs for the roof retrofit solution described in this guide are expected to be generally higher and more variable than the estimates derived from NREMD.

2.1.2 Wall Retrofit

The NREMD does not directly provide a cost estimate for retrofitting an existing wood-framed wall with insulation board; however, a composite of measures can be used to develop an estimate from this source. The NREMD provides a range and an average cost for various exterior insulation measures. The database also provides a figure for the cost of removing wall cladding ($0.66 regardless of cladding type), and estimated cost ranges for installation of new cladding.

Table 3 represents these cost data.

Table 3. National Residential Efficiency Measures Database Unit Costs for Insulation Board Wall Retrofit ($/ft^2)

Insulation Thickness and Material	NREMD Insulation Board Measure Cost	Cost With Removal of Wall Cladding and Installation of Vinyl Siding	Cost With Removal of Wall Cladding and Installation of Wood Siding	Cost With Removal of Wall Cladding and Installation of Fiber-Cement Siding
1 in. XPS	0.93–1.60	4.19–5.06	4.89–6.26	4.69–5.96
1 in. PIC	0.86–1.40	4.12–4.86	4.82–6.06	4.62–5.76
2 in. XPS	1.30–2.20	4.56–5.66	5.26–6.86	5.06–6.56
2 in. PIC	1.10–1.90	4.36–5.36	5.06–6.56	4.86–6.26
3 in. XPS	1.60–2.80	4.86–6.26	5.56–7.46	5.36–7.16

Interestingly, the NREMD data do not show a significant cost jump from 1 in. thick insulation board to 2 in. of insulation board. Such a cost jump would be expected because with an insulation board thicker than 1 ½ in., furring strips would be required for cladding attachment. Baker (2012) used data from RS Means to derive estimates of installed cost of insulation board (not including cladding) (Table 4). Baker estimated the cost of installing 1.5 in. PIC insulation board at $1.56/ft^2, whereas the estimate for 2 in. PIC insulation board is $3.53, a difference of $1.97. Given the modest $0.19 cost difference that Baker estimated between 1 in. and 1 ½ in. insulation board, it is reasonable to assume that most of the cost difference he projects between 1 ½ in. and 2 in. insulation board is due to the installation of 1 × 4 wood furring strips. Given this, Baker's estimates for the installed cost of insulation board at these thicknesses can be taken to be otherwise consistent with NREMD. For insulation board thicker than 2 in., Baker projects installation in two layers (recommended practice), which results in another price jump between 2 in. and 3 in. thickness of insulation board.

Table 4. Estimates of Insulation Board Costs

Baker (2012)

Insulation Board	Estimated Insulation Board Installed Cost ($/ft²)	Cost Increment ($/ft² Difference Relative to Previous)
1 in. PIC	1.35	–
1 ½ in. PIC	1.56	0.21
2 in. PIC With 1 × 4 Wood Furring	3.53	1.97
3 in. PIC in 2 Layers With 1 × 4 Wood Furring	4.99	1.46
4 in. PIC in 2 layers With 1 × 4 Wood Furring	5.38	0.39

Gates and Neuhauser (2014) reported on the experience of 42 DER projects that participated in a National Grid-sponsored pilot program. For 36 projects that implemented a wall retrofit including 4 in. of insulation board (in two layers, with wood furring strips), the reported energy-related (e.g. excluding siding and trim) unit cost (excluding outliers) ranged from $4.67/ft^2 to $19.15/ft^2. Estimates derived from NREMD or from RS Means are within the range reported by Gates and Neuhauser; however, the data from the National Grid DER pilot provides evidence that the range for costs in actual projects is likely to be large.

2.1.3 Translating the Cost of Foam Plastic Insulation Board to Mineral Fiber Insulation Board

The above measure cost estimates all use data for foam plastic insulation board. Cost data for residential mineral fiber insulation board are not widely available in the United States. Wilson (2013) used data from a single building supply house for a benchmark comparison. Wilson reported these cost in terms of board feet (bf) of material. Given the R-value/inch of the material, the bf cost can be used to derive a cost/ft^2-R-value (Table 5). This is a very useful metric for comparing materials and for deriving a unit material cost estimate for meeting a given R-value assembly target.

Table 5. Board-Foot Material Costs for Various Insulation Board Materials From a Single Supplier and the Resulting Cost per Unit Area R-Value ($/ft²-R)

Insulation Board Material	Board Foot Cost ($/bf)	R-Value per Inch	Cost per Unit Area R-Value Cost ($/ft²-R)
Comfort Board Insulated Sheathing	0.64	4	0.160
PIC	0.48	6.5	0.074
Foil-Faced, Fire Exposure-Rated PIC	0.75	6.5	0.115
XPS	1.07	5	0.214

According to data from this one source, the material cost relative to thermal resistance for XPS is roughly 2–3 times that for an equivalent amount of thermal resistance provided by PIC. The material cost relative to thermal resistance for mineral fiber insulation board appears to be somewhere between that of XPS and PIC. Therefore, one might expect that the cost for insulation board retrofits using mineral fiber would be comparable to otherwise similar solutions that use foam plastic insulation board.

It is worth noting that the NREMD data do not show the same cost difference between XPS and PIC as the data from one building supply outlet that Wilson reported. Material costs are thus likely to vary considerably between markets.

In addition to material cost difference, other factors would influence cost difference between mineral fiber retrofit solutions and otherwise similar retrofit approaches that employ foam plastic insulation board. The fibers from mineral fiber insulation can cause skin irritation. This may be a considerable challenge to installation of mineral fiber insulation board in warmer weather, when maintaining full skin coverage may cause workers to be uncomfortable. The author observed that mineral fiber may also increase the risk of eye injury on the job site. In one construction project in which the author participated, construction was delayed on multiple occasions when a worker was taken for urgent medical treatment when he apparently rubbed his eye after handling mineral fiber material.

Because mineral fiber has lower thermal resistance per unit thickness than either PIC or XPS, mineral fiber assemblies will require greater thickness to achieve the same nominal R-value. Therefore, a mineral fiber insulation board retrofit may require longer screws and more material for trim returns than an otherwise similar retrofit strategy using either PIC or XPS.

Also important to installation cost is the weight of the insulation board. As shown in Table 6, mineral fiber insulation board is more than 6 times heavier than either PIC or XPS for a given R-value and area. This will affect the effort needed to move material into place and brace it while fastening. The relative weight of mineral fiber insulation board as well as general strength characteristics of the material typically require use of smaller pieces of material. This would impact the time and effort required to cover a given area of wall or roof with insulation board.

Table 6. Weight per Unit Area R-10 Insulation for Various Insulation Board Materials (lb/ft^2)

Insulation Board Material	Board Foot Cos ($/bf)	R-Value per Inch	Weight per Unit Area at R-10 (lb/ft^2)
Comfort Board Insulated Sheathing	8	4	1.67
PIC	2	6.5	0.26
XPS	1.3–1.55	5	0.18-0.26

To estimate the magnitude of these various factors beyond material cost would be mere speculation. In time, experience of contractors will yield approximate installation costs for mineral fiber insulation board retrofit solutions.

2.2 Fire Code Issues

Before deciding to use mineral fiber insulation board in the retrofit, it is important to determine whether its fire resistance property is a code issue. Mineral fiber is a noncombustible material that, at adequate thickness, is recognized in codes as providing a thermal barrier. Mineral fiber insulation achieves its fire resistance without the use of chemical flame retardants such as those used in foam plastic insulation materials.

Exterior retrofit systems using mineral fiber insulation board can be constructed such that they offer enhanced fire protection. However, as noted by Lstiburek (2013a), mineral fiber insulation board assemblies have not been "officially burned" to earn recognition as fire-resistance rated assemblies. Design of systems to meet fire-resistance rating requirements is beyond the scope of this guide.

Fire Separation Distance

The International Residential Code for One and Two Family Dwellings (IRC) requires that assemblies have a 1-hour fire-resistance rating if the minimum fire separation distance between structures is 5 ft or shorter. Under the IBC, the requirement for fire-resistance rating applies with the minimum fire separation distance is 10 ft or shorter. Very few listed assemblies contain insulation board that carries the required fire-resistance rating. The IBC provides a potential avenue for the use of mineral fiber insulation board that relies upon interpretation by the building official. Section 703.2 reads:

> Where material, systems, or devices that have not been tested as part of the fire-resistance-rated assembly are incorporated into the building element, component or assembly, sufficient data shall be made available to the building official to show that the required rating is not reduced.

2.3 Moisture Performance

The decision about the robustness of a moisture control assembly depends on the decision-maker's willingness to pay. Design of retrofit assemblies must consider management of bulk water loads, interior water vapor loads, and exterior water vapor loads. For roofs and walls, the principal bulk water load is generally related to rain and (in some climates) melting snow. Capillary transfer of water will impact foundation assemblies and may impact the base of a frame wall that is not separated from the foundation by a capillary break. Surface water, roof runoff, and groundwater are typical bulk water loads that must be managed by the foundation. Irrigation may also contribute a bulk water load that impacts foundation walls and above-grade walls.

Interior water vapor loads apply to assemblies of occupied structures that use heating systems and/or that have significant interior moisture generation (e.g., swimming pool, greenhouse, extensive cooking).

Exterior water vapor loads apply to assemblies of occupied structures that include mechanical air conditioning. Exterior water vapor loads are also pertinent to structures that have reservoir claddings (e.g., brick veneer, stucco, wood, fiber cement) that are exposed to wetting (from rain or irrigation) and sunlight.

Exterior insulation board brings the primary sheathing closer to interior conditions and thus reduces the condensation potential at the primary sheathing relative to outward (heating season) vapor drive. LePage and Lstiburek (2012) found that exterior insulation greater than R-5 is a better outward vapor control strategy than interior vapor retarders. Smegal and Straube (2011) evaluated thicker vapor-permeable and vapor-impermeable insulation board relative to management of interior water vapor loads. Their analysis suggests that with thick insulation board the vapor permeability of insulation board is not a significant factor in managing interior vapor loads.

LePage et al. (2013) found through hygrothermal modeling that a high R-value wall with 4 in. of exterior insulation provided sufficient condensation resistance in cold climates but that a significant rain water leak (5% of wind-driven rain) to the insulation board-sheathing interface would most certainly result in damage.

Ueno (2010) noted some moisture management advantages in the exterior insulation board approach to superinsulation:

> For the most part, the retrofit assembly tends to improve durability of the wall, due to the drained and ventilated cavity, the redundant drainage planes (multiple layers of foam, housewrap), and the reduction in interstitial condensation risk by elevating the condensing surface temperature with exterior insulation.

Ueno notes, however, that the loss of drying to the exterior could have durability implications. He found that a leak (in terms of percentage incident rain penetration) that is "survivable" (in terms of maintaining sheathing moisture content below a critical threshold) in pre-retrofit conditions is not survivable when the building is retrofitted with vapor-impermeable insulation board. Based on this analysis, Ueno indicated, it is critical to ensure proper flashing when implementing an exterior superinsulation retrofit. BSC guidance and review of superinsulation retrofit using exterior insulation board has strongly emphasized robust water management (Baker 2012; BSC 2010; Neuhauser 2011; Pettit 2009; Pettit et al. 2013).

Smegal and Straube (2011) compared the performance of wood-framed walls with either XPS or mineral fiber insulation board. At greater R-value of insulating the mineral fiber showed little advantage in managing outward vapor drive compared to the XPS. A difference in simulated performance was more noticeable with thinner (lower R-value) insulation board. The hygro-thermal analysis also showed some appreciable difference in the drying potential for the mineral fiber assemblies in simulated winter and summer conditions. For OSB or engineered wood products, rapid drying from moisture concentrations would be more critical. Plywood or sawn wood sheathing offers some benefit of hygric redistribution within the material (Lstiburek 2010).

Lstiburek (2013a) observed that OSB sheathing with low permeability materials to interior and low permeable or impermeable insulation board require an air gap between sheathing and insulation board for drying and hygric redistribution. Lstiburek also notes that vapor open insulation board can provide useful drying without this added air gap.

Inward vapor drive is a risk factor associated with warm-humid climates, air conditioning, and reservoir claddings. Dérome et al. (2010) observed that warm-humid and mixed-humid climates pose a risk to vapor-permeable wall assemblies. They further observed that rain-wetted reservoir claddings exposed to strong solar radiation (sunlight) can produce a very strong inward vapor drive.

Through hygrothermal simulation, Lepage and Lstiburek (2012) found that a vapor control membrane with a vapor permeance of up to 10 perms is sufficient to protect OSB sheathing from sustained elevated moisture content, provided that no significant vapor retarders are placed to the interior of the sheathing (e.g., polyethylene or vinyl wall covering). This study evaluated vapor control membranes with a permeance of 0.1, 1, 10, and 50 and located an inflection point in wall behavior with a vapor control of 10 perms. This analysis showed that vapor control at the exterior of sheathing (between vapor permeable insulation board and structural sheathing) is more important to protecting the wall where drying to the interior is impeded by a significant vapor retarder such as may be represented by vinyl wall covering, polyethylene, or foil facing.

2.4 Cladding Attachment

Rigid foam insulation board has long been established as a suitable substrate behind furring strips used for cladding attachment. The compressive resistance of mineral fiber insulation board is appreciably less than the compressive resistance of rigid foam typically used for insulation board.

As summarized by Holladay (2011), laboratory testing has demonstrated that a wall configuration using 8/ft^3 mineral fiber insulation and furring strips for cladding attachments can support common cladding systems with negligible initial as well as long-term deflection. However, long-term testing in exposed conditions, with significant diurnal and seasonal temperature variations (unlike in a lab) shows considerably more movement of furring strips attached over insulation board and with imposed cladding loads. Ongoing research by BSC and Building Science Labs has shown that mineral fiber insulation board performs very similarly to PIC and XPS relative to movement of furring strips under loads representative of lightweight (e.g., vinyl, wood siding) to medium weight (e.g., stucco) cladding. This research has yielded the conclusion that cladding weight should be limited to 10 lb/fastener over insulation board (including mineral fiber insulation board) at thicknesses up to 4 in. Further research is needed to confirm the capacity of furring strip cladding attachment with thicker insulation board.

Critical Takeaway

Space screw fasteners in furring strips such that the cladding load amounts to no more than 10 lb per fastener at thicknesses up to 4 in.

A challenge noted for installation of furring strips over a “softer” insulation board such as mineral fiber insulation board, is maintaining plumb and planar furring strips (Cowan and Walsh 2013). The initial force of setting the fastener through the furring strip can easily compress the mineral fiber insulation board. Contractors have developed various methods to assist in maintaining plumb and planar furring.

2.5 Other Material Characteristics or Criteria

Styrene foam plastic building insulation is manufactured with brominated flame retardants. These are widely recognized as persistent organic pollutants (Wilson 2013). Other foam plastic building insulation materials also incorporate chemical flame retardants. As noted above, mineral fiber insulation does not use added chemical flame retardants.

Mineral fiber insulation products currently available do, however, use formaldehyde-based binders. As such, certain building labeling and recognition programs, such as the Living Building Challenge, preclude the use of mineral fiber building insulation. Wilson (2013) relayed manufacturers' explanations that the high temperature production process drives off nearly all of the free formaldehyde. Wilson also alluded to test data showing formaldehyde emissions from mineral fiber insulation to be below or near background levels.

Strategies To Achieve Plumb and Planar Furring Strips

A persistent challenge with installing furring strips over mineral fiber insulating is maintaining plumb and planar furring strips. Setting and adjusting fasteners to plumb furring strips and plane out a wall can be time consuming. Strategies that contractors have developed to make this step easier include:

- Hand setting cap nails to act as spacers prior to installing furring strips. The cap nails also mark the location of framing.
- Using broken thread fasteners (fasteners with an unthreaded section of the shaft that allows the fastener to be firmly set into the structure before threads engage the furring strip).
- Predrilling furring strips.

Methods that risk damaging the air and water control membrane, such as coring through the mineral fiber insulation board with a hole saw should be avoided.

2.6 Trade Resources

Despite recent gains and the development of manufacturing capacity in the United States, the distribution network for mineral fiber insulation board is still nascent. Mineral fiber batt insulation is—and has been—widely available; however, mineral fiber insulation board sheathing is not stocked in "big box" consumer-oriented building supply retailers.

Experience with insulation board installation is still far from universal in the residential building sector. Immediate adoption of mineral fiber insulation board retrofit solutions is probably best suited to contractors who have been trained in these techniques, because they require exacting attention to details.

3 Technical Description

3.1 High Performance Mineral Fiber Retrofit Assemblies

The high performance mineral fiber retrofit solutions are described in outline below.

3.1.1 Mineral Fiber Retrofit Roof Assembly

From interior to exterior the retrofit roof assembly is as follows (see Figure 1 and Figure 2):

- Fibrous cavity insulation (SPF also acceptable with conditions)
- Existing roof sheathing
- Air and water control membrane
- Mineral fiber insulation board as needed for condensation control and high R-value performance
- Sheathing (for cladding attachment) fastened to structure through the mineral fiber insulation sheathing. Where roof cladding is vented, furring strips are used.
- Water control membrane (underlayment and ice and water membrane)
- Roofing (shingles).

Note that some variations are inherent with different roof cladding systems such as metal or tile roof cladding.

3.1.2 Mineral Fiber Retrofit Wall Assembly

From interior to exterior the retrofit wall assembly is as follows (see Figure 3 and Figure 4):

- Existing interior finish
- Fibrous cavity insulation (SPF also acceptable with conditions)
- Existing wall sheathing
- Air and water control membrane
- Mineral fiber insulation board with R-value per Table 8 for condensation control and high R-value performance
- 1 × 4 furring strips fastened to the structure through the mineral fiber insulation board
- Cladding and trim.

The foundation retrofit strategy also includes groundwater and roof runoff control measures. A ground roof of rubber roofing or similar material is installed at the bottom of the excavation and sloped to a perforated drainpipe that is routed to a daylight outlet or to a storm water collection system. The drainpipe must not be connected to the foundation drain. In cold climates or in houses with crawlspaces or basements, non-moisture-sensitive insulation is placed over clean aggregate at the bottom of the excavation before the ground roof is installed.

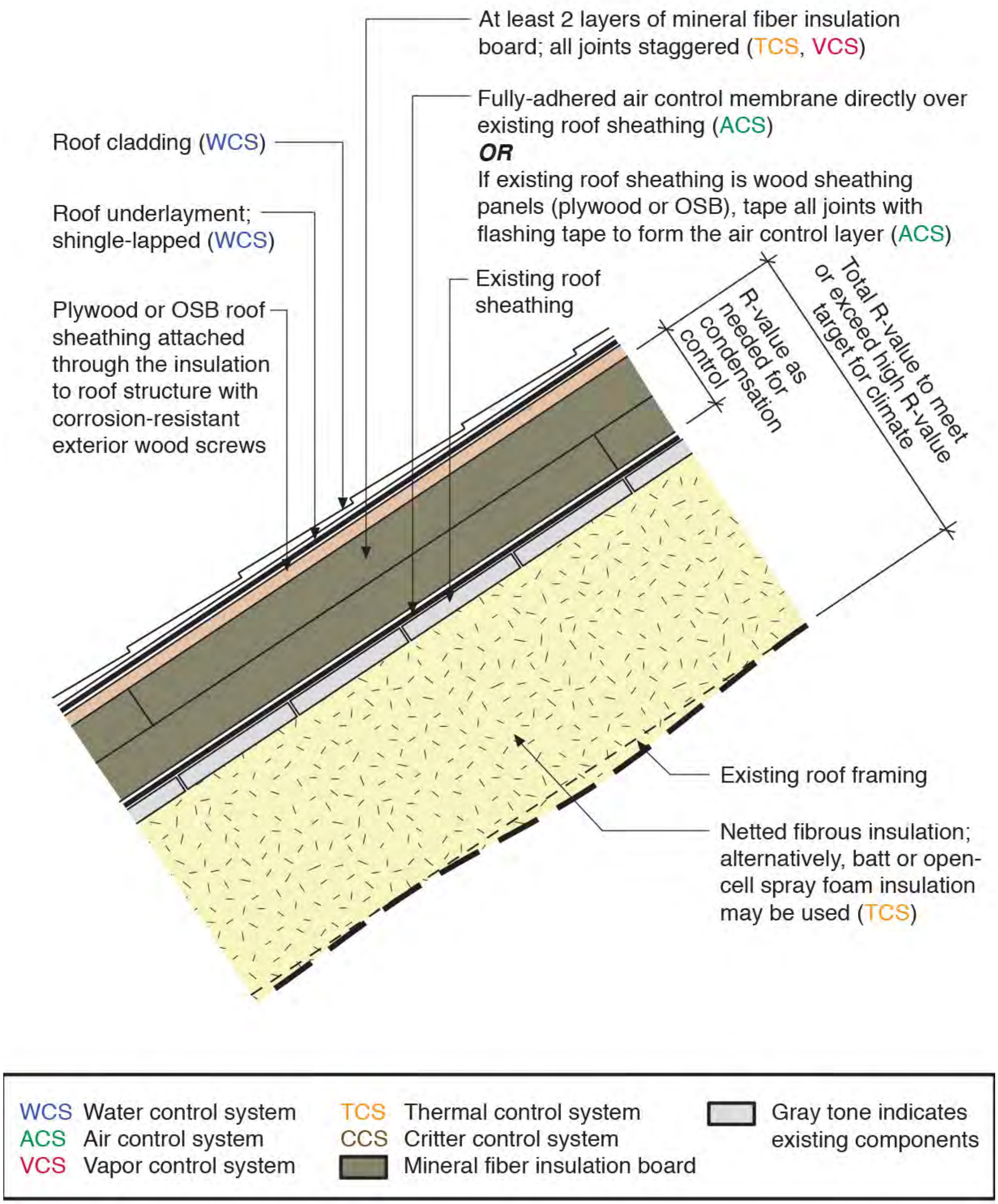


Figure 1. Mineral fiber retrofit roof assembly

In high snow-load areas, a vented roof cladding is recommended. This alternative is shown in Figure 2 below.

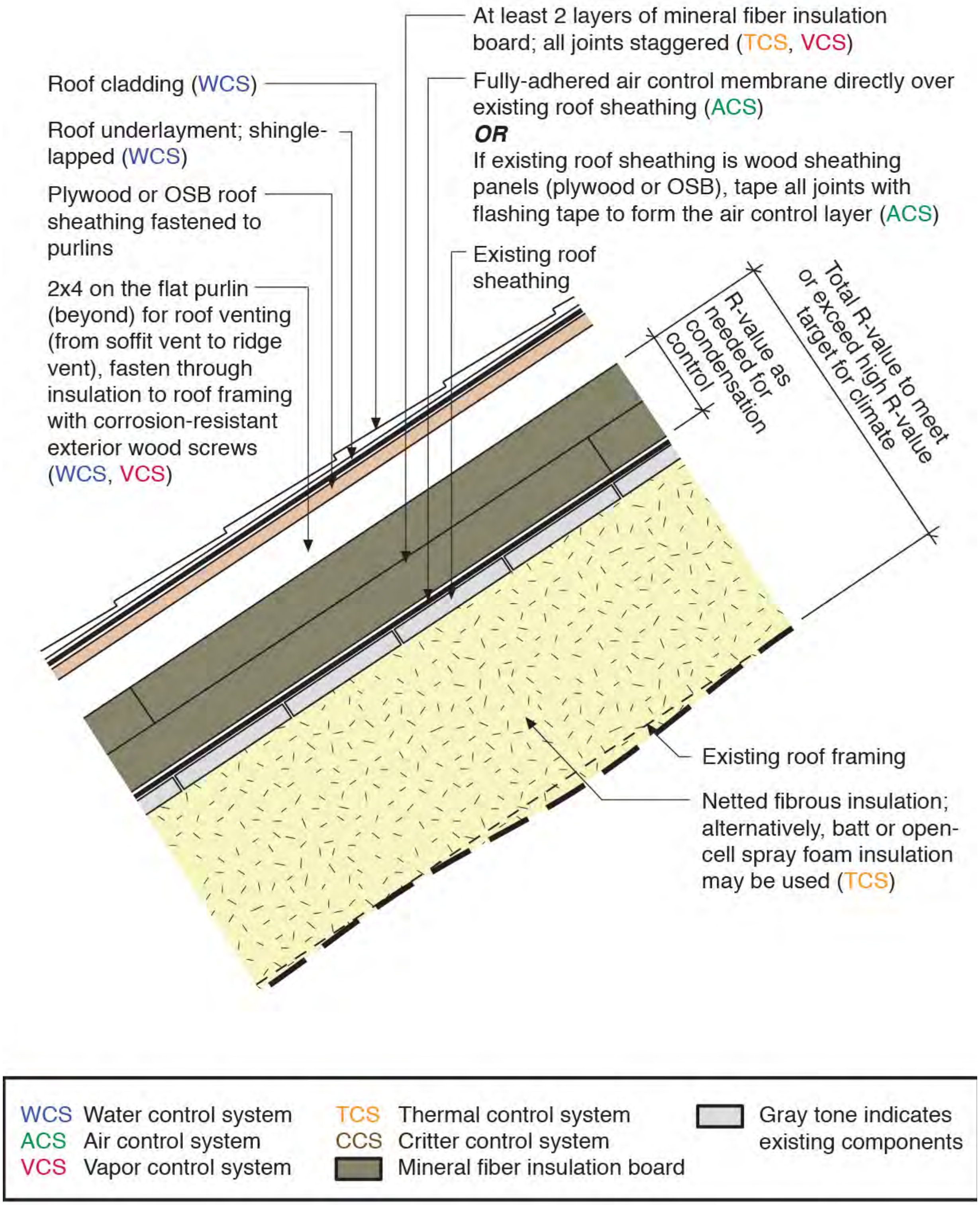


Figure 2. Mineral fiber retrofit roof assembly with a vented roof cladding

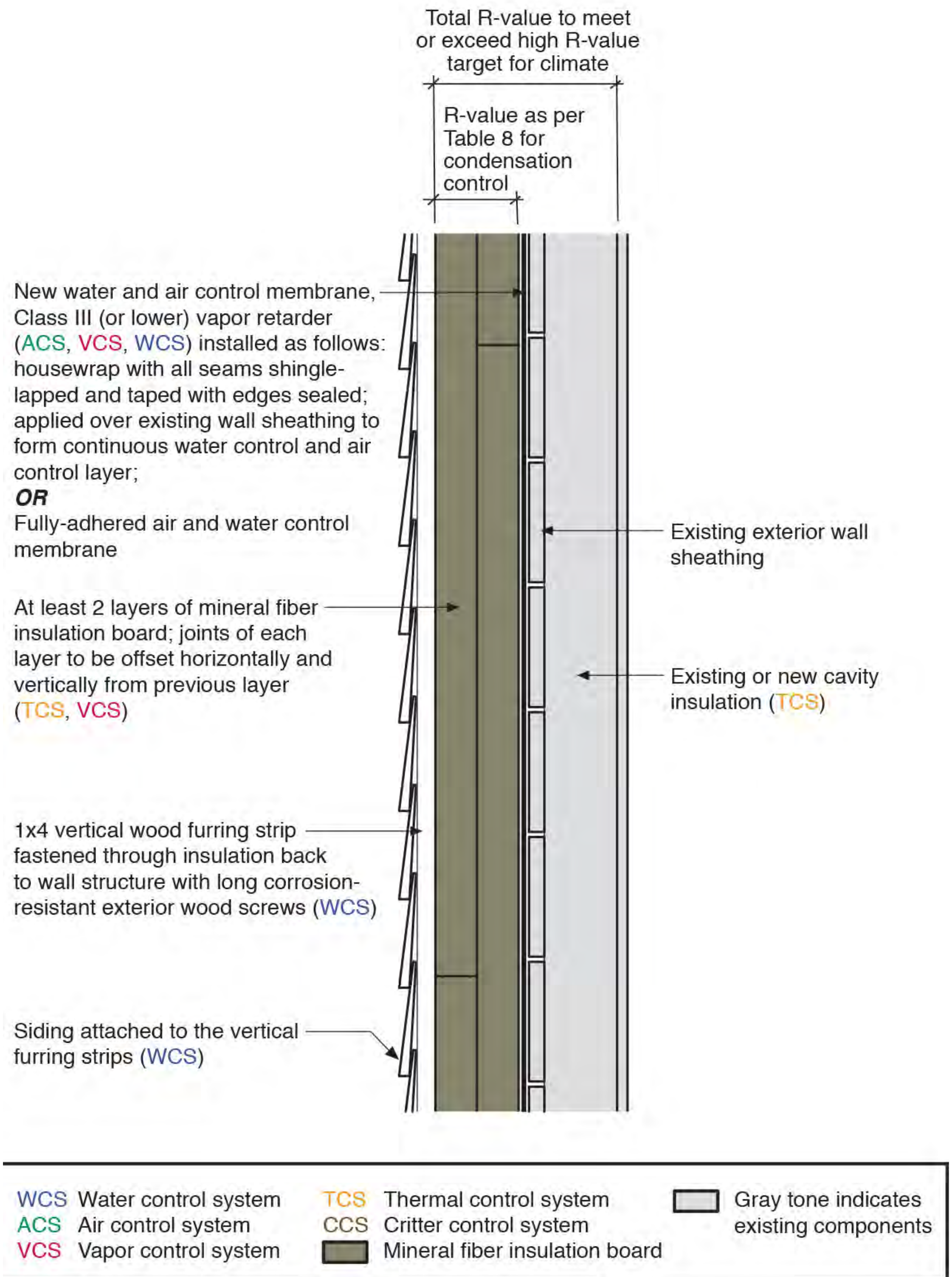


Figure 3. Mineral fiber retrofit wall assembly

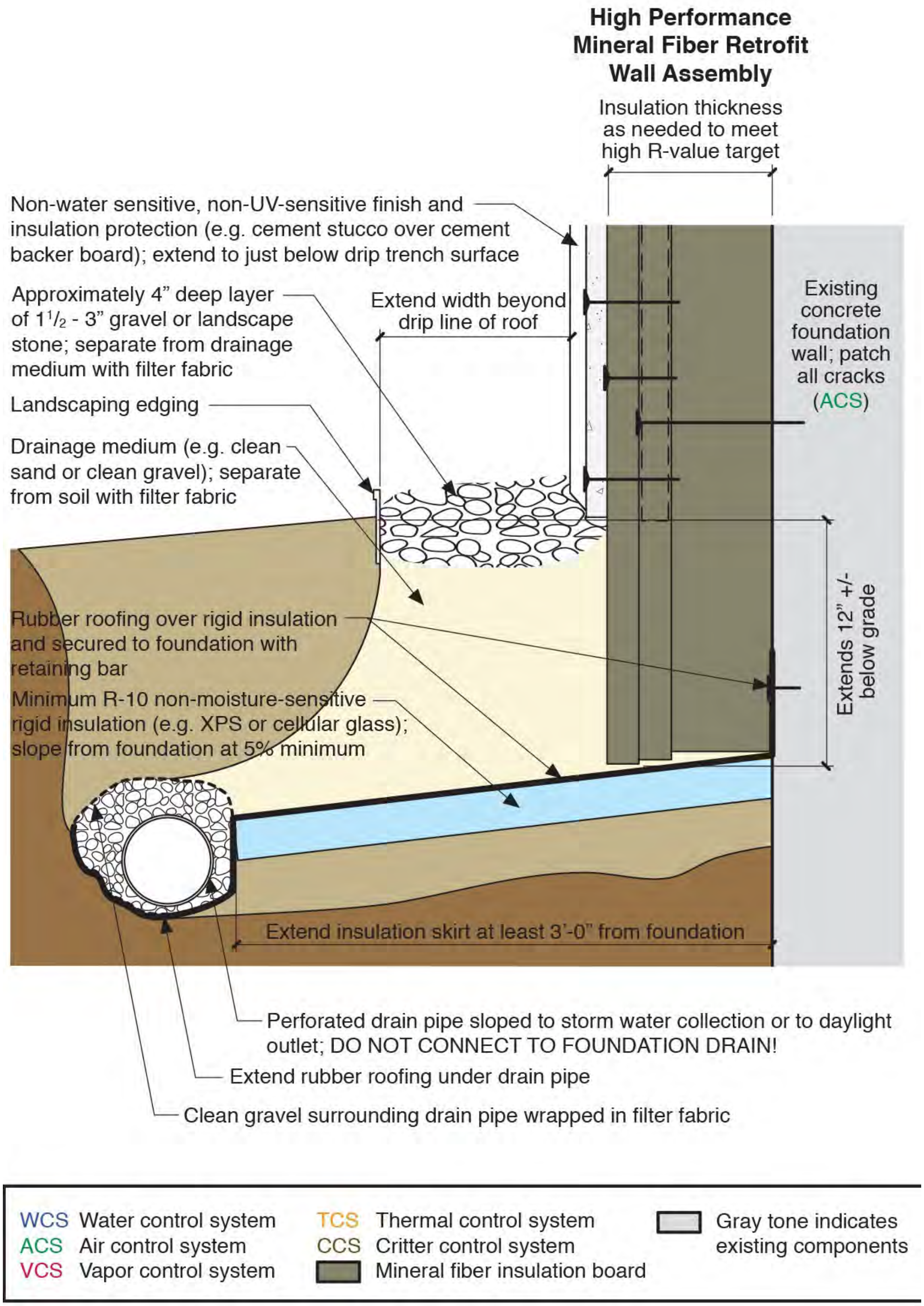


Figure 4. Insulated ground roof included with mineral fiber retrofit foundation wall approach

3.2 Material Properties and Criteria for Mineral Fiber Insulation Board

Table 7 lists the material properties necessary or assumed for the mineral fiber retrofit solutions described in this Measure Guideline.

Table 7. Material Properties and Criteria for Mineral Fiber Insulation Board

Material Property	Criteria	Relevant Standard
Density	Approximately 8/ft^3	
Compressive Resistance	5/ft^2 at 10% deformation, 8/ft^2 at 8% deformation	
Hygrophobic	moisture sorption 0.1%	ASTM C1104
Thermal Resistance	R-value 3.8–4.3/in.	
Stone Wool Melting Temperature	> 2,000°F	
	non-combustible at 750°F	ASTM E136
Flame Spread	< 5	ASTM E84
Smoke Development	≤ 10	ASTM E84
Water Vapor Permeance	~30 U.S. perms @ 2 in. thickness	
Coefficient of Thermal Expansion	< 5 10^{-6} in./in./°F	

3.3 System Interaction

This is a high performance retrofit solution. Approaching from the exterior side, as this retrofit solution does, presents an opportunity to completely overhaul the major building enclosure functions—water control, air control, vapor control, and thermal control—of the above-grade enclosure so that it can provide a very high level of performance well into the future. In keeping with this opportunity, the retrofit solutions outlined in this Guide include robust water, air, and vapor control measures in addition to high R-value thermal performance. The solutions outlined also have the potential to benefit the building enclosure's "critter" (insect and rodent) control performance.

The performance of the mineral fiber retrofit solutions relative to critical control functions is described below.

3.3.1 Water Control

3.3.1.2 Water Control in Mineral Fiber Retrofit Roof Solution

In the retrofit roof assembly, the new roofing installed above insulation board provides the primary water control. The air control membrane installed over the existing roof sheathing is recommended to be detailed as a water control (backup and construction phase water control) membrane.

> **Vented Roof Option**
>
> Where the ground snow load is 50/ft^3 or greater, a vented roof cladding is recommended as a method to further control ice dam formation.

To prevent ice dams in high snow load areas (areas with > 50/ft^2 ground snow load) the roof cladding nail base sheathing should be vented above the insulation board. Vented roofing is accomplished with 2 × 4 on the flat purlins installed between the insulation board and the nail base sheathing and then providing eave and ridge vents. Note that purlins need not be continuous from the eave to the ridge. Breaks in the purlins can allow for cross-ventilation as would facilitate ventilation of complex roofs involving hips, valleys, or interruptions such as dormers and skylights.

Critical Takeaway

Through-wall and kick-out flashings need to be extended to accommodate the added thickness of insulation and furring strips.

3.3.1.2 Water Control at the Roof-to-Wall Transition

The roof overhangs provide the transition of bulk water control at the roof-to-wall transition.

For the transition from a wall to a lower roof, see the details in Section 4.

3.3.1.3 Water Control in Mineral Fiber Retrofit Wall Solution

The mineral fiber insulation board material, although hygrophobic, is not suitable for creating a drainage plane at the surface of the insulation as may be done with foil-faced PIC or XPS insulation board. Instead, a water control membrane is installed on the face of the existing sheathing (in a manner similar to new construction) to serve as the drainage plane/water control layer. Flashings are then integrated with this drainage plane.

The flashing details for this system are very similar to those provided in Baker (2012) for "Exterior Insulation over Wood Frame Wall Drainage Plane at Face of Wood Frame."[1]

Some flashings such as kick-out flashing or through-wall flashings that are intended to direct water from the drainage plane out over the face of the cladding will need to anticipate the added thickness of the insulation and furring strips.

3.3.1.4 Water Control at the Wall-to-Foundation Wall Transition

The transition of bulk water control at the wall-to-foundation wall transition is provided by a sloped metal closure/flashing at the base of the wall retrofit assembly or top of the foundation wall retrofit assembly.

3.3.1.5 Water Control in Mineral Fiber Retrofit Foundation Wall Solution

At the foundation wall, this retrofit solution enhances the control of roof runoff and surface water near the foundation wall, as shown in Figure 6. The retrofit assembly for the foundation includes mineral fiber insulation and cladding at the above-grade portion of the wall as well as a "ground roof" or "skirt" with a drainpipe below grade. The treatment on the above-grade surface of the foundation wall prevents splash-back and other minor surface water from being absorbed into the foundation by capillary action. The retrofit assembly also allows for some drying of moisture (e.g., capillary moisture from groundwater) from the foundation wall. The ground roof intercepts

[1] The details for exterior insulation with drainage plane at the face of wood framing appear in Appendix A to Baker's report on pages 63–78.

roof runoff and surface water that is draining near the foundation and directs this water into a drainpipe that conveys it to daylight or a drywell. This drainpipe must NOT be connected to an existing foundation drain, because this would result in charging the foundation drain system with roof runoff and groundwater.

Clean stone in a drip trench adjacent to the foundation wall provides a capillary break between the soil and the protective insulation finish. This capillary break is important for protecting finish material, such as stucco, that is not appropriate for ground contact. The stone also serves to dissipate the energy of rain or roof runoff, thereby limiting splash-back.

A capillary break of clean aggregate is also needed under the rigid insulation used in an insulated ground roof/insulated foundation skirt.

This retrofit approach involves only a shallow excavation around the perimeter of the building rather than a full excavation of the foundation walls. The retrofit measures significantly improve water management, but the home may still require measures at the interior such as a sump pump or an interior perimeter drain to manage elevated groundwater.

3.3.2 Air Control

3.3.2.1 Air Control in Mineral Fiber Retrofit Wall and Roof Solutions

Mineral fiber insulation is not an air barrier material. In the mineral fiber retrofit assembly for the wall and roof, air control is established at the face of the existing sheathing. Often the water control membrane can be detailed to serve as both a water control and an air control layer. In cases where the sheathing is wood panels (OSB or plywood), it may be possible to establish the air control layer at the wood sheathing by taping the seams and sealing penetrations through the sheathing. Wood panels may also be added to a roof or wall to serve as an air control membrane. In some cases, adding wood panel sheathing of sufficient thickness over existing wood sheathing can create a continuous layer of adequate wood thickness for fastener embedment (typically 1 ½ in. is required).

3.3.2.2 Air Control at the Roof-to-Wall Transition

With the “chainsaw” retrofit configuration, the air control membrane of the roof connects directly to the air control membrane of the wall.

For a non-chainsaw configuration, a sheathing infill extends from the top of the existing wall sheathing to the underside of the roof sheathing. This infill sheathing is sealed to the roof sheathing, sealed to the air control layer of the wall, and sealed around all penetrations through the plane of the infill sheathing/wall sheathing.

For the transition from a wall to a lower roof, see the details under Measure Implementation.

3.3.2.3 Air Control at the Wall-to-Foundation Wall Transition

At the base of the frame wall, the air control membrane is adhered to or sealed to the bottom of the wall sheathing. The bottom of the wall sheathing is sealed to the foundation wall.

3.3.2.4 Air Control in Mineral Fiber Retrofit Foundation Wall Solution

With a cast concrete foundation wall, the foundation wall typically provides the air control layer for the assembly. Holes and cracks in the cast concrete foundation wall must be patched and sealed. With foundation walls constructed of block, brick, or field stone, effective air control relies upon an air control membrane applied at the interior of the foundation wall.

3.3.3 Vapor Control

Insulation board makes the framing cavity more similar to the conditioned interior. During the heating season, insulation board makes the framing cavity and sheathing warmer and drier. During cooling seasons or periods of air conditioner use, insulation boards make the framing cavity and sheathing colder and *potentially* wetter. Especially in a building that uses air conditioning, but even in a cool climate where air conditioning will not be used, drying to the interior is important. Drying to the interior can be inhibited by interior-side vapor retarders such as polyethylene, foil-facing or kraft facing on insulation, vinyl wall coverings, tiles, or even multiple layers of paint. In a retrofit situation, the presence or absence of interior-side vapor retarders may not be known without opening an exterior wall. Exploratory openings should be made, if needed, to determine the existing enclosure assembly configuration.

Super-insulated wall and roof assemblies that use thick exterior insulation board usually have sufficient insulation to the exterior of the sheathing to control condensation of interior water vapor. The amount of insulation needed to the exterior of the sheathing to control this condensation is determined by a number of factors. The dew point of the interior air determines the critical temperature above which the sheathing must be maintained. The temperature of the sheathing is determined by the outdoor temperature, the indoor temperature, and the part of the total assembly R-value that is to the exterior of the sheathing. Infrequent and short-lived condensation conditions are typically not a concern for sheathing materials with reasonable moisture tolerance such as OSB, plywood, or board sheathing. Condensation that accumulates and is sustained over a significant period of time is a concern. Design for air leakage condensation control in this context can use the average temperature of the three coldest months for a particular location as the outdoor temperature condition. Table 8 shows the ratio of exterior insulation R-value to total assembly R-value needed to control the temperature of sheathing above the dew point of interior air given interior air at 68°F.

Table 8. Ratio of Exterior Insulation to Total Assembly Insulation for Air Leakage Condensation Control at 68°F Indoor Temperature

(adapted from Straube 2011)

	Indoor Relative Humidity (%)	20	25	30	35	40	50	60
	Dew Point of Interior Air (°F)	26.6	32	36.6	40.5	44	49.9	54.8
Outdoor Temperature (°F)		Ratio of Exterior Insulation R-Value to Total Assembly R-Value for Condensation Control						
50		0	0	0	0	0	0	0.24
41		0	0	0	0	0.1	0.31	0.48
32		0	0	0.12	0.23	0.32	0.47	0.6
23		0.08	0.19	0.29	0.37	0.45	0.57	0.68
14		0.23	0.32	0.4	0.48	0.54	0.64	0.73
5		0.33	0.42	0.49	0.55	0.6	0.69	0.77
–4		0.41	0.49	0.55	0.6	0.65	0.73	0.8
–13		0.48	0.54	0.6	0.65	0.69	0.76	0.82
–22		0.53	0.59	0.64	0.68	0.72	0.78	0.84

1. *Vapor Control in Mineral Fiber Retrofit Roof Solution*

Outward vapor drive is controlled in the roof assembly by insulation to the exterior of existing roof sheathing. It is important to maintain sufficient ratio of exterior insulation (insulation board) to total roof assembly insulation. Table 8 shows the ratio of insulation needed for various interior humidity conditions and an interior temperature of 68°F.

> **Key Point**
>
> For vapor control in a hot-humid climate, the air control membrane over the existing sheathing must be a class II (or lower) vapor retarder and must also be a water control membrane.

Inward vapor drive must be managed for all roofs. In roof assemblies with plywood or board sheathing and fibrous cavity insulation and no interior-side vapor retarders the inward vapor drive is managed by allowing drying to the interior. However, if the roof assembly includes significant vapor retarders on the interior side of the roof cavity, closed-cell foam insulation (SPF or board foam) to the interior of the structural sheathing, or OSB sheathing, then additional vapor control measures are needed. In hot-humid climates, the air control membrane installed above the existing roof sheathing must be a class II (or lower) vapor retarder and also be a water control membrane. In other climates, the air control membrane should be a class III (or lower) vapor retarder. Information about classes of vapor retarders has been provided by Lstiburek (2011).

3.3.1 Vapor Control at the Roof-to-Wall Transition

See Section 3.3.4.2.

3.3.2 Vapor Control in Mineral Fiber Retrofit Wall Solution

Condensation caused by outward vapor drive is controlled in the wall assembly by insulating to the exterior of existing wall sheathing. The ratio of exterior insulation (insulation board) to total wall assembly insulation is critical to controlling the risk of condensation at the sheathing. The ratio needed varies with climate and interior conditions (see Figure 5). Table 8 shows the ratio of insulation needed for various interior humidity conditions and an interior temperature of 68°F.

The wall assembly manages inward vapor drive through a vented cladding and a water and air control membrane over the sheathing that is also a class III (or lower) vapor retarder. In hot-humid climates, a class II (or lower) vapor retarder over the sheathing is appropriate. For walls that have a non-reservoir cladding such as vinyl siding and that are located in either a dry or cold (climate zone 5 or above) climate, the class III vapor retarder is necessary with significant air conditioner use and interior-side vapor retarders only.

Limiting the Impact of Reservoir Claddings

The water uptake of reservation claddings can be significantly reduced by preventing water from reaching the surface of the cladding. For example, large overhangs can shield the cladding from incident rain water. Paints and coatings can also block the capillary pores that wick water into the material. For wood and fiber cement cladding, it is important to prime or paint all sides of the cladding pieces—including cut ends—to limit the uptake of water through capillary action.

Insulation for Condensation Control

To control condensation of interior water vapor, the sheathing must be maintained above the dew point of the interior air. The temperature of the sheathing is determined by the indoor and outdoor temperature and by the ratio of insulation outside of the sheathing to insulation inside of the sheathing. As the outdoor temperature decreases, the amount of insulation needed to maintain the sheathing temperature increases. Also, as the interior humidity increases the dew point temperature of interior air increases, so the sheathing must be maintained at a higher temperature to avoid condensation.

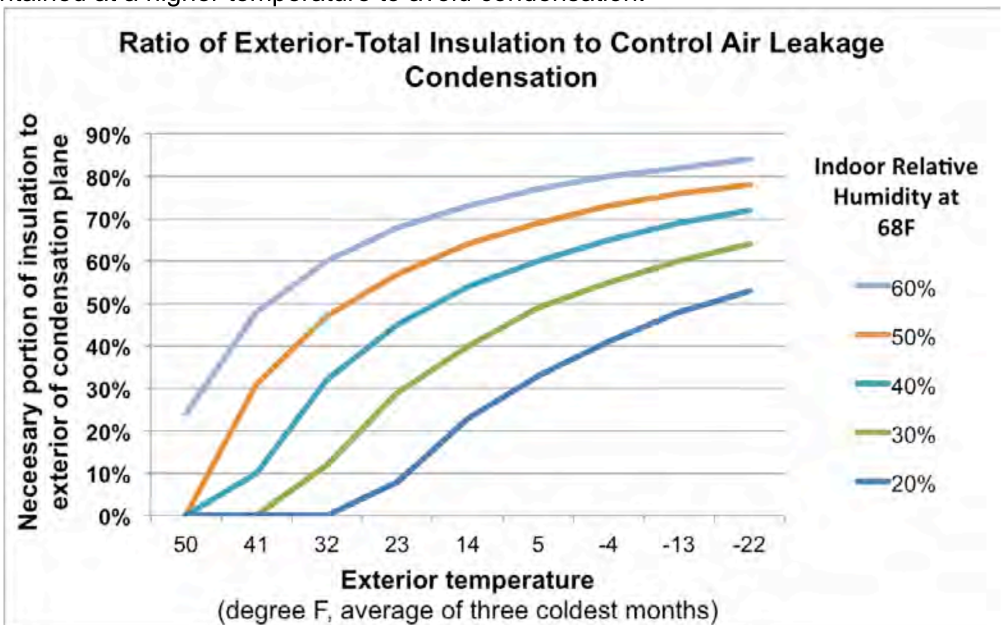


Figure 5. Ratio of exterior to total insulation to control condensation of interior water vapor

3.3.3 Vapor Control at the Wall-to-Foundation Wall Transition

See Section 3.3.4.2.

3.3.4 Vapor Control in Mineral Fiber Retrofit Foundation Wall Solution

The foundation retrofit assembly permits drying from the foundation wall into the mineral fiber exterior insulation. Whether moisture is able to dry to the exterior depends upon the properties of the protective finish selected for the above-grade part of the mineral fiber insulation. A sheet metal covering would not allow diffusion drying but condensate could safely drain away between the metal covering and the insulation board.

The interior of the foundation wall may still present a condensation surface when interior air dew point exceeds the ground temperature. Also, the part of the foundation wall below the foundation skirt will remain exposed to ground moisture. Comprehensive vapor management for foundation walls may require additional measures to the interior of the foundation wall.

3.3.4 Thermal Control

Table 1 provides the thermal resistance (R-value) targets for the enclosure components addressed in this guide. The "Basement Wall" targets define the performance criteria for exterior insulation of the foundation wall. The target performance for the insulated foundation skirt (used in cold climates or where the home has a crawlspace or basement) is given by the targets for "Slab Edge" insulation in the table.

3.3.4.1 Thermal Control in Mineral Fiber Retrofit Roof Solution

The retrofit roof assembly is thermally controlled by insulation board, usually in combination with cavity insulation directly to the underside of the sheathing. It is important that the ratio of exterior insulation board to total assembly thermal resistance is as needed to control condensation. See Section 3.3.1.

3.3.4.2 Thermal Control at the Roof-to-Wall Transition

In a "chainsaw" configuration, the continuity of thermal control is inherently achieved by direct connection between roof insulation board and wall insulation board. In cold climates, continuous insulation at the transition is important to the control of condensation or elevated relative humidity at the thermal bridging elements represented by framing.

In non-chainsaw configurations, the roof insulation board is continuous onto the overhang. The wall insulation board is fit around projecting framing and butted to the roof sheathing. Closed-cell SPF is used to complete the transition of air, vapor, and thermal control at non-chainsaw roof-to-wall transitions.

For the transition from a wall to a lower roof, see the details in Section 4.

3.3.4.3 Thermal Control in Mineral Fiber Retrofit Wall Solution

The retrofit wall assembly is thermally controlled by insulation board, usually in combination with insulation in the framing cavities of exterior walls. It is important that the ratio of exterior insulation board to total assembly thermal resistance is as needed to control condensation. See the Section 3.3.4.

3.3.4.4 Thermal Control at the Wall-to-Foundation Wall Transition

Metal flashing at the base of the wall represents a thermal bridging element with respect to the insulation board. When connected to the mass of the foundation wall, the impact is dispersed and should not represent a specific cold-weather condensation risk.

The bottom of the exterior wall retrofit assembly should extend past the bottom of the wood sheathing where possible to ensure that the sheathing is maintained closer to the interior conditions.

Continuity of the thermal control is improved by cutting the bottom of the wall insulation board and the top of the foundation wall insulation board on an angle to fit snug against the sloped metal flashing/closure between the foundation and wall exterior retrofit treatments.

3.3.4.5 Thermal Control in Mineral Fiber Retrofit Foundation Wall Solution

The insulation board installed at the exterior exposed part of the foundation wall should at least meet the high R-value target for basement walls. This is true even if the interior is insulated as the exterior exposed part of the foundation wall represents a more significant heat transfer surface than the below-grade (by more than 1 ft) sections. To the extent that a significant part of the foundation wall remains in contact with ground below the exterior insulation treatment, the foundation wall will remain significantly ground coupled. Therefore, additional insulation to the interior may be warranted to improve comfort conditions.

The R-value of the insulated foundation skirt (used in cold climates or where the home has a crawlspace or basement) should be at least as given by the targets for “slab edge” insulation in the table. Because of the position of the foundation skirt insulation, the insulation material must be a rigid material with robust compressive strength and the material must be non-moisture sensitive. XPS and foamed glass rigid insulation are appropriate materials for this application. Even with these relatively non-moisture-sensitive materials, the insulation is recommended to be laid over a capillary break of clean aggregate.

3.4 Climate Considerations

Mineral fiber insulation board is a vapor-permeable material that supports outward drying of assemblies. Because of its high vapor permeability the material offers negligible resistance to inward vapor drive. Inward vapor drive occurs when the ambient air is humid and the interior of the enclosure is cooler than ambient air. This condition is typical of buildings when air conditioning is in operation. It is a sustained condition in hot-humid climates.

Inward vapor drive also occurs—and can be significant—when a wetted reservoir cladding is exposed to direct solar radiation. This type of inward vapor drive can affect buildings with reservoir claddings regardless of the climate.

Inward vapor drive presents a risk to moisture-sensitive materials located in a part of the assembly where it would lead to condensation or elevated relative humidity.

To provide control of exterior water vapor, a class III (or lower) vapor retarder between mineral fiber insulation board and sheathing is the base recommendation for mineral fiber framed assembly retrofit solutions. In hot-humid climates, a class II (or lower) vapor retarder over the sheathing is recommended.

For walls that have a non-reservoir cladding, such as vinyl siding, and that are located in either a dry or cold (climate zone 5 or above) climate, the class III vapor retarder is necessary with significant air conditioner use and interior-side vapor retarders only.

4 Measure Implementation

4.1 High Performance Mineral Fiber Retrofit Roof Assembly

4.1.1 Scope of Work

1. Remove roof cladding and prepare the roof sheathing for air and water control membrane.
2. Implement a "chainsaw" retrofit where structural configuration of the roof permits.
3. Install a continuous air and water control membrane over the roof sheathing to provide vapor control in accordance with code. Transition the roof air and water control membrane to adjacent assemblies.
4. Install mineral fiber insulation board in accordance with code to satisfy the high R-value performance target for the assembly and for adequate condensation control (the higher R-value requirement shall govern).
5. Install sheathing as a nail base for roof cladding. Fasten the sheathing to the roof structure through the insulation board.
   OR
   Install purlins for ventilated roof sheathing. Fasten the purlins to the roof structure through the insulation board. Install sheathing as a nail base for roof cladding. Fasten the sheathing to the purlins.
6. Install roof underlayment, ice and water membrane, flashing, and roofing per new construction best practices.

4.1.2 Climate-Specific Factors

In hot-humid climates, the air and water control membrane between the mineral fiber insulation board and the roof/wall sheathing must be a class II (or lower) vapor retarder.

4.1.3 Field Inspection

Identify and address risks to occupants or the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed. Determine the feasibility of the retrofit solution and of options.

Inspect and assess the building for:

- Structural integrity of the frame and foundation
- Safety and serviceability of the electrical system
- Hazardous materials (e.g., lead, radon, asbestos)
- Rainwater, groundwater, or plumbing water leaks
- Rot or decay in framing
- Insect and pest damage and activity.

Deficiencies or hazards must be remediated before the project begins, or remediation must be incorporated into the scope of the project.

Identify any atmospherically vented (or naturally aspirated) combustion appliances in the home. With the exception of gas stoves and cooktops, combustion appliances—including fireplaces—should be direct-vented or direct exhaust-vented equipment. Atmospherically vented appliances must be replaced or reconfigured to direct-vented or direct exhaust-vented operation prior to or as part of the project.

Verify that all kitchen and bathroom exhausts are vented to the exterior of the building. Source control ventilation deficiencies must be corrected either prior to or as part of the project.

If the home lacks a ventilation system meeting the requirements of 2012 IRC, Section M1507.3, a ventilation system meeting this requirement must be installed either prior to or as part of the project.

Ensuring Success

Significant retrofit of building enclosure components will change the dynamics of water, air, vapor, and heat flow within the home. To ensure that these changing dynamics do not have negative ramifications for health and safety or for building durability, the following conditions must be met either prior to or as part of the project.

- Combustion safety—All non-cooking appliances, including fireplaces, must be direct-vented or direct exhaust-vented appliances.
- Ventilation—Whole-house ventilation meeting the requirements of 2012 IRC, Section M1507.3 is installed and operational.

The following is also recommended:

- Soil gas control system—An active or passive soil gas control system is installed and operational.

4.1.4 Implementation Risks

Construction and renovation work entails inherent risks to workers. All applicable safety procedures must be followed.

Implementation risks specific to mineral fiber insulation board retrofit derive from the fibrous nature of the material. It is recommended that all workers handling or cutting material:

1. Wear protective clothing and avoid exposed skin.
2. Wear goggles or similar enclosed eye protection.
3. Wear gloves that are impermeable to fibers.
4. Use tight-fitting dust masks to provide appropriate protection from airborne fibers.
5. Refer to material safety data sheets and manufacturer instructions for safe handling and exposure.

4.1.5 Installation Procedure

1. Remove existing cladding and prepare the roof sheathing to receive the air and water control membrane.

Removal of roof cladding is a well-established procedure.

Appropriate preparation of the roof sheathing will depend upon the nature of the existing sheathing and the air control strategy pursued. If a sheet good is used as the air and water control layer, all protruding fasteners must be removed to avoid punctures or tears in the membrane. Gaps or voids in the sheathing layer may need to be in filled. Use a primer for self-adhered membranes if recommended by the membrane manufacturer.

1a. Chainsaw retrofit: Remove roof overhangs.

If roof framing allows, remove roof sheathing, rafter tails, and gable rake framing to flush with the exterior wall sheathing. Provide structural sheathing infill and/or blocking as needed to allow wall sheathing plane to meet roof sheathing plane.

2. Install an air and water control membrane.

Install a continuous water and air control membrane.
OR
Tape the wood panel sheathing with flashing tape (acrylic or bituminous adhesive) to form a continuous air control membrane (see Figure 6) and install a water control membrane over the wood panel sheathing (see Figures 7 and 8).

Connect the air control membrane to the air control layer of adjacent assemblies in an airtight and durable manner (see Figures 7 and 8). Seal all penetrations against air and water leaks.

The air and water control membrane or water control membrane must provide vapor control as required: class II (or lower) in hot humid climates, class III (or lower) elsewhere. See Section 3.

Figure 6. Taped wood panel roof sheathing as air control membrane

Figure 7. "Chainsaw" transition of air and water control membrane

Figure 8. "Chainsaw" transition of air and water control membrane at rake

3. Install a mineral fiber insulation board.

Install over the air and water control membrane. Butt joints tight. When installing multiple layers, offset seams in two directions.

3a. Chainsaw retrofit: Install framing for new overhangs.

Install framing for new roof overhangs over continuous insulation board. Many contractors who have experience with "chainsaw" retrofits prefer to pre-assemble framing for new roof overhangs (see Figure 9).

Figure 9. Pre-assembled insulated roof overhang framing being lifted into place at a gable rake for a "chainsaw" retrofit

3b. Vented roof option: Install purlins for ventilation and attachment or roof sheathing.

For a vented roof, install 2 × 4 on the flat purlins over the insulation board and fasten through the insulation board to the roof structure. Purlins need not be continuous from the eave to the ridge. Breaks in the purlins can allow for cross-ventilation as would facilitate ventilation of complex roofs involving hips, valleys or interruptions such as dormers and skylights. A structural engineer should be consulted for sheathing/purlin attachment type and number used, because it will be based on wind loads and potential uplift.

4. Install roof sheathing/cladding.

Install roof sheathing to serve as a nail base for roof cladding (e.g., shingles). Attach the sheathing to the roof structure through insulation board.

In the vented roof approach, attach the roof sheathing to purlins.

5. Install roof cladding and flashing.

Install underlayment, ice and water membrane, flashings, and roofing per new construction best practices.

6. Install rafter cavity insulation.

Install insulation in framing cavities to the underside of the existing roof deck. Refer to Table 8 and calculated ratios to ensure that the level of insulation does not upset the ability of the exterior insulation to provide condensation control.

See Figure 10 through Figure 17 for details about this procedure.

4.1.6 High Performance Mineral Fiber Retrofit Details

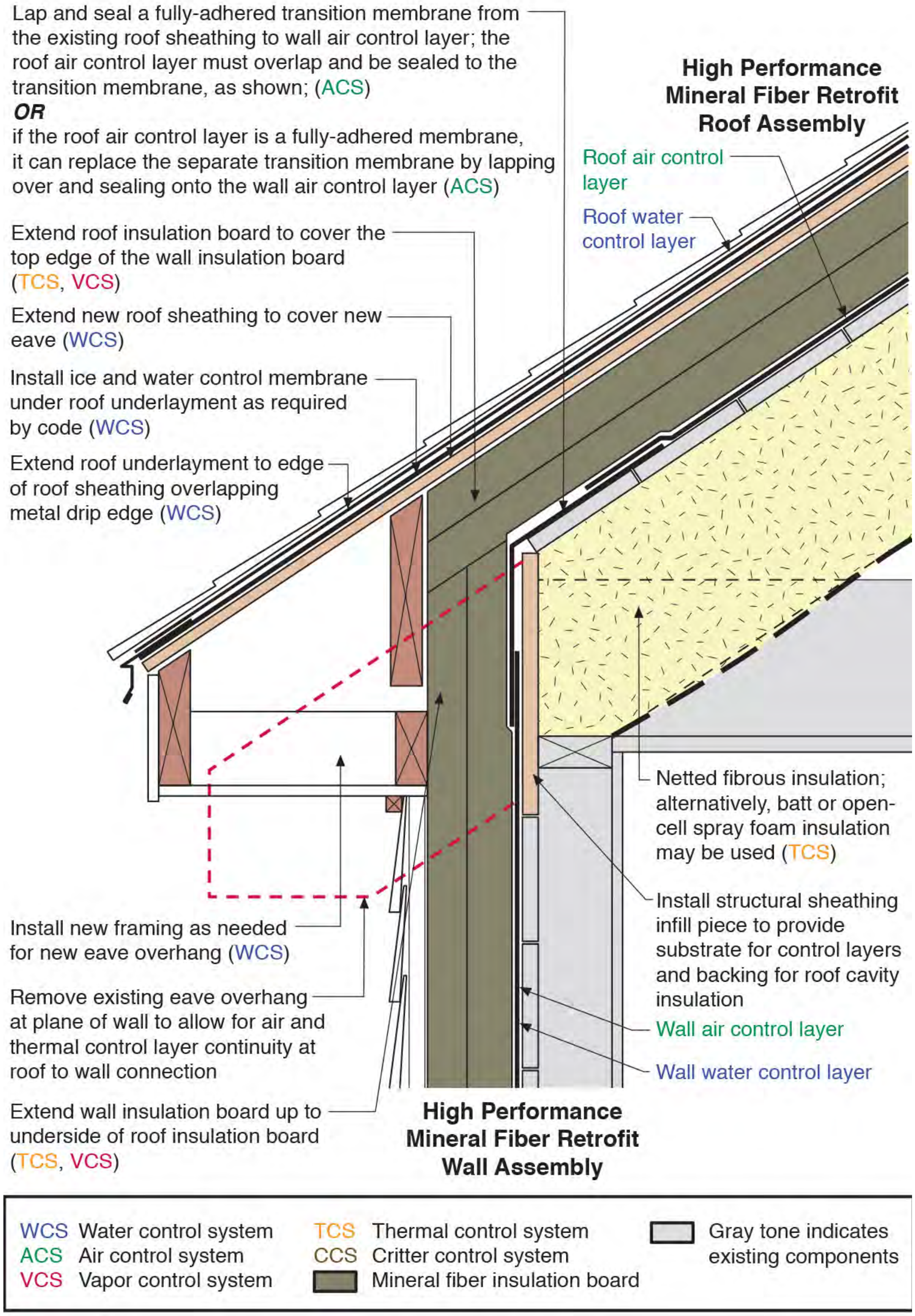


Figure 10. Schematic detail for "chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

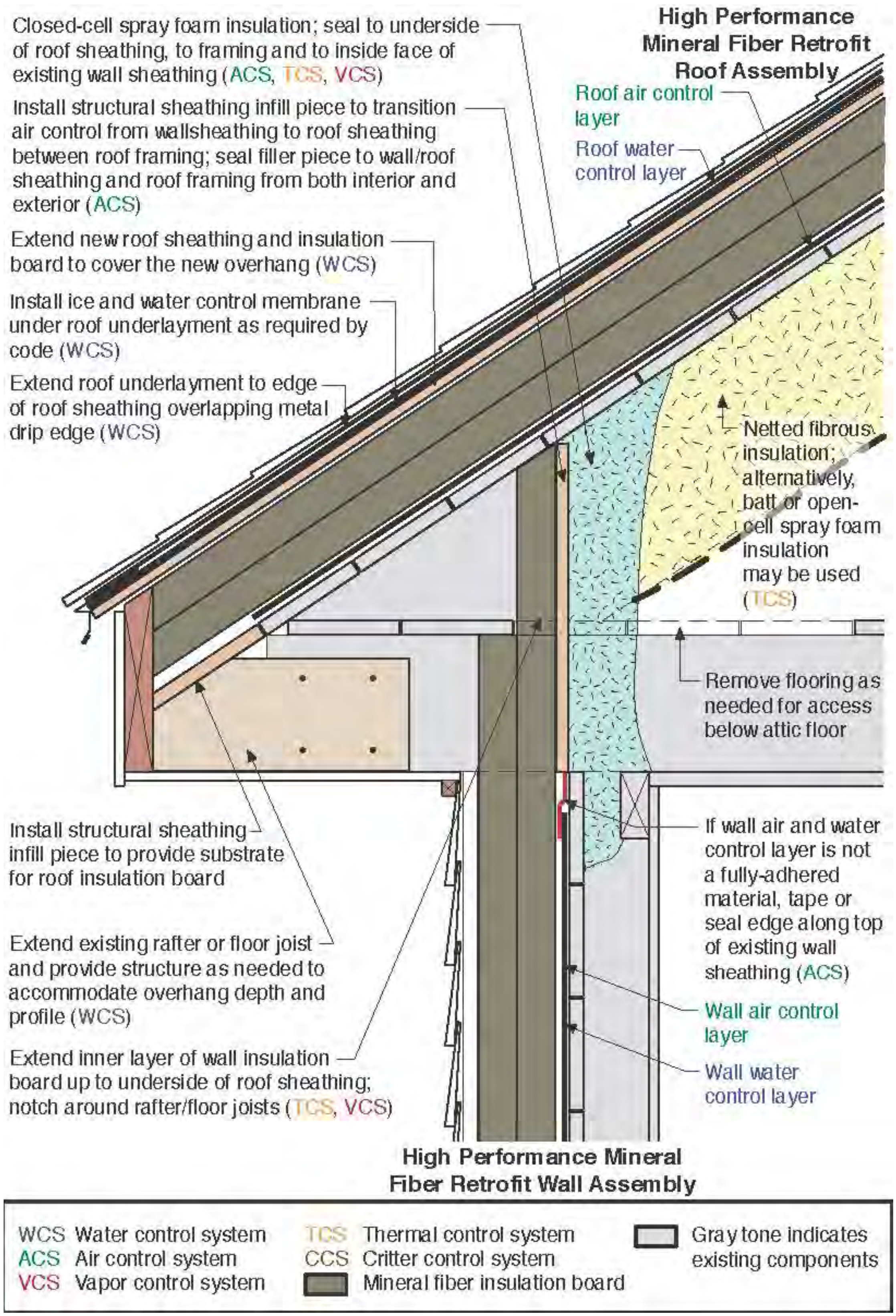


Figure 11. Schematic detail for non-"chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

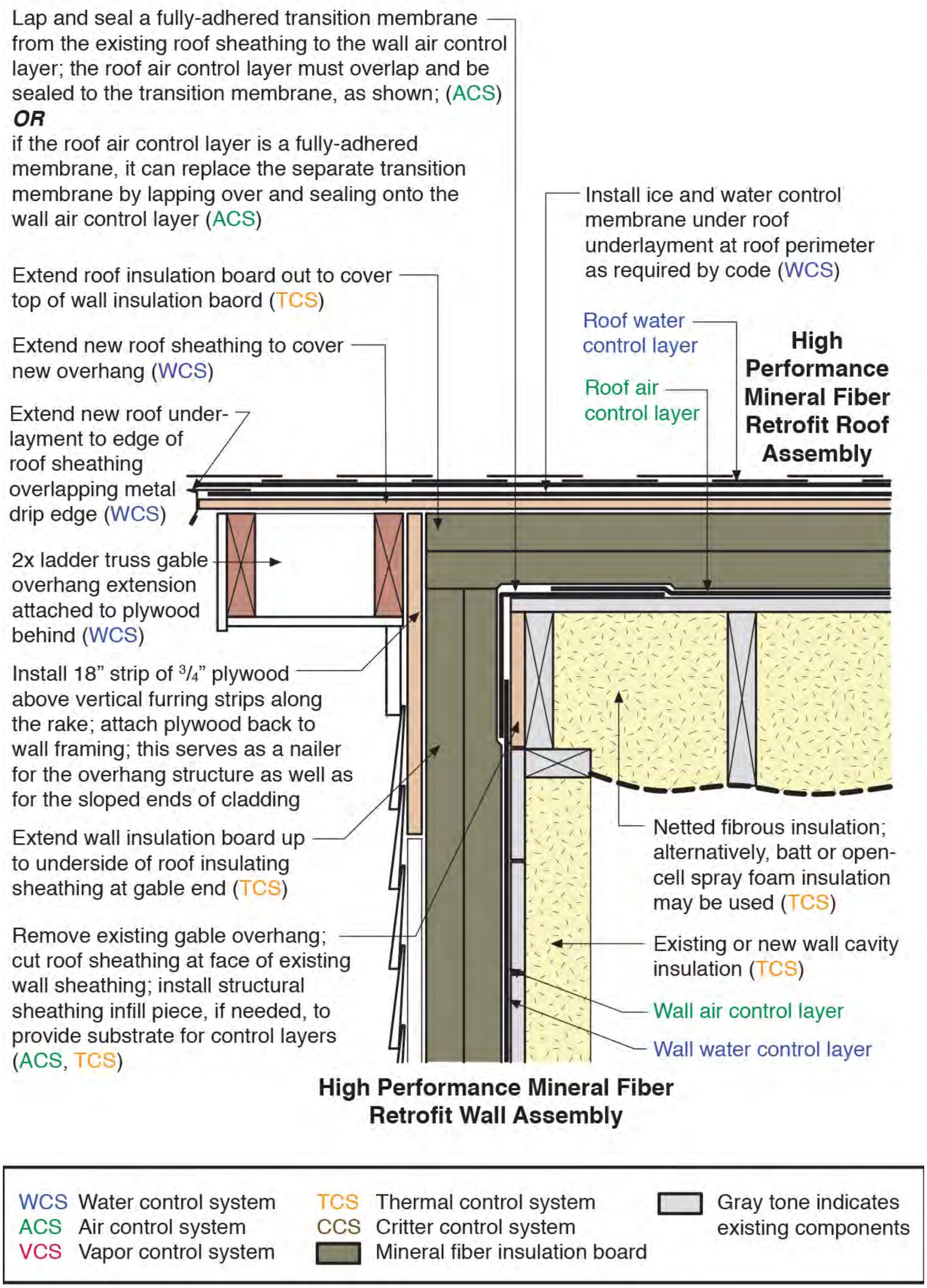


Figure 12. Schematic detail for "chainsaw" gable rake transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

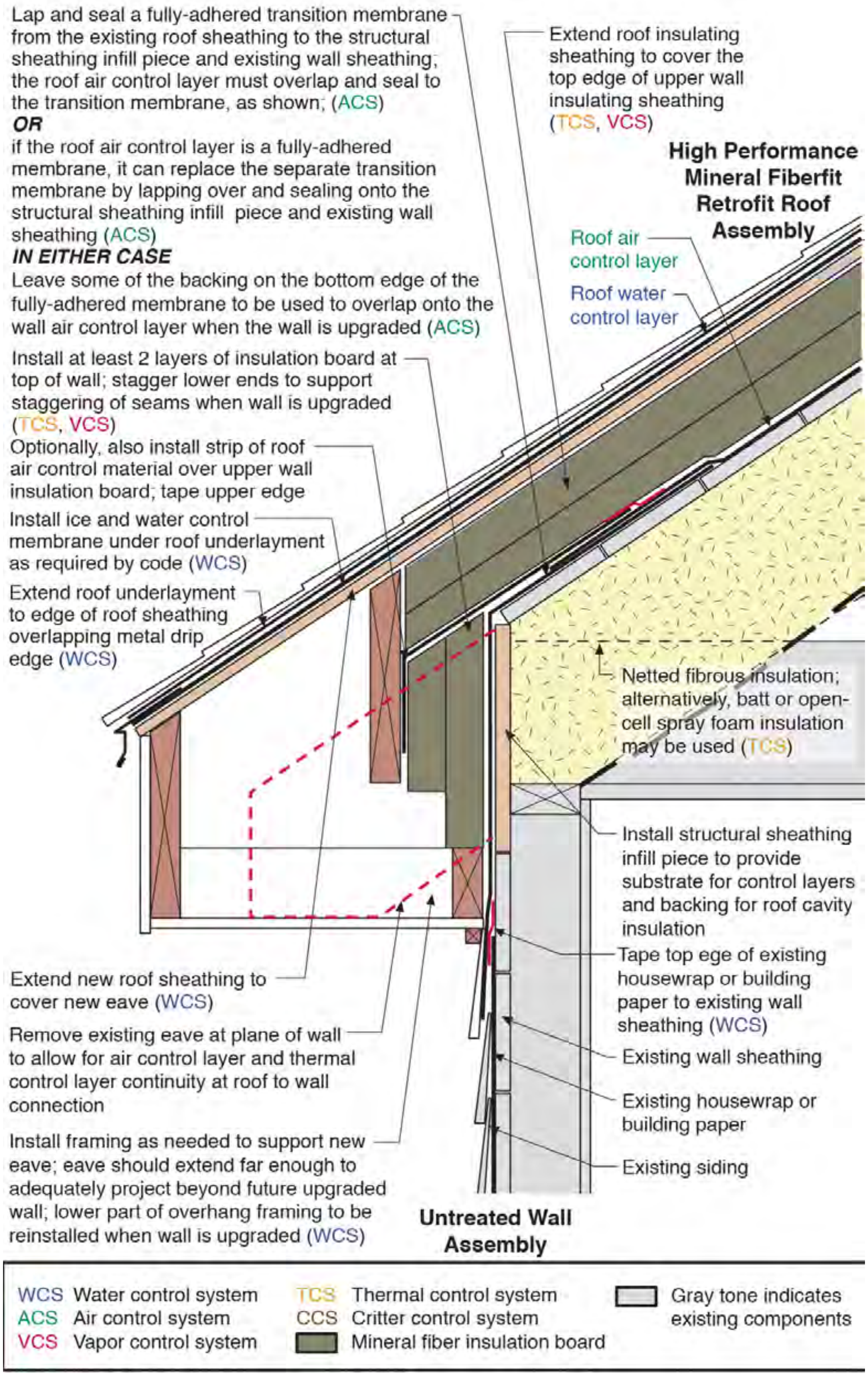


Figure 13. Schematic detail for "chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a non-retrofit wall assembly

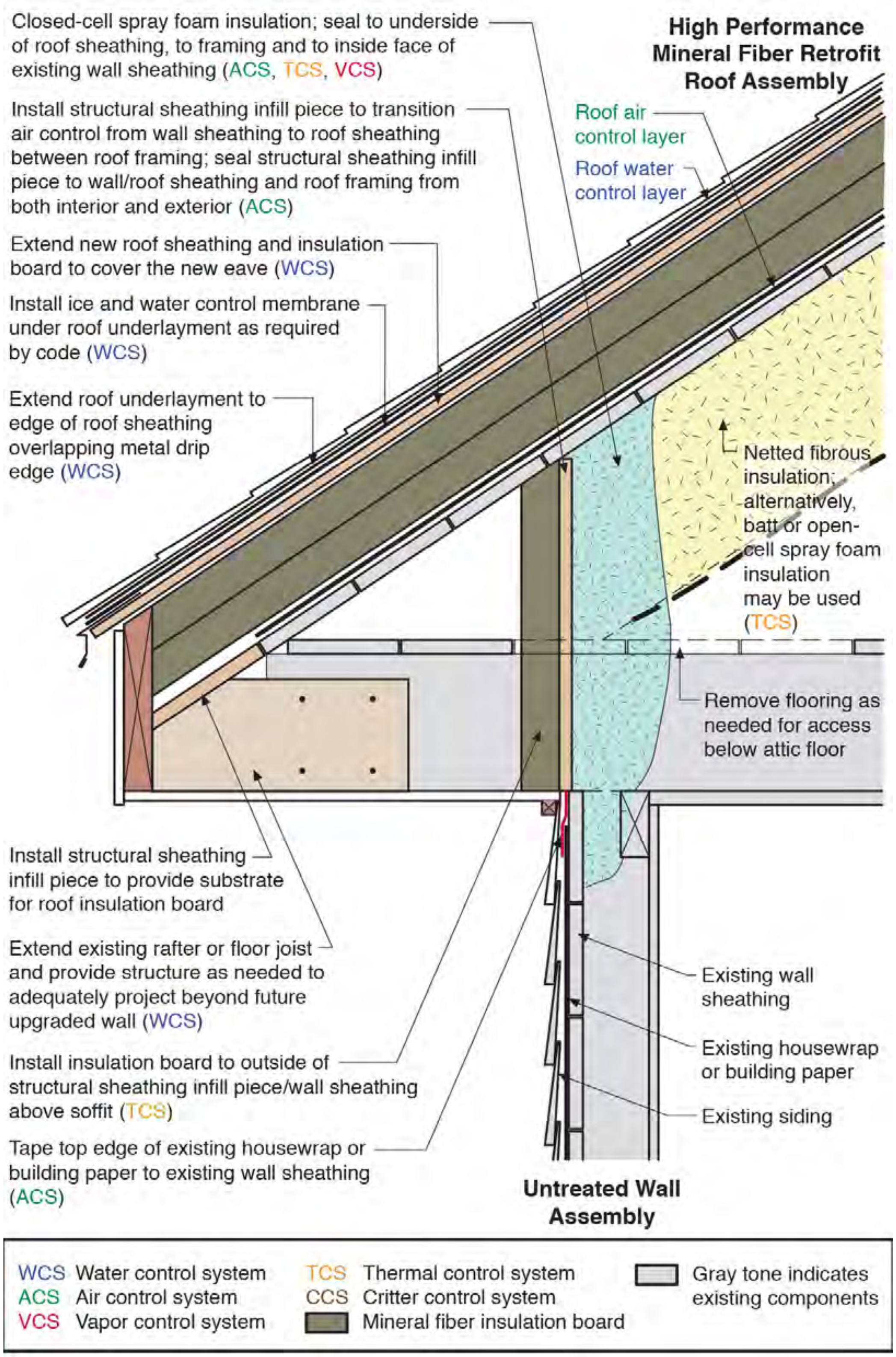


Figure 14. Schematic detail for non-"chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a non-retrofit wall assembly

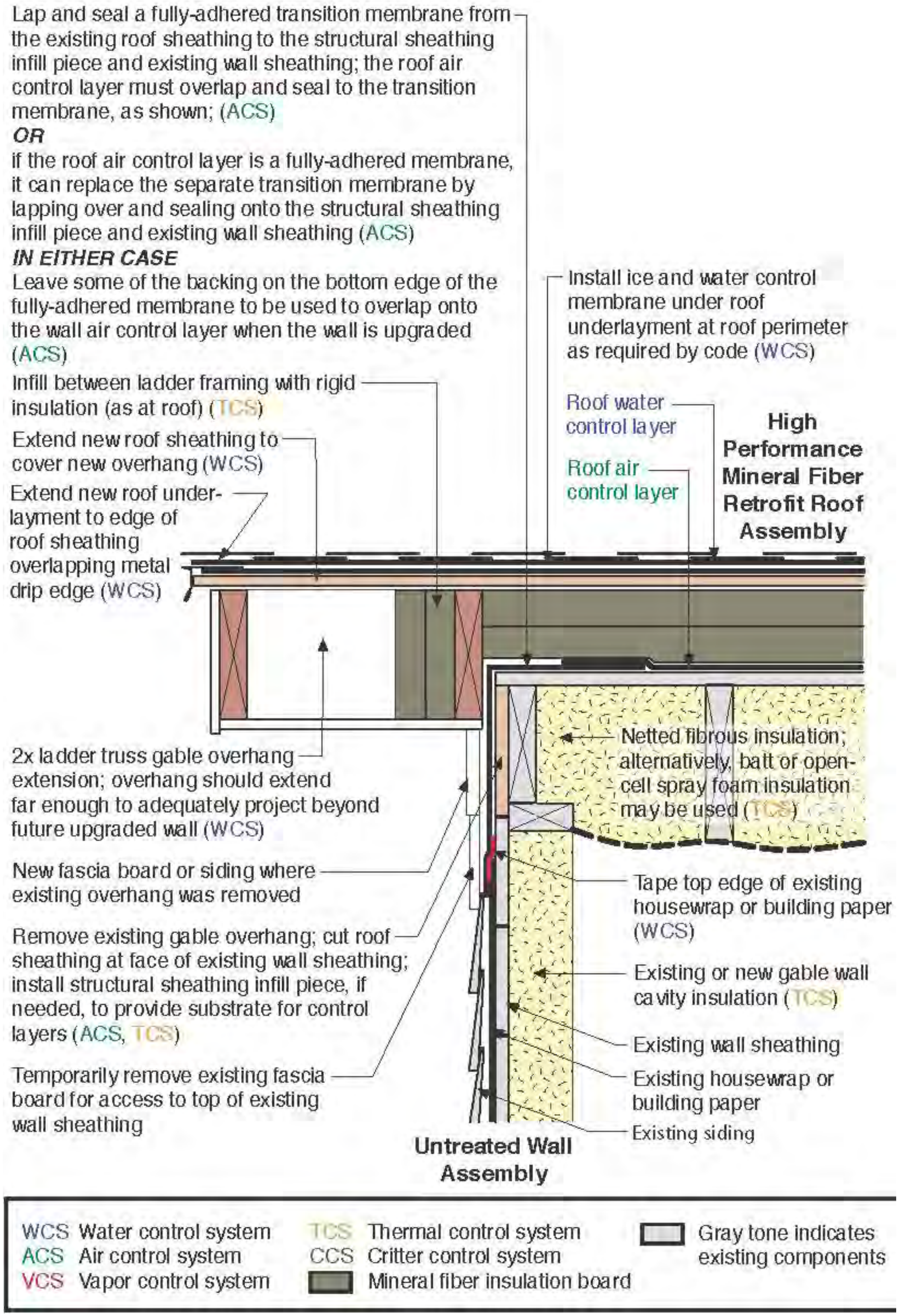


Figure 15. Schematic detail for "chainsaw" gable rake transition from a high performance mineral fiber retrofit roof assembly to a non-retrofit wall assembly

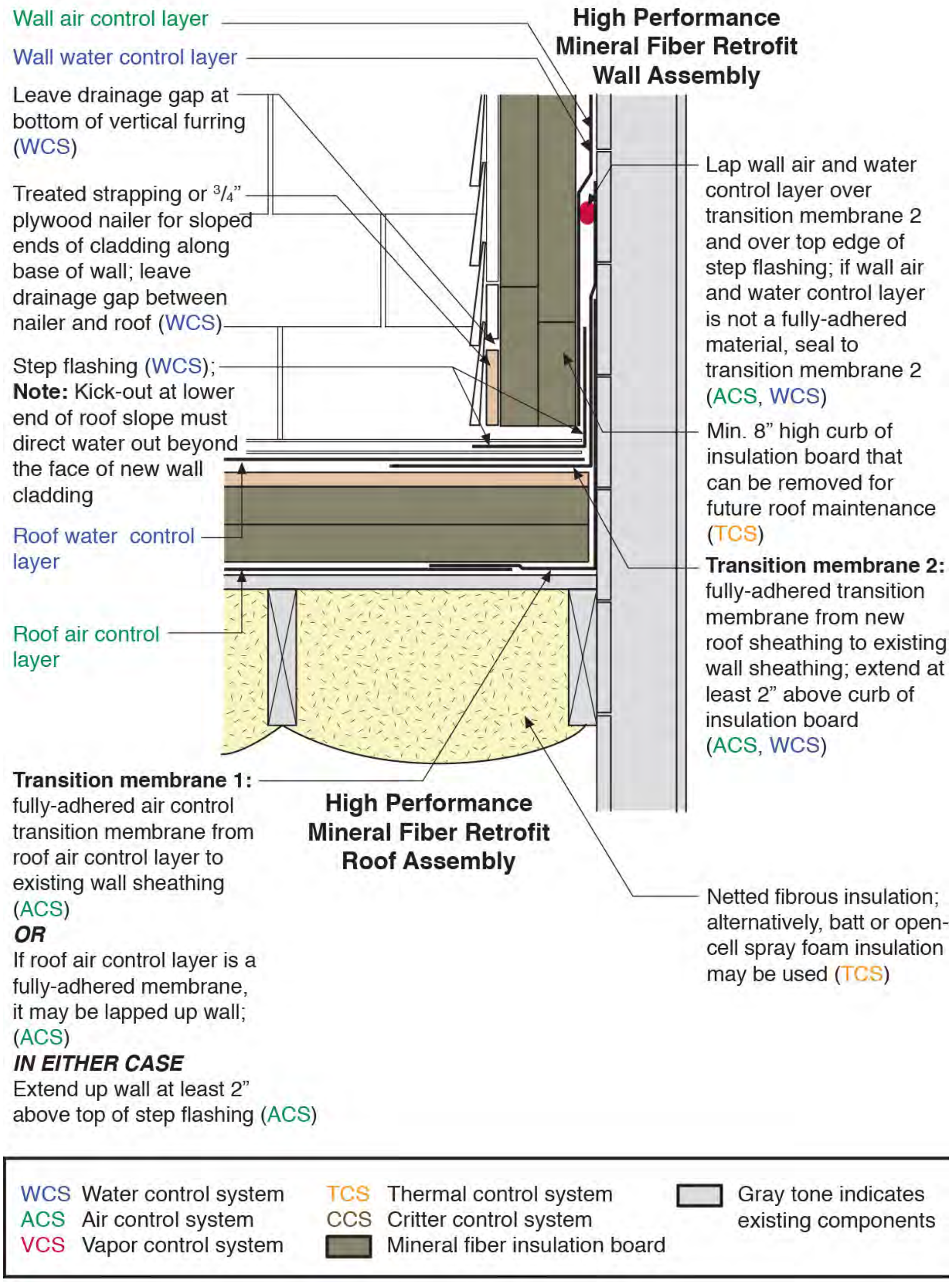


Figure 16. Schematic detail for transition from a lower high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

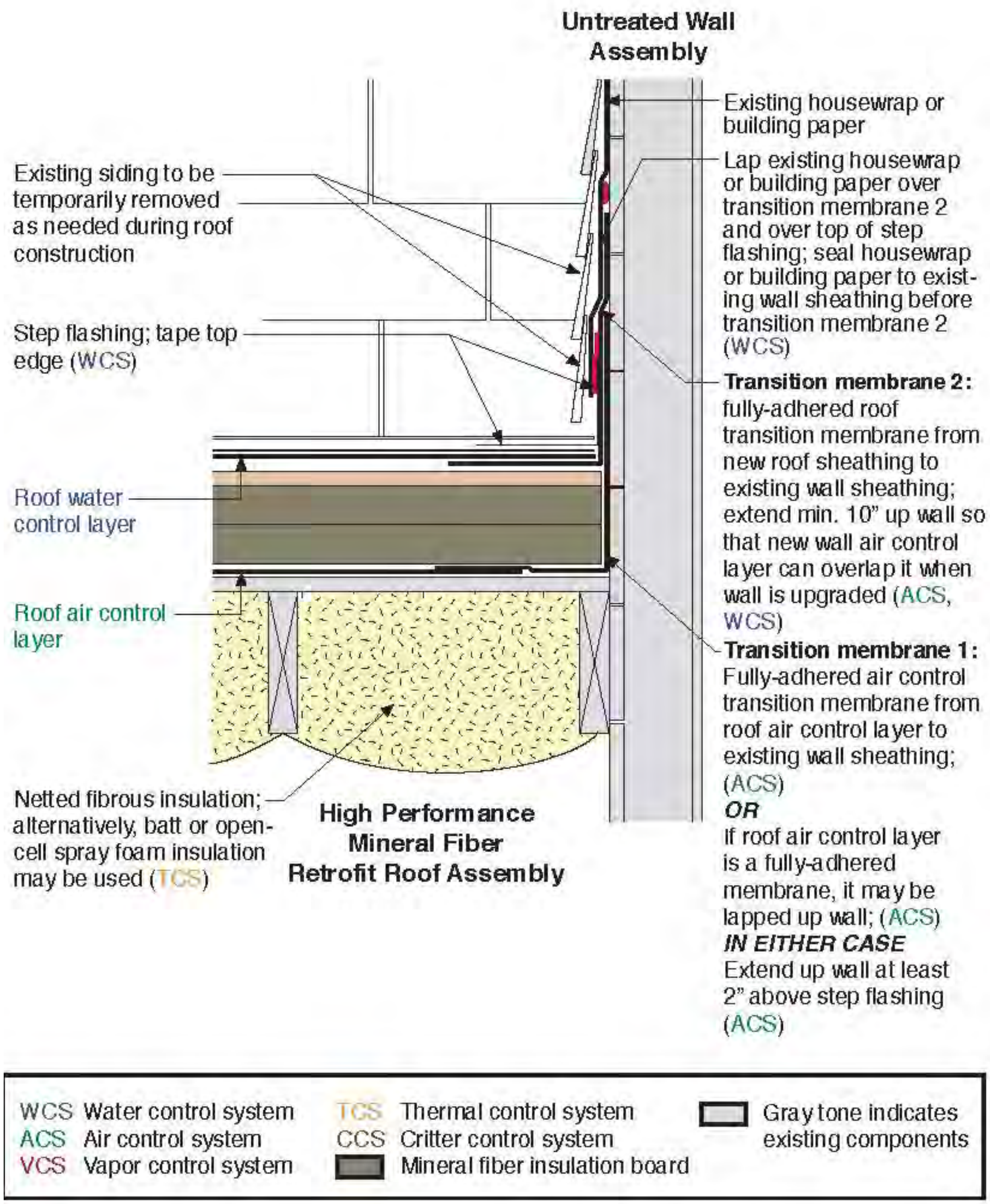


Figure 17. Schematic detail for transition from a lower high performance mineral fiber retrofit roof assembly to a non-retrofit wall assembly

4.2 High Performance Mineral Fiber Retrofit Wall Assembly

4.2.1 Scope of Work

1. Remove wall cladding and trim. Prepare the wall sheathing for the water and air control membrane.
2. Remove windows and doors as needed to allow flashing of openings and air control transitions into openings.

3. Install a continuous water and air control membrane over the wall sheathing to provide vapor control in accordance with code. Transition the wall air and water control membrane to adjacent assemblies.
4. Install flashings and air control transitions.
5. Reinstall windows and doors or install new windows and doors in properly flashed openings.
6. Install mineral fiber insulation board in accordance with code to satisfy the high R-value performance target for the assembly and for adequate condensation control (the higher R-value requirement shall govern).
7. Install furring strips over insulation board and attached to structure through insulation board. Install furring strips in a *vertical orientation only*.
8. Install wall cladding and trim. Attach to furring strips.

4.2.2 Climate-Specific Factors

In hot-humid climates, the air and water control membrane between the mineral fiber insulation board and the roof/wall sheathing must be a class II (or lower) vapor retarder.

4.2.3 Field Inspection

Identify and address risks to occupants or the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed. Determine the feasibility of the retrofit solution and of options.

Inspect and assess the building for:

- Structural integrity of the frame and foundation
- Safety and serviceability of the electrical system
- Presence of hazardous materials (e.g., lead, radon, asbestos)
- Rainwater, groundwater, or plumbing water leaks
- Rot or decay in framing
- Insect and pest damage and activity.

Deficiencies or hazards must be remediated prior to or as part of the project.

Identify any atmospherically vented (or naturally aspirated) combustion appliances in the home. With the exception of gas stoves and cooktops, combustion appliances—including fireplaces—should be direct-vented or direct exhaust-vented equipment. Atmospherically vented appliances must be replaced or reconfigured to direct-vented or direct exhaust-vented operation prior to or as part of the project.

Verify that all kitchen and bathroom exhausts are vented to the exterior of the building. Source control ventilation deficiencies must be corrected either prior to or as part of the project.

If the home lacks a ventilation system meeting the requirements of 2012 IRC, Section M1507.3, a ventilation system meeting this requirement must be installed either prior to or as part of the project.

4.2.4 Implementation Risks

Construction and renovation work entails inherent risks to workers. All applicable safety procedures must be followed.

Implementation risks specific to mineral fiber insulation board retrofit derive from the fibrous nature of the material. It is recommended that all workers handling or cutting material:

1. Wear protective clothing and avoid exposed skin.
2. Wear goggles or similar enclosed eye protection.
3. Wear gloves that are impermeable to fibers.
4. Use tight-fitting dust masks to provide appropriate protection from airborne fibers.
5. Refer to material safety data sheets and manufacturer instructions for safe handling and exposure.

> **Ensuring Success**
>
> Significant retrofit of building enclosure components will change the dynamics of water, air, vapor, and heat flow within the home. To ensure that these changing dynamics do not have negative ramifications for health and safety or for building durability, the follow conditions below must be met either prior to or as part of the project.
>
> - Combustion safety—All non-cooking appliances, including fireplaces, direct-vented or direct exhaust-vented appliances.
> - Ventilation—Whole-house ventilation meeting the requirements of 2012 IRC, Section M1507.3 is installed and operational.
>
> The following is also recommended:
>
> - Soil gas control system—An active or passive soil gas control system installed and operational.

4.2.5 Installation Procedure

1. Remove existing cladding and trim. Prepare the wall sheathing to receive the air and water control membrane.

Removal of siding and trim is a well-established procedure. Also remove decking that is adjacent to the exterior wall as needed to allow for continuous insulation of the wall.

Appropriate preparation of the wall sheathing will depend upon the nature of the existing sheathing and the air control strategy pursued. If a sheet good is used as the air and water control layer, all protruding fasteners must be removed to avoid punctures or tears in the membrane. Gaps or voids in the sheathing layer may need to be in filled. Use a primer for self-adhered membranes if recommended by the membrane manufacturer.

2. Remove windows and doors.

Typically, the windows and doors will need to be removed to allow proper flashing of the window and door openings and to permit the installation of air control transition membranes.

3. Install and implement air and water control membrane.

Install a continuous water and air control membrane.
OR
Tape the wood panel sheathing with flashing tape (acrylic or bituminous adhesive) to form a continuous air control membrane and install a water control membrane over the wood panel sheathing.

Connect the air control membrane to the air control layer of adjacent assemblies in an airtight and durable manner. Seal all penetrations against air and water leaks.

The water and air control membrane or water control membrane must provide vapor control as required: class II (or lower) in hot humid climates, class III (or lower) elsewhere. See Section 3.

4. Install flashings and air control transitions.

Transition the air control into window and door rough openings and air seal all penetrations through the wall. Flash window and door rough openings as well as all wall penetrations.

5. Install windows and doors.

Reinstall windows and doors or install new windows and doors in properly flashed openings. Air seal window and door units to the air control transition membranes at the interior perimeters of window and door units.

6. Install mineral fiber insulation board.

Install over the air and water control membrane. Butt joints tight. When installing multiple layers, offset seams in two directions. Until furring strips are installed, mineral fiber insulation board pieces can be held in place with cap nails or screws with roofing washers.

7. Install furring strips.

Install furring strips over insulation board and attached furring strips to the wall structure through the insulation board. Install furring strips in a *vertical orientation only*. It is important to install furring strips in a vertical orientation only to allow drainage from behind the cladding/trim and to prevent water from dwelling within the system. With mineral fiber insulation board 1 × 4 furring is recommended. The furring need not be preservative treated for moisture protection.

The spacing of fasteners through the furring strips must be such that the cladding load is distributed to no more than 10 lb per fastener.

8. Install cladding and trim.

Attach the wall cladding and trim to the vertical furring strips.

See Figure 18 through Figure 31 for details about this procedure.

4.2.6 High Performance Mineral Fiber Retrofit Details

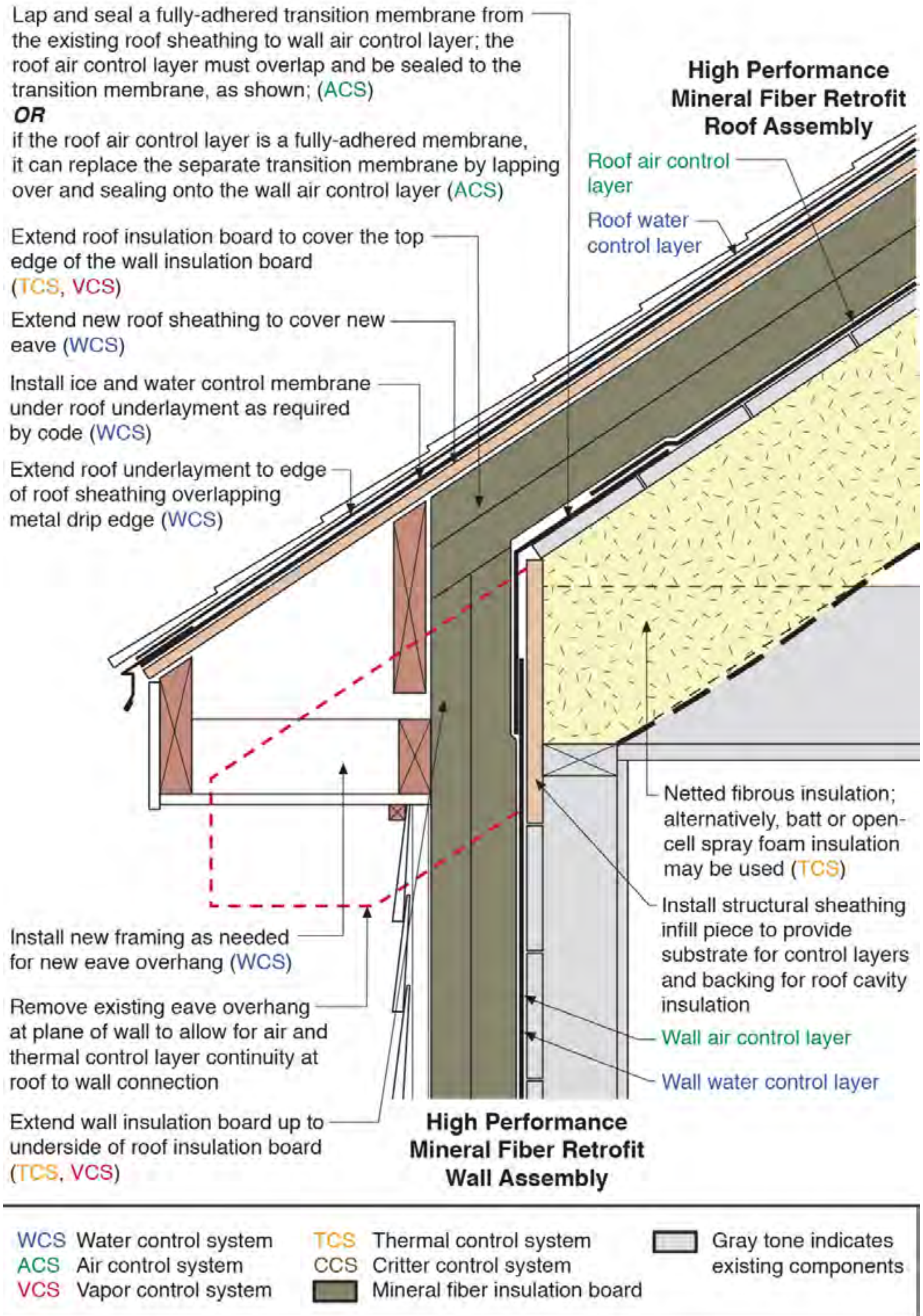


Figure 18. Schematic detail for "chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

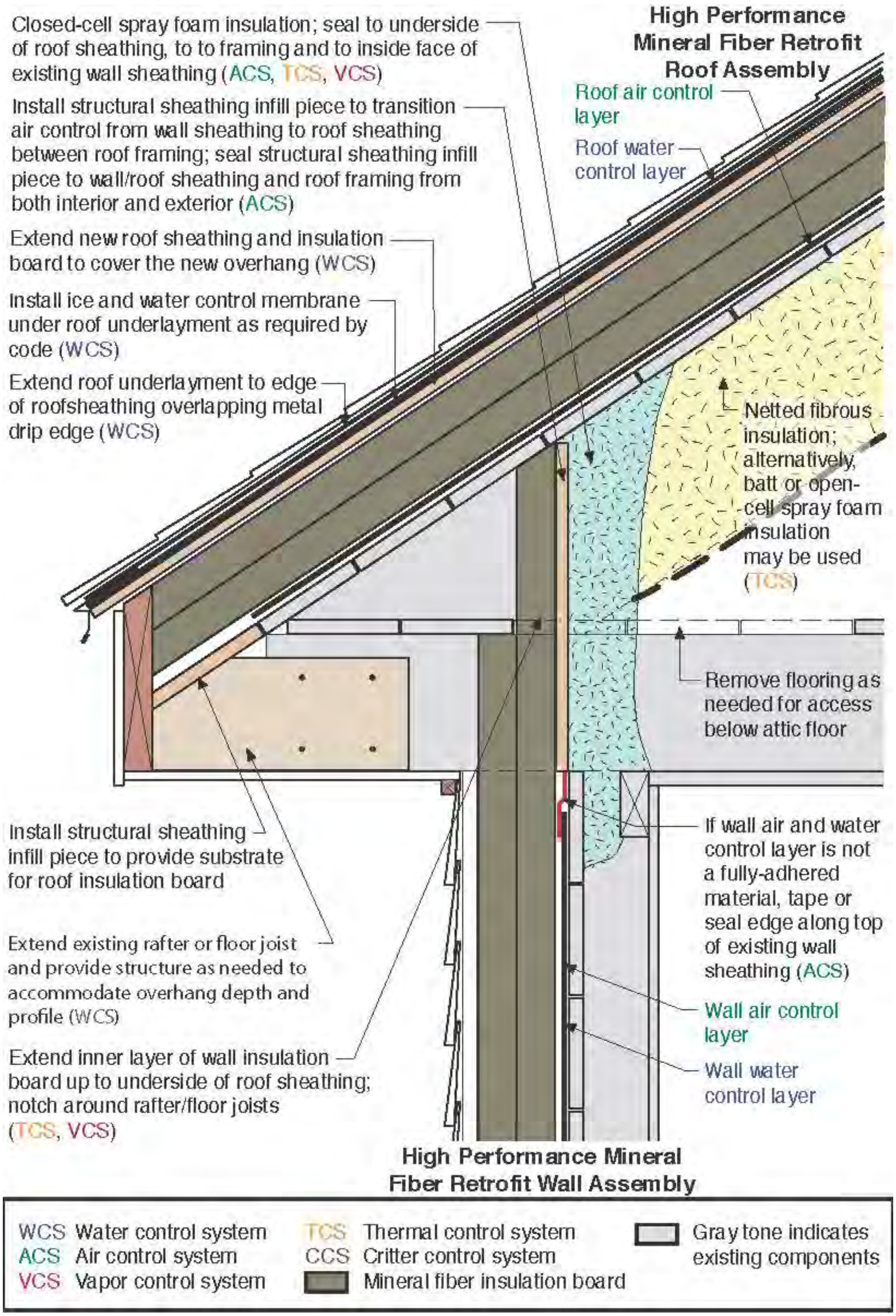


Figure 19. Schematic detail for non-"chainsaw" eave transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

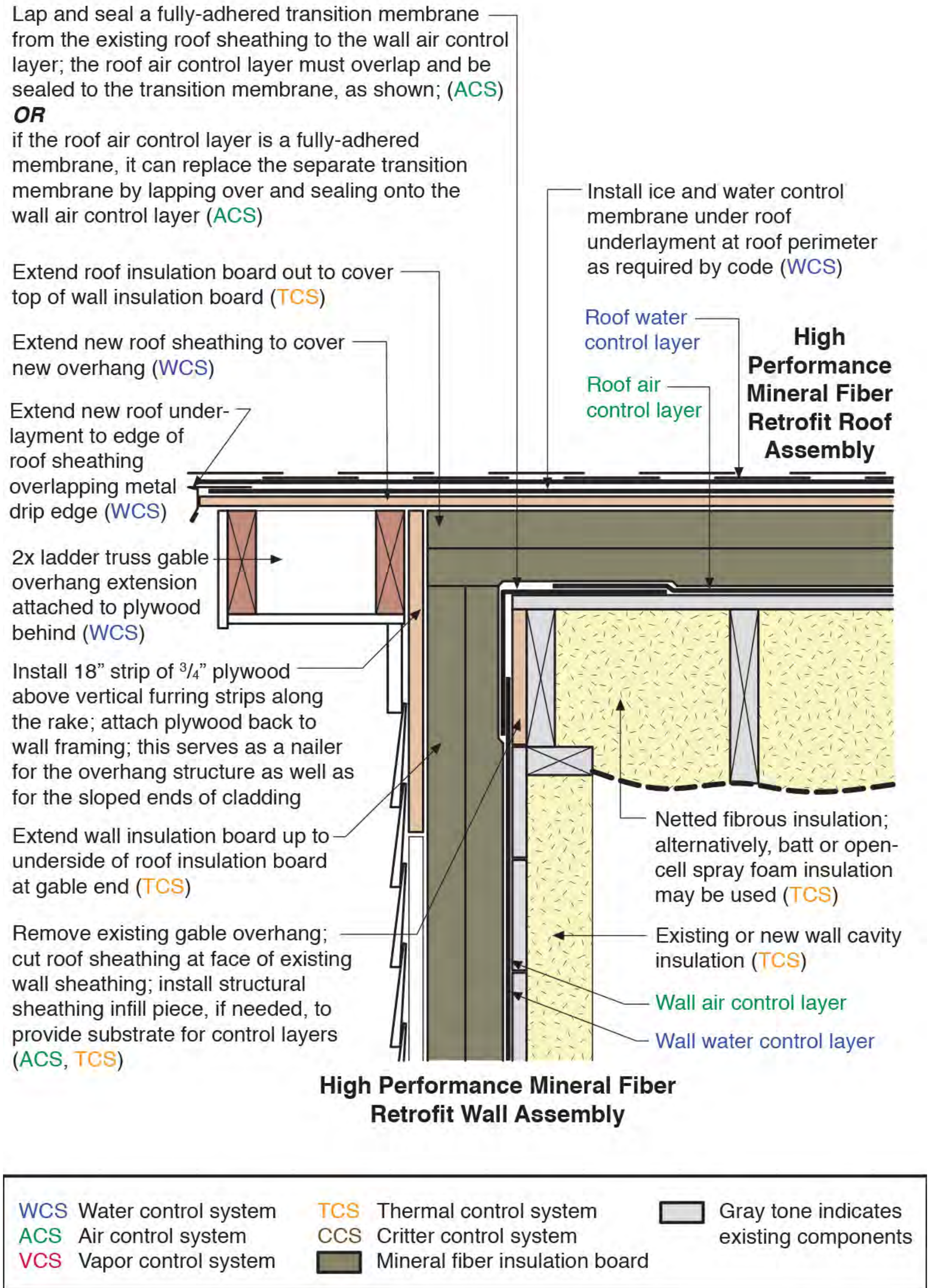


Figure 20. Schematic detail for "chainsaw" gable rake transition from a high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

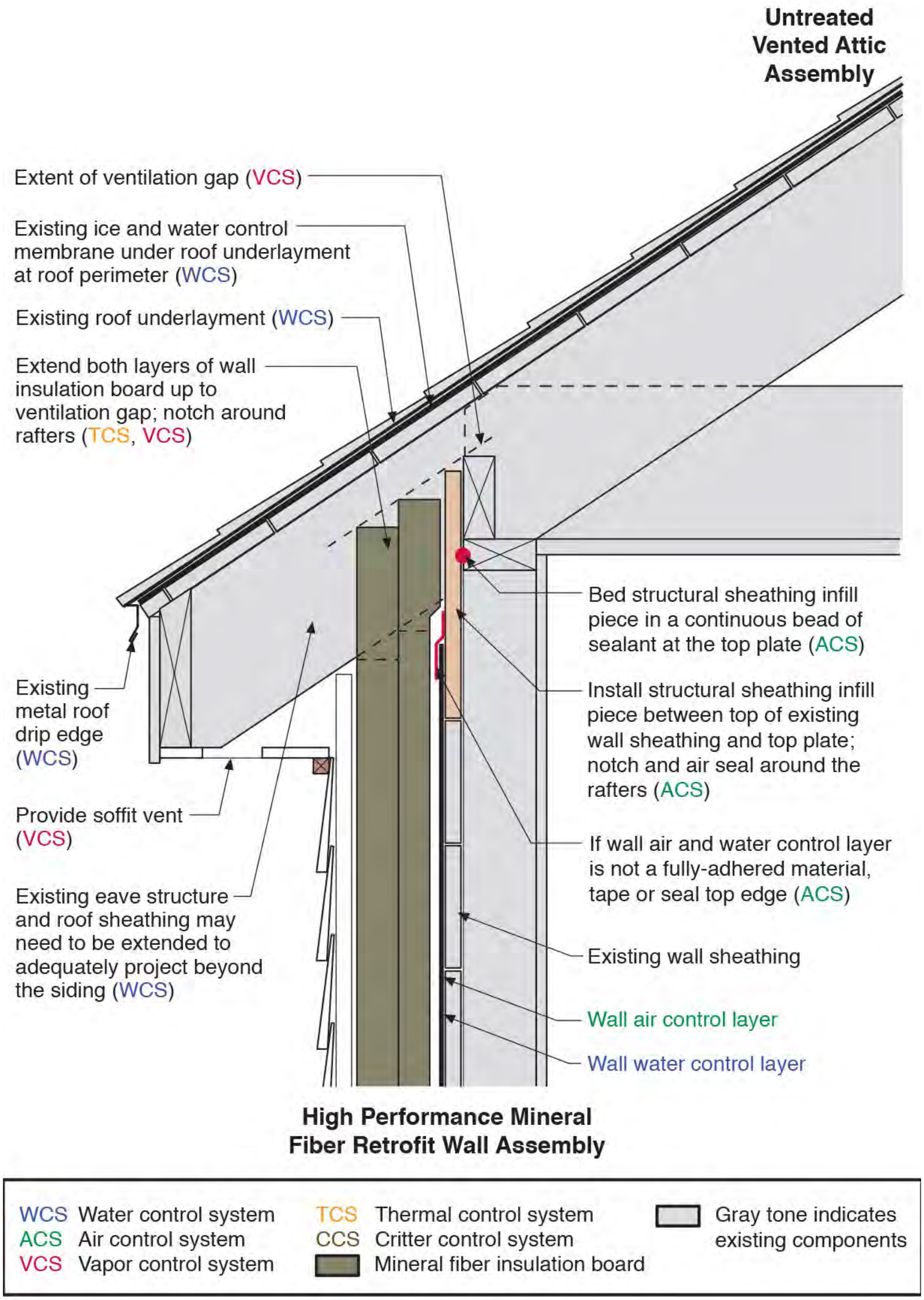


Figure 21. Schematic detail for eave transition from a high performance mineral fiber retrofit wall assembly to a non-retrofit roof assembly

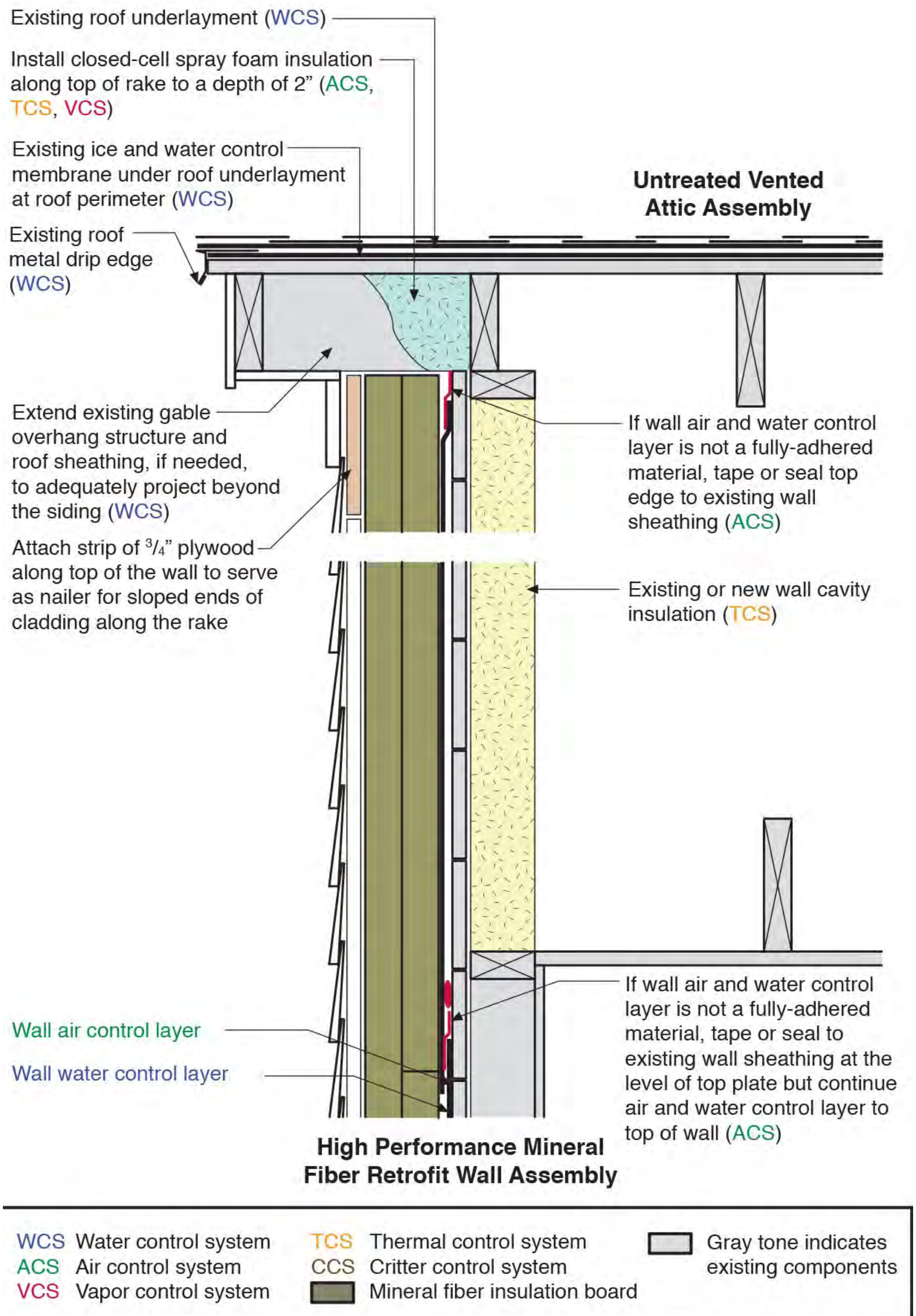


Figure 22. Schematic detail for gable/rake transition from a high performance mineral fiber retrofit wall assembly to a non-retrofit roof assembly

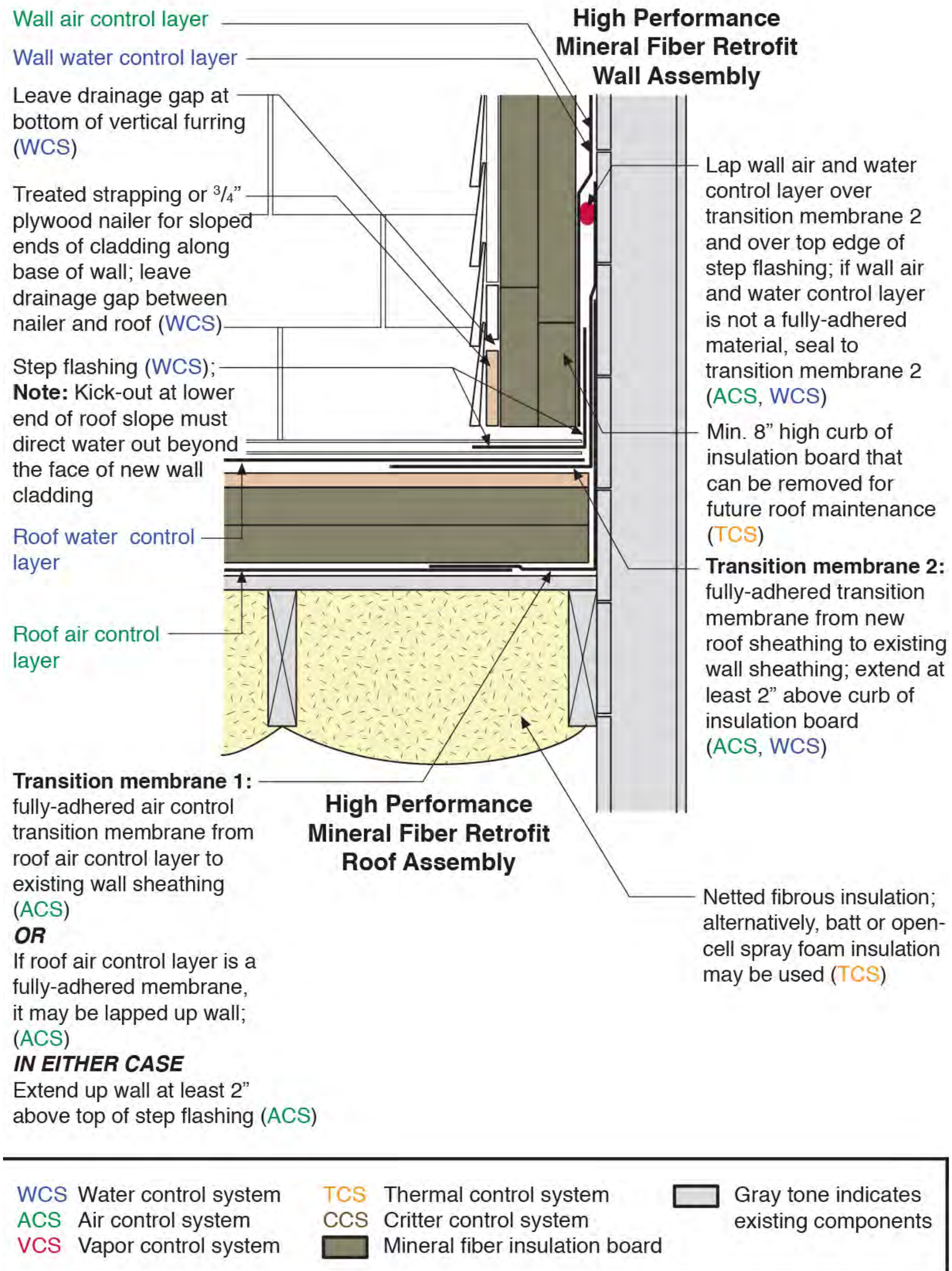


Figure 23. Schematic detail for transition from a lower high performance mineral fiber retrofit roof assembly to a high performance mineral fiber retrofit wall assembly

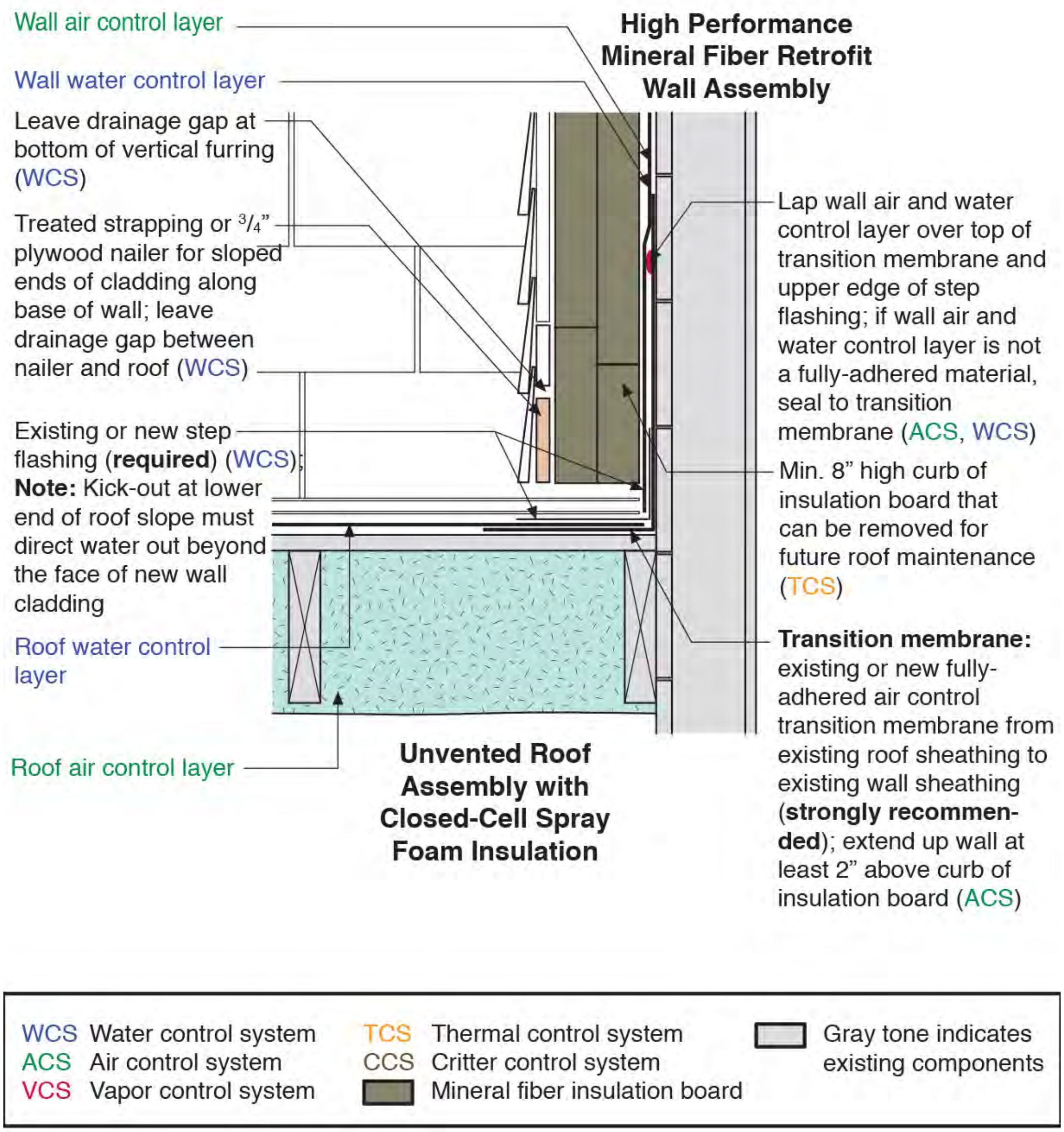


Figure 24. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to an insulated lower roof assembly

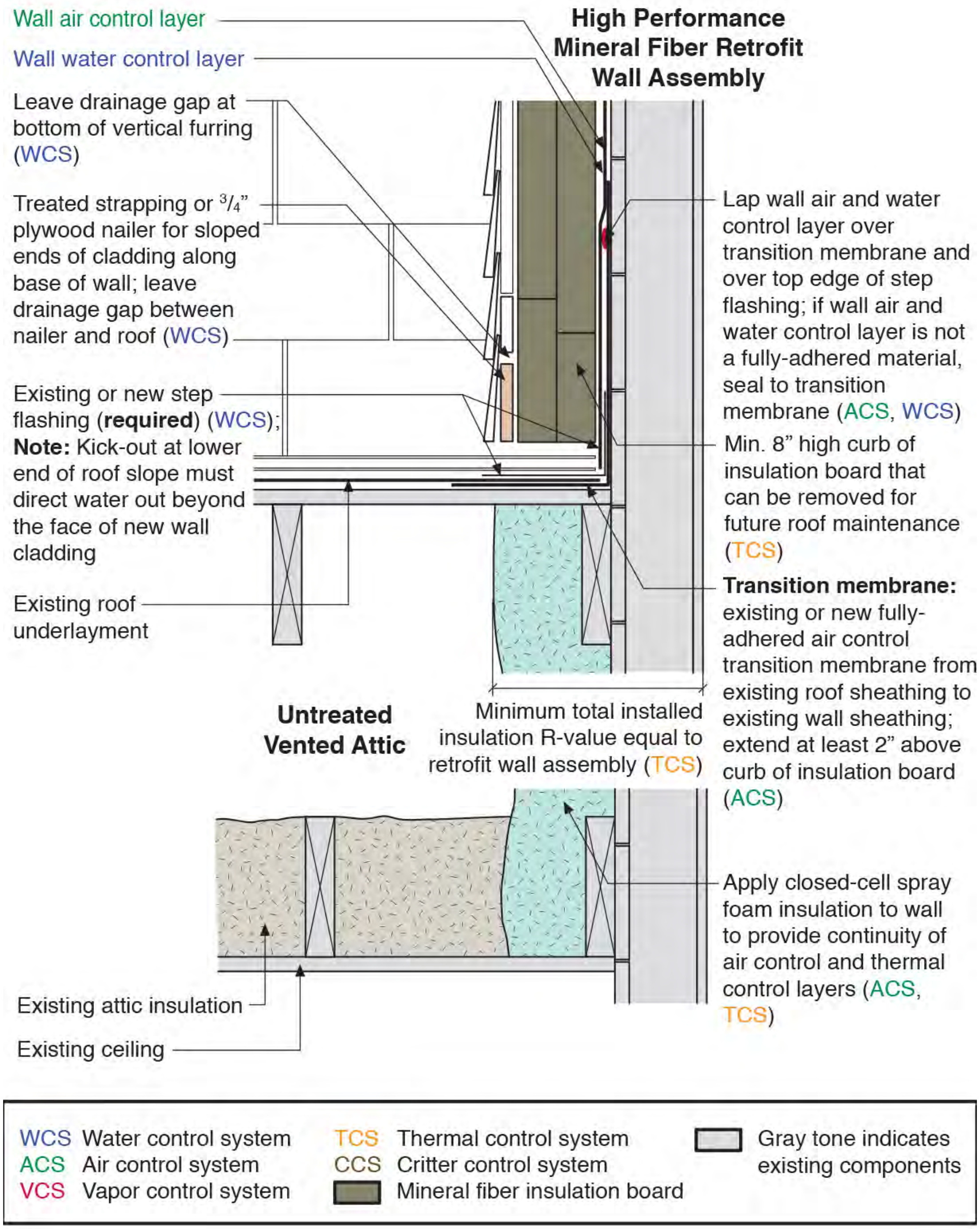


Figure 25. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to an existing lower attic

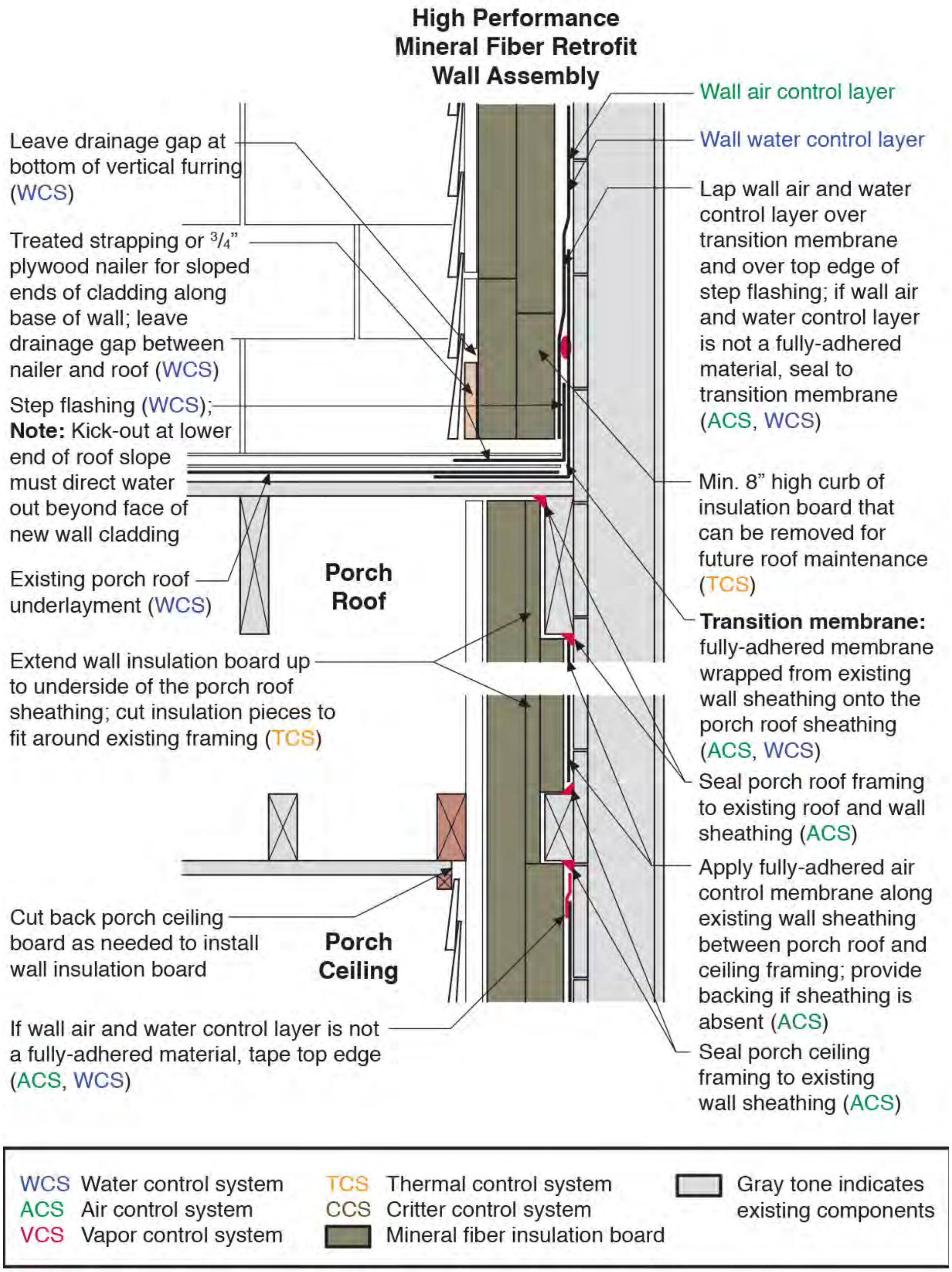


Figure 26. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to a porch roof

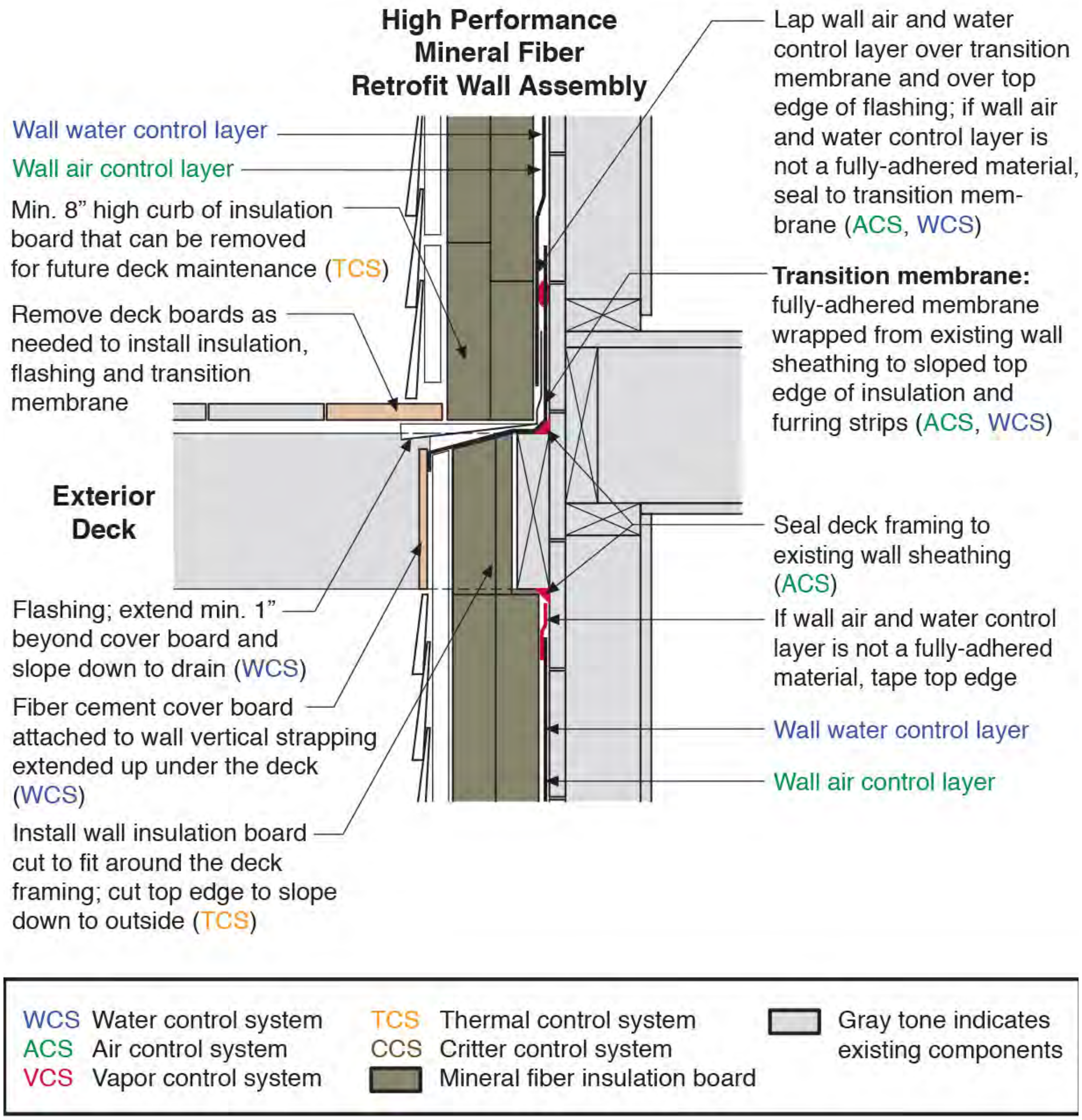


Figure 27. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to an attached deck in a field of wall

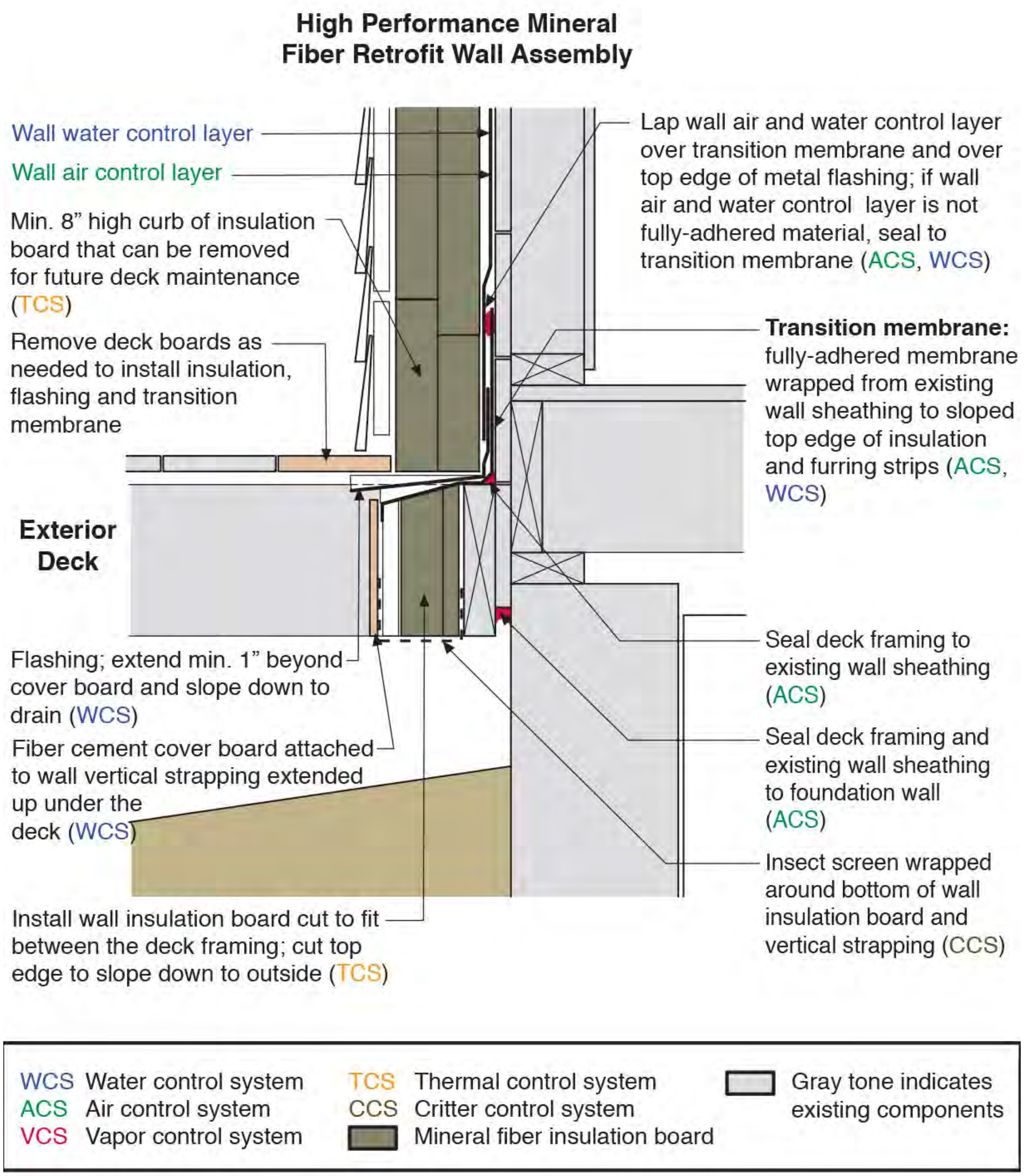


Figure 28. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to an attached deck at base of wall

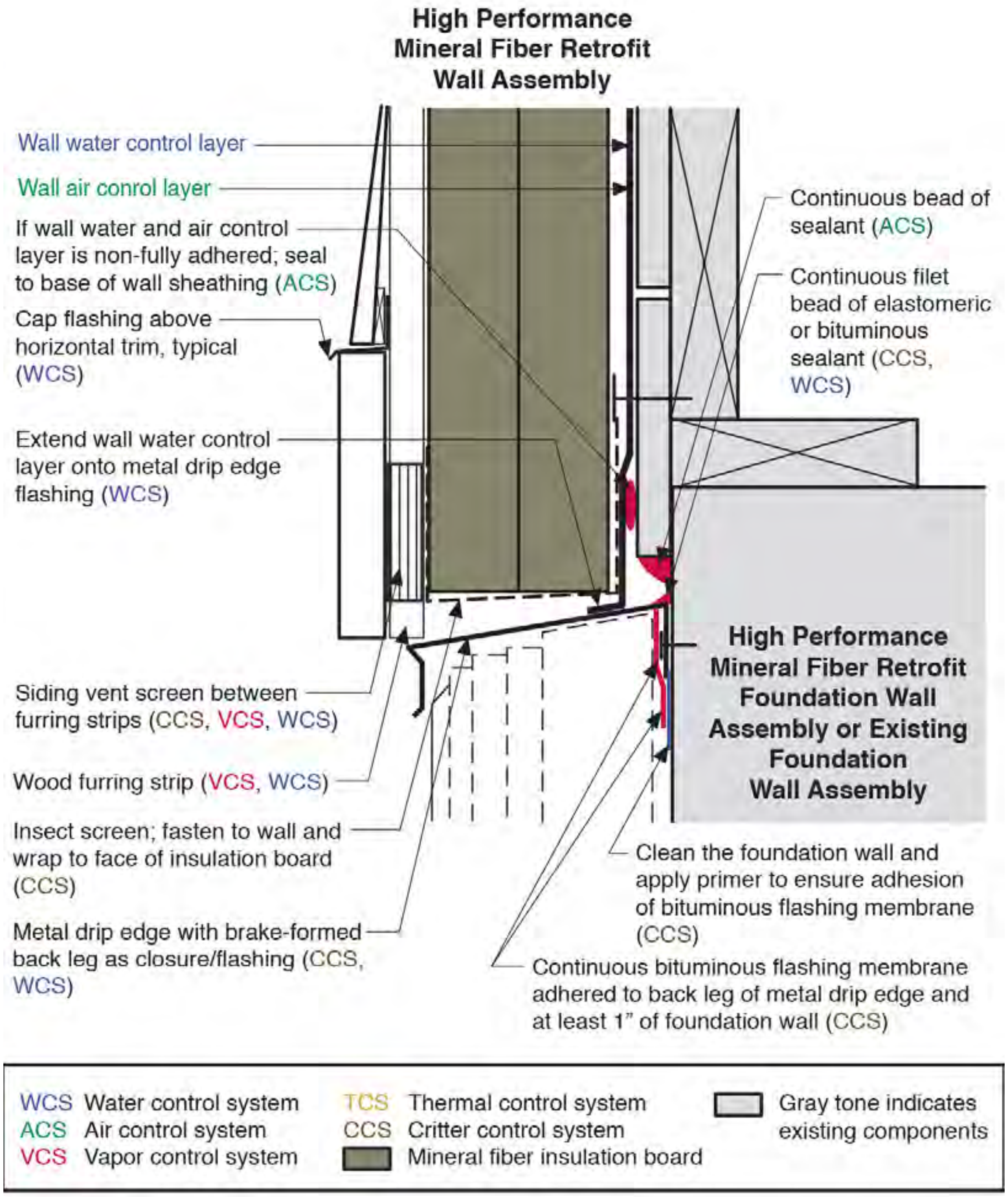


Figure 29. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to a top of high performance mineral fiber retrofit foundation wall assembly

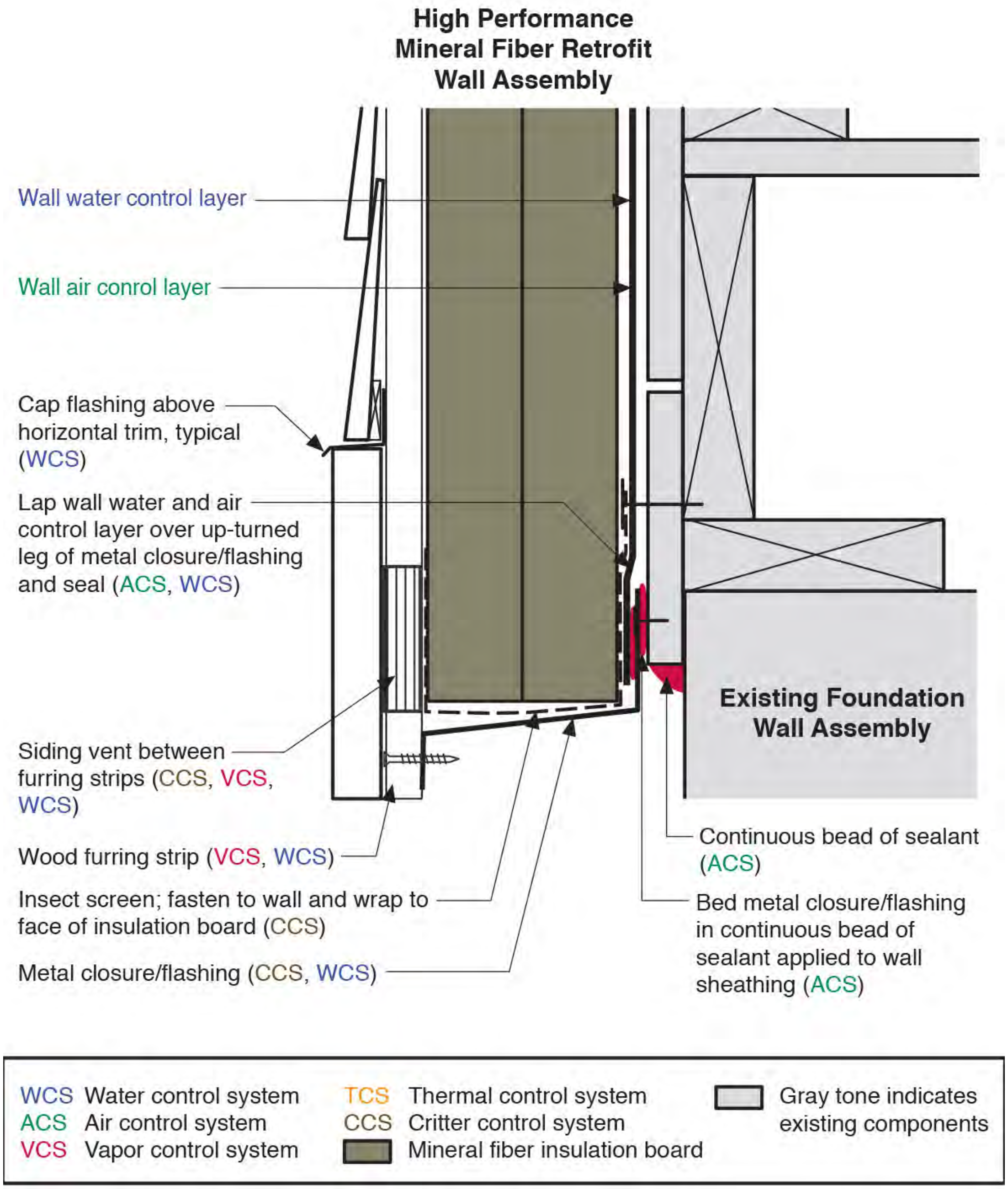


Figure 30. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to a flat-surface foundation wall without exterior retrofit

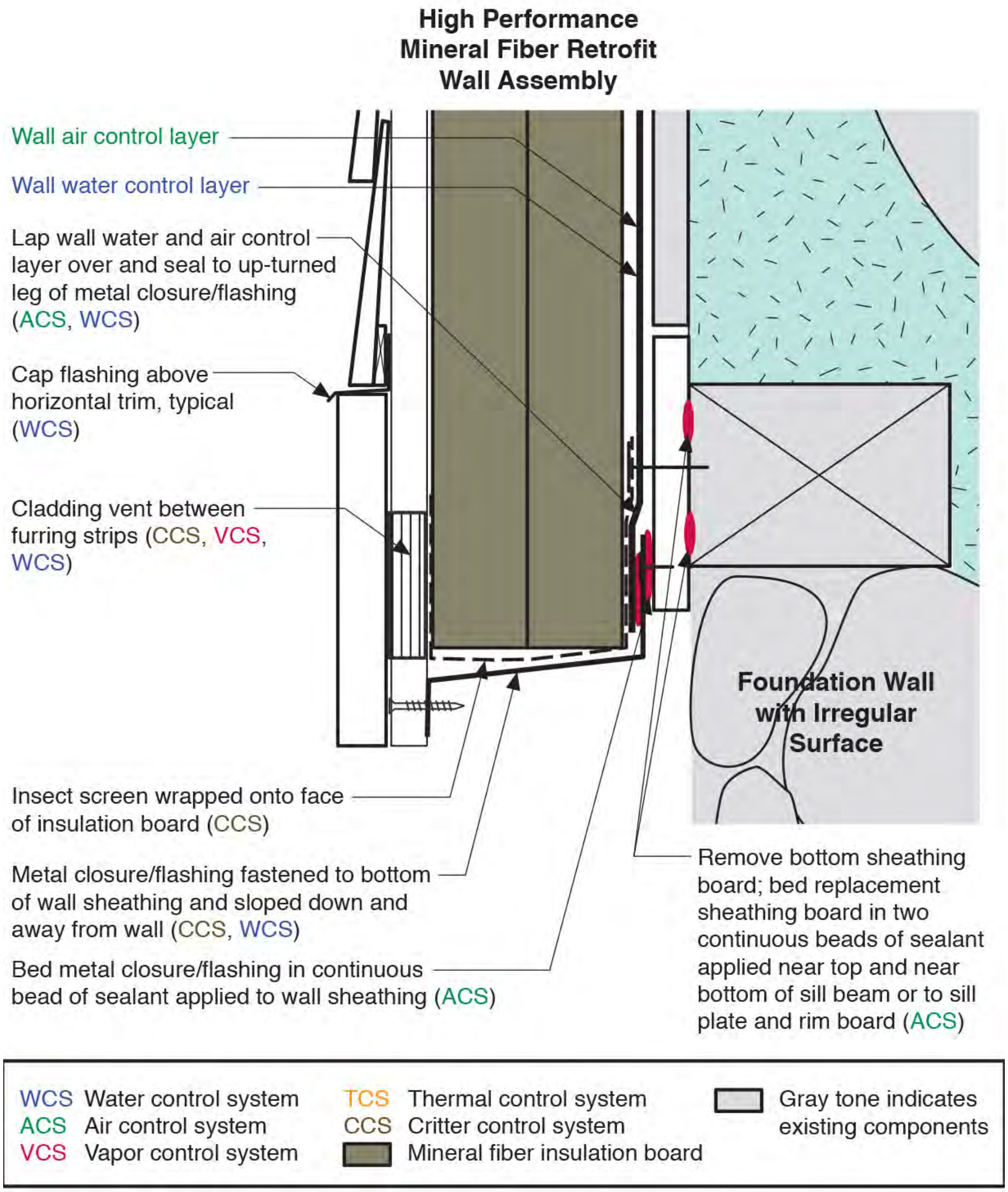


Figure 31. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to a bumpy-surface foundation wall

Figure 32 through Figure 43 show the installation of a new window or the reinstallation of a window in the high performance mineral fiber retrofit wall assembly. The schematic details include schematics for the head, jamb, and sill of the window opening. The sequence illustrations demonstrate (1) installation of a window in a wall assembly using a non-adhered sheet good water and air control membrane; and (2) installation of the exterior trim extension. The window installation sequence for a fully adhered or liquid-applied water and air control membrane is slightly different in how the head flashing is integrated into the water and air control membrane.

The trim installation sequence is applicable to situations where the existing window is left in place.

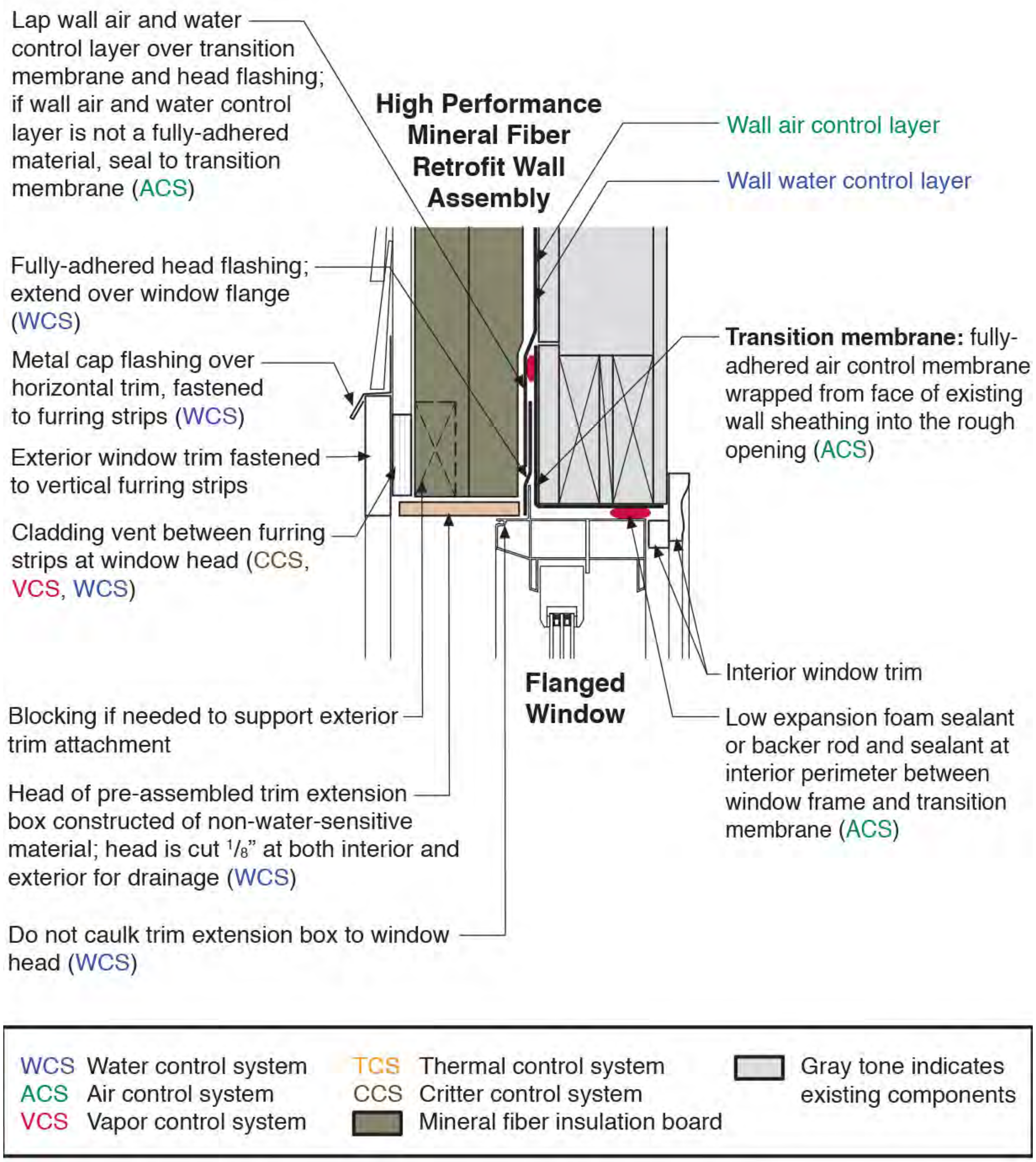


Figure 32. Schematic detail for window head of new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

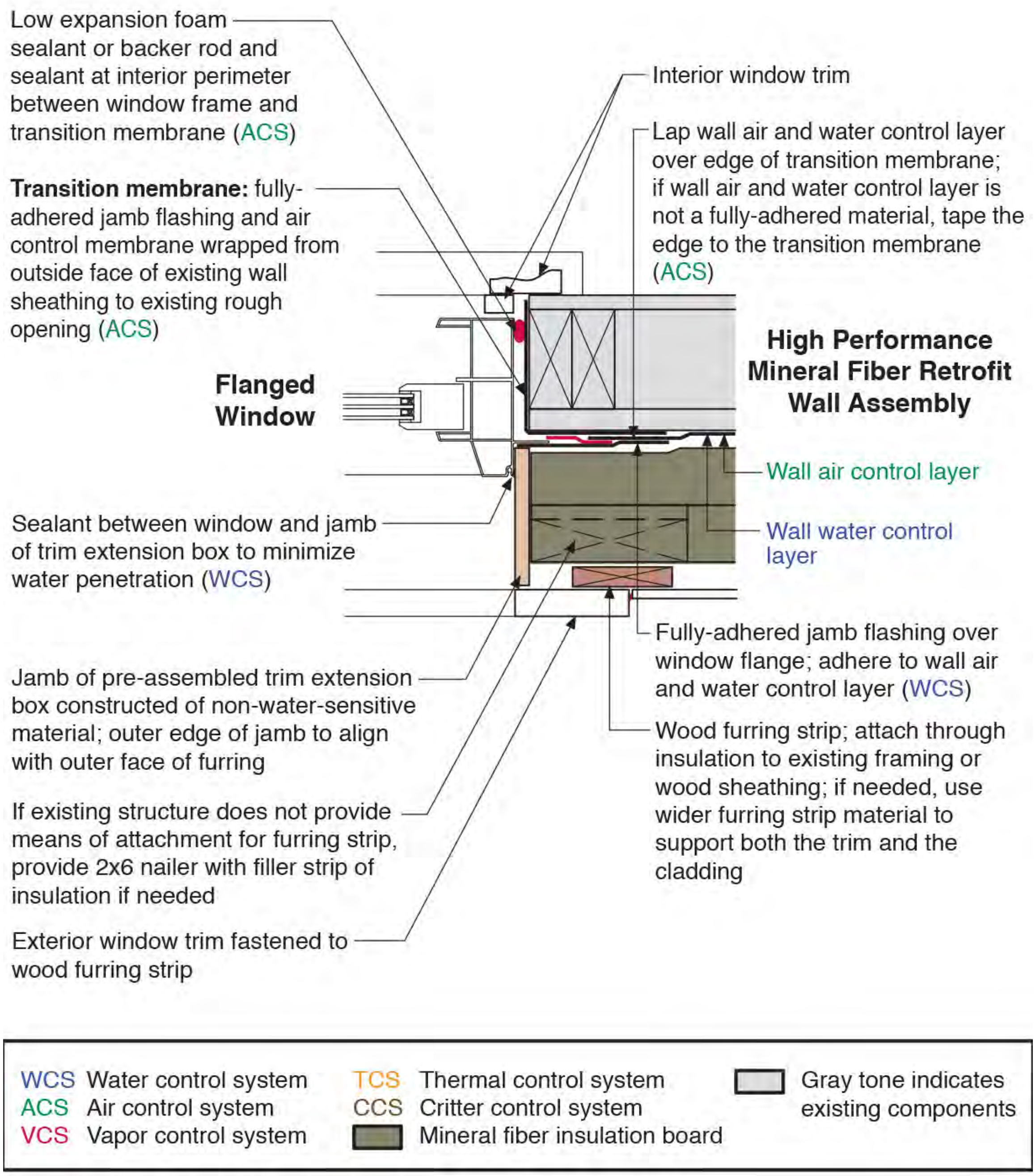


Figure 33. Schematic detail for window jamb of new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

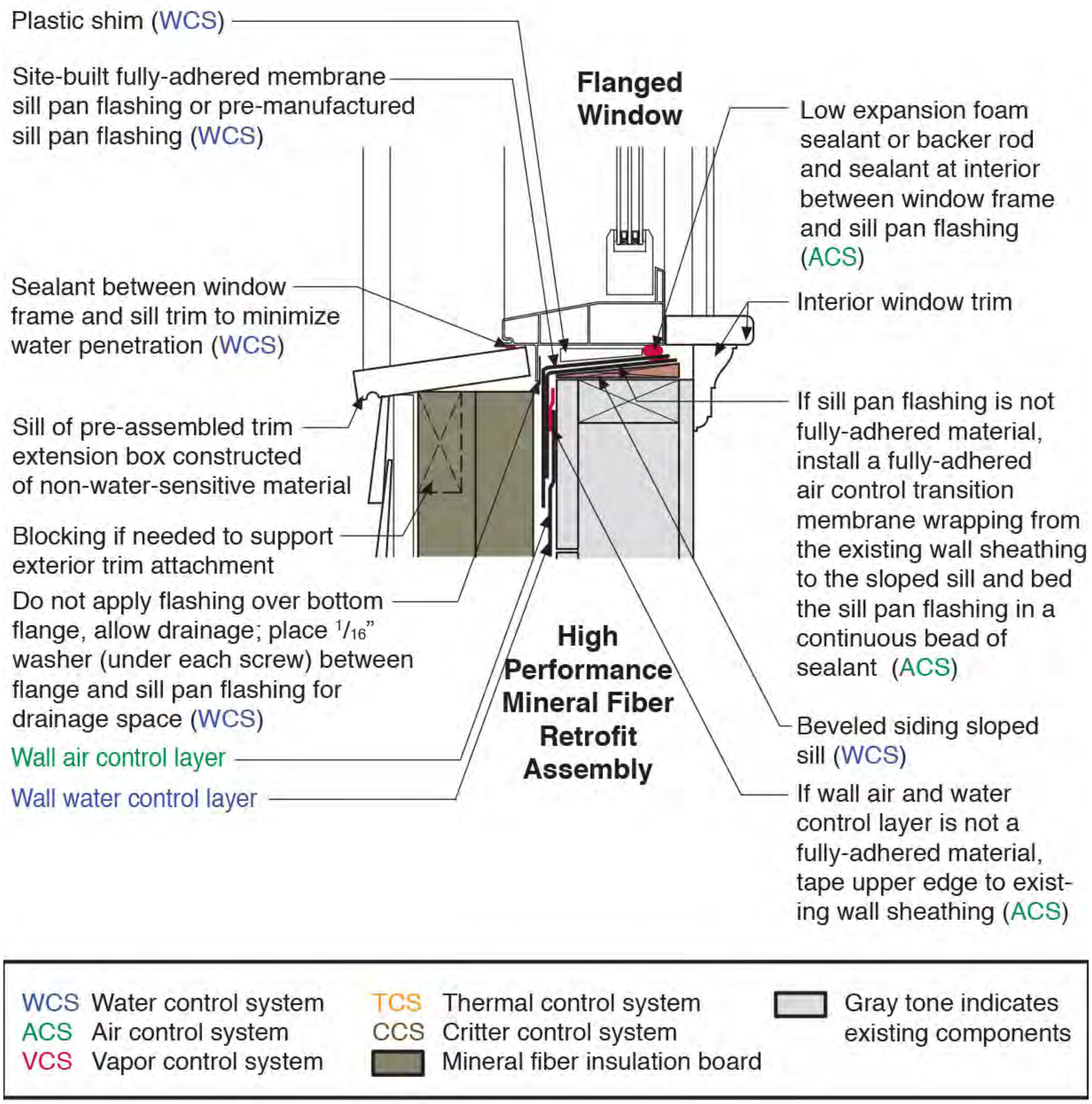


Figure 34. Schematic detail for window sill of new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

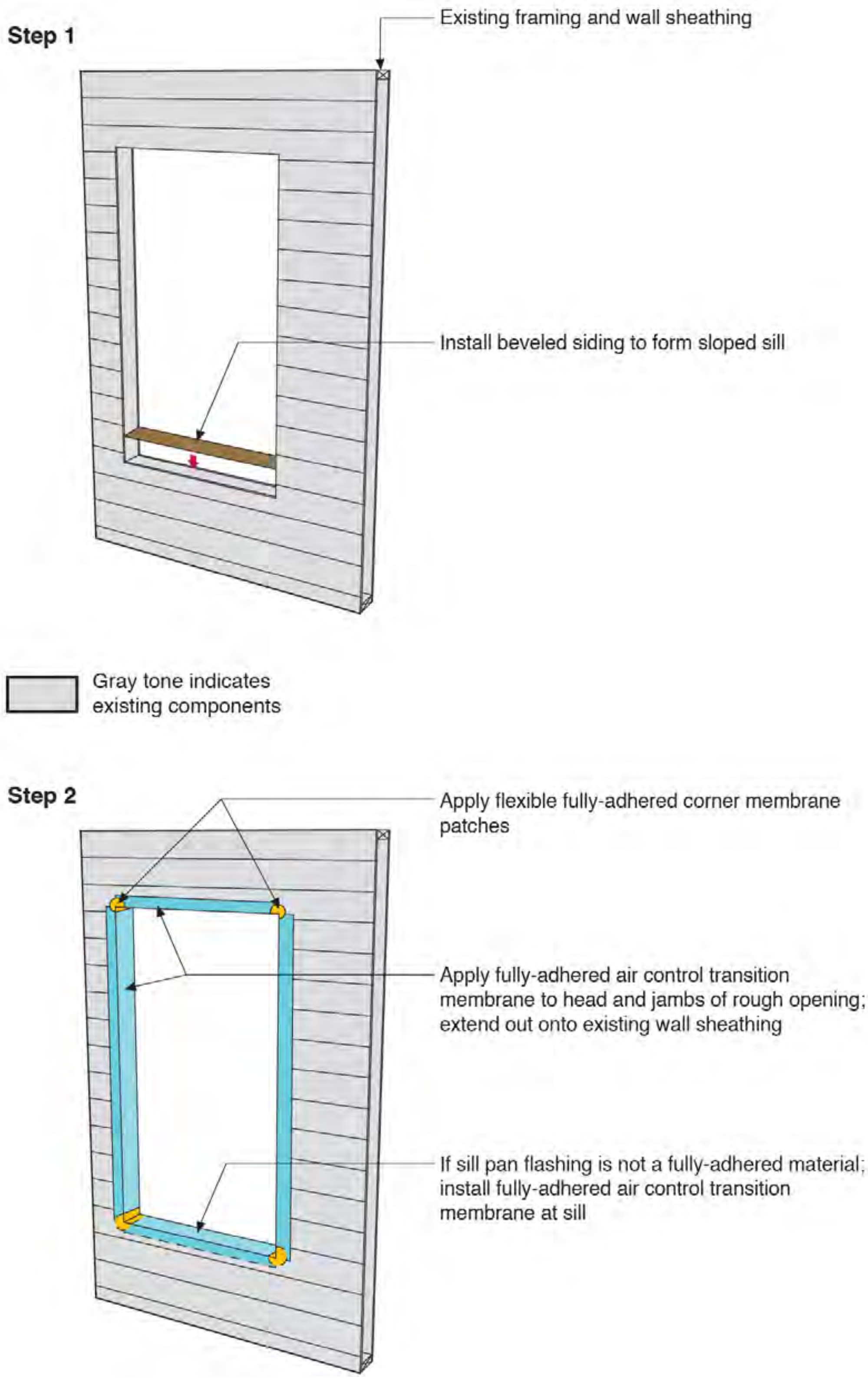
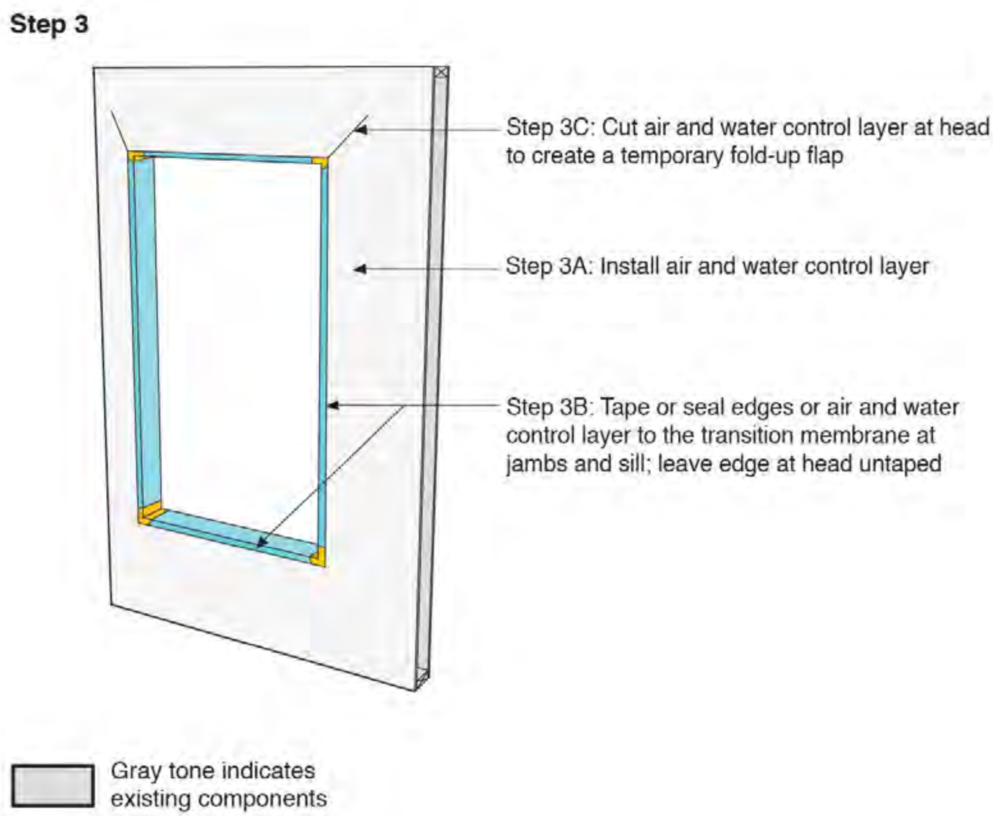


Figure 35. Steps 1 and 2 of installation sequence for new window or reinstalled window in a high performance mineral fiber retrofit wall assembly



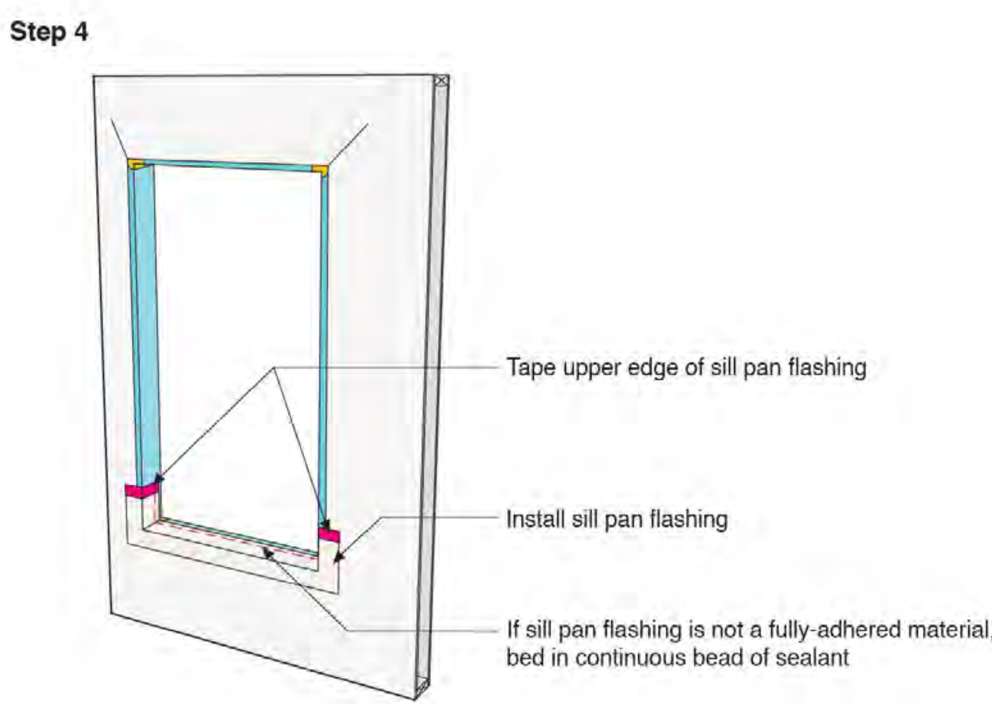


Figure 36. Steps 3 and 4 of installation sequence for new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

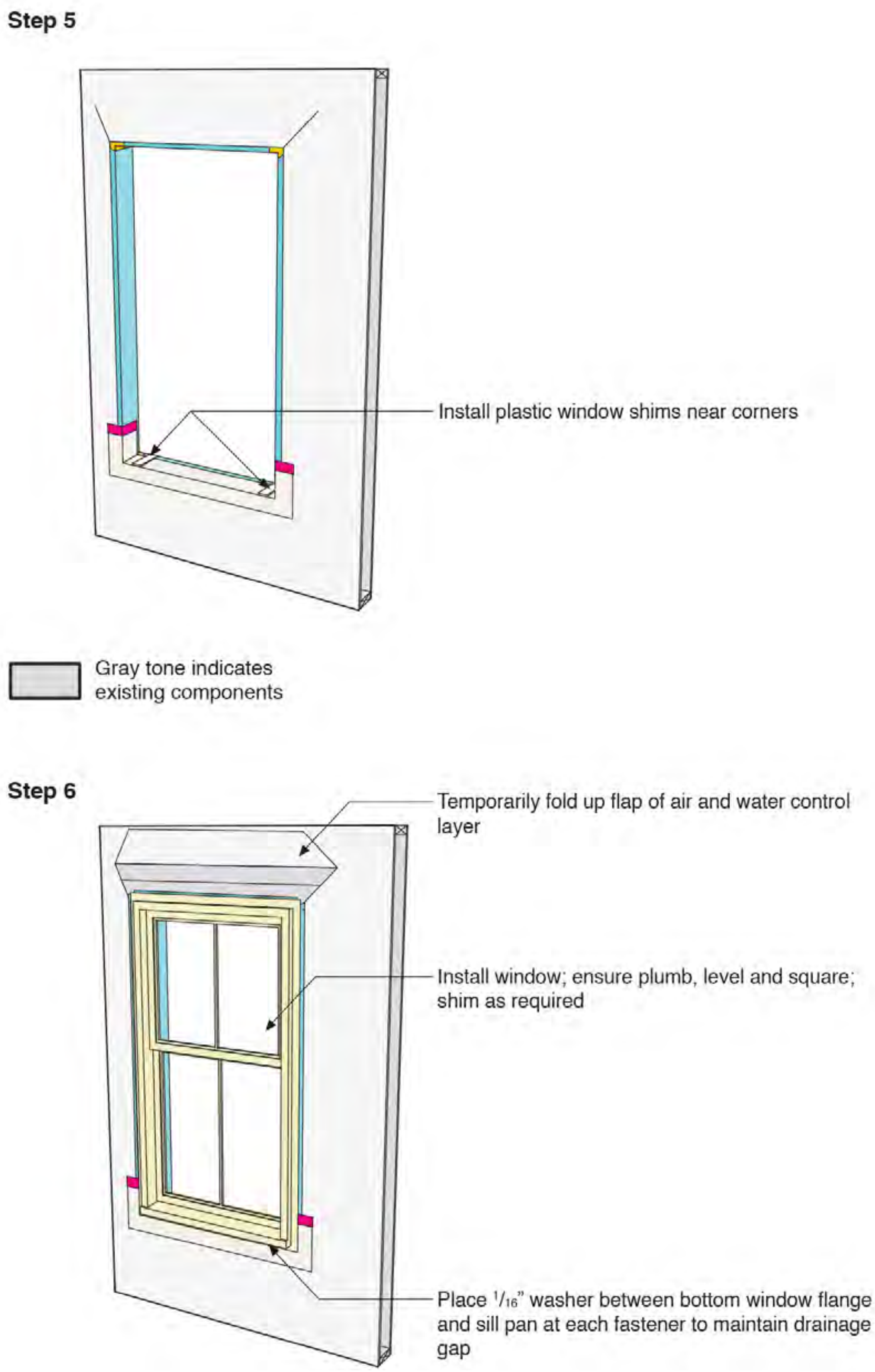
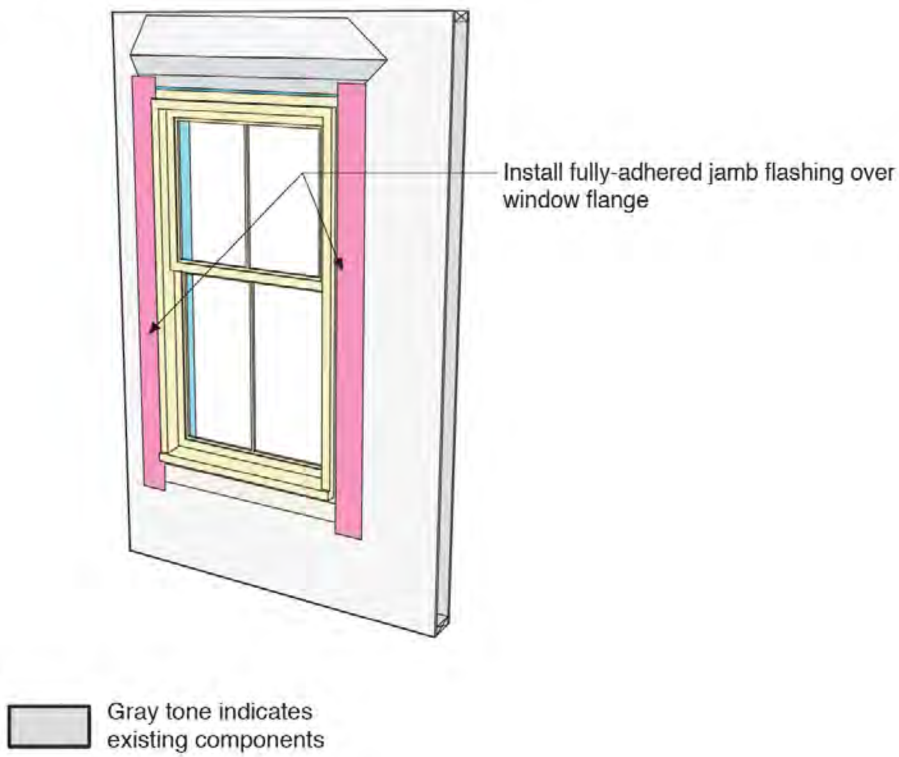


Figure 37. Steps 5 and 6 of installation sequence for new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

Step 7



Step 8

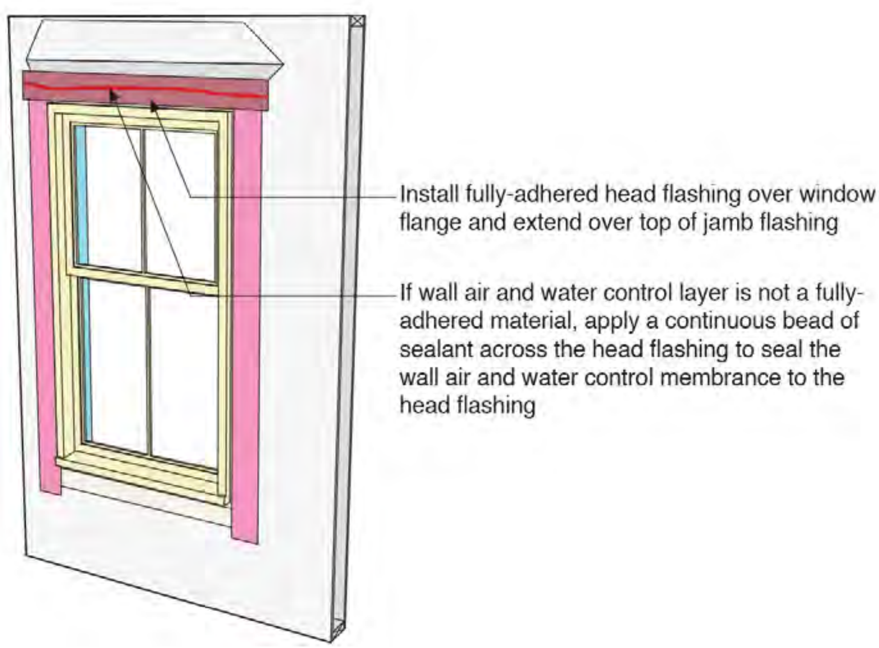


Figure 38. Steps 7 and 8 of installation sequence for new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

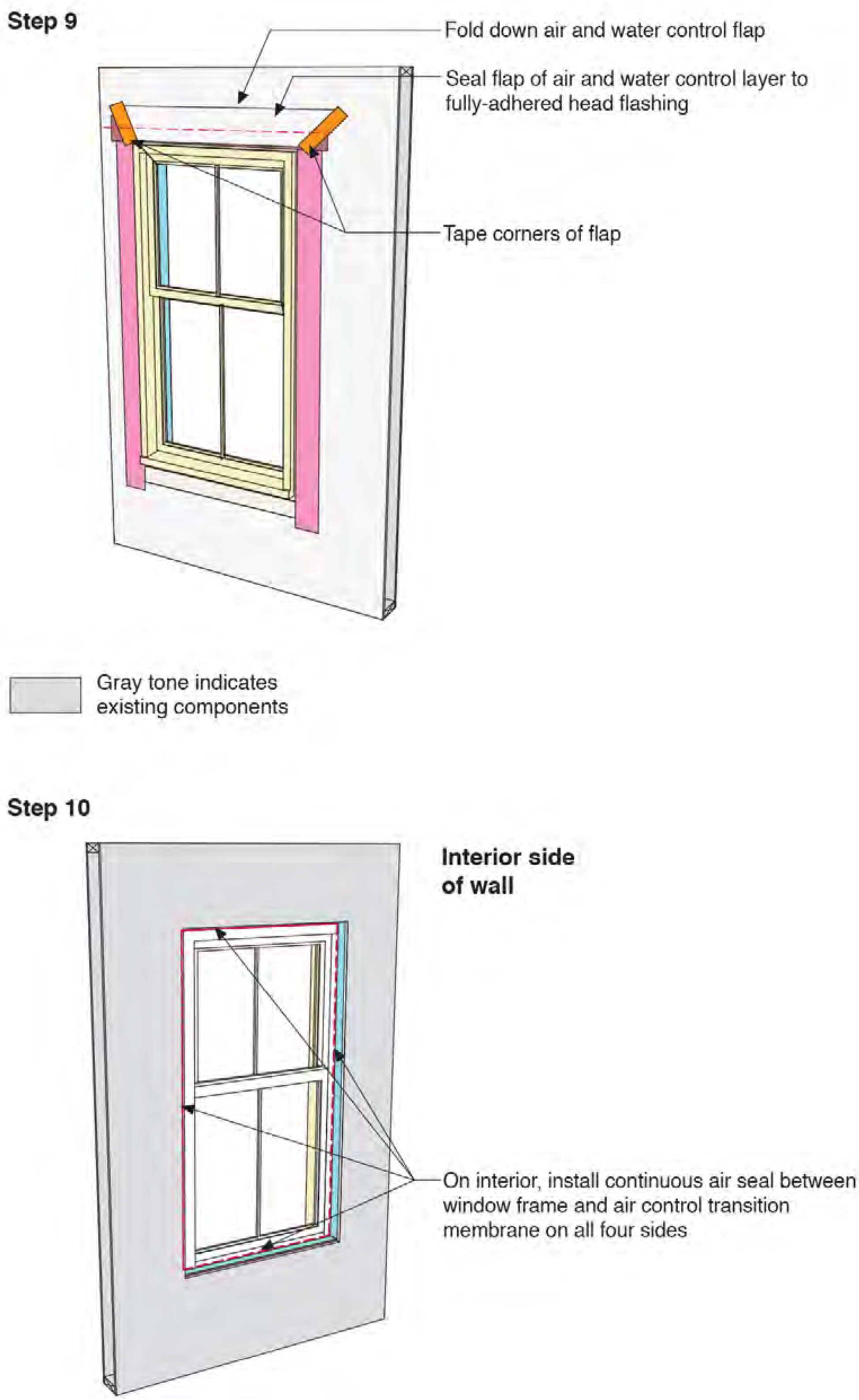


Figure 39. Steps 9 and 10 of installation sequence for new window or reinstalled window in a high performance mineral fiber retrofit wall assembly

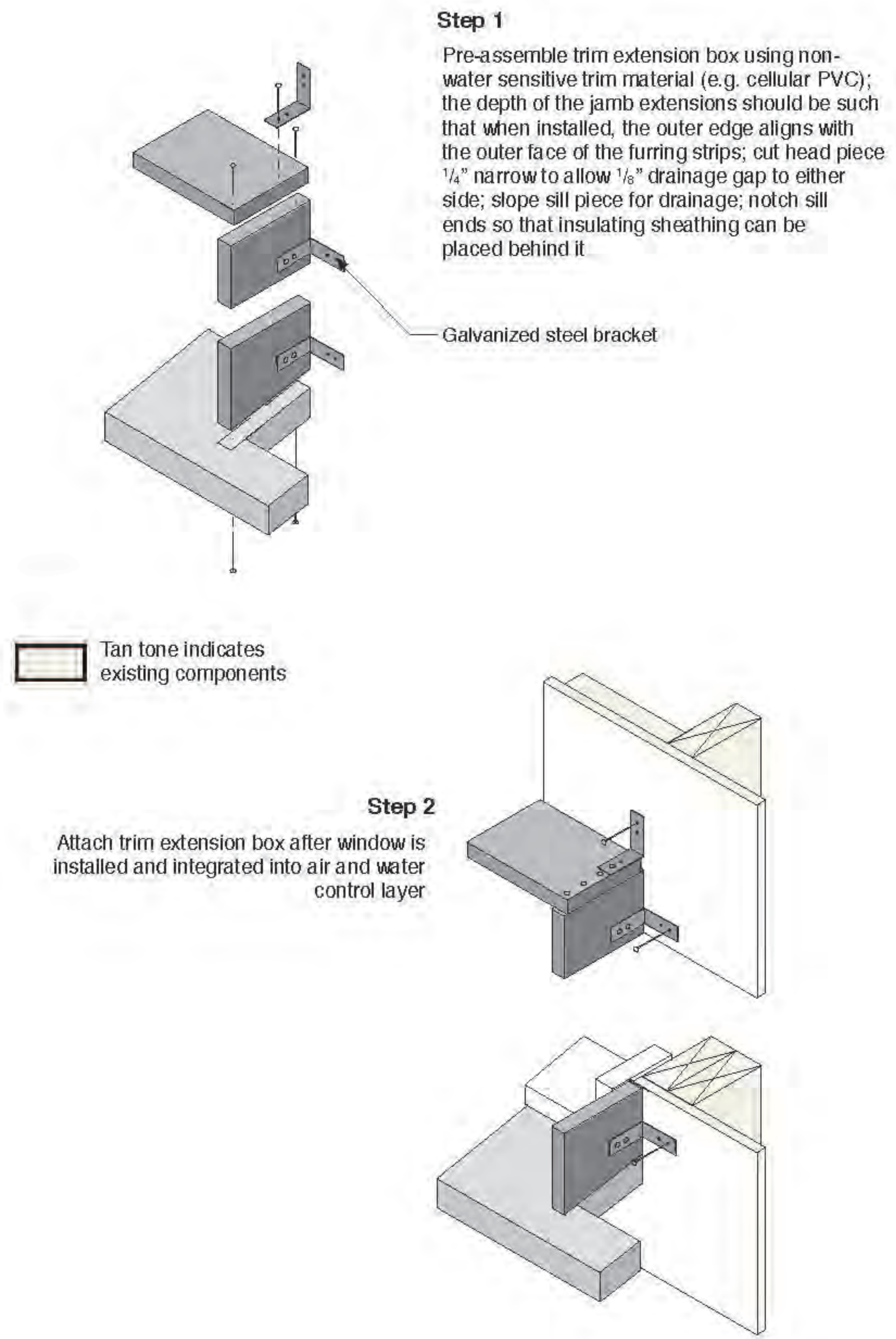


Figure 40. Steps 1 and 2 of exterior trim installation sequence for window in a high performance mineral fiber retrofit wall assembly

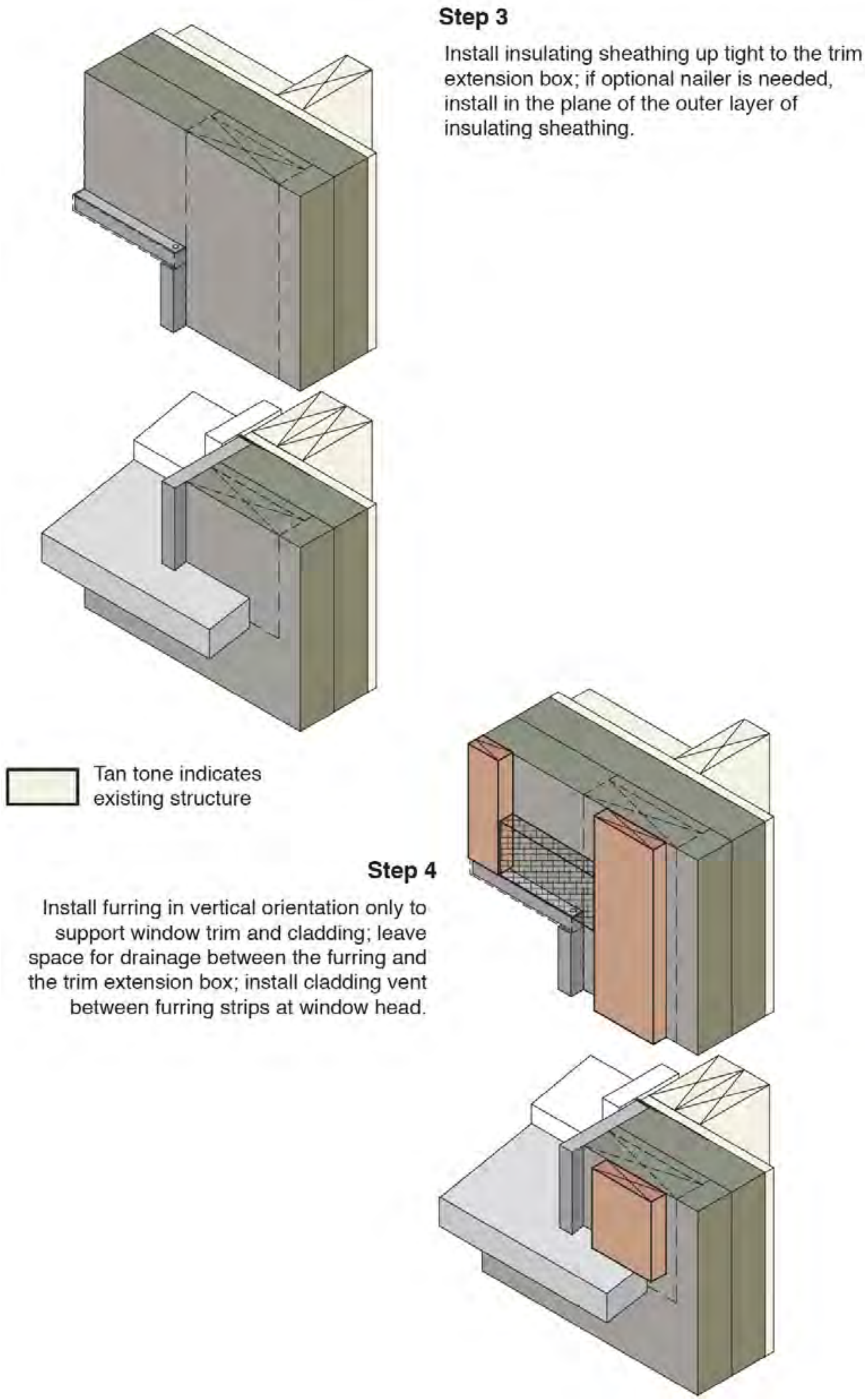


Figure 41. Steps 3 and 4 of exterior trim installation sequence for window in a high performance mineral fiber retrofit wall assembly

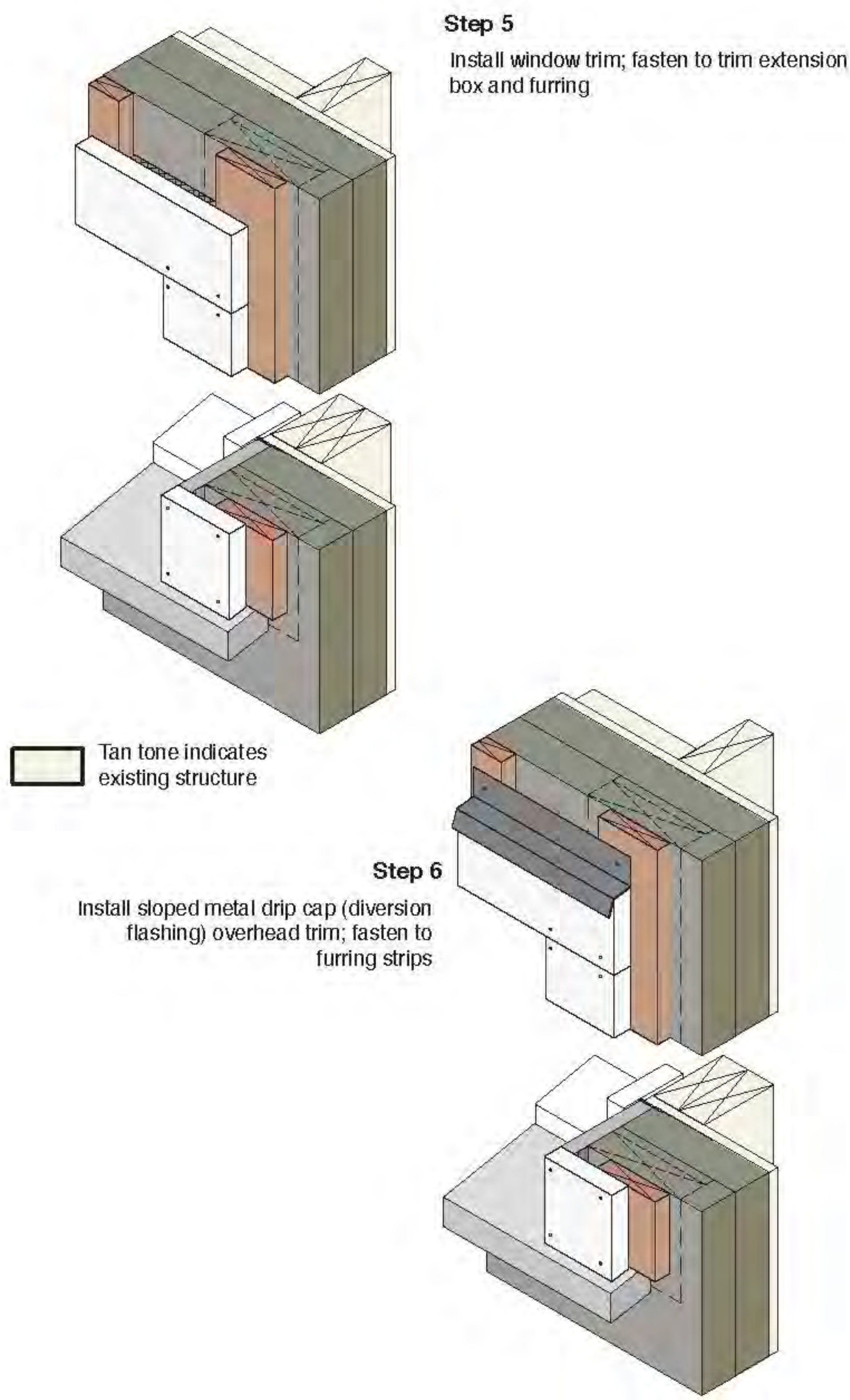


Figure 42. Steps 5 and 6 of exterior trim installation sequence for window in a high performance mineral fiber retrofit wall assembly

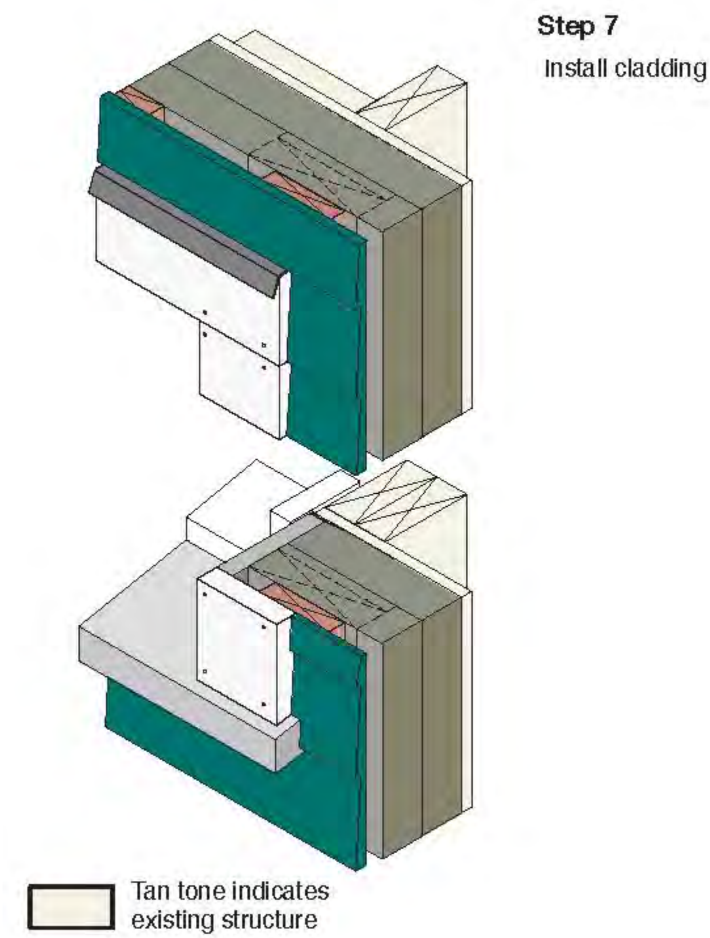


Figure 43. Step 7 of exterior trim installation sequence for window in a high performance mineral fiber retrofit wall assembly

Figure 42 through Figure 46 show the implementation of the high performance mineral fiber retrofit wall assembly at a window opening where the existing window is to remain in place. There may be many reasons for leaving an existing window in place; however, this prevents the contractor from ensuring that the window opening is properly flashed. The air control and water control transitions around a window that remains in place are not as robust as for a window opening that can be flashed and lined as part of the retrofit project. The exterior trim sequence illustrated above is applicable to this condition.

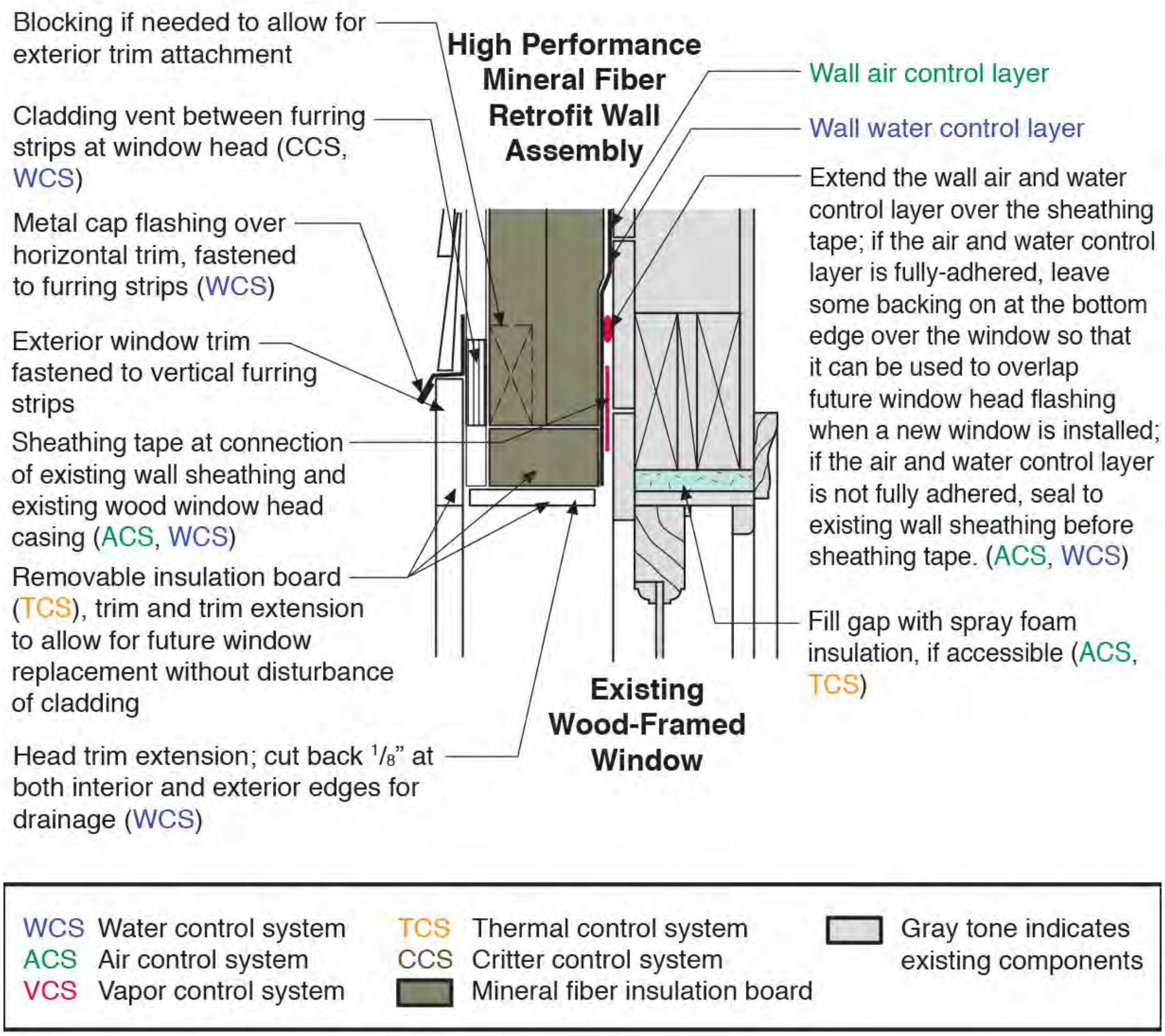


Figure 44. Schematic detail for window head of an existing window remaining in place in a high performance mineral fiber retrofit wall assembly

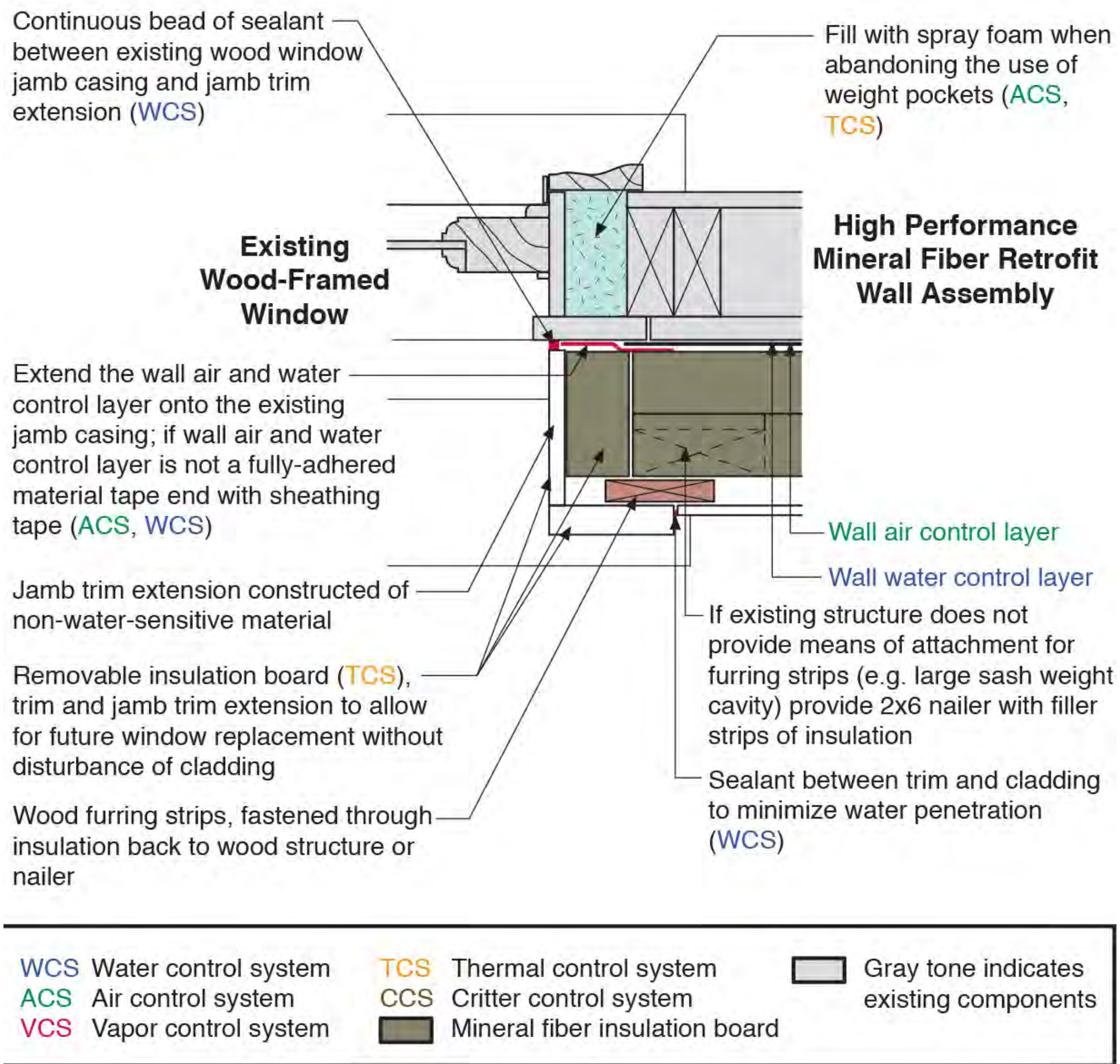


Figure 45. Schematic detail for window jamb of an existing window remaining in place in a high performance mineral fiber retrofit wall assembly

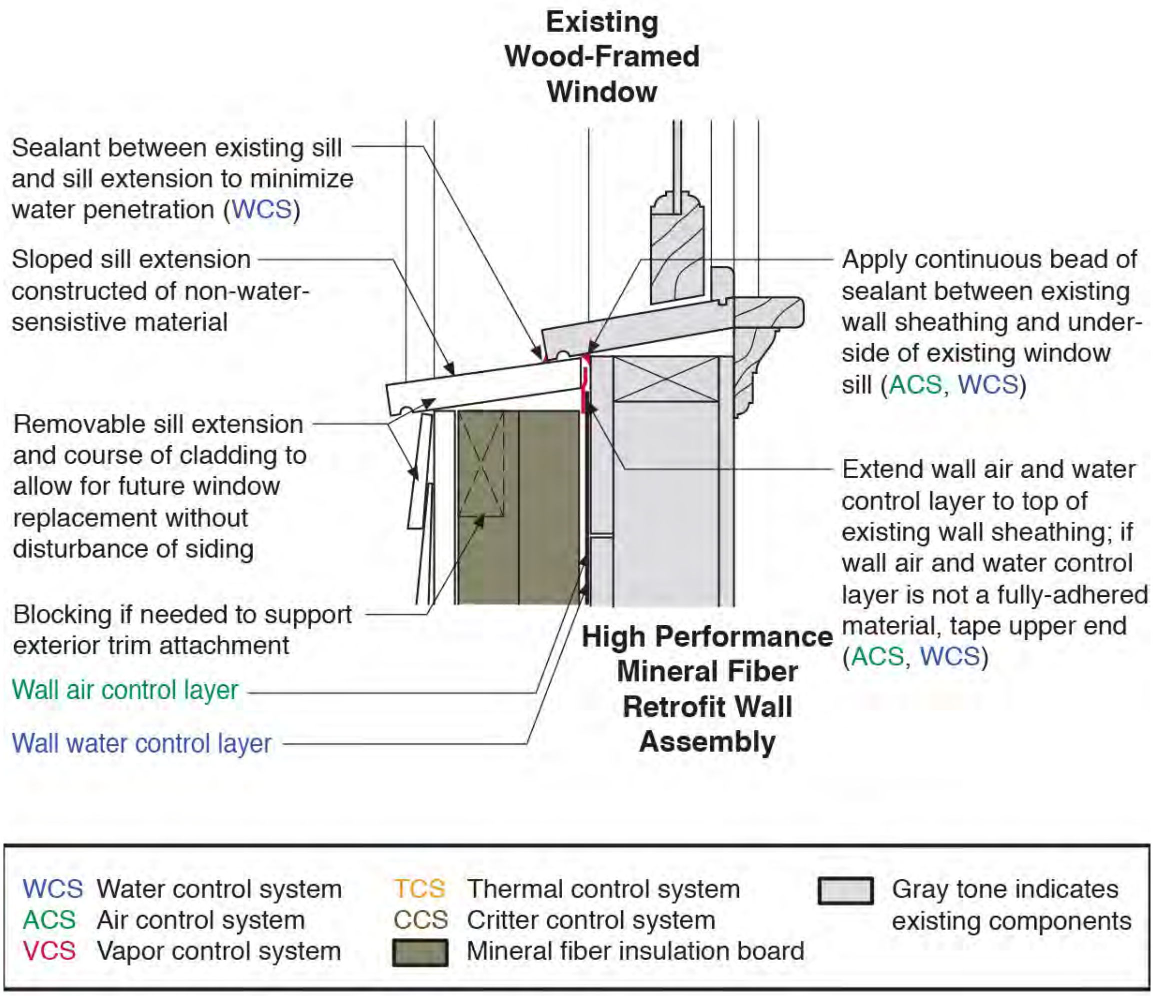


Figure 46. Schematic detail for window sill of an existing window remaining in place in a high performance mineral fiber retrofit wall assembly

Figure 47 through Figure 59 show the installation of a new door or the reinstallation of a door in the high performance mineral fiber retrofit wall assembly.

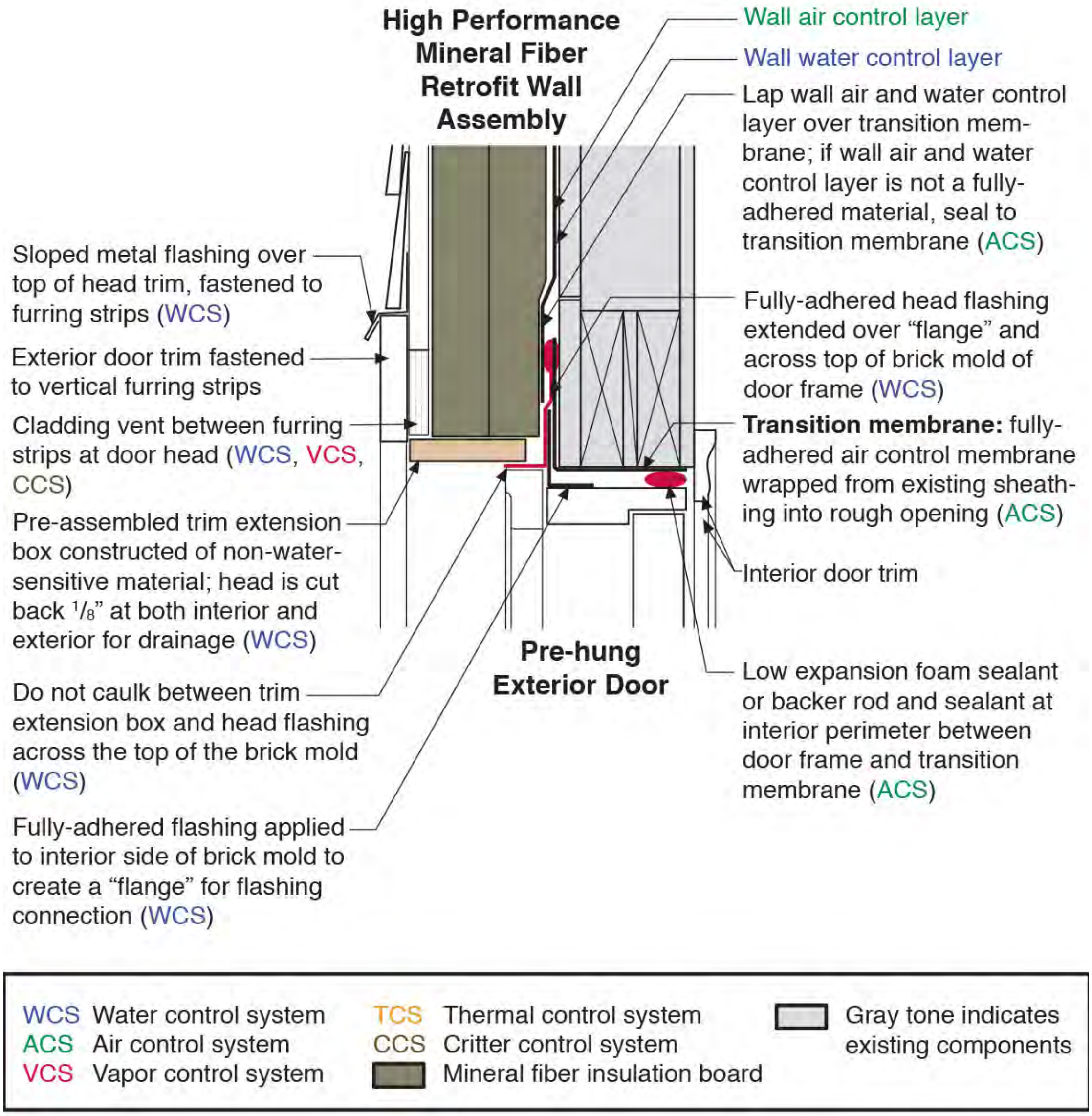


Figure 47. Schematic detail for door head of new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

Note: See installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly for flashing installation details.

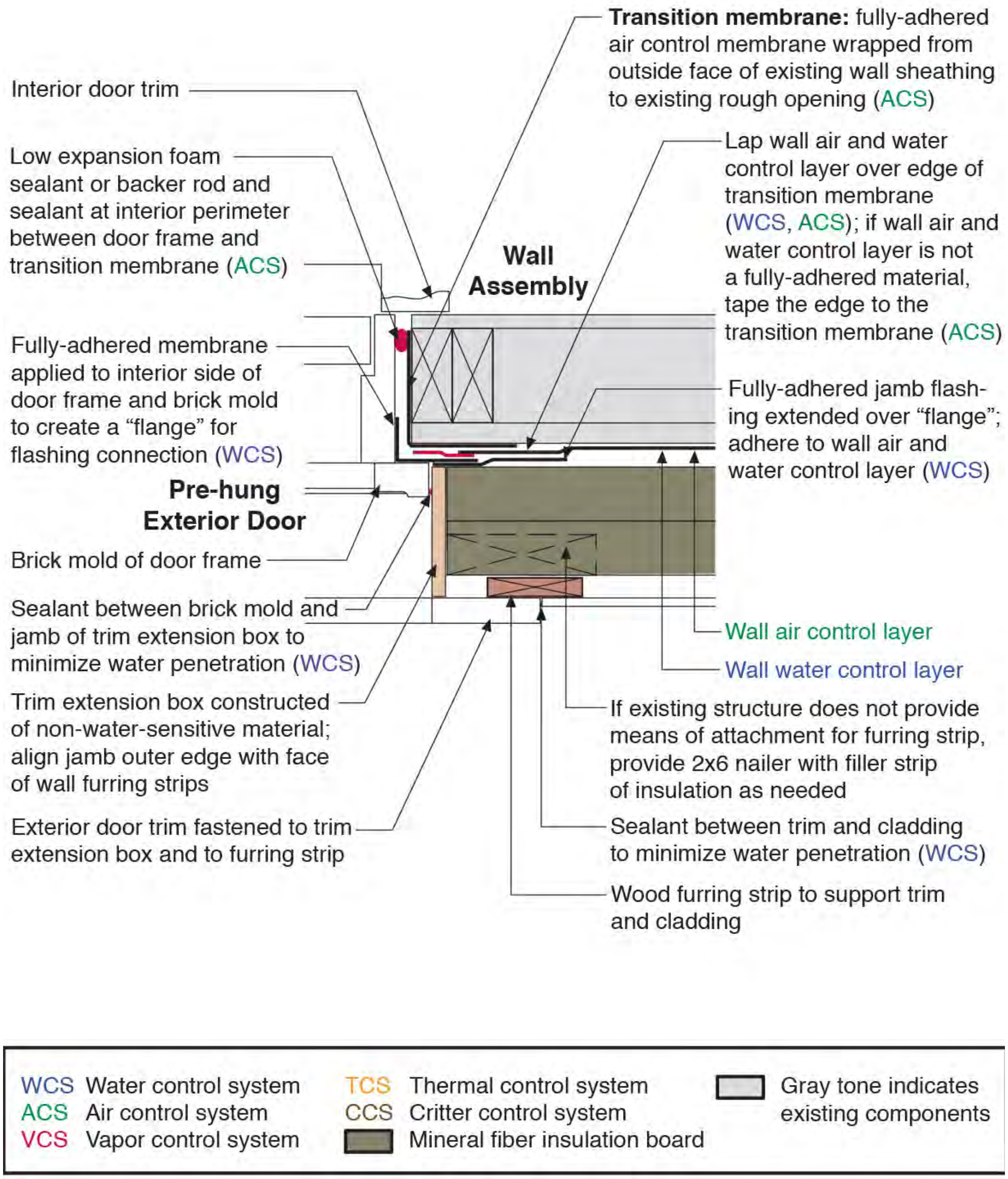


Figure 48. Schematic detail for door jamb of new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

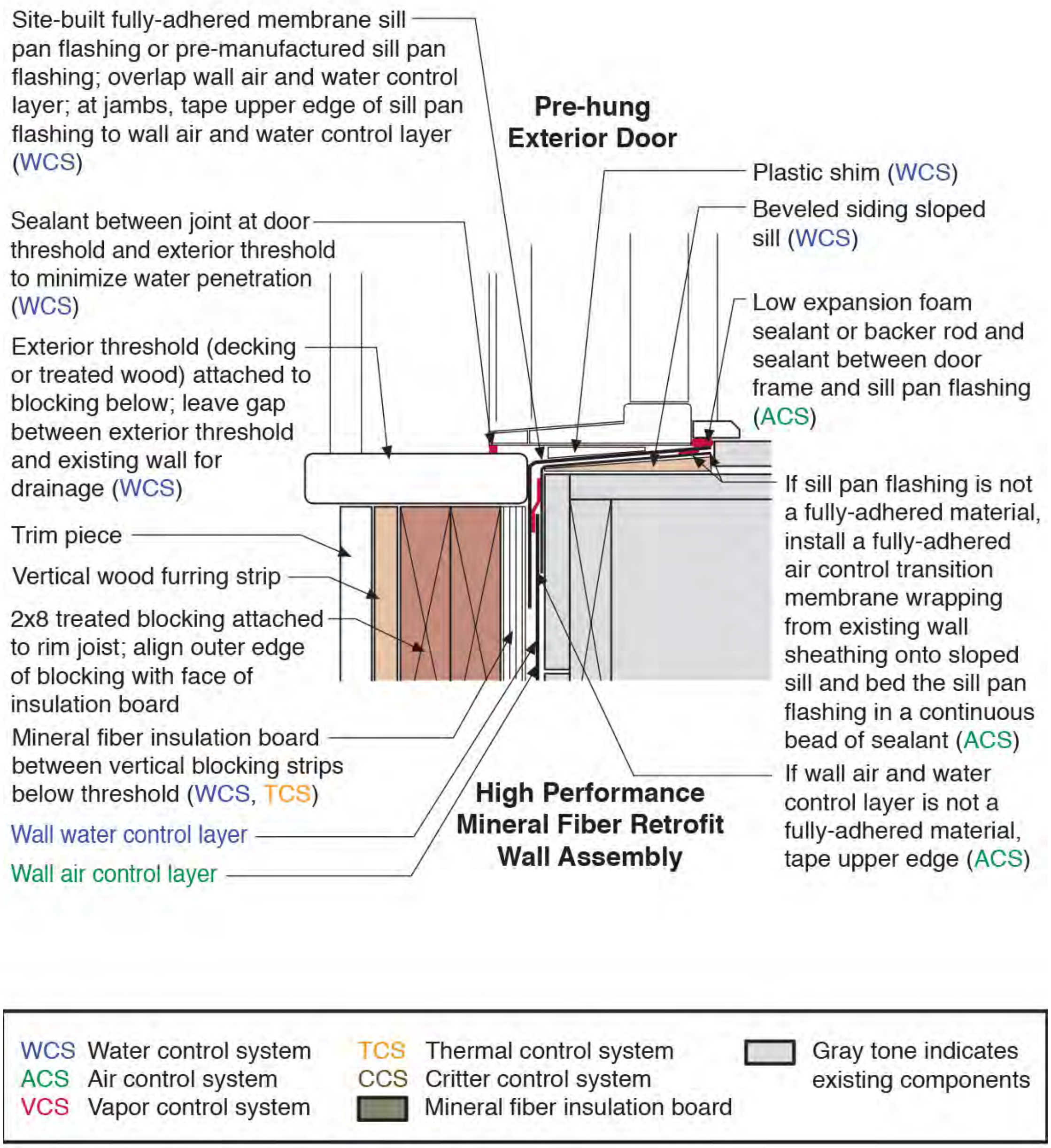


Figure 49. Schematic detail for door sill of new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

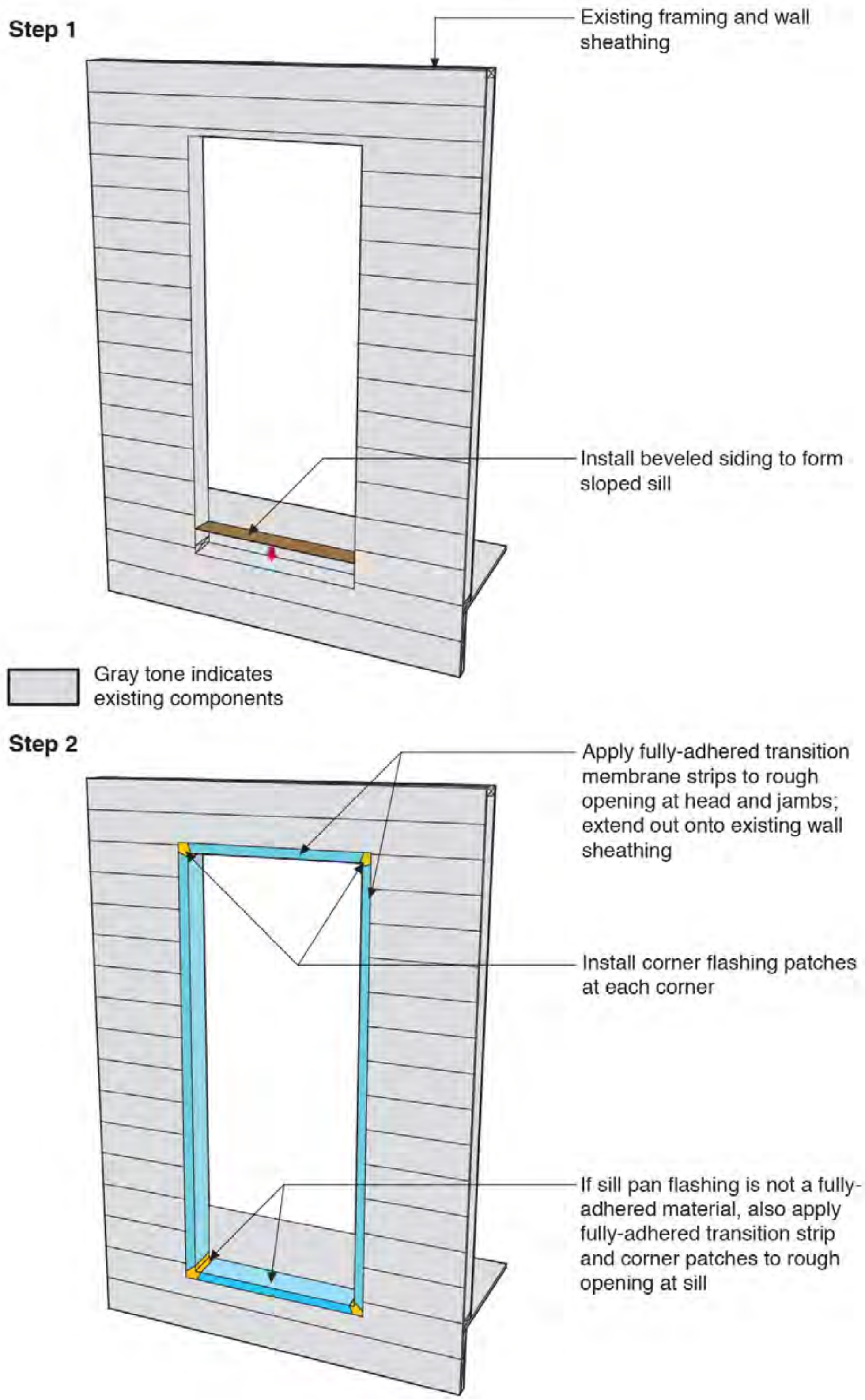


Figure 50. Steps 1 and 2 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

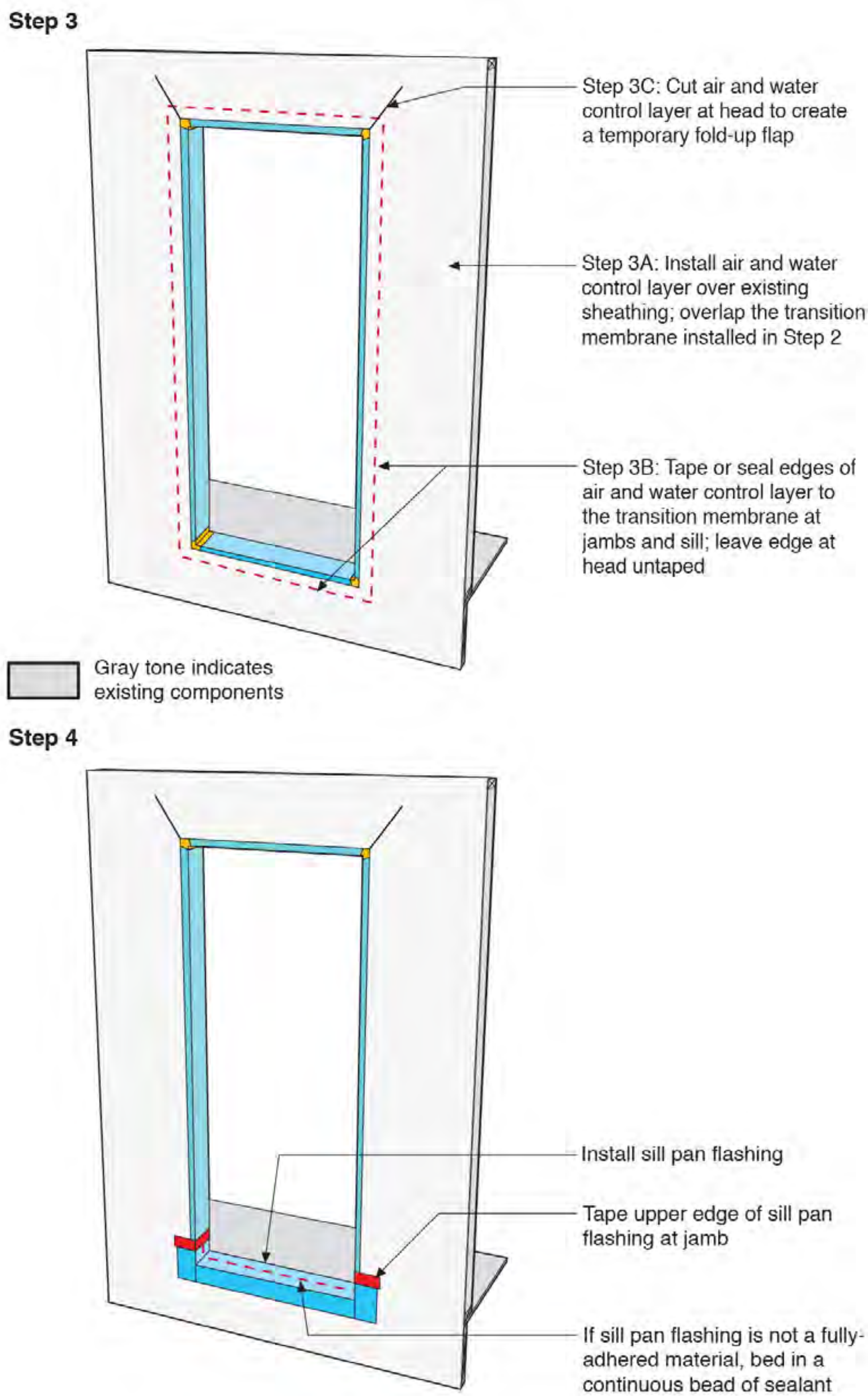


Figure 51. Steps 3 and 4 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

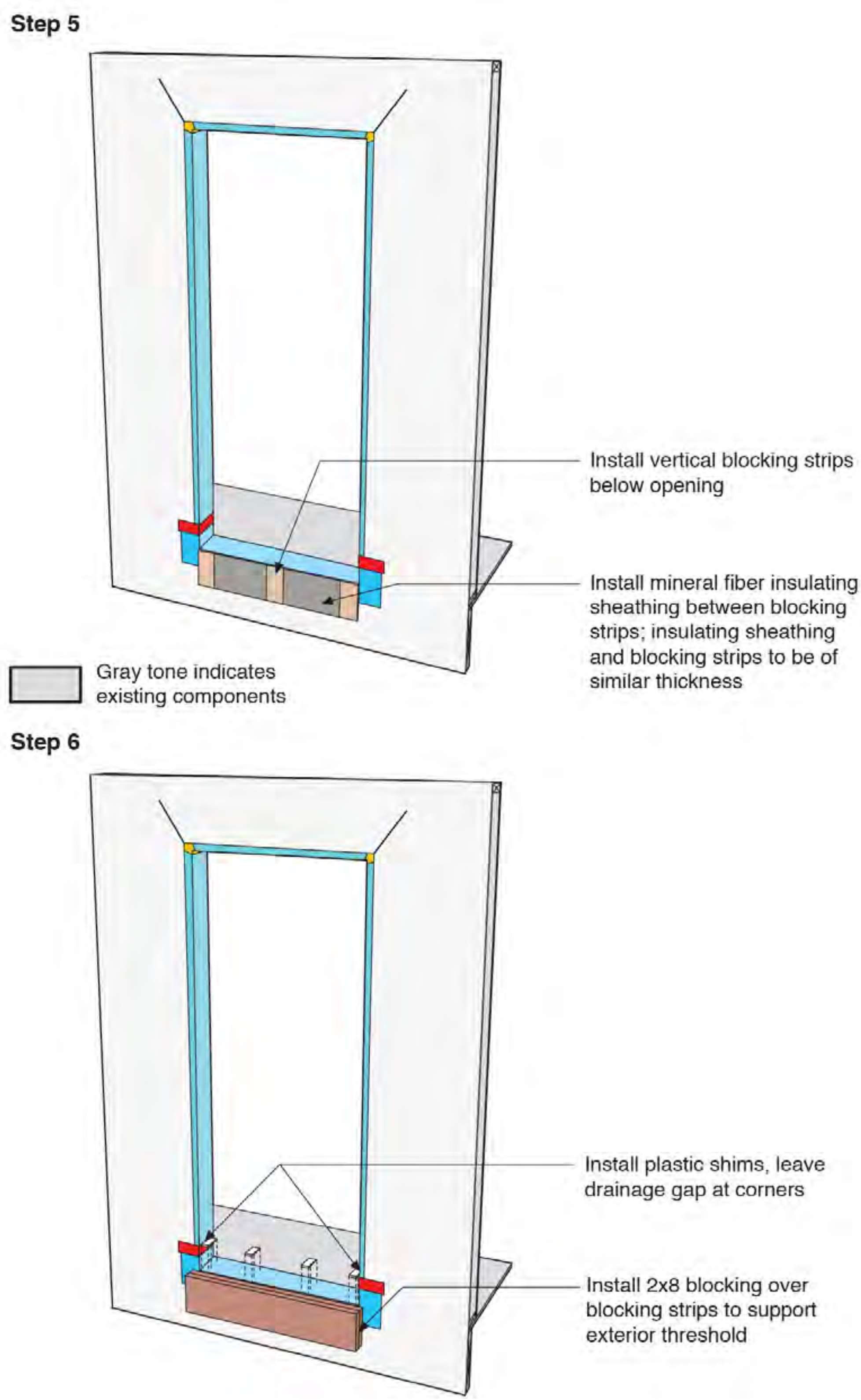
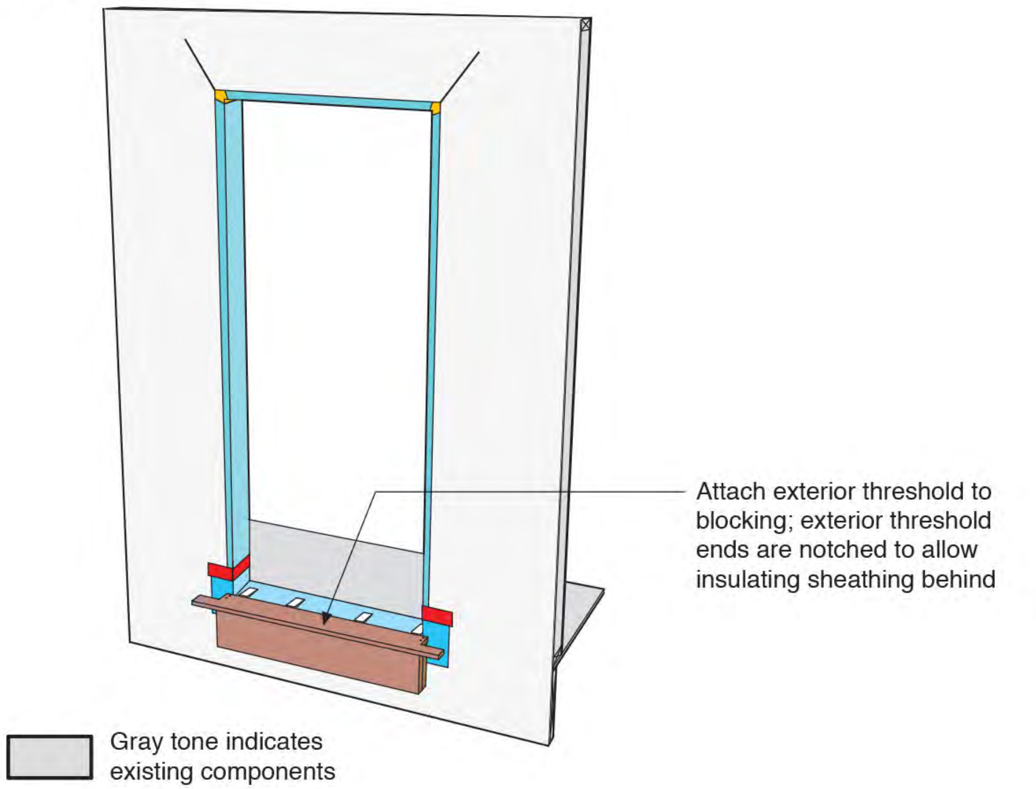


Figure 52. Steps 5 and 6 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

Step 7



Step 8 (reverse view)

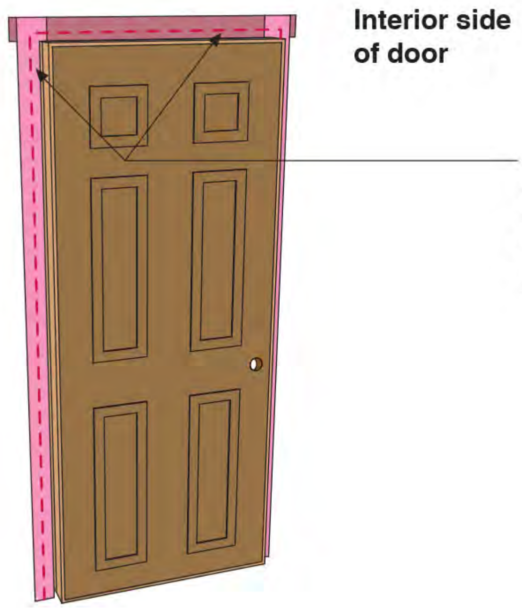


Figure 53. Steps 7 and 8 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

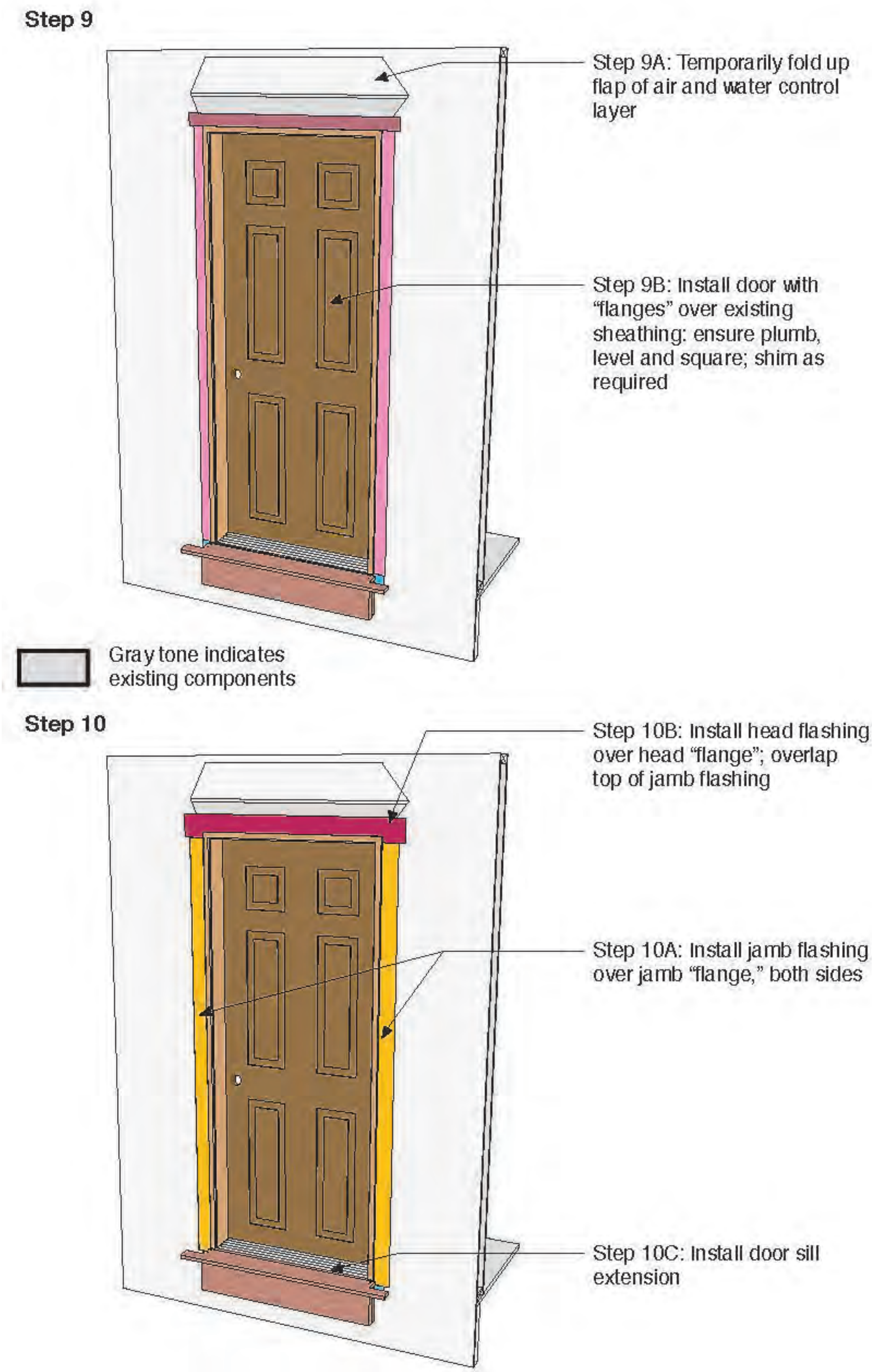


Figure 54. Steps 9 and 10 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

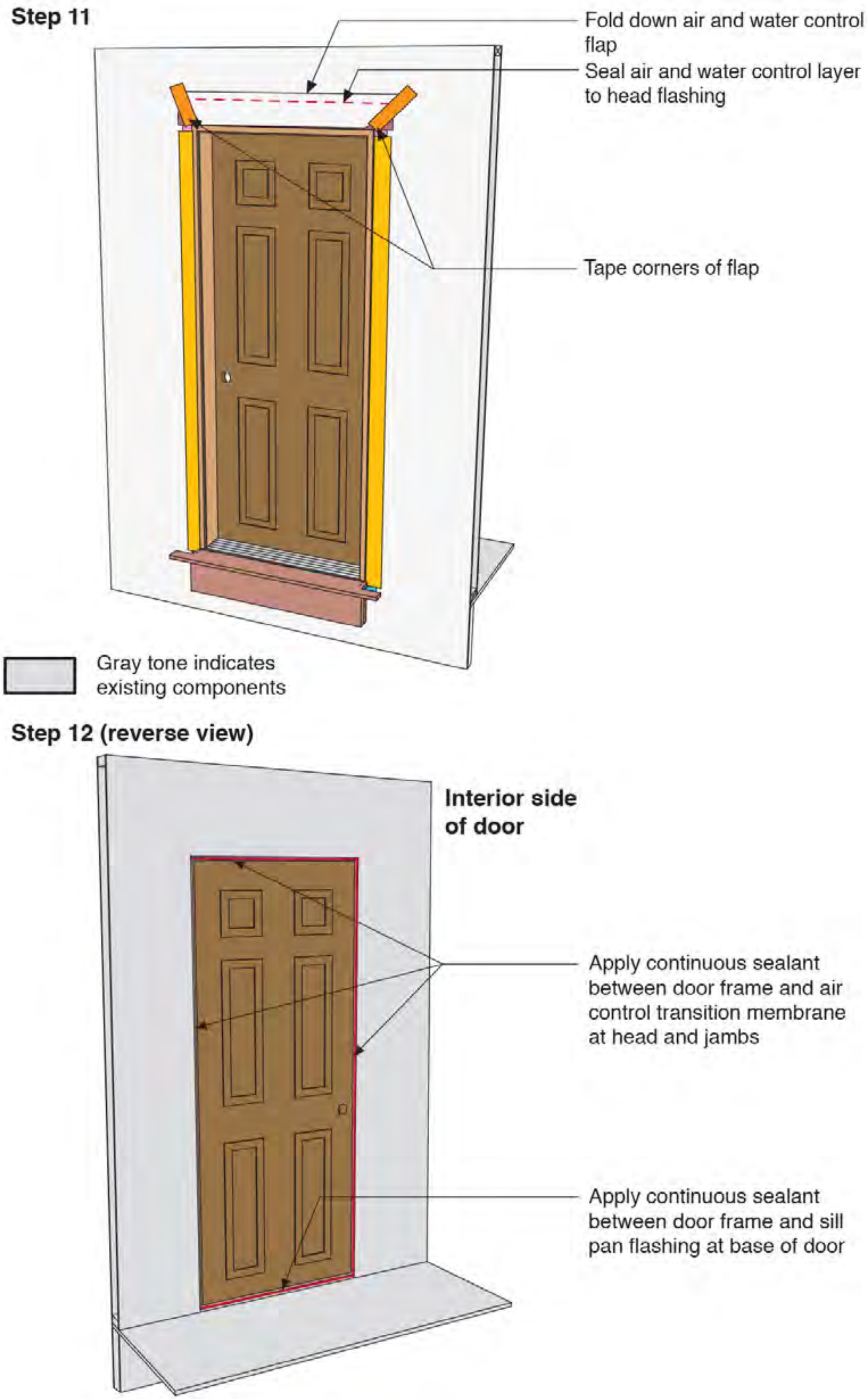


Figure 55. Steps 11 and 12 of installation sequence for new door or reinstalled door in a high performance mineral fiber retrofit wall assembly

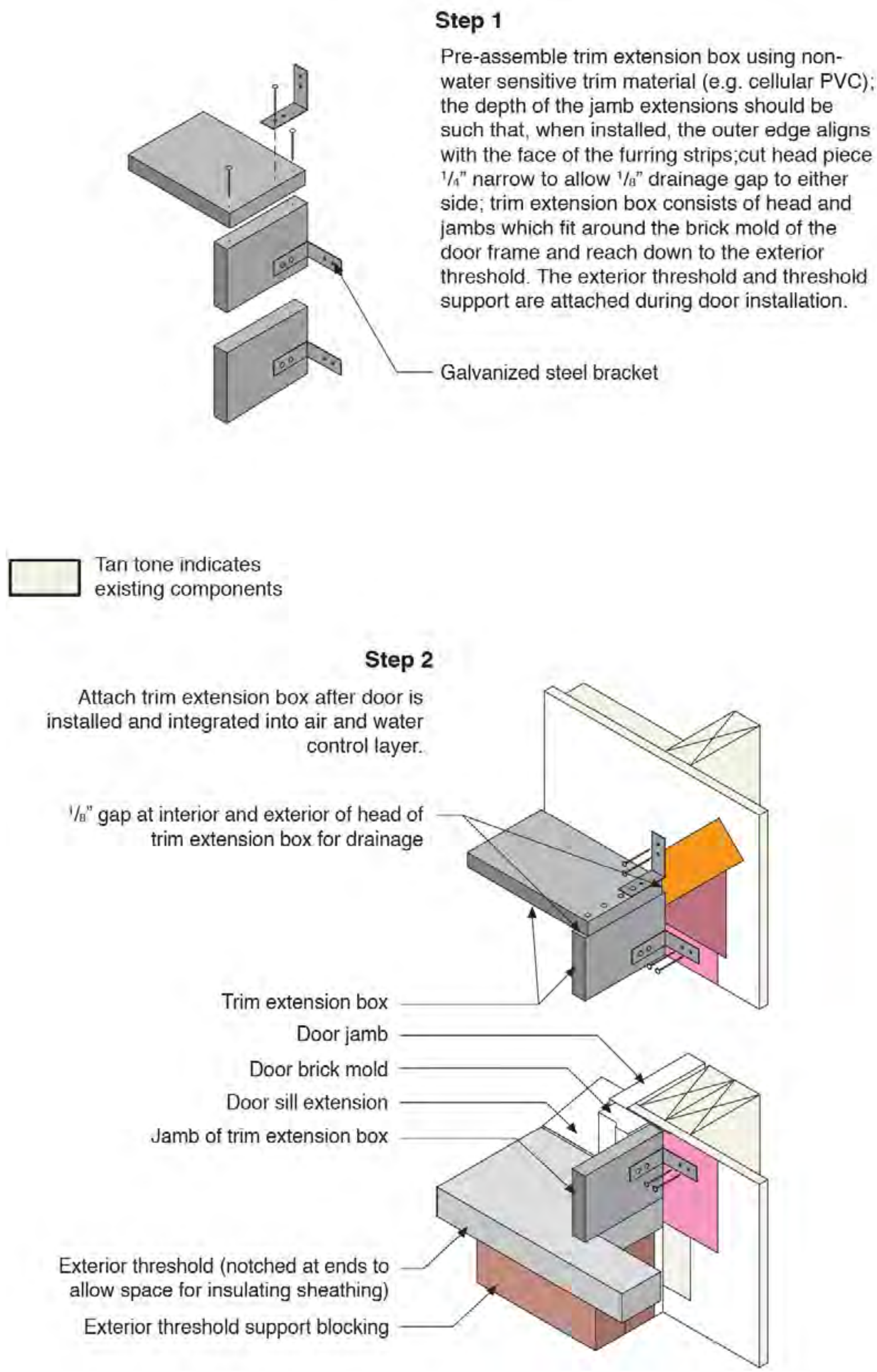


Figure 56. Steps 1 and 2 of exterior trim installation sequence for door in a high performance mineral fiber retrofit wall assembly

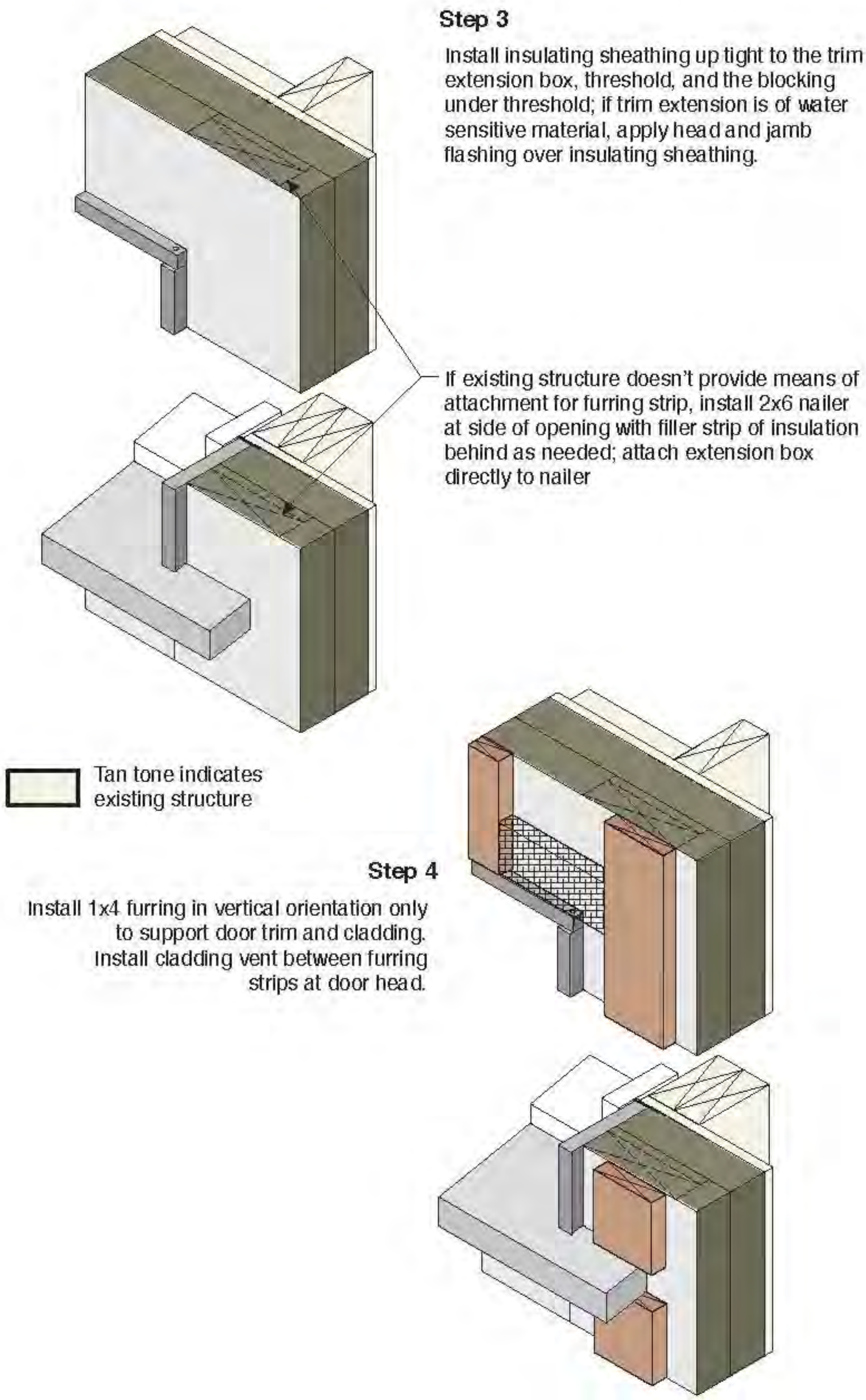


Figure 57. Steps 3 and 4 of exterior trim installation sequence for door in a high performance mineral fiber retrofit wall assembly

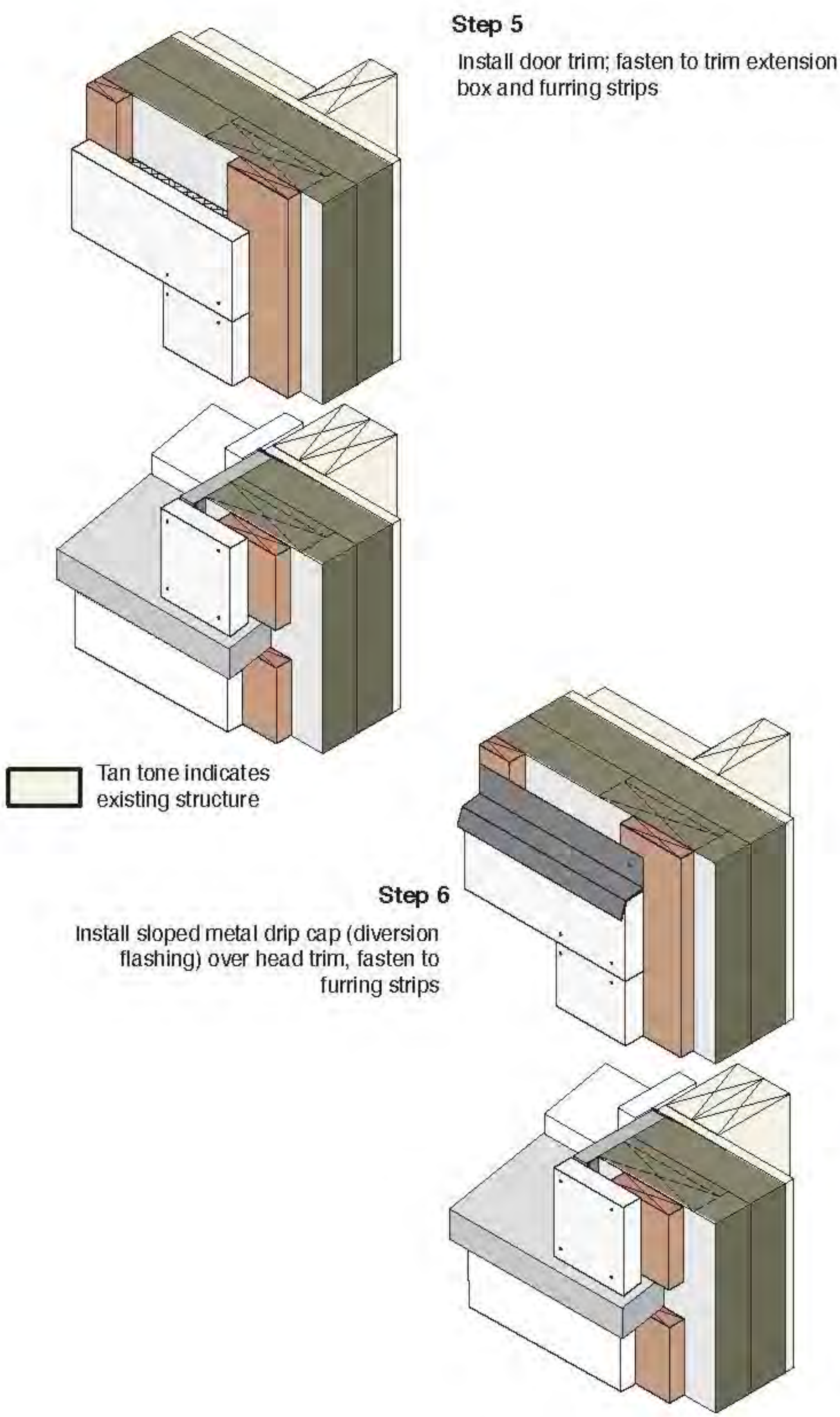


Figure 58. Steps 5 and 6 of exterior trim installation sequence for door in a high performance mineral fiber retrofit wall assembly

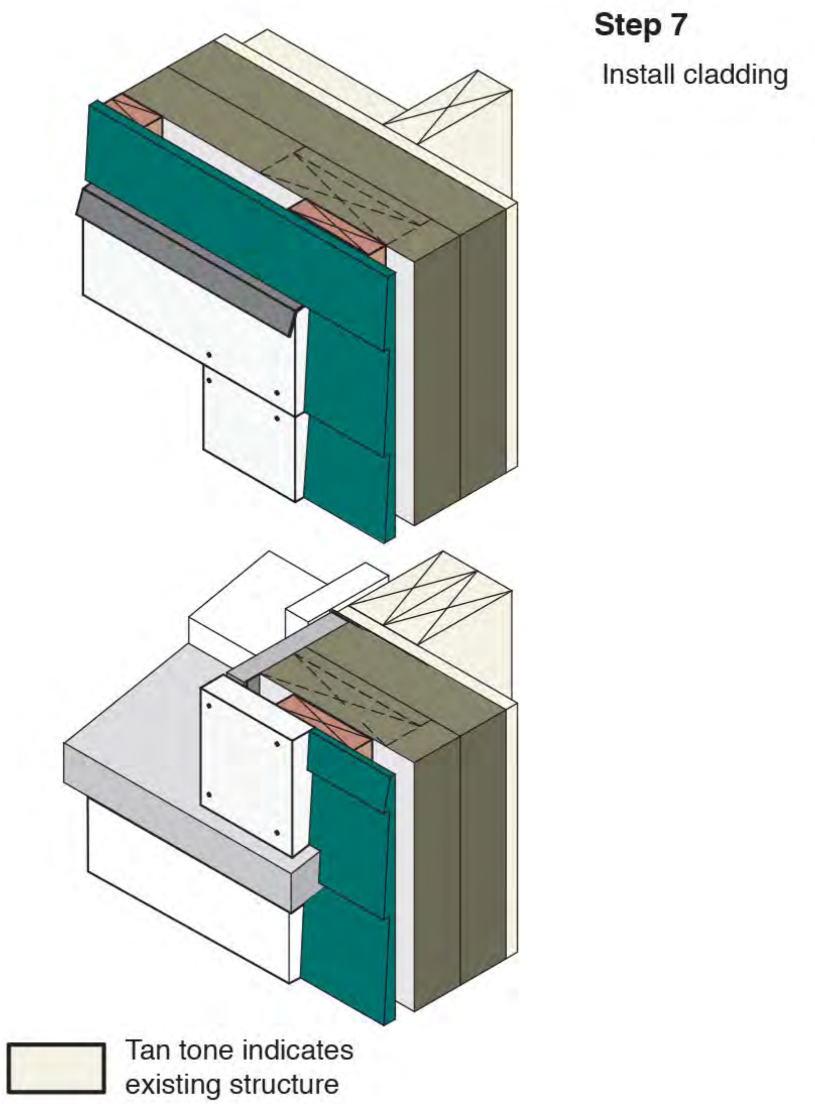


Figure 59. Step 7 of exterior trim installation sequence for door in a high performance mineral fiber retrofit wall assembly

Figure 60 through Figure 67 show the treatment of typical wall penetrations through the high performance mineral fiber retrofit wall assembly.

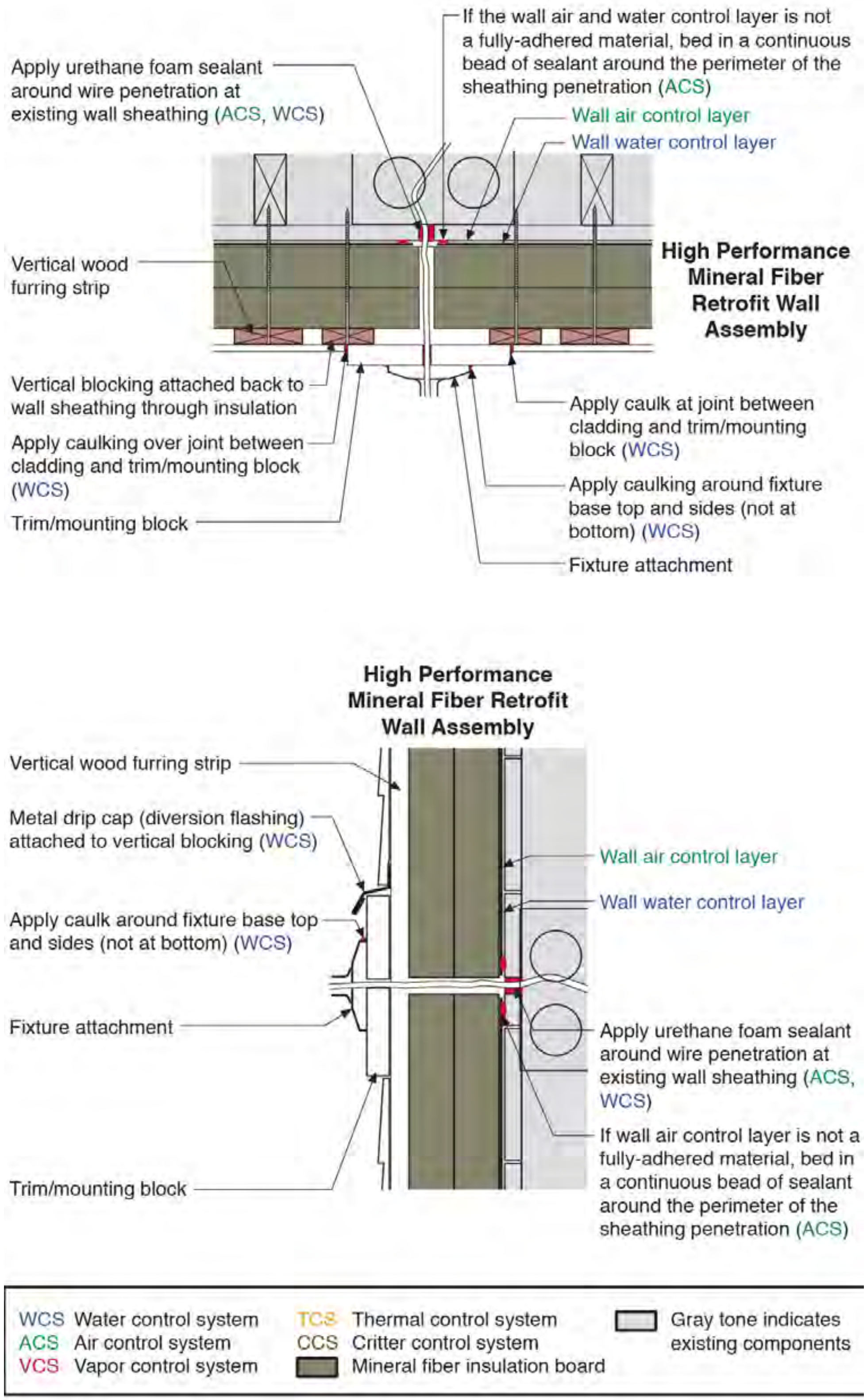


Figure 60. Schematic plan (above) and section (below) details for wire penetration and fixture mount in a high performance mineral fiber retrofit wall assembly

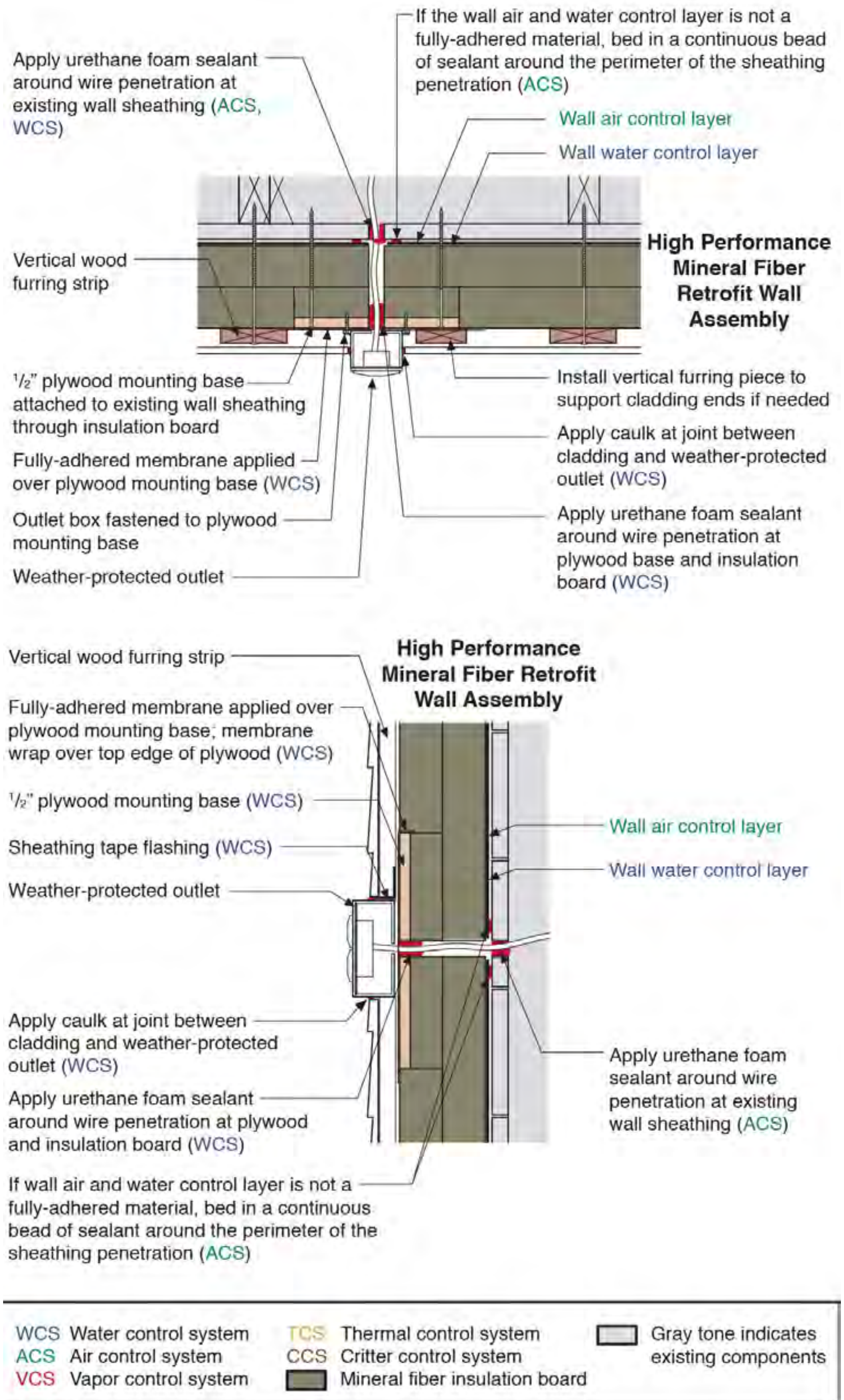


Figure 61. Schematic plan and section details for wire penetration and exterior outlet box mount in a high performance mineral fiber retrofit wall assembly

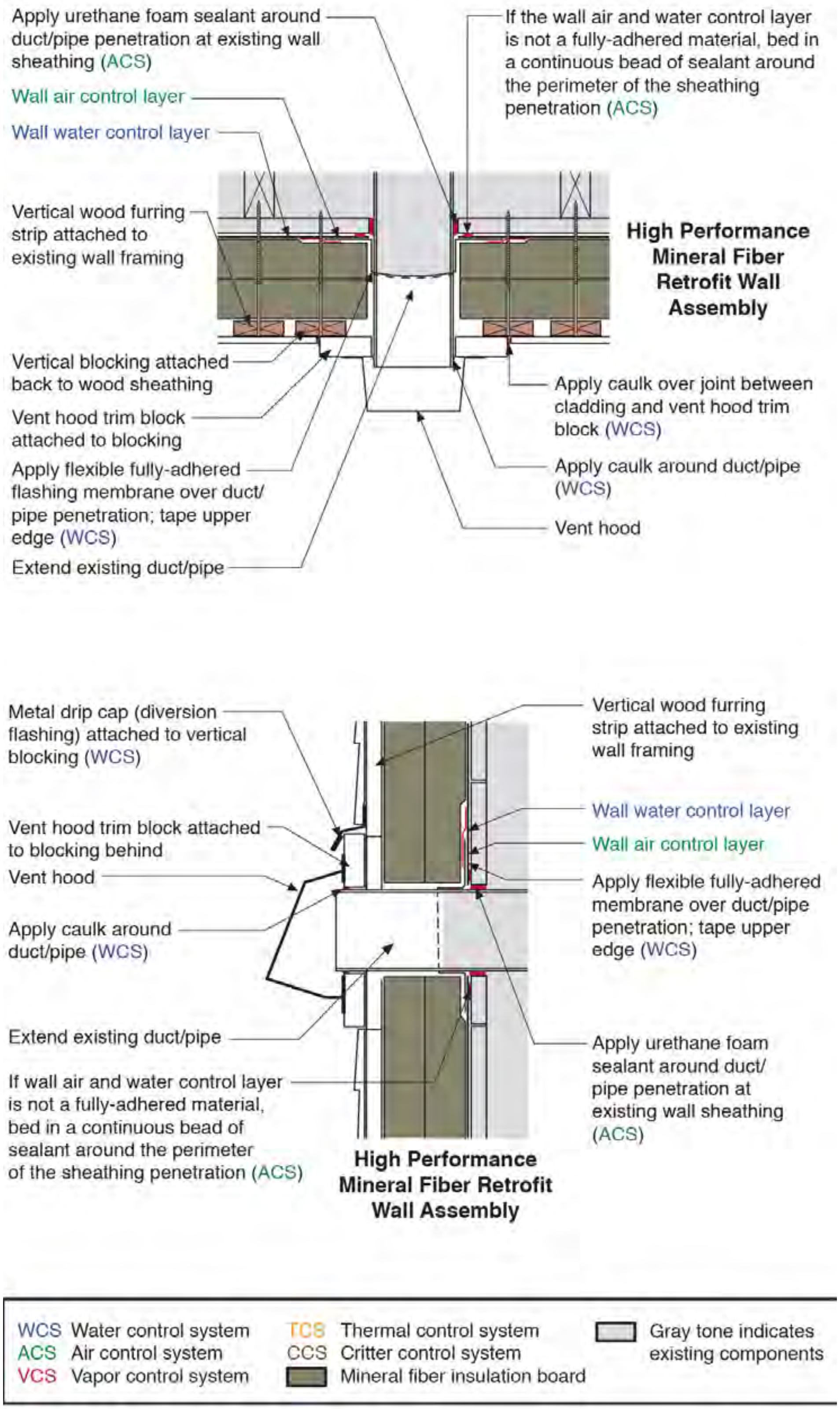


Figure 62. Schematic plan and section details for duct penetration and vent hood trim mount in a high performance mineral fiber retrofit wall assembly

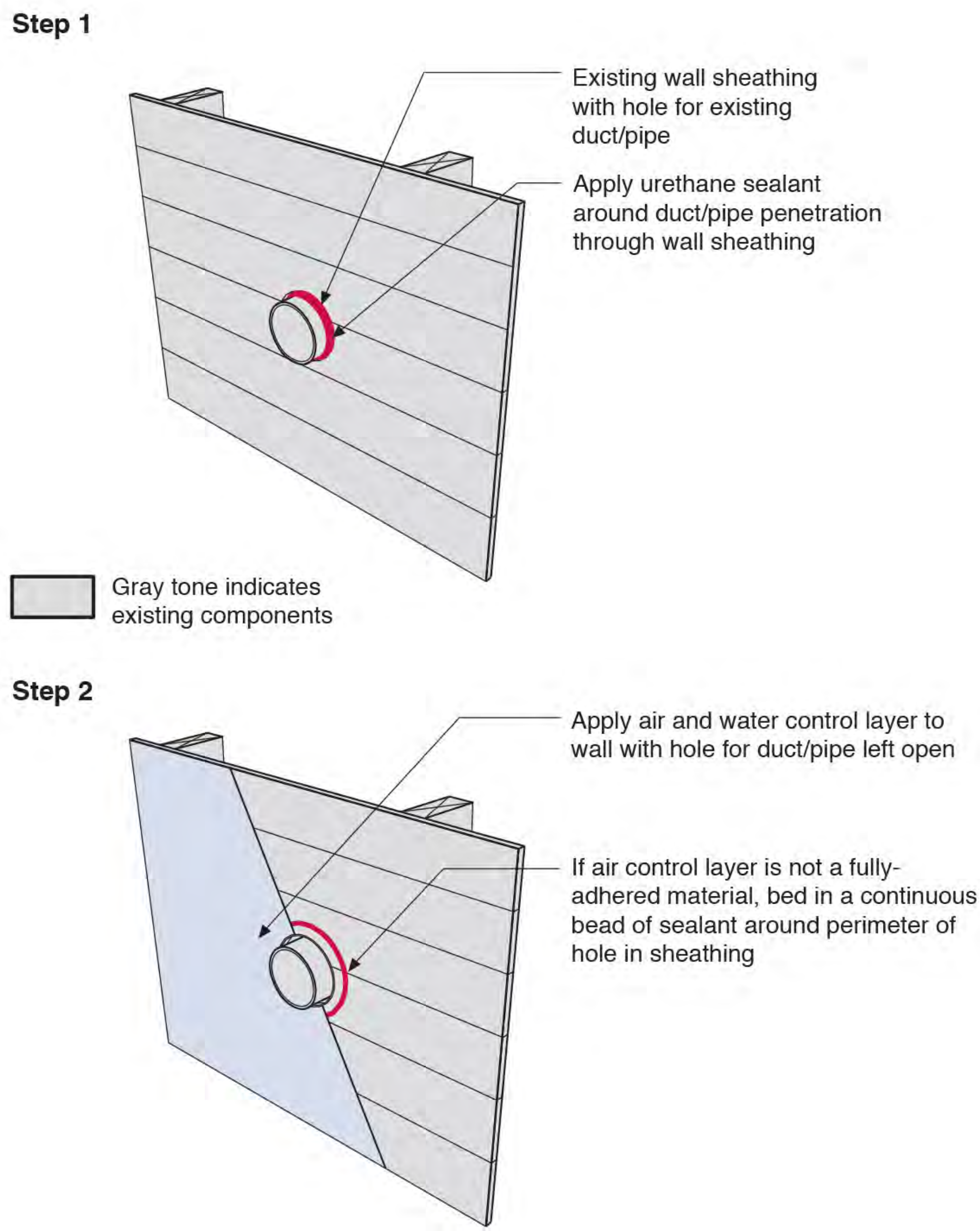
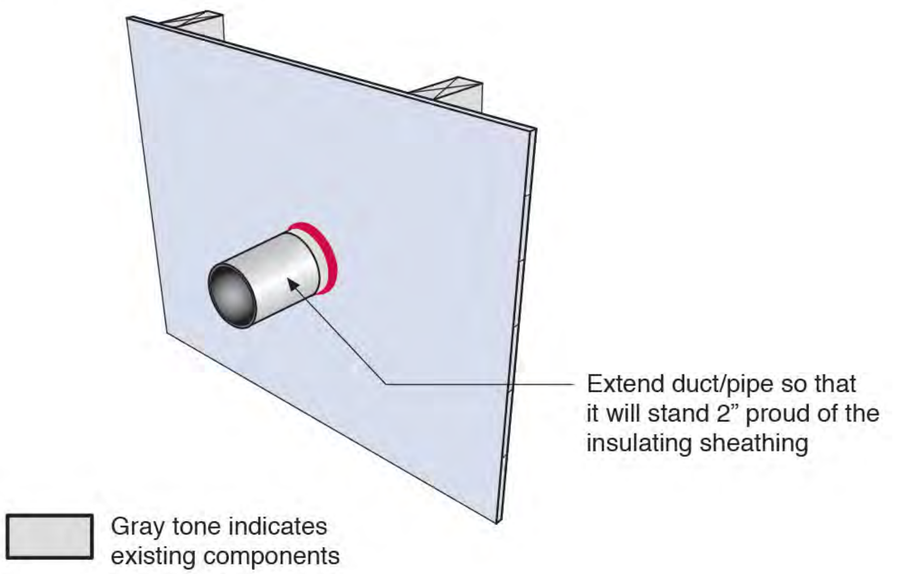


Figure 63. Steps 1 and 2 of sequence for treatment of duct/pipe penetration through a high performance mineral fiber retrofit wall assembly

Step 3



Step 4

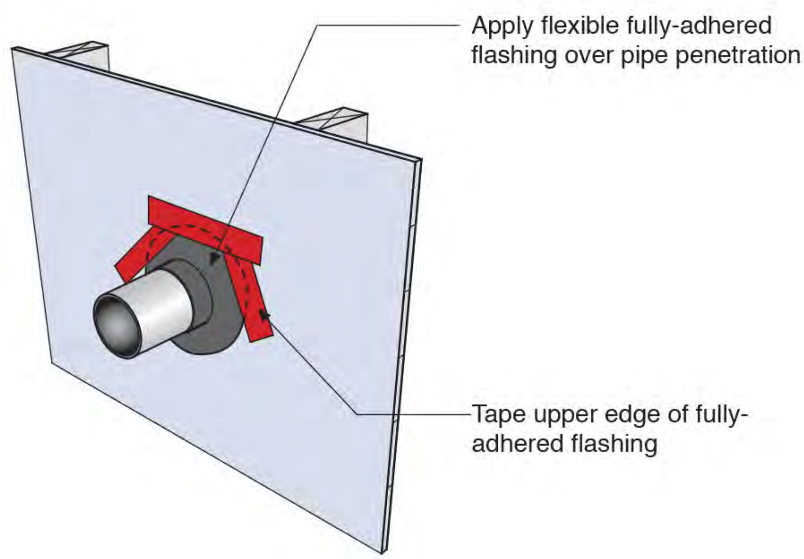


Figure 64. Steps 3 and 4 of sequence for treatment of duct/pipe penetration through a high performance mineral fiber retrofit wall assembly

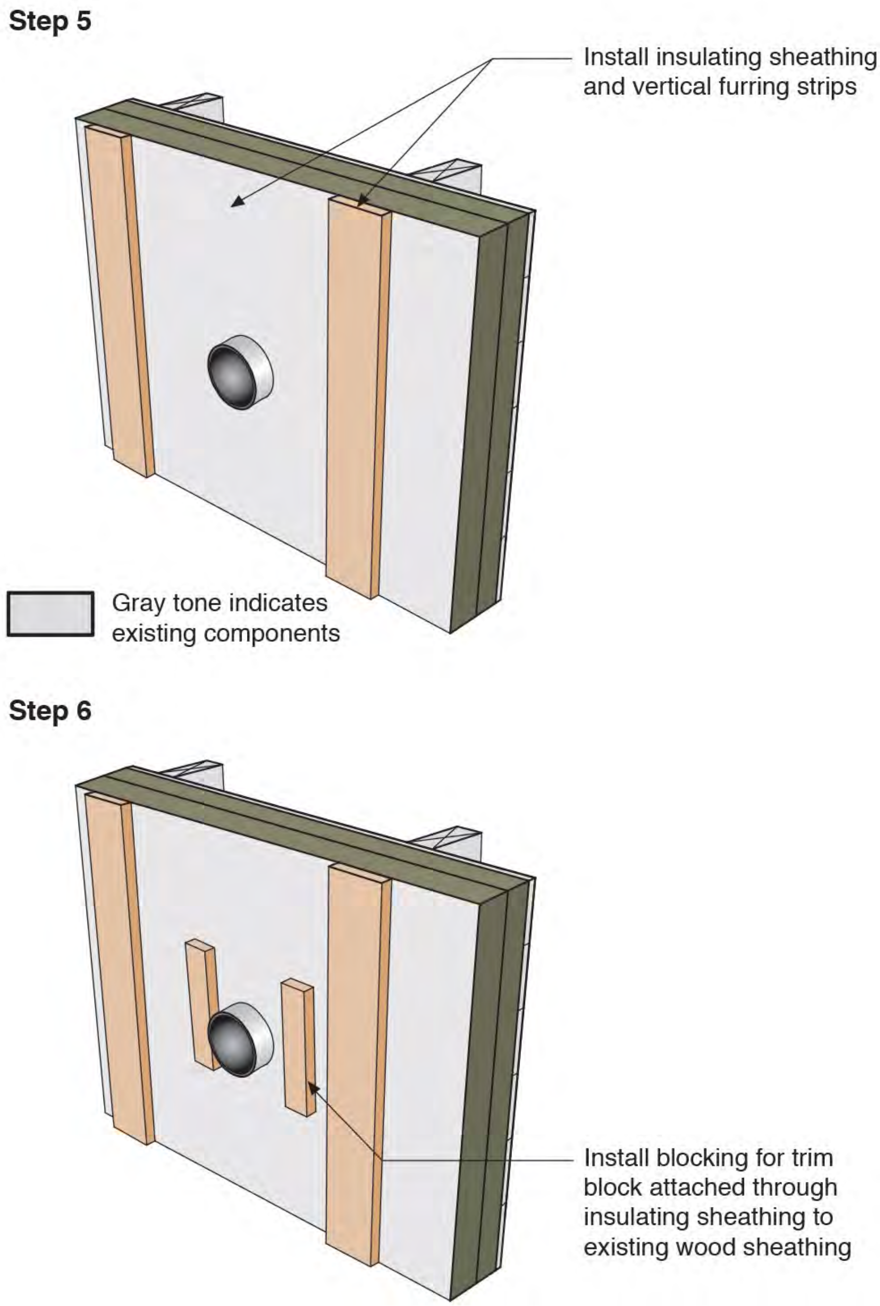


Figure 65. Steps 5 and 6 of sequence for treatment of duct/pipe penetration through a high performance mineral fiber retrofit wall assembly

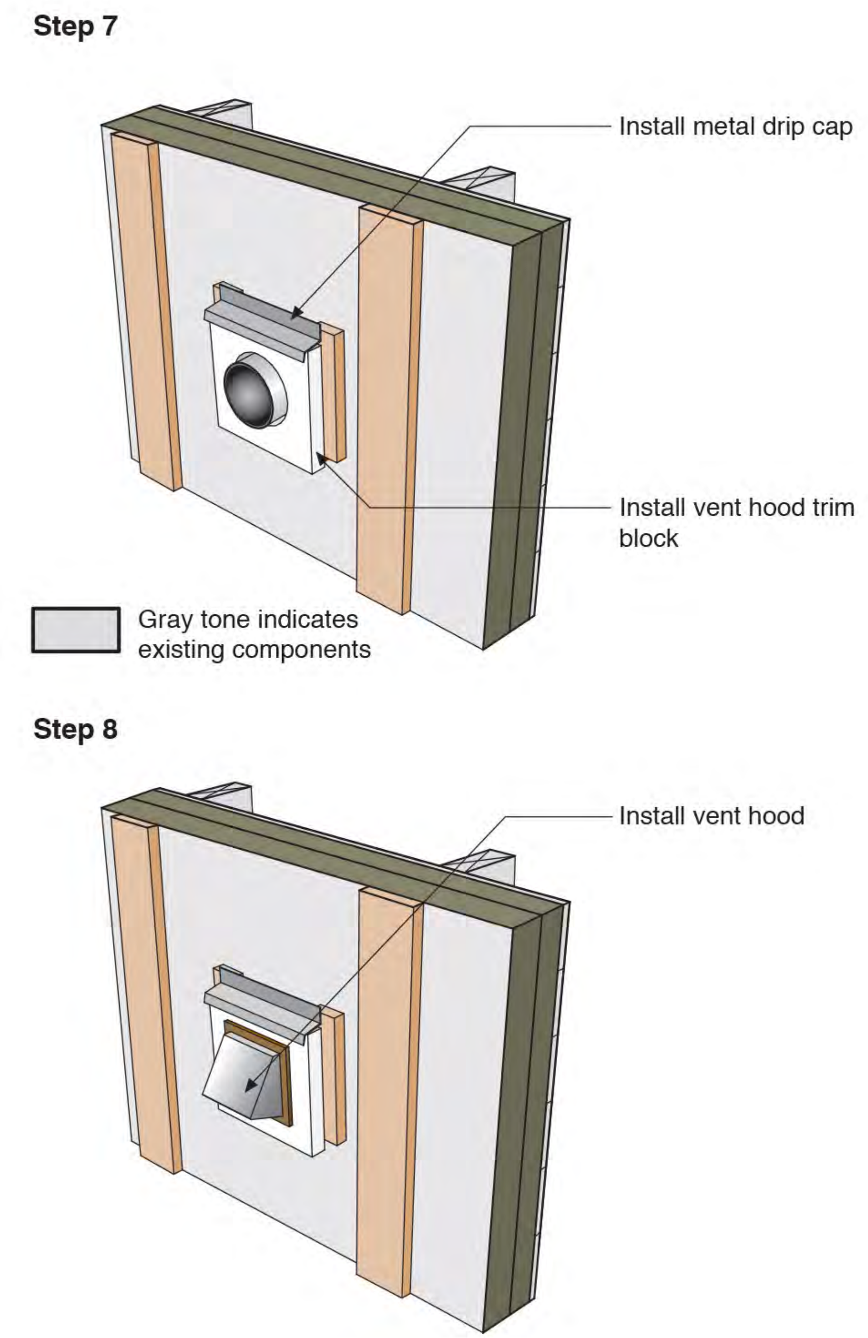


Figure 66. Steps 7 and 8 of sequence for treatment of duct/pipe penetration through a high performance mineral fiber retrofit wall assembly

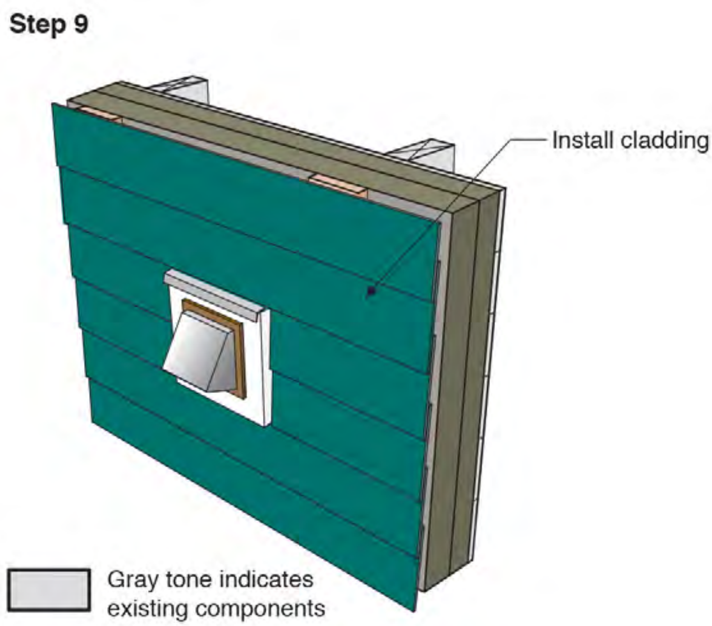


Figure 67. Step 9 of sequence for treatment of duct/pipe penetration through a high performance mineral fiber retrofit wall assembly

4.3 High Performance Mineral Fiber Retrofit Foundation Wall Assembly

4.3.1 Scope of Work

1. Locate underground utilities and implement measures to ensure their protection. Verify safe conditions for perimeter excavation.
2. Excavate the foundation perimeter to a depth and width required to implement the wall retrofit and foundation skirt measures. Install clean aggregate for insulated foundation skirt. Grade bottom of excavation to slope at least 5% away from foundation.
3. Install metal closure/transition flashing at top of foundation wall.
4. Install non-moisture-sensitive rigid insulation at bottom of excavation as required.
5. Install ground roof/foundation skirt and secure high end to foundation with retaining bar.
6. Install drainpipe at low end of ground roof/foundation skirt. Slope to daylight outlet or storm water collection. DO NOT connect drainpipe to foundation drain.
7. Install mineral fiber insulation board with protective finish to the exterior of the foundation wall.
8. Backfill excavation to within 4 in. of finished grade with free-draining backfill.
9. Install a drip trench adjacent to foundation wall and separated from backfill/soil with a durable filter fabric.

4.3.2 Climate-Specific Factors

In climate zone 5 and above, the ground roof/foundation skirt for a slab-on-grade foundation should be insulated. The ground roof/foundation skirt should be insulated in climate zone 2 and above if the home has a crawlspace or basement. The level of recommended insulation is as follows:

- R-5 in climate zone 2
- R-7.5 in climate zones 3 and 4
- R-10 minimum in climate zones 5 and 6
- R-15 minimum in climate zone 7
- R-20 minimum in climate zone 8.

The insulation used must be approved for below-grade applications (e.g., XPS or foamed glass) and placed over a capillary break consisting of a sloped bed of clean aggregate.

4.3.3 Field Inspection

Identify and address risks to occupants or the building that could be aggravated by the work. Verify safe working conditions. Determine whether the building has more urgent problems that must be addressed. Determine the feasibility of the retrofit solution and of options.

Inspect and assess the building for:

- Structural integrity of the frame and foundation
- Contaminated soil (e.g., with lead, pesticides) surrounding the foundation
- Safety and serviceability of the electrical system
- Hazardous materials (e.g., lead, radon asbestos) in or on the building
- Rainwater, groundwater, or plumbing water leaks
- Rot or decay in framing
- Insect and pest damage and activity.

Deficiencies or hazards must be remediated prior to or as part of the project.

Locate any underground utilities (electric, gas, water, sewer) serving the building or passing near the foundation. Ensure these are protected during the retrofit project.

Identify any atmospherically vented (or naturally aspirated) combustion appliances in the home. With the exception of gas stoves and cooktops, combustion appliances—including fireplaces—should be direct-vented or direct exhaust-vented equipment. Atmospherically vented appliances must be replaced or reconfigured to direct-vented or direct exhaust-vented operation prior to or as part of the project.

Verify that all kitchen and bathroom exhausts are vented to the exterior of the building. Source control ventilation deficiencies must be corrected either prior to or as part of the project.

If the home lacks a ventilation system meeting the requirements of 2012 IRC, Section M1507.3, a ventilation system meeting this requirement must be installed either prior to or as part of the project.

4.3.4 Implementation Risks

Construction and renovation work entails inherent risks to workers. All applicable safety procedures must be followed.

Implementation risks specific to mineral fiber insulation board retrofit derive from the fibrous nature of the material. All workers handling or cutting material should:

1. Wear protective clothing and avoid exposed skin.
2. Wear goggles or similar enclosed eye protection.
3. Wear gloves that are impermeable to fibers.
4. Use tight-fitting dust masks to provide appropriate protection from airborne fibers.
5. Refer to material safety data sheets and manufacturer instructions for safe handling and exposure.

Ensuring Success

Significant retrofit of building enclosure components will change the dynamics of water, air, vapor, and heat flow within the home. To ensure that these changing dynamics do not have negative ramifications for health and safety or for building durability, the following conditions must be met either prior to or as part of the project.

- Combustion safety—All non-cooking appliances, including fireplaces, direct-vented or direct exhaust-vented appliances.
- Ventilation—Whole-house ventilation meeting the requirements of 2012 IRC, Section M1507.3 is installed and operational.

The following is also recommended:

- Soil gas control system—An active or passive soil gas control system installed and operational.

4.3.5 Installation Procedure

0. Locate underground utilities. Ensure these are protected throughout the project.

Locate utilities serving the building or passing near the foundation. Implement measures to protect these throughout the project.

STOP! Do not proceed if underground utilities are not located.

1. Excavate the perimeter.

Excavate to a depth of at least 2 ft below grade and 4 ft from the foundation wall. The bottom of excavation must slope at least 5% away from the foundation. For an insulated ground roof/foundation skirt, the depth of the excavation must also accommodate a clean aggregate layer and the insulation thickness.

The base of the excavation furthest from the foundation should be shaped and graded to allow the ground roofing material to form a trough for the drainpipe that is sloped to the drain outlet.

2. Install a metal closure and transition flashing.

Install a continuous metal closure and transition flashing at the top of the foundation wall. This must be sealed to the foundation wall with bituminous flashing membrane and sealant. Use primer to ensure robust adhesion of bituminous flashing membrane. Seal lapped seams in the metal closure and transition flashing with bituminous membrane flashing or bituminous sealant.

3. Install an insulated ground roof/foundation skirt.

Where an insulated ground roof/foundation skirt is recommended or otherwise desired, place a capillary break of clean aggregate at the bottom of the excavation. Ensure that the surface of the aggregate slopes away from the foundation at 5% minimum. Place rigid insulation board over the aggregate and extending from the foundation wall to at least 3 ft from the foundation wall. The rigid insulation can be temporarily held in place with stakes at the bottom edge of the insulation boards.

The insulation material used in this application must be a rigid insulation board that is non-moisture sensitive. XPS and foamed glass rigid insulation meet these requirements. Even with the non-moisture-sensitive insulation material, it is important to provide capillary protection because sustained exposure to ground moisture could lead to moisture absorption and degradation in the insulation.

4. Install rubber roofing.

Place rubber roofing or similar material across the bottom of the excavation or on top of the rigid insulation and secure to the foundation with a retaining bar. Seams in the roofing material should be lapped at least 8 in.

5. Install a drainpipe.

Install a perforated drainpipe at the low end of the ground roof/foundation skirt. Slope the drainpipe to a storm water collection system or to a daylight outlet. Wrap the drainpipe in clean aggregate and filter fabric.

6. Install mineral fiber insulation board.

Install mineral fiber insulation board in multiple layers to a thickness as required to meet the thermal performance target for the foundation wall. The first layer installed against the foundation wall should be continuous with joints between insulation board pieces butted tight. Furring strips of plastic or preservative material (e.g., 1 in. decking ripped to width) is installed over the continuous insulation layer. Furring strips are fastened to the foundation wall using masonry fasteners. Mineral fiber insulation board with a thickness matching that of the furring strips is in filled between the furring strips. Additional layers of mineral fiber insulation board can be installed over the furring strip layer as needed or desired.

7. Install a protective finish.

Install an impact-resistant, non-ultraviolet-sensitive, non-moisture-sensitive finish over the mineral fiber insulation board from the top of the insulation to the level of finished grade. Examples of suitable protective finishes include brake-formed aluminum coil stock and cement stucco parge coat over cement backer board. The protective finish can be fastened to the furring inset in the second layer of mineral fiber insulation board.

The mineral fiber exterior foundation insulation does not need to be protected below grade. Certain protective finish materials such as stucco are not appropriate for ground contact and, therefore, are best terminated within the thickness of the drip trench and above the top of the backfill material.

8. Backfill with free-draining material.

The excavation should be backfilled to within 4 in. of finished grade with free-draining material. Separate free draining material from the soil with filter fabric.

9. Install a drip trench and finished grade.

Install a drip trench of clean stone that extends from the foundation wall finish past the drip line of the roof. The drip trench should be separated from the surrounding soil and backfill with landscape edging (at the side) and durable filter fabric. The drip trench serves two important functions: (1) it serves as a capillary break between the soil and the above-grade foundation retrofit assembly; and (2) it dissipates the energy of falling rain or roof runoff, thereby limiting splash-back. The drip trench may also serve an aesthetic landscape design purpose.

Finished grade should be sloped away from the foundation at a 5% or greater slope.

4.3.6 High Performance Mineral Fiber Retrofit Details

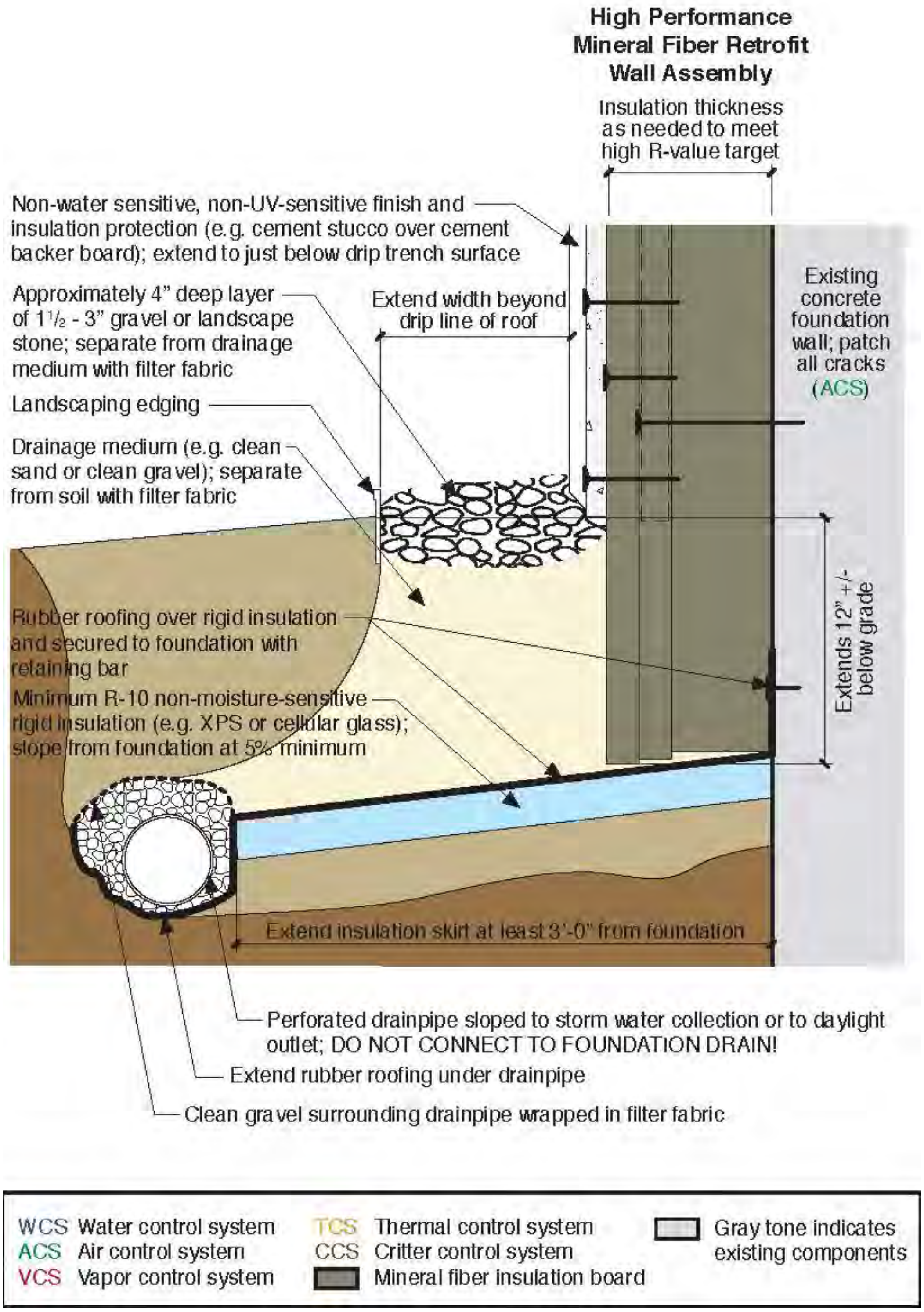


Figure 68. Schematic detail for insulated ground roof/foundation skirt with a high performance mineral fiber retrofit foundation wall assembly

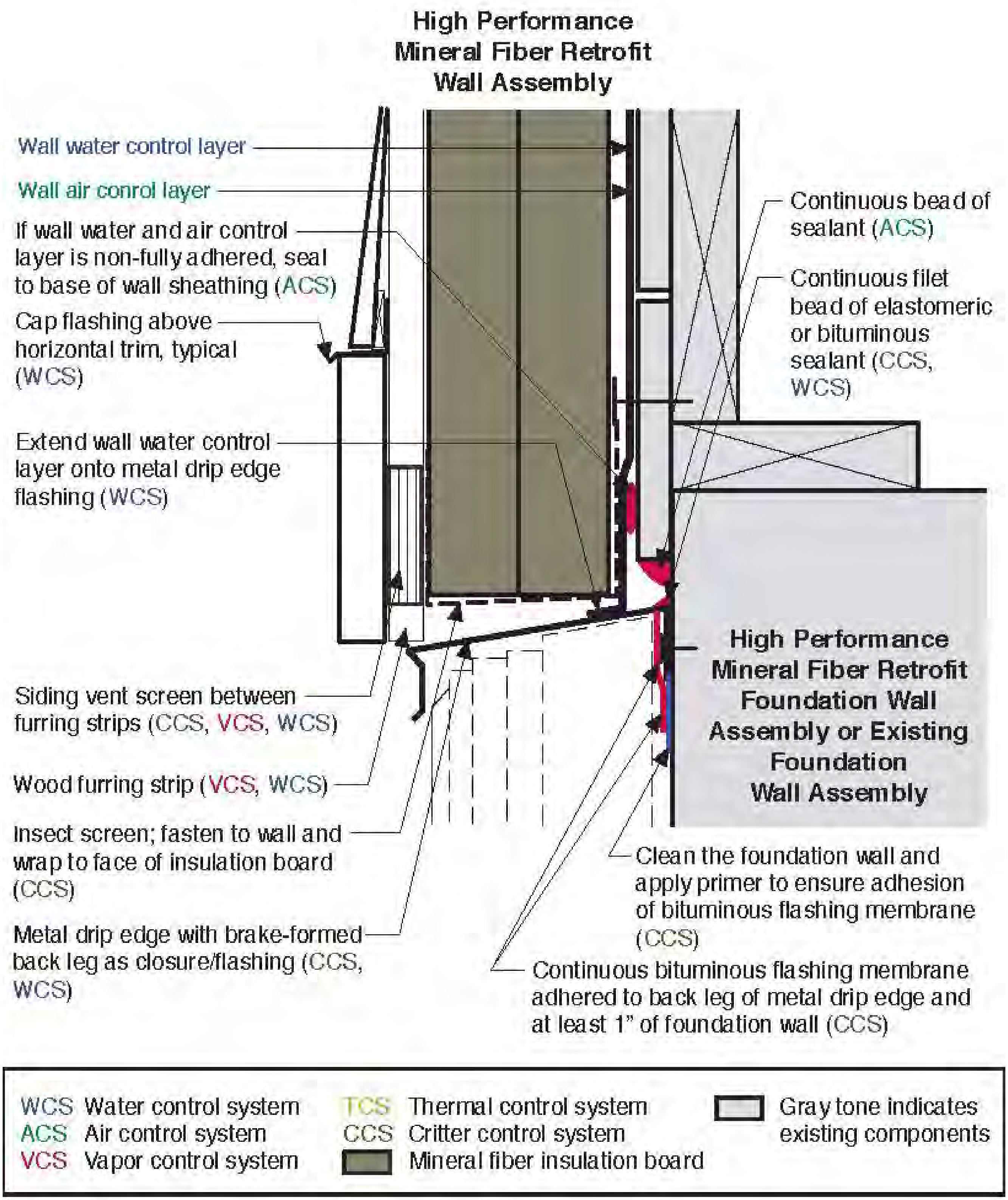


Figure 69. Schematic detail for transition from a high performance mineral fiber retrofit wall assembly to a top of high performance mineral fiber retrofit foundation wall assembly showing how the metal closure/transition flashing is secured and sealed to the foundation wall.

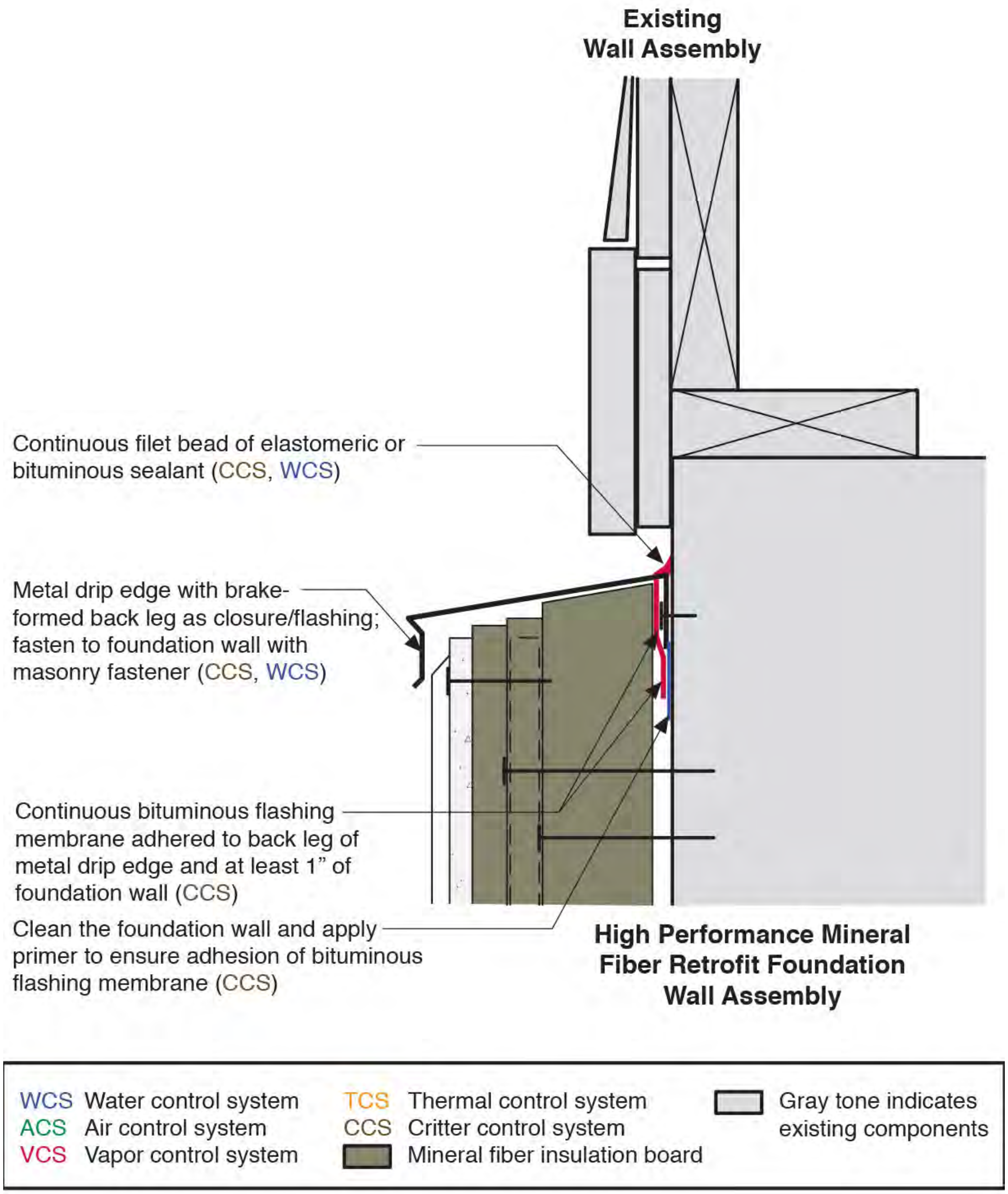


Figure 70. Schematic detail for transition from a non-retrofit wall assembly to a top of high performance mineral fiber retrofit foundation wall assembly showing how the metal closure/transition flashing is secured and sealed to the foundation wall.

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