U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Window Repair, Rehabilitation, and Replacement

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November 2011

Building America

U.S. Department of Energy

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Task 7 Evaluation of Advanced Retrofit Measures

Deliverable 7.5.2 – Window Repair, Rehabilitation and Replacement: Draft Measure Guideline

Prepared for:

Building America

Building Technologies Program

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U.S. Department of Energy

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Definitions

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Building America Program. More information about BA can be found at www.buildingamerica.gov
BSC	Building Science Corporation. More information about BSC can be found at www.buildingscience.com
DOE	U.S. Department of Energy
IGU	Insulated glazing unit
NFRC	National Fenestration Rating Council
SHGC	Solar Heat Gain Coefficient
U-Value	Window Conductance Value
WRB	Water Resistive Barrier

Executive Summary

There is a significant push for energy performance upgrades to existing homes. An important target is often the existing windows. Old single glazed windows have such a low thermal resistance, that the effect of the windows on the overall thermal resistance of the walls can be staggering. Improving the performance of the existing window stock is therefore central to the goal of reducing the energy consumption of the existing building stock.

The following draft measure guideline provides information and guidance on rehabilitating, retrofitting, and replacing existing wood window assemblies in residential construction. This document is intended to be used primarily by contractors and homeowners to help understand the options available to them for safely improving the performance of their existing wood windows.

Deciding which window measure will be most appropriate for the building retrofit project has several facets to consider, including current existing conditions, desired appearance or aesthetic goals, energy performance goals, cost, disruption to occupant, durability risks, historic requirements, or any other project goals or requirements.

The following measures would be the most common approaches to improve the performance of existing wood windows:

	Measure	Description
1	Window Rehabilitation	Repair/rehabilitation of the old window sashes, leaving the original wood window frame in place. Frame and sash rehabilitation to improve water management and air infiltration performance. Measure does not improve conductance or solar gain. Cost can be highly variable depending on window condition and extent of work needed.
2	Exterior storm windows	Recommended installation practice for exterior storm windows, including preparation of existing window preparation to accommodate storm. Measure improves the air infiltration performance, conductance, and solar gain. Additional benefits can be achieved through the use of hard coat Low-E glazing. Cost is relatively low compared to other measures.
3	Interior removable storm windows	Recommended installation practice for removable interior storm windows, including preparation of existing window preparation to accommodate storm. The measure improves the air infiltration performance, conductance, and solar gain. Condensation potential on outer prime window could be a durability concern. Cost is relatively low compared to other measures.
4	Interior permanent	Recommended installation practice for permanent interior storm windows, including preparation of existing window preparation

	storm windows	to accommodate storm. The measure improves the air infiltration performance, conductance, and solar gain. Condensation potential on outer prime window could be a durability concern. Cost is moderate to high compared to other measures depending on options chosen.
5	Window sash modification	Modification of the old window sashes leaving the original wood window frame in place. Frame preparation to accommodate original sashes to accept high performance insulating glass units (IGU). The measure improves the air infiltration performance, conductance, and solar gain, while maintaining the original appearance of the windows. Cost can be moderate to high compared to other retrofit measures.
6	Window sash replacement	Removal of the old window sashes leaving the original wood window frame in place. Frame preparation to accommodate high performance replacement sashes and tracks. The measure improves the air infiltration performance, conductance, and solar gain, while maintaining a similar appearance of the windows. Cost can be moderate to high compared to other retrofit measures.
7	Insert replacement window	Removal of the old window sashes and reconfiguration of window frame to accommodate a replacement window installed in the existing wood window frame. The measure improves the air infiltration performance, conductance, and solar gain. Work can be done quickly with low disruption to the building occupants. Cost can be moderate to high compared to other retrofit measures depending on performance of replacement window chosen.
8	Complete window replacement	Removal of the old window including frame, and reconfiguration of the rough opening to accommodate a new high performance window, following current recommended water management installation techniques. The measure improves the air infiltration performance, conductance, and solar gain. It provides the most control over the window size, location, placement, and integration with other enclosure retrofit measures. Cost is high compared to other retrofit measures and typically a significant disruption to the building occupant.

Introduction

There is a significant push for energy performance upgrades to existing homes. An important target is often the existing windows. Poor window performance can have significant impacts on the overall thermal resistance of the home as well as the overall air tightness of the home. Within the existing housing stock there is an extremely wide range of window types, ages, and conditions. All of these play a factor in the overall energy performance and comfort performance of the home. Along with the various types of windows out there, there is a significant amount of window retrofit attempts that have been done over the years to varying degrees of success. These retrofits are done by homeowners that are trying to address problems that they are experiencing, without having adequate knowledge of how to safely, effectively and economically address their problems.

Old single glazed windows have such a low thermal resistance, that the effect of the windows on the overall thermal resistance of the walls can be staggering. A simple Ua analysis that compares the total wall effective R-value to the window U-value for opaque wall assemblies of varying effective R-values shows just how significant this impact can be.

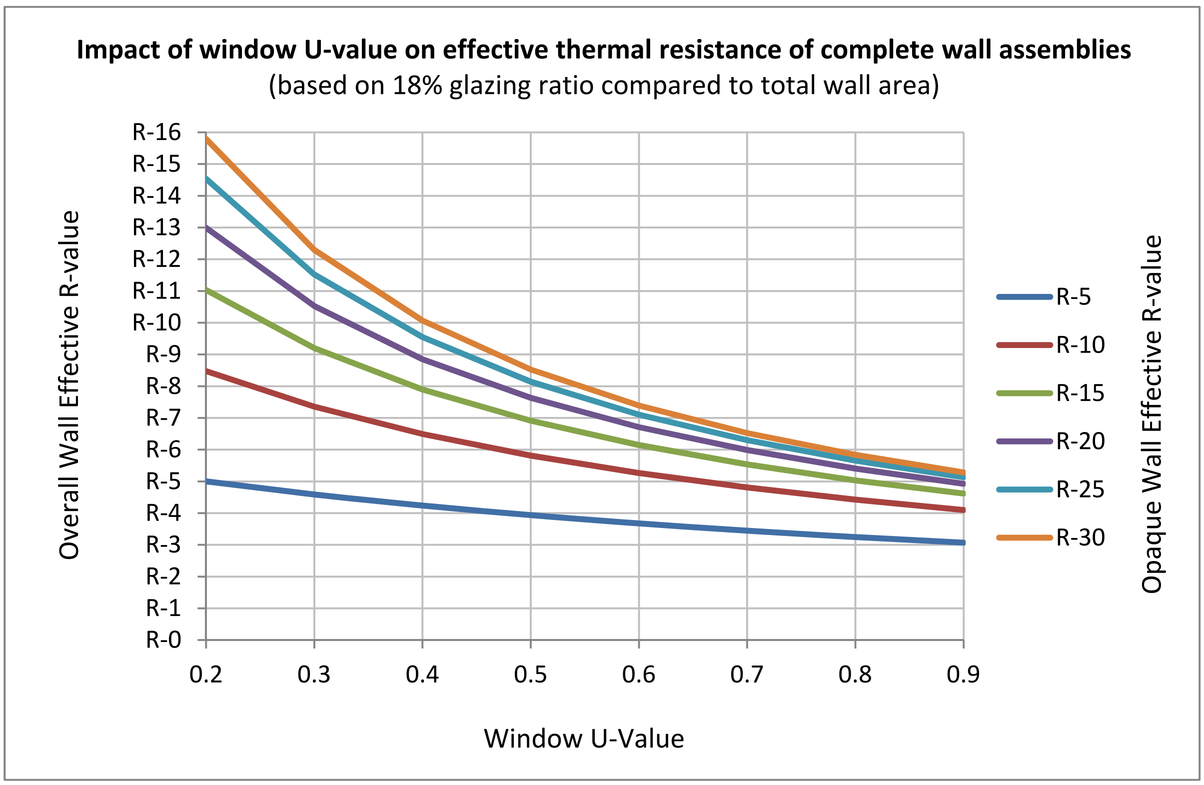


Figure 1. Impact of window U-value on effective thermal resistance of complete wall assemblies

In addition to poor thermal resistance, older windows typically represent a significant portion of the total house air infiltration. The combined effect of poor thermal performance and air infiltration results in windows in being a major component to the total energy use of the building. Improving the performance of the existing window stock is therefore central to the goal of reducing the energy consumption of the existing building stock.

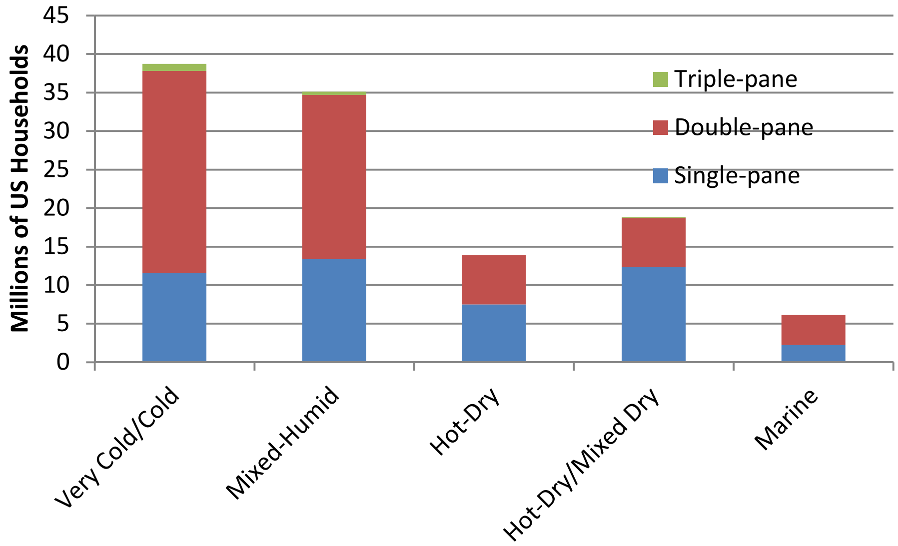


Figure 2. Glazing type (single, double triple) by climate region (RECS 2009)

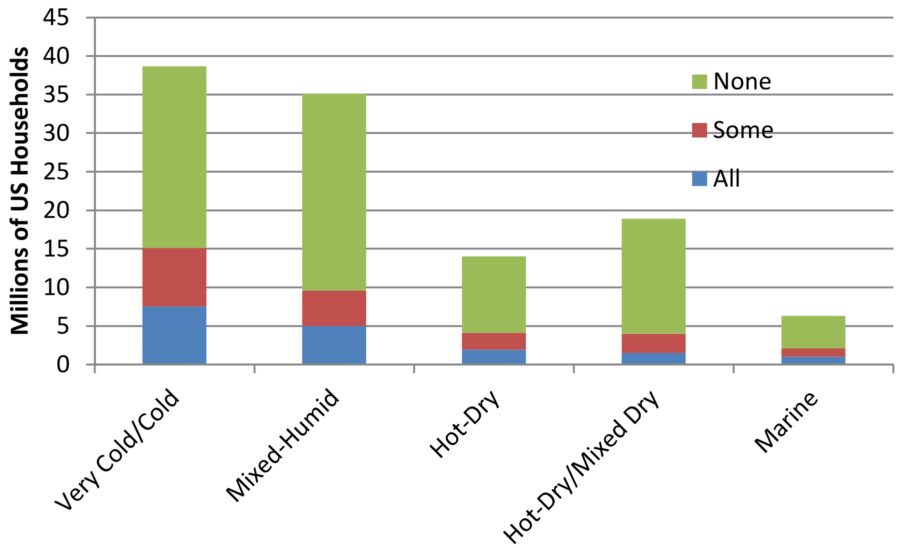


Figure 3. Window replacement history by climate region (RECS 2009)

The following draft measure guideline provides information and guidance on rehabilitating, retrofitting, and replacing existing window assemblies in residential construction. The intent is to provide information regarding means and methods to improve the energy and comfort performance of existing wood window assemblies in a way that takes into consideration component durability, in-service operation, and long term performance of the strategies. The main focus of the document is on proper detailing of strategies to provide a visual reference of how to properly implement these recommendations.

Table 1: Window performance improvement measures

	Measure	Description
1	Window Rehabilitation	Repair/rehabilitation of the old window sashes, leaving the original wood window frame in place. Frame and sash rehabilitation to improve water management and air infiltration performance
2	Exterior storm windows	Recommended installation practice for exterior storm windows, including preparation of existing window preparation to accommodate storm.
3	Interior removable storm windows	Recommended installation practice for removable interior storm windows, including preparation of existing window preparation to accommodate storm.
4	Interior permanent storm windows	Recommended installation practice for permanent interior storm windows, including preparation of existing window preparation to accommodate storm.
5	Window sash modification	Modification of the old window sashes leaving the original wood window frame in place. Frame preparation to accommodate original sashes to accept high performance insulating glass units (IGU).
6	Window sash replacement	Removal of the old window sashes leaving the original wood window frame in place. Frame preparation to accommodate high performance replacement sashes and tracks.
7	Insert replacement window	Removal of the old window sashes and reconfiguration of window frame to accommodate a replacement window installed in the existing wood window frame
8	Complete window replacement	Removal of the old window including frame, and reconfiguration of the rough opening to accommodate a new high performance window, following current recommended water management installation techniques

This document is intended to be used primarily by contractors and homeowners to help understand the options available to them for safely improving the performance of their existing wood windows. The details are simple and clear while providing specific information on building condition review, material preparation, installation, as well as other considerations that would not normally be explained in a general retrofit recommendation.

Do-it yourself homeowners (as opposed to professional contractors) are likely to use this information: therefore, it is important that clear information regarding means and methods be provided, so that retrofits can be executed in a manner which will promote long term durability of the building enclosure systems.

1 Home and/or Document Inspection

Prior to any retrofit work being conducted, it is important that the conditions of the building systems be reviewed.

1.1 Lead and other hazardous materials

Old wood windows and trim are a common location of lead paint in homes. Any work being completed on the window systems should follow all appropriate state and federal laws regarding handling of hazardous materials.

1.2 Site conditions and project staging

The home and site should be reviewed to identify impacts and potential risks with completing the work.

If the work is to be done for the exterior, scaffolding, lifts, ladders, or other means to access work areas may be needed. Work done at height may require fall protection be used. Proximity to adjacent property or vegetation may limit access or create unsafe work areas. Exterior staged work may also damage existing landscaping or vegetation.

If the work is intended to be complete from the interior, consideration should be given to disruption of the occupant, clearances for moving equipment and materials into and out of the space. With any interior work there is always a chance of damage to interior finishes. Appropriate planning and protection is required.

1.3 Identification of water infiltration concerns

Windows, above all other enclosure systems, are a common location of water infiltration issues. It is important to understand the various pathways for potential water infiltration, and identify current water leakage problems. While the details presented in this document are all intended to improve the moisture performance of the window assemblies, it is not intended to address all possibilities, and is not a replacement for inspection and evaluation of the performance of an individual window. Existing problems should be identified, and the strategy chosen that will be most appropriate to address the concern.

Window systems water leaks can be grouped in four general categories:

1. Between the window frame and rough opening
2. Through the joints in the window frame
3. Between the window frame and the operable sashes
4. Between the joints between the glass and the sash frames

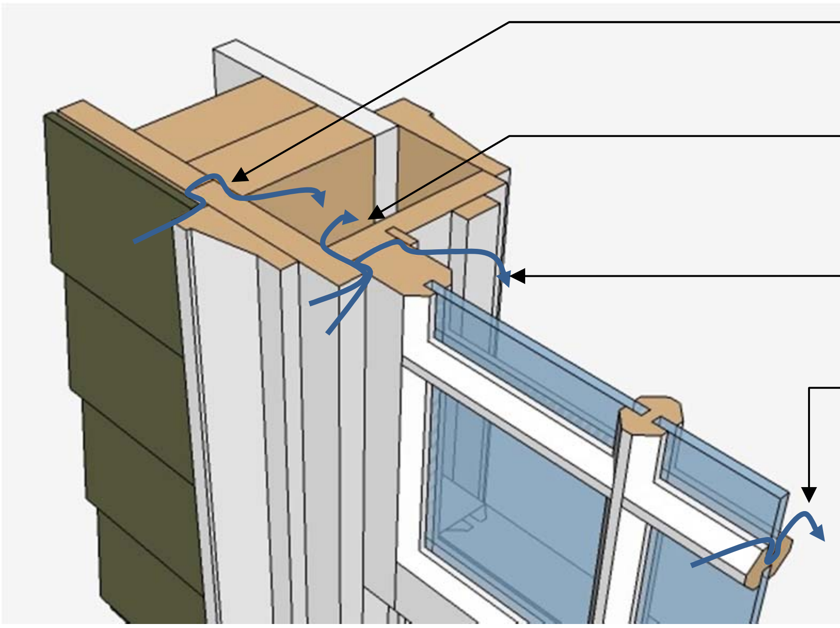


Figure 4. Common window water infiltration pathways

Prior to any work being done, interior and exterior inspection and monitoring of the conditions of the building should be completed. Water staining, peeling paint or wall paper, and staining on trim or floor assemblies below window systems are indications of water infiltration and/or condensation. Leakage between the sashes and the frame and between the glass and the sash is usually marked by water staining on the interior window frame itself. Condensation on the window frames can also lead to staining of the interior finishes. It is important to monitor the questionable area to prevent a false diagnosis of the water management problem being experienced.

Leakage between the window and rough opening or through the joints in the window itself are typically contained within the wall assembly and may go unnoticed, or could develop as staining and peeling paint below the window or damaged flooring.

Other problems such as water infiltration at the window head may be indications of failed or missing head flashing. However, from experience other problems not associated with the window system may in fact be the cause of the water infiltration. Care must be taken to properly diagnose the infiltration pathway.

If it is a known recurring problem, then the infiltration problem must be addressed prior to or in conjunction with the window retrofit work.

If no obvious signs of water infiltration problems exist and the window elements and connection wall components are in good condition, no additional work may be needed. However, as stated above, water infiltration problems are often concealed within wall cavities with no outward signs. This becomes more of a concern if the window retrofit work is being done in conjunction with the addition of cavity fill insulation. With the addition of insulation to the wall cavities, water infiltration problems that previously may have had sufficient drying ability, may now lead to prolonged moisture accumulation. Prolonged moisture accumulation can lead to material deterioration. If there is suspected leakage, then further investigation, including but not limited to thermal scans, moisture content measurements, and cutting of investigation holes below window assemblies to look for signs of moisture problems would be recommended.

Unless the problem is obvious, it may be prudent to contact someone with experience with diagnosing water infiltration problems prior to proceeding.

1.4 Identification of deteriorated or damaged materials

If damage to existing elements is noted, the materials should be removed and replaced as part of the retrofit. Certain elements will be more critical to the proper implementation of the chosen strategy.

The window sill is arguably the most important element of the window assembly, as water will drain downward by gravity either into the wall (e.g., hole through sill) or directly onto the wall (failure of the sill extension). For all proposed measures in this document excluding complete window replacement, the condition of the sill is critical to the performance of the measure. Cracked or rotting sills need to be replaced prior to any work being done.

Figure 5. Failed window sill with replacement window installed

The window frame including the exterior casings are the next most critical element. If the casing is deteriorating, its replacement may be warranted. This should not be confused with the exterior trim, which is often installed as a decorative element on top of the casing. Deteriorating trim may not affect the water management performance of the window however; it may be an indication of other problems and generally creates an aesthetic problem.

Depending on the measure being examined, the condition of the window sashes may or may not be a concern to the performance of the measure taken. For window rehabilitation, sash retrofit, or interior storm retrofit, the condition of the sashes is critical to the performance of the window. For exterior storms, the sashes are more protected from the elements, and the condition is less important from a water management perspective, yet still critical from an energy and condensation resistance perspective. For sash replacement, window insert, or full window replacement, the condition of the sash is irrelevant, as they are will be removed. For this reason, windows with severely deteriorated sashes may be better candidates for the latter retrofit measures.

1.5 Identification of user comfort concerns

As part of the initial review, associated comfort concerns relating to the window systems should be evaluated. Window air leakage is a significant source of occupant comfort problems. Unlike other common enclosure leakage pathways, window air leakage is commonly very direct, resulting in distinct drafts.

Radiation effects from cool glass surfaces are another common comfort problem. This is more difficult to identify, as the tendency is to assume that the discomfort felt when near a window is from air leakage or drafts. This results in some misdiagnosis of the dominant function. A general recommendation is to increase the interior surface temperature of the window system to reduce the radiant heat transfer between from the occupant to the window. This is commonly done by adding additional panes of glass (or films) to create an insulating air (or other gas) space between the layers.

Contractor/Homeowner Safety

US EPA: Lead in Paint, Dust, and Soil: Renovation, Repair and Painting (RRP)
http://www.epa.gov/lead/pubs/renovation.htm

OSHA: Fall Protection (if window work is to be done at height, from the exterior)
http://www.osha.gov/SLTC/fallprotection/index.html

2 Trade Offs

2.1 Measure Selection Criteria

Deciding which window measure will be most appropriate for the building retrofit project has several facets to consider. The following is a list of the proposed measures and some key points to consider with each.

Measure 1: Window Rehabilitation

The first measure looks to improve the existing performance of the window without significant modification or addition to the window. This measure has practically no impact on the appearance of the window as the modifications are all concealed and minor. The work focuses around adding gaskets and seals at common air infiltration locations to improve the overall air tightness of the window assembly. Some methods are covered in detail by Davis (2007).

Key points:

1. Maintains both the interior and exterior appearance of the building. Important strategy where historic preservation is required.
2. This work is best done in conjunction with other measure strategies, including interior and exterior retrofit approaches (such as the addition of interior and exterior storms).
3. This work will improve the energy performance of the assembly by reducing air infiltration; however it will not improve the thermal conductance of the window system.
4. This work will not address any current condensation problems that may be occurring on the window system.
5. If sash weights are maintained, other potential energy and durability considerations may not be addressed, such as air leakage and thermal conductance losses at weight pockets.
6. Cost can be highly variable depending on the size, complexity, condition, and value of the windows.

Measure 2: Exterior Storm Windows

A common and long standing window retrofit approach is the addition of storm windows to the exterior of the existing window frames. The most common design is a triple track window that combines a screen with operable upper and lower sashes. Traditionally, storms have been single glazed with clear glass, but more recently, hard coat low-E glass has become available.

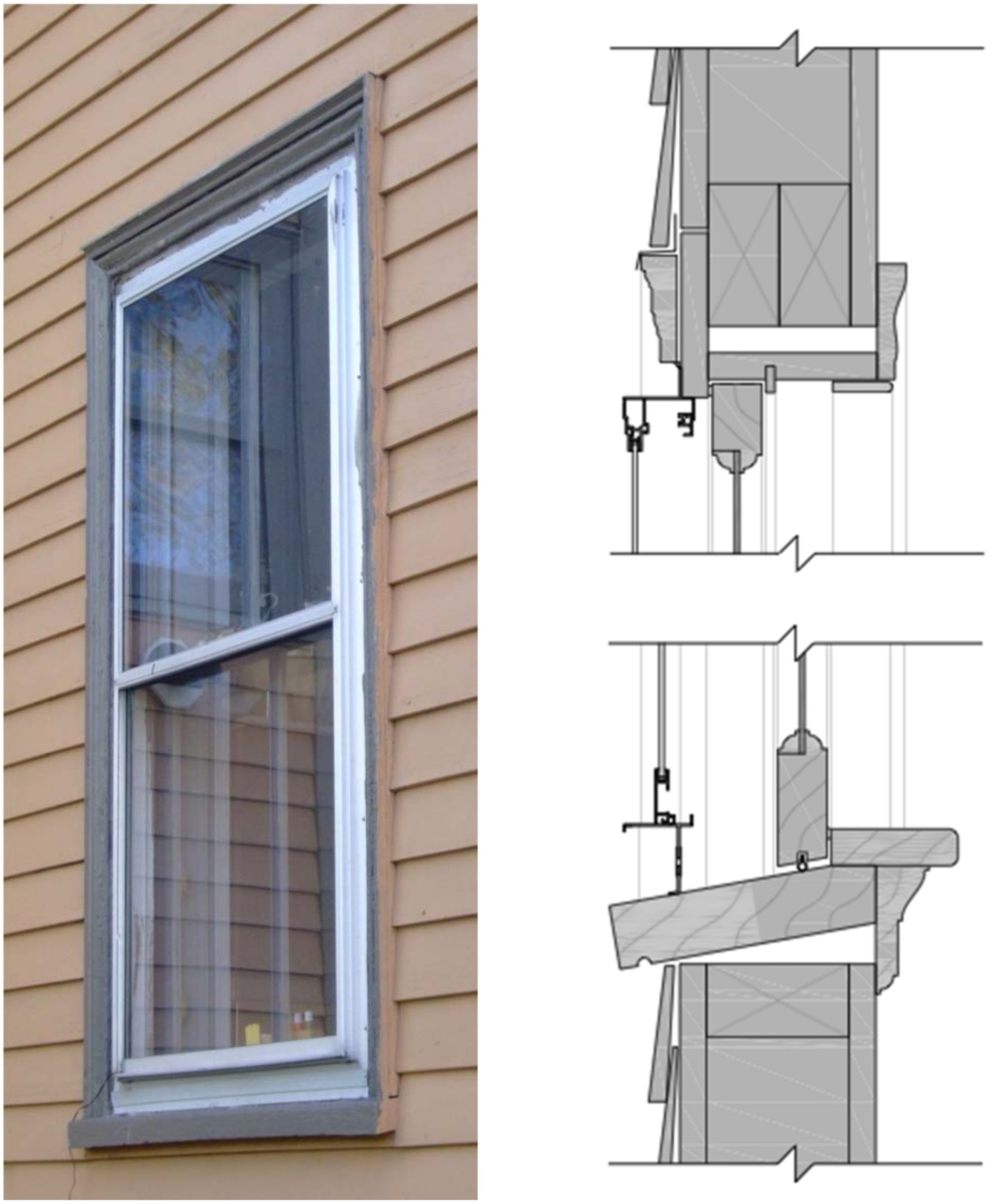


Figure 6. Exterior storm window example

Key points:

1. Maintains interior appearance of the window; however the exterior appearance will change. The addition of exterior storms is typically acceptable for most historic preservation projects.
2. The measure is reversible. This is an important consideration for historic preservation.
3. This work should be done in conjunction with the rehabilitation work set out in *Measure 1 – Window Rehabilitation*.

4. This work will improve the energy performance of the assembly by reducing air infiltration, as well as thermal conductance through the assembly. Hard coat low-E storm window glazing can provide additional thermal benefits.
5. This work will reduce the potential for interior condensation problems on the window system, though it adds some risk of interstitial condensation between the original window and the exterior storm (generally an aesthetic/operational concern, as opposed to a durability concern).
6. Cost is low to moderate depending on system chosen.

Measure 3: Interior Removable Storm Windows

An alternate to exterior storm windows is removable interior storm windows. These can take a wide variety of forms, from films adhered to the interior of the window jambs, to site built frame wrapped with films that are friction fit into the window opening, to pre-manufactured fixed or operable glass or acrylic lites in a thin metal frame. The pre-manufactured versions are often installed via a metal angle and magnetic track fastened to the window frame.

Figure 7. Interior removable storm window sample

These systems are typically less permanent, and intended to be installed on a seasonal basis (usually during the winter in cold climates), as most of them limit the option of opening or closing the window after installation.

Key points:

1. Maintains the exterior appearance of the window; however the interior appearance will change. The addition of removable interior storms is also often acceptable for historic preservation projects.
2. The measure is reversible. This is an important consideration for historic preservation.
3. This work should be done in conjunction with the rehabilitation work set out in *Measure 1 – Window Rehabilitation*.
4. This work will improve the energy performance of the assembly by reducing air infiltration, as well as thermal conductance through the assembly.

5. This work will reduce the potential for interior condensation problems on the window system, though it creates a risk of interstitial condensation between the interior storm and original window (both an aesthetic/operational concern, as well as potential for durability risks).
6. Typically a seasonal installation (requires removal and storage during the summer months).
7. Could impact egress
8. Cost is low to moderate depending on system chosen.

Measure 4: Interior Permanent Fixed Storm Windows

In certain cases, there is no urgent need for seasonal changeover, and a more permanent solution is desired. In these cases, permanent interior storms can be added. There are two approaches with this solution: 1) installation of a fixed glazing unit, 2) installation of an operable unit.

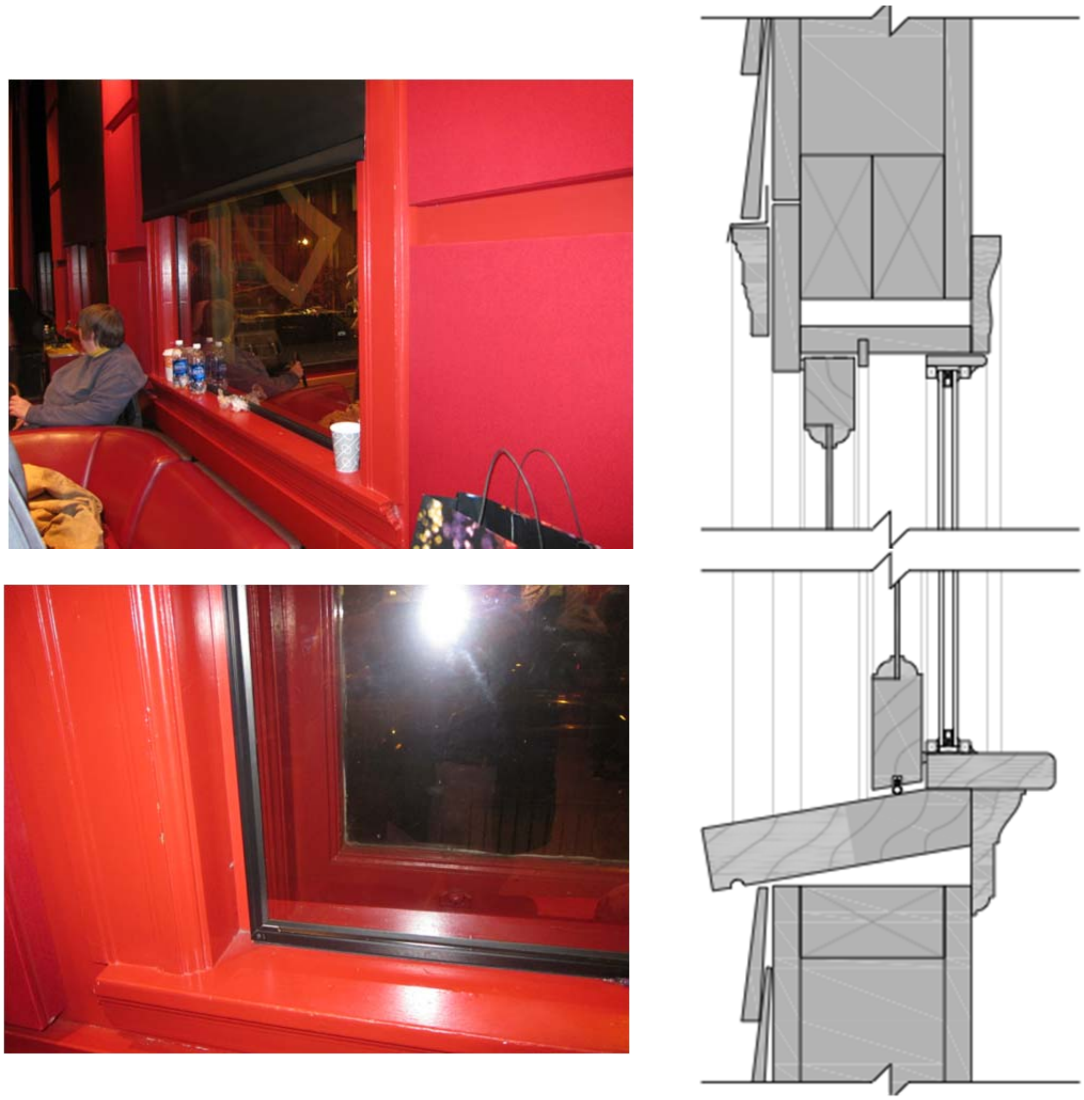


Figure 8. Interior storm window on double-hung original window

Fixed glazing units meet requirements if operation of the window is no longer needed. Fixed units can typically be made more airtight, and will have thinner frame profiles, so that the amount of vision area is not impacted. Also, they can often be installed in a manner that has minimal impact on the interior appearance of the window, so that interior aesthetics can be more closely maintained. An operational concern with this approach is that cleaning of the windows is no longer possible from the interior, and may be difficult from the exterior as well. While the more common approach has been to use single glazed lites (often clear acrylic for retrofits by homeowners), there is an option to use double and triple glazed IGUs (insulated glazing units) as well, for increased energy performance.

Alternately, if an operable window is required, a new window frame and sash could be installed to the interior of the original window. Since the window is not required to address the water management needs of the system, lower standards may be acceptable for the window frame. The ideal frame would be one that would have a thin profile frame, for minimal disruption to the vision area of the rough opening, and have excellent air tightness. These would be the critical areas of performance for these windows. This is an area of potential product development for window manufacturers. The benefit of this approach is that the windows can still be operable (though two sashes would be needed to be opened), allowing for egress, natural ventilation, and easier cleaning. The cost however will be roughly the same as for replacement windows, and will similarly reduce the vision area of the window. This option will be limited based on the width of the wall assembly and the depth of the window returns. In addition, in warmer climates and/or unshielded solar orientations, heat buildup may begin to become a concern, and should be studied in more detail.

Key points

1. Maintains the exterior appearance of the window; however the interior appearance will change. The addition of permanent interior storms may be acceptable for historic preservation projects.
2. The measure is reversible. This is an important consideration for historic preservation.
3. This work should be done in conjunction with the rehabilitation work set out in *Measure 1 – Window Rehabilitation*.
4. This work will improve the energy performance of the assembly by reducing air infiltration as well as thermal conductance through the assembly. The use of double or triple glazed units will work in conjunction with the existing window to provide better performance than just the double or triple glazed IGU’s.—unclear what this sentence means.
5. This work will reduce the potential for interior condensation problems on the window system, though it creates a risk of interstitial condensation between the interior storm and original window (both an aesthetic/operational concern, as well as potential for durability risks).
6. Permanent installation
7. Could impact egress, ventilation, and cleaning (concern for fixed units).
8. Could impact vision area of window (concern for operable interior storms)

9. May not be possible given interior dimension constraints.
10. Cost could be moderate for interior fixed IGU, to high for operable interior storms (similar to the cost of a replacement window).

Measure 5: Window Sash Modification

For existing wood windows, there is a potential in some cases to retrofit the existing wood sashes to accept new double glazed sealed units. This is a good approach if there is a demand to maintain the original appearance from both the interior and the exterior (i.e., historical applications).

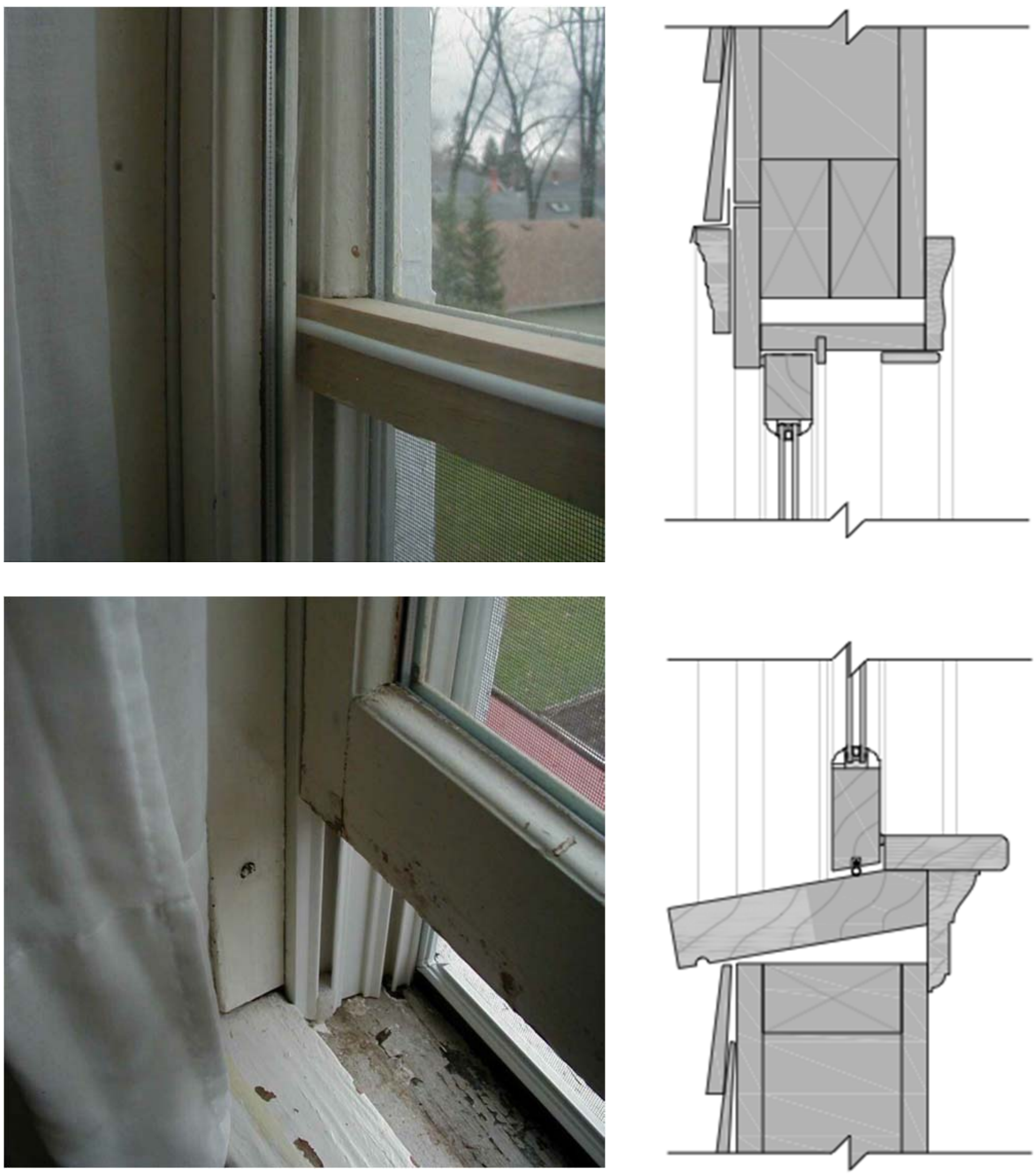


Figure 9. Commercially available window sash modification, sill and meeting rail details

Key points

1. Maintains both the interior and exterior appearance of the building. Important strategy where historic preservation is required.
2. This work may be done in conjunction with other measure strategies including interior and exterior retrofit approaches (such as the addition of interior and exterior storms).
3. This work will improve the energy performance of the assembly due to air infiltration as well as thermal conductance through the sashes; however, it will not improve the thermal conductance of the window frame.
4. This work will reduce the potential for interior condensation problems on the window system.
5. If sash weights are maintained, other potential energy and durability considerations may not be addressed, such as air leakage and thermal conductance losses at weight pockets.

Measure 6: Window Sash Replacement

It is an option to replace the window sashes while leaving the existing frame in place. This is a good option if there is a desire to maintain the original appearance, but the existing sashes cannot accommodate new IGUs, or are in sufficiently poor condition to warrant replacement in lieu of rehabilitation. The replacement sashes must be custom built for the frame opening, as there is very little opportunity for adjustment. Window frame condition and geometry can be a factor. The window jambs however need to be very close to parallel to allow for smooth operation and to prevent unwanted air leakage between the frame and sash. If the replacement sashes are made from wood, the windows can be out of square to a certain degree since the top and bottom of the sashes can be cut to match the angles.

Figure 10. Sash replacement, showing out of square opening and requirement for sash extension

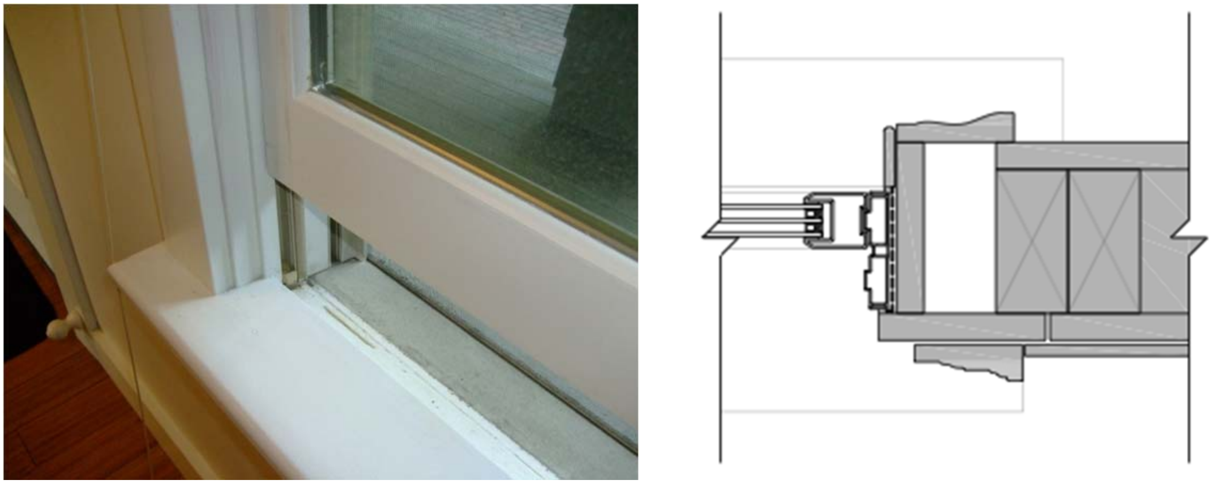


Figure 11. Window sash replacement jamb liners

Key points:

1. Affects the interior and exterior appearance of the building (though the effect could be minimal depending on how closely the replacement sashes can match the existing sashes). The replacement of sashes may be acceptable for historic zoned projects.
2. The measure is not reversible.
3. This work should be done in conjunction with a partial rehabilitation (window frame only) as set out in *Measure 1 – Window Rehabilitation*.
4. This work will improve the energy performance of the assembly by reducing air infiltration, as well as thermal conductance through the assembly. The replacement sashes can accommodate up to triple glazed IGUs, allowing for significant improvements in thermal performance.
5. This work will reduce the potential for interior condensation problems on the window system.
6. Work will likely replace the sash weight and balance system (with a spring-loaded jamb liner), allowing for retrofit of the weight pockets and voids around the window frame.
7. Work requires tight tolerances and is workmanship sensitive; significant air leakage can result if tolerances are too loose
8. Expensive option (equal to or more expensive than an equivalent replacement window).

Measure 7: Insert Replacement Window

For window sashes that are in poor condition and/or the cost of sash rehabilitation, retrofit, or replacement is too high, a common retrofit approach is to install a replacement window in the existing wood window frame. The benefit to this is the speed of installation (very little rehabilitation of the existing window frame is needed), low disruption to the homeowner (the installation does not overly affect interior or exterior trim and finishes), and adjustment ability (while the windows do need to be custom ordered to fit the existing window frames, the tolerances do not need to be as tight or the measurements as precise as the replacement sash option). The result is a completely new window assembly. A down side to this approach is that the amount of vision area of the windows is reduced by the addition of an additional window frame with sashes. For already small window openings, this reduction may be significant and undesirable. For larger windows, the impact will be less noticeable.

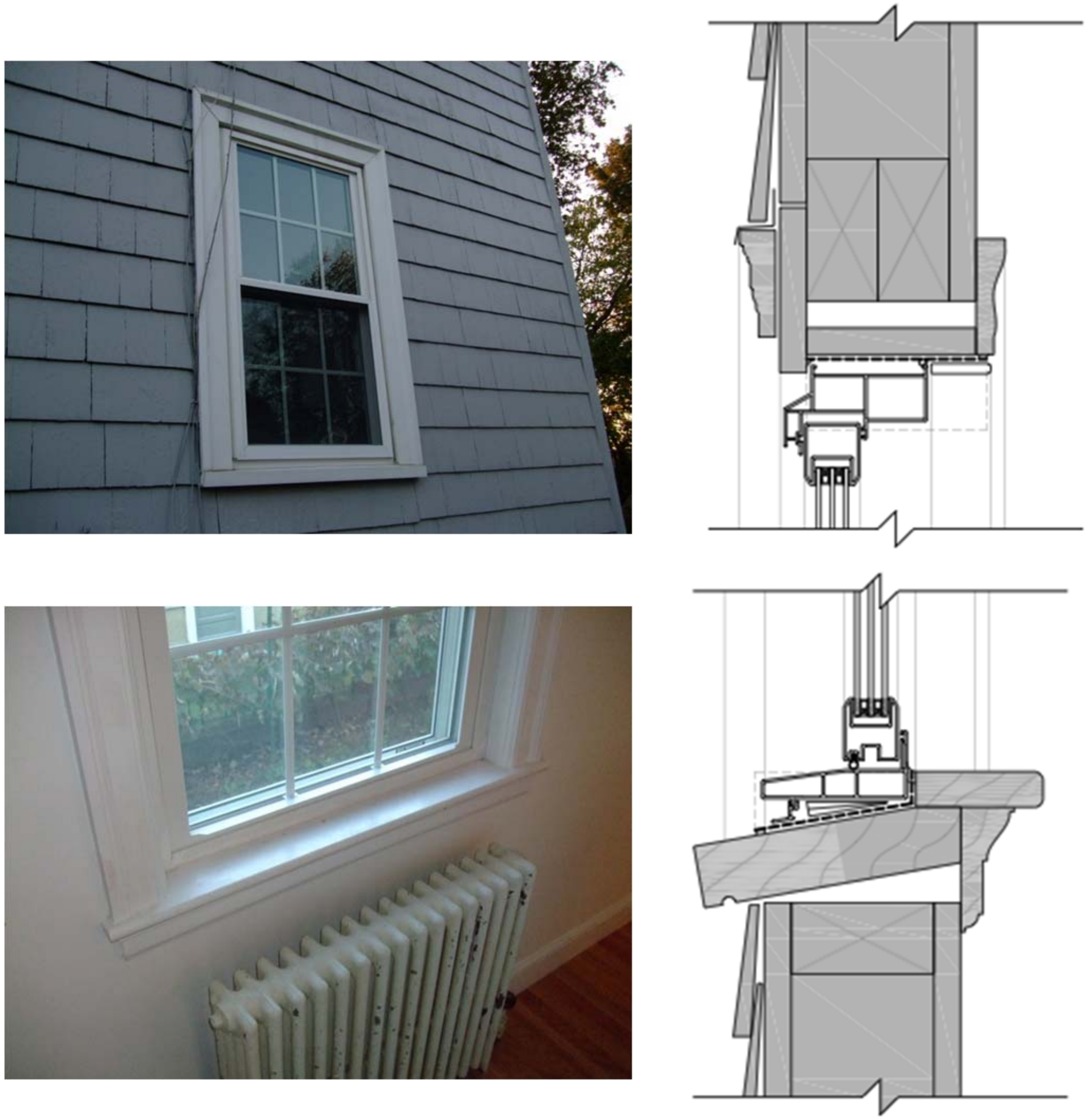


Figure 12. Insert replacement vinyl frame window

Key points:

1. Affects the interior and exterior appearance of the building. Typically not an acceptable approach for historic zoned projects.
2. The measure is not reversible.
3. This work should be done in conjunction with a partial rehabilitation (window frame only) as set out in *Measure 1 – Window Rehabilitation*.

4. This work will improve the energy performance of the assembly by reducing air infiltration, as well as thermal conductance through the assembly. The replacement windows can be high performance units (e.g., U<0.25, such as triple glazed with high performance pultruded fiberglass frames), allowing for significant improvements in thermal performance.
5. This work will reduce the potential for interior condensation problems on the window system.
6. Existing sash weight and balance system will be abandoned, allowing for an air sealing and insulation retrofit of the weight pockets and voids around the window frame.
7. Windows must be custom ordered to size; however, they do not require as tight an installation tolerance as the replacement sash option.
8. Vision area is reduced.
9. Expensive option.

Measure 8: Complete Window Replacement

Ultimately the existing window can be completely removed and replaced with a new window. The benefit of this measure is that the window installation details can be brought up to current window installation standards. This approach is typically most common with more extensive building retrofits, as it generally requires disturbance to both interior as well as exterior finishes. When combined with a more extensive energy retrofit that includes the addition of exterior insulation to the building, it provides the most freedom for design and placement of the window. The windows can be installed in place with the framing or be pushed towards the exterior to line up more traditionally with the plane of the siding.

Figure 13. New window rough opening framed with and extension box to allow for the addition of exterior insulation

Key points

1. Affects the interior and exterior appearance of the building. Typically not an acceptable approach for historic zoned projects.
2. The measure is not reversible.
3. This work requires complete removal of the window sashes and frame and a reconstruction of the window rough opening.
4. This work will improve the energy performance of the assembly by reducing air infiltration, as well as thermal conductance through the assembly. The replacement windows can be triple glazed with high performance pultruded fiberglass frames allowing for significant improvements in thermal performance.
5. This work will reduce the potential for interior condensation problems on the window system.
6. Existing sash weights are removed as part of the frame removal, allowing for the thermal and air bypass in these locations to be addressed.
7. Windows sizes can be adjusted as necessary/desired.
8. Freedom for window placement in the plane of the wall: if the wall is being made thicker in a deep energy retrofit (addition of rigid foam insulation), the window can be detailed at the plane of the original wall (“Innie” window) or at the face of the foam (“Outie” window).
9. Expensive option.

2.2 System Interaction

It is important to understand the system components and connection/interaction details with the wall enclosure, as well as the functions of a traditional wood window in order to properly apply the various measure recommendations.

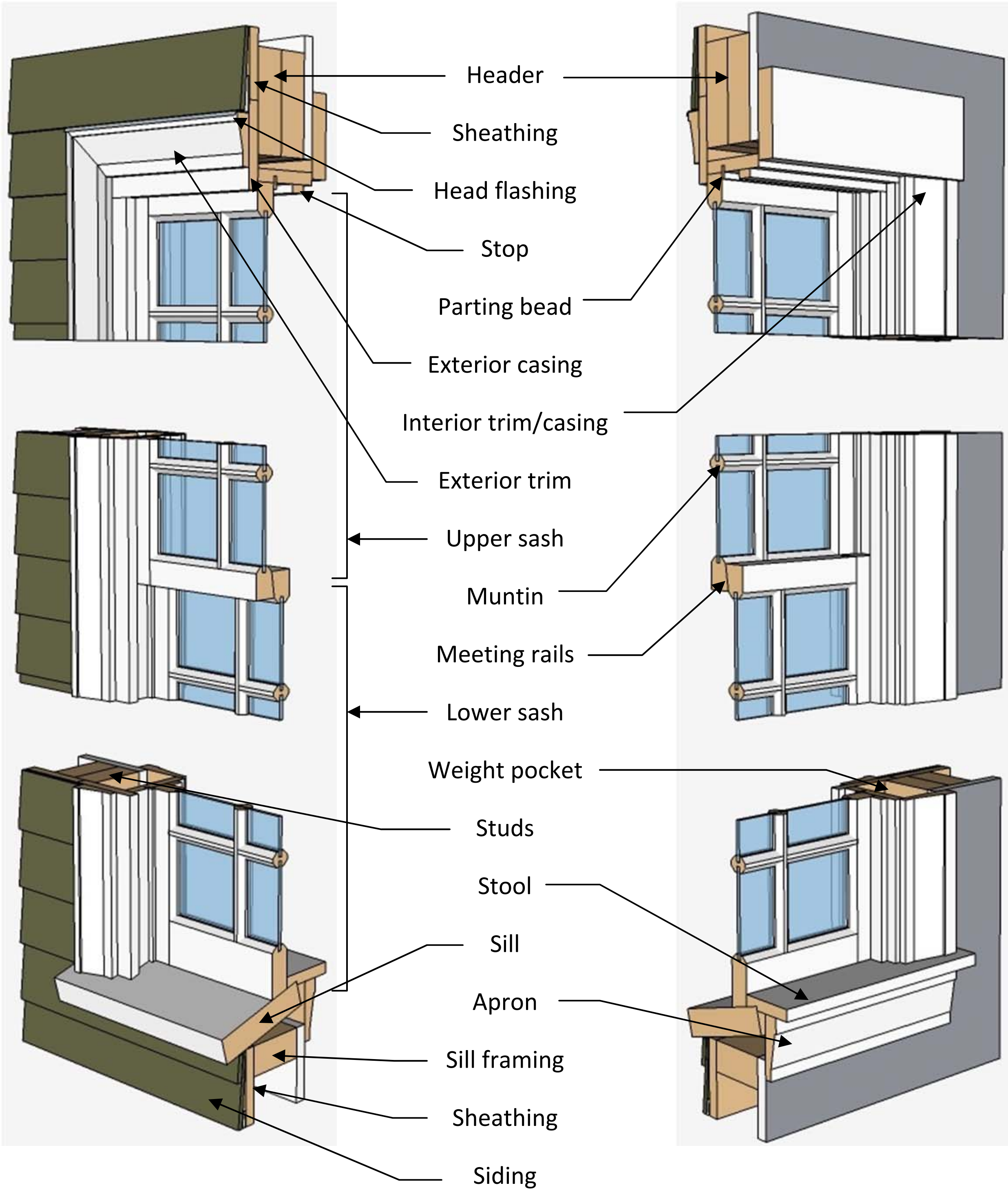


Figure 14. Window components

Window Water Management Functions

Traditional double hung wood windows function by shingle lapping the various components of the window assembly (including its surrounding trim components).

For wood framed walls, a metal flashing is common at the window head to shed water from the siding out over the face of the trim and exterior window casing. The casing is shingle lapped over the upper sash. The upper sash is always installed outboard of the lower sash. The lower sash sits on the window sill. The window sill projects out over top of the siding or cladding element.

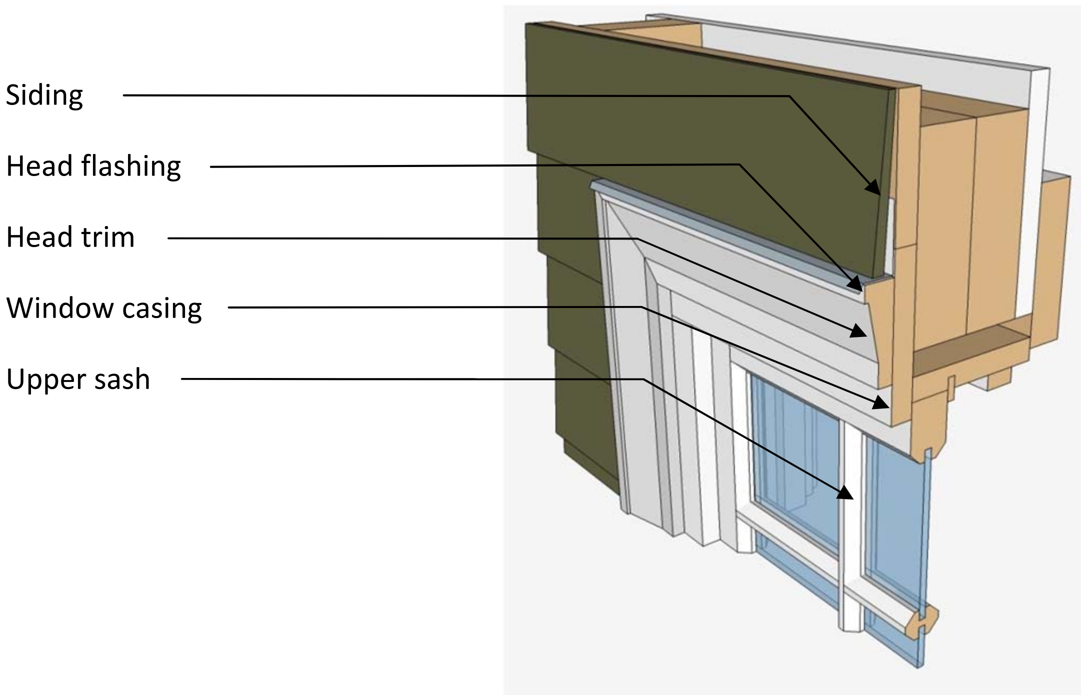


Figure 15. Window head component lapping

At the jambs, the water management is generally from a similar concept of overlapping of materials. The wall siding overlaps onto the exterior window casing, and the casing overlaps the sashes. Since the lapping at the jambs cannot wholly rely on gravity to prevent water from being able to infiltrate into the enclosure, sealant are often used between the siding and the window trim to limit the potential for infiltration.

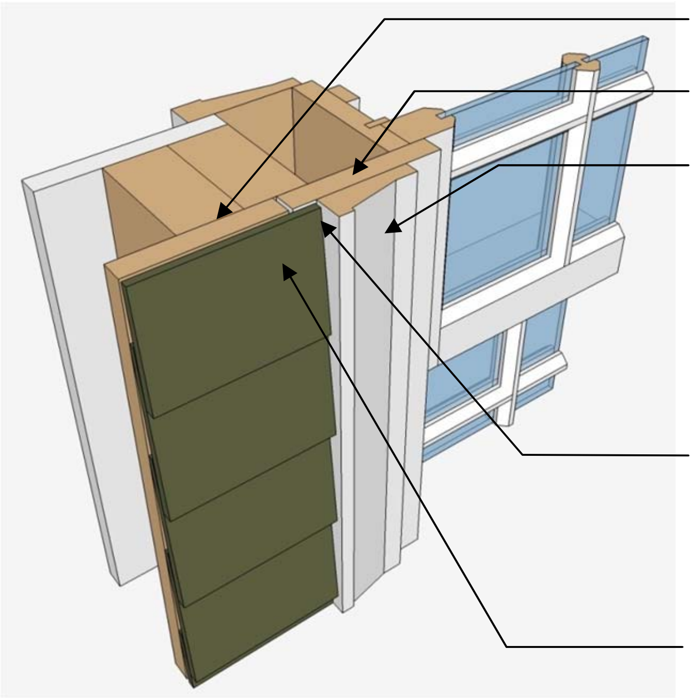


Figure 16. Window jamb component lapping

Similar approaches are used in mass masonry walls with a few slight changes to the concept. At the window head, the window frame is set back from the face of the masonry (approximately 1 wythe), so the head flashing is traditionally eliminated. At the jambs, the window casing either butts directly up against the brick, or is overlapped by the outer wythe with the joint caulked. The sill is shingle lapped over a stone, concrete, or brick sill. The masonry sill is usually sloped to the exterior.

Figure 17. Wood window sill on top of masonry sill

The continuous sloped wood sill is a critical element to the performance of wood windows. The sill provides a tremendous amount of protection for the wall assemblies below. In essence, the wood sill acts similar to a sloped pan flashing that is part of current recommended new construction practice. In some cases, a pan flashing may have been installed below the window frame; however, this is by no means guaranteed for all construction, and tends to be more common for masonry buildings then for wood framed buildings. Unfortunately, these sub sill flashings often deteriorate over time and lose their effectiveness.

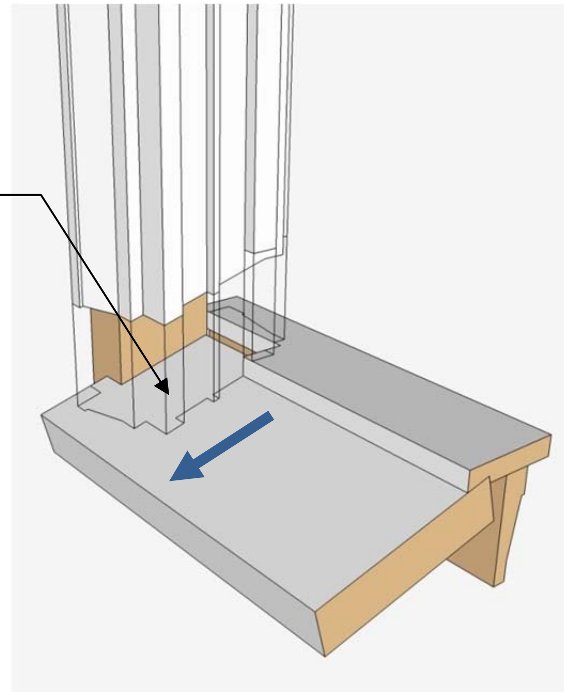


Figure 18: Window sill component lapping

Critical Takeaway

The condition of the existing wood window frame is critical to the water management performance for all proposed measures except for complete window replacement. Damaged or deteriorating window sills must be repaired or replaced.

Window Air Leakage

There are multiple pathways for air leakage through a window frame. The most common are between the meeting rails, and between the sashes and the frame. Since these are the operable elements of the window they typically cannot be too tight, as this would affect operation. In addition, repetitive operation results in a wearing of materials at the interface, increasing dimensional tolerances

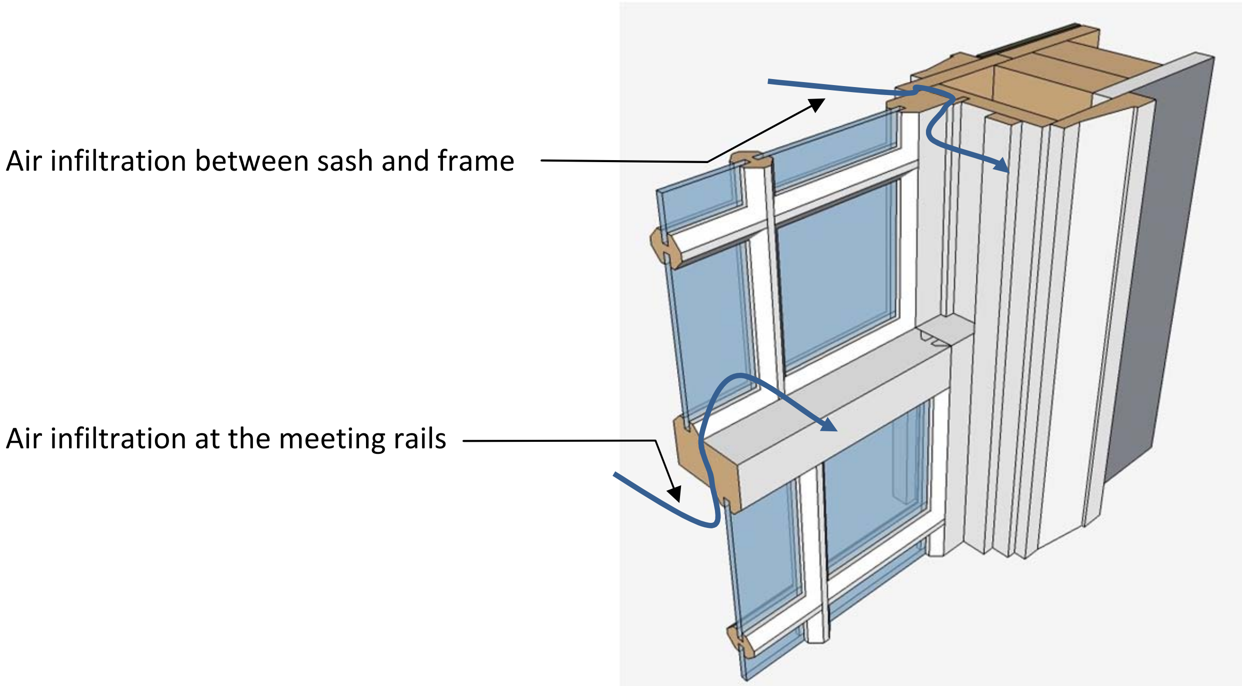
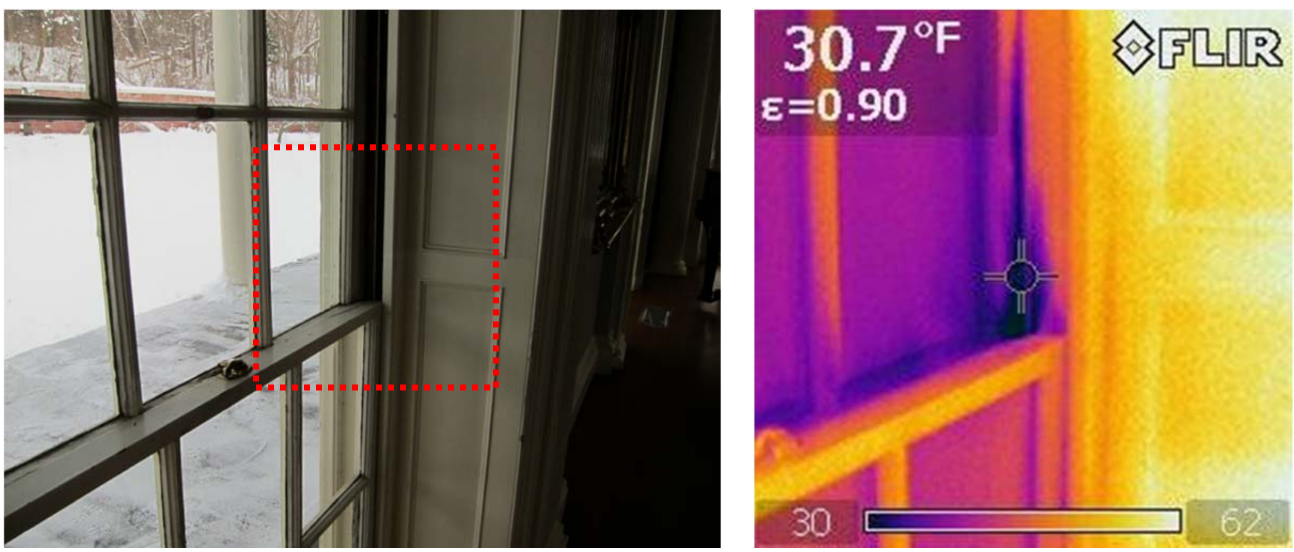


Figure 19. Window air leakage pathways

In addition to the meeting rail and jamb air leakage, leaks can also be found at the head and sill, as shown in Figure 20.



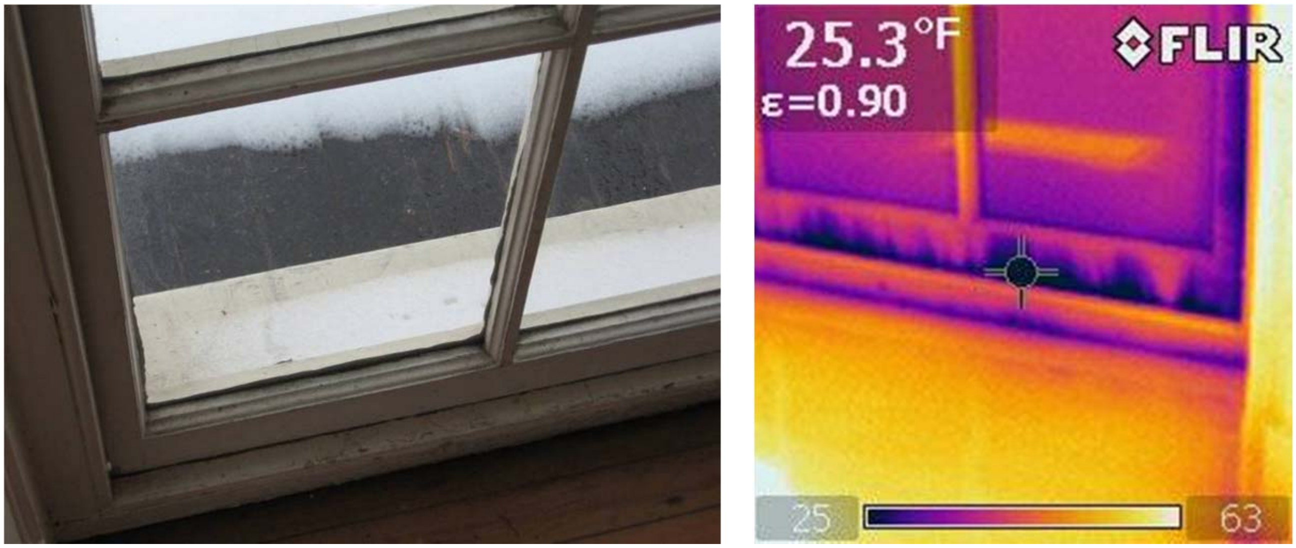


Figure 20. Infrared images of window air leakage (depressurization test)

In a typical window installation, there are void spaces between the window frame and the window rough opening. The gaps are also common areas of uncontrolled air leakage; however, the pathway is not as direct, and therefore not as significant from a user comfort perspective.

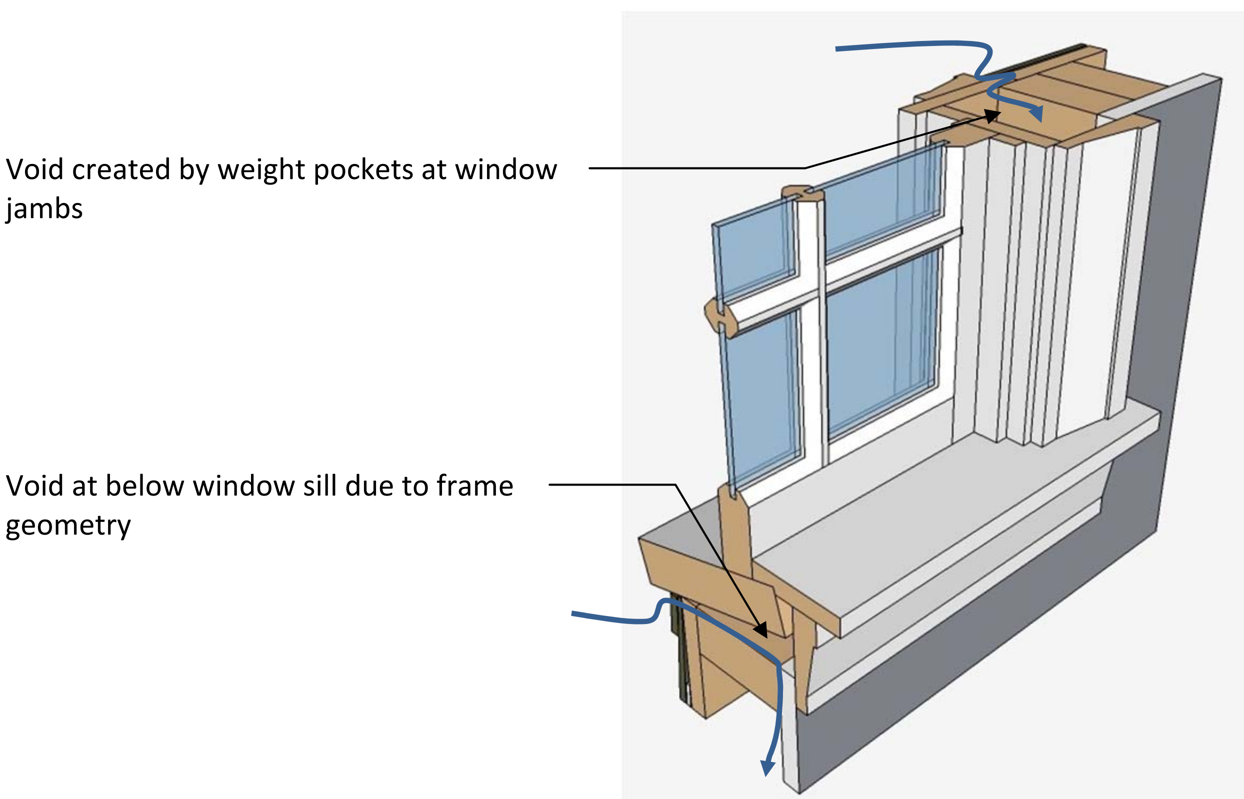


Figure 21: Window to wall interface air leakage pathways

These voids are typically disconnected from the framing cavities of wood framed walls, and therefore would not be filled during common cavity fill insulation retrofits, such as blown in cellulose. Specific measures need to be taken to address the air leakage pathway and associated concerns of conductance losses.

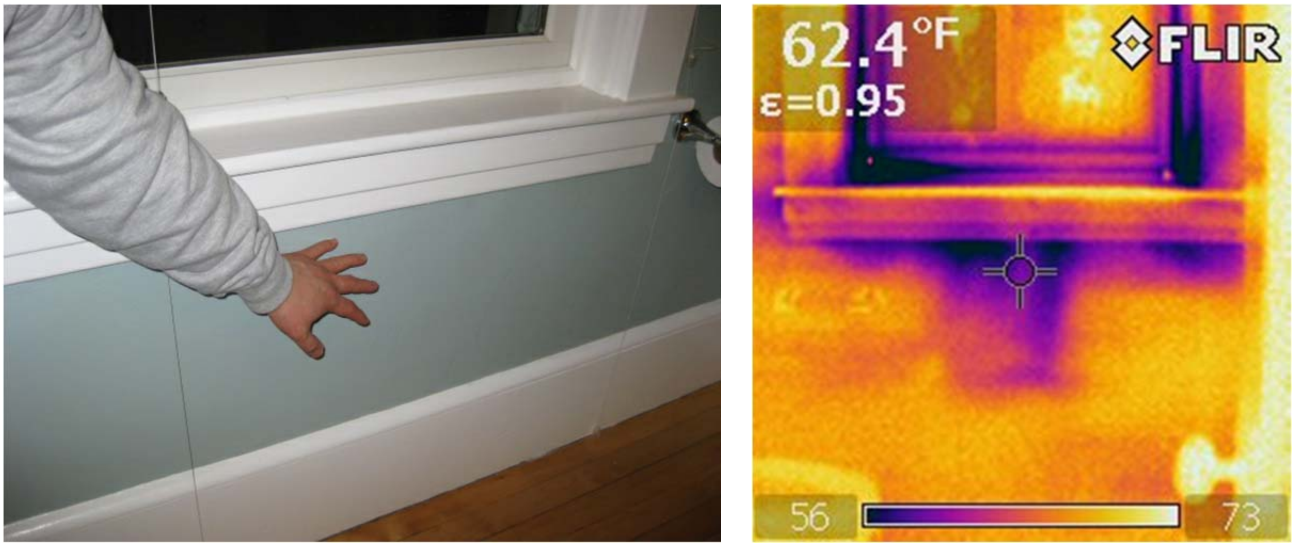


Figure 22: Infrared images of window air leakage at window interior apron trim

The largest of the voids are typically at the weight pockets, created to house the sash counter weights. The weights are connected to the sashes through either ropes or chains that run from the sash to a pulley near the top of the window jamb and into the weight pocket. When combined with an interior storm window (both temporary and permanent), the pulley weight pockets can create a condensation potential (discussed below), as they are a pathway for movement of interior air into the space between the existing window and the new interior glazing element. Often, the sash weights can be eliminated by retrofitting the windows a spring-loaded tape balance. Abandoned weight pockets are a source of energy loss from both a conductance perspective as well as from uncontrolled air leakage. Even when they are insulated, it is often done in a “blind” manner (inserting insulation through an access hole in the jamb), resulting in poor installation quality.

Figure 23. Sash weight pockets, showing abandoned sash weight and insulation installation

It is recommended that the spaces be filled with spray polyurethane foam to address all of these concerns. If done, the weights should be removed prior to filling the void. In addition to the weight pockets, there are typically gaps between the window frame and the rough opening at the head and sill. It is recommended that these voids be filled as well.

Critical Takeaway

Air leakage associated with window systems is from two general sources 1) leakage through the window system (such as between the frame and sashes) and 2) leakage between the frame and the rough opening. Most of the measures only directly impact the leakage through the frame. Consideration should be given to the spaces between the frame and the rough opening when planning the retrofit. Abandoning and insulating weight pockets can have a significant effect on the overall performance.

Interstitial Condensation

The addition of interior or exterior glazing elements to the original window creates a potential for the formation of condensation between the two glazing elements. The placement of the interior or exterior of the window creates an insulating air pocket, resulting in the outer glazing element to be at a lower temperature at wintertime conditions. This increases the chance of condensation forming, if interior moisture laden air is able to infiltrate into the space.

Figure 24: Examples of condensation problems with interior storm retrofits

Condensation at exterior storms is typically not a durability concern: instead they are mostly an operational and aesthetic concern, as it disrupts the clear vision out through the window. In addition, exterior storm windows are typically made of moisture-insensitive materials (aluminum extrusions).

However, retrofit of interior storms can create a durability risk: if there is air leakage, the condensation will occur on the existing ("prime") window, which is often part of the historical fabric of the house, and is made of moisture sensitive materials, such as wood (Brown 1997). Therefore, airtightness of interior storms is of vital importance in cold climate installations.

From past research it is known that a small amount of ventilation of the space with dry air can mitigate condensation concerns (Wilson 1960). Therefore in cold climates, it is important that the inner glazing element be as air tight as possible to reduce air infiltration into the void space. Additionally, air bypass of the glazing elements must also be considered and addressed.

Critical Takeaways

Airtightness of interior storms is of vital importance in cold climate installations. Condensation that could occur on the existing ("prime") window can create a durability risk, as the window is made of moisture sensitive materials.

2.3 Cost and Performance

Cost and achieved performance are very important factors in determining the most appropriate measure to use.

Window Thermal Performance

Energy is transferred across a window assembly by several mechanisms. Conduction, convection (air movement such as air leakage), and radiation are all components of the performance. With so many different materials (wood, polymers, glass, metal) being combined to create a window system, the interaction between all of these elements is not necessarily simple or straight forward.

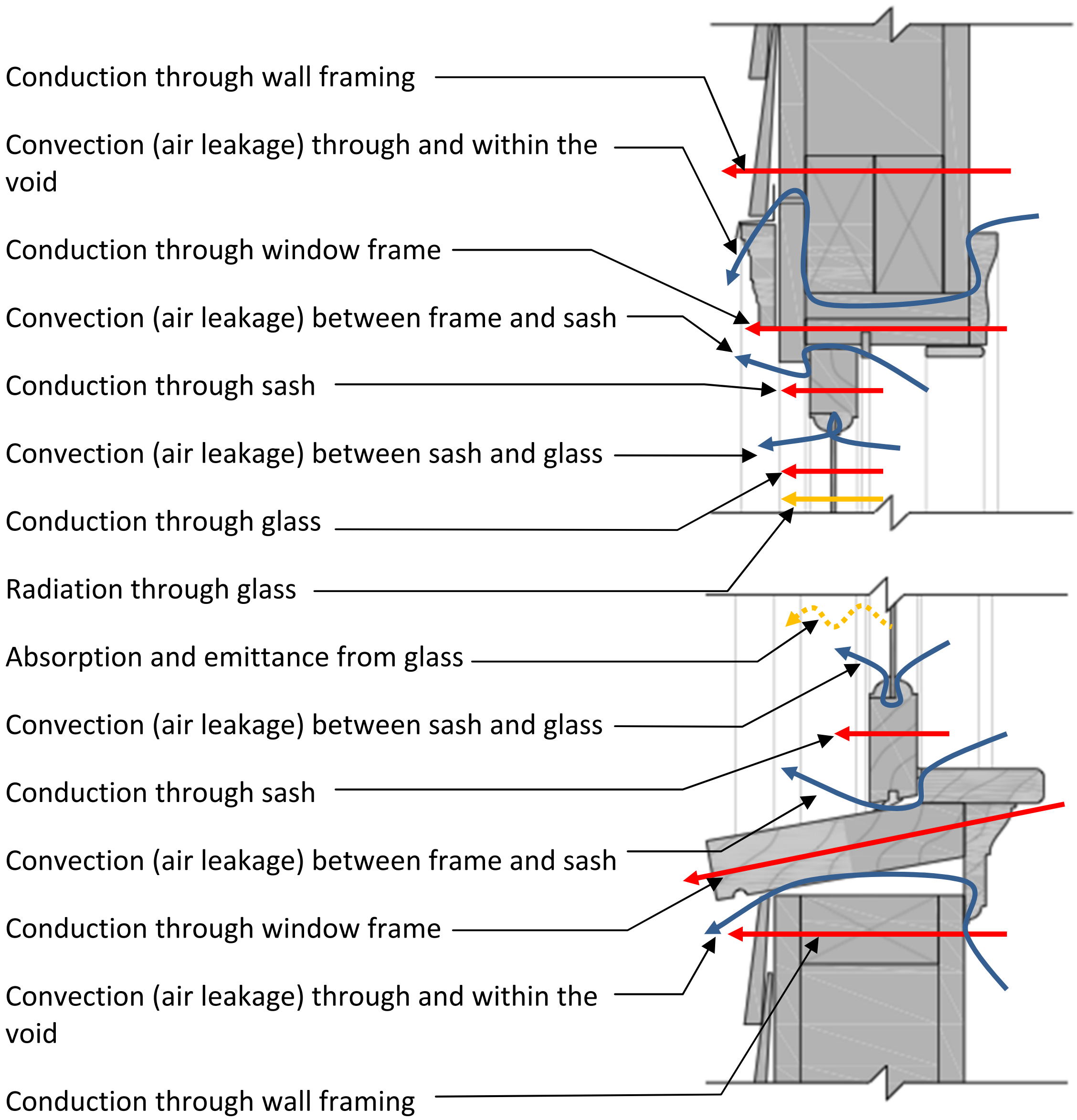


Figure 25: Window energy transfer components

The above graphic is a simplification of the energy transfer through a window and its surrounding enclosure elements. In reality, the actual energy transfer mechanisms are three dimensional in nature, with all of the mechanisms interacting and impacting the actual performance. In order to get a closer quantification of window performance, extensive laboratory testing (or at minimum two-dimensional heat flow computer simulation modeling) is generally required.

However, understanding the general mechanisms can help understanding of how a certain measure will modify the performance. Elements such as interior and exterior storm windows will impact mechanisms such as the conductance through the glass and sashes, air leakage between the frame and sashes or between the sashes and glass, and the radiation, absorption and emittance from the vision glazing elements.

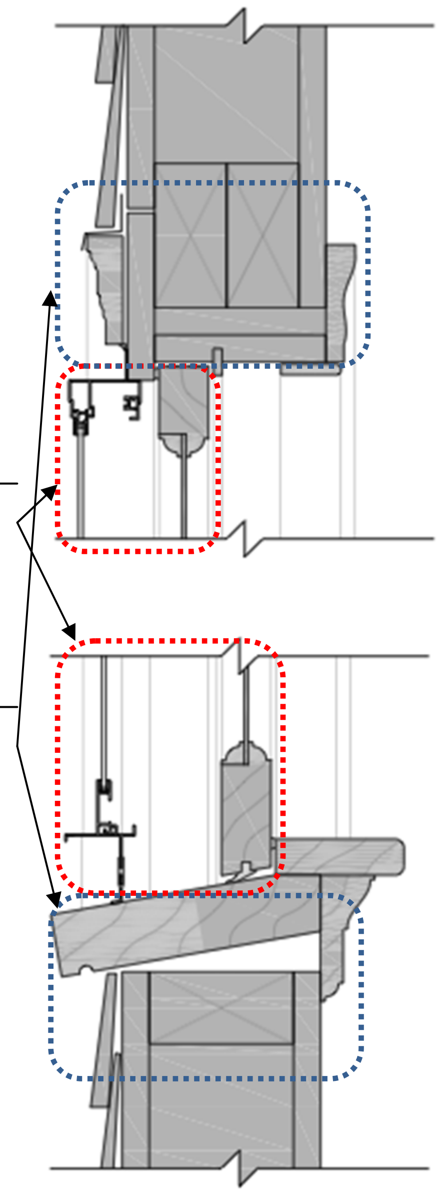


Figure 26: Areas of energy transfer affected by the addition of exterior storms

Until recently, information was only available on the energy performance of the window system itself. However, new standards for rating fenestration attachment products[1] have recently been introduced by the National Fenestration Rating Council (NFRC), to help quantify the effects of

[1] NFRC 100A-2010 *Procedure for Determining Fenestration Attachment Product U-factors*, and NFRC 200A-2010 *Procedure for Determining Fenestration Attachment Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence.*

the addition of various window coverings to existing windows. The new standards will help to further quantify the performance question of various strategies, though it may be some time before a significant database of rated products is developed.

In the interim, there is some information available to help in the determination. Some work coordinate under the DOE's High Performance Windows Volume Purchase Program assigned some values to various high performance windows and configurations of existing windows with exterior storms.

Existing Window Types	U-factor	SHGC
Single-pane clear window (metal frame)	1.18	0.78
Single-pane clear window (non-metal frame)	0.86	0.68
Double-pane clear window (metal frame)	0.80	0.70
Double-pane clear window (non-metal frame)	0.49	0.60

New Window Options	U-factor	SHGC
Highly-insulating window	0.22	0.30
ENERGY STAR window for northern climates	0.30	0.30
Double-pane low-E window (non-metal frame)	0.35	0.35
Double-pane clear window (non-metal frame)	0.49	0.60

Storm Window Options	Primary Window Types	U-factor	SHGC
Low-E Storm Window	Single-pane clear window (metal frame)	0.70	0.61
	Single-pane clear window (non-metal frame)	0.40	0.52
	Double-pane clear window (metal frame)	0.63	0.57
	Double-pane clear window (non-metal frame)	0.34	0.48
Clear Glass Storm Window	Single-pane clear window (metal frame)	0.79	0.70
	Single-pane clear window (non-metal frame)	0.49	0.60
	Double-pane clear window (metal frame)	0.67	0.64
	Double-pane clear window (non-metal frame)	0.38	0.55

Figure 2. Window U-value and SHGC for various windows systems and exterior storm configurations (source US DOE)

While some general ranking of the expected performance improvements can be made, it is recommended that each individual project make their own evaluation of the expected performance in order to determine of the best approach.

Cost Effectiveness

The cost effectiveness of a window retrofit will depend on numerous factors, though possibly most critical to this is the existing window performance. Single glazed windows have proportionally very poor performance compared to other glazing systems. The worst of which are single glazed windows in non-thermally broken metal frames (U = 1.18, SHGC = 0.78). A close second however are single glazed wood windows (U = 0.87, SHGC = 0.62). If the baseline begins from this point, almost any window retrofit strategy will provide a cost justifiable improvement to the existing conditions.

The cost effectiveness is harder to achieve, if the starting point is a reasonably performing window such as a double glazed clear window in a wood or vinyl frame (U = 0.49, SHGC =

0.60). Because of the proportionally high cost of glazing products, it can be difficult to justify all retrofit options when starting from this condition.

A preliminary evaluation was completed looking at the cost vs. energy performance of several window systems and retrofit measures. Cost data for the windows was taken from several sources including averages based on direct quotes from manufacturers for multiple product lines and from RS Means Construction Data (2011 Reed Construction Data). Due to the extremely wide range in product costs, estimated averages were used to try to develop a representative sample. It should be noted that for each project, specific cost analysis will be required to ensure the cost effectiveness.

Simulations were run using BEopt simulation software developed by the National Renewable Energy Laboratory (NREL). An example home was used as the baseline to help demonstrate the benefits of using exterior insulation as part of a house energy retrofit. This benchmark home was assumed to be around 1950's era two story slab on grade construction and had the following basic characteristics.

Table 2. Benchmark House Characteristics

House Characteristics	ft2
Finished Floor Area	2312
Ceiling Area	1156
Slab Area	1156
Wall Area	2799
Window Area	410 (17.7% glazing ratio)

The window performance was isolated from all other aspects of the home, to examine the effectiveness of this single strategy. For colder climate zones (4 and above), the baseline window was chosen to be a double hung single glazed wood window. For warmer climates (3 and below), the baseline window was chosen to be a single glazed non-thermally broken metal window. In addition to the performance changes in both the U-value and the SHGC, increases in air tightness to the building were also included as part of the analysis. Levels of increased air tightness were estimated due to a lack of measured data relating specifically to window air tightness increases.

The following parametrics were run to see the effectiveness of the various window retrofit strategies to the energy performance and utility cost.

Table 2. Parametric Steps and Cost for Climate Zones 4 and Above

Parametric step	Cost/ft2
Benchmark = single glazed wood (U=0.87, SHGC=0.62)	N/A
Single glazed wood + clear exterior storm (U=0.49, SHGC=0.60)	$7.81
Single glazed wood + lowE exterior storm (U=0.40, SHGC=0.52)	$12.14

Double Glazed LowE Energy Star Window (U=0.30, SHGC=0.30)	$40.73
Single glazed wood + interior Double Glazed LowE Energy Star Window (U=0.25, SHGC=0.25)[2]	$40.73
Triple Glazed LowE Window (U=0.20, SHGC=0.20)	$77.76

Table 3. Parametric Steps and Cost for Climate Zones 3 and Below

Parametric step	Cost/ft2
Benchmark = single glazed metal (U=1.18, SHGC=0.78)	N/A
Single glazed metal + clear exterior storm (U=0.79, SHGC=0.70)	$7.81
Single glazed metal + lowE exterior storm (U=0.70, SHGC=0.62)	$12.14
Double Glazed LowE Energy Star Window (U=0.30, SHGC=0.30)	$40.73
Single glazed metal + interior Double Glazed LowE Energy Star Window (U=0.25, SHGC=0.25)[3]	$40.73
Triple Glazed LowE Window (U=0.20, SHGC=0.20)	$77.76

Simulations were run for the following cities:

Table 4. Reference Cities

City	Climate Zone
Dallas, TX	3A
Kansas City, MO	4A
Boston, MA	5A
Duluth, MN	7A

Results indicated that for almost all strategies chosen in all climate zones were economically justifiable when the baseline windows were single glazed windows. The exterior clear storms and lowE storms provided the cost optimized solutions for colder climates, however in Dallas, a much narrower gap between the storm windows and the window replacement was noted. This is due in part to both the lesser effect of the overall performance of storm on the single glazed metal framed window, and due to Dallas being in a cooling dominated climate that is affected predominantly from SHGC and not U-value.

Critical Takeaways

Almost all measures chosen in all climate zones were economically justifiable when the baseline windows were single glazed wood windows.

[2] Values were assumed due to unavailability of actual modeled or measured values for this configuration
[3] Values were assumed due to unavailability of actual modeled or measured values for this configuration

3 Measure Implementation

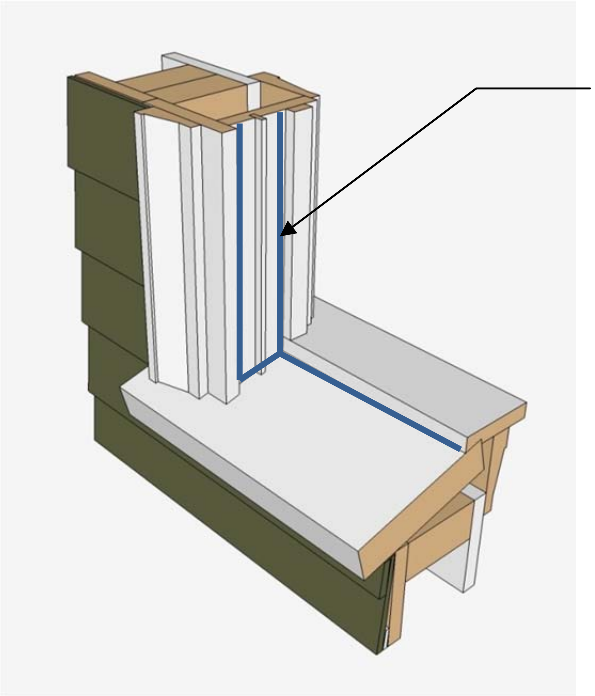
The following section steps through eight options for improving existing wood window systems. The order of the measures is in a general order for least improvement to the window energy performance, to the most improvement. The intent is not to determine specific incremental performance improvement; however, the focus is on the detailing of the implementation of the strategies.

3.1 Measure 1: Window rehabilitation

The amount of work required to rehabilitate the windows will depend on the starting condition of the windows. The window should be assessed as outlined in the earlier sections of this document.

For windows that are generally good condition (square, with sashes that properly fit to the window frame, and no broken or missing lites), the following work would be recommended (this work is covered in detail by Davis 2007):

1. Remove the sashes by removing the interior stops and parting bead of the window frame.
2. Clean the frames and sashes of any flaking paint or other coatings that may impede the proper installation of gaskets and seals.
3. Caulk and seal the corners and joints in the window frame. This includes all joints between the sill and jambs as well as between the casings and frames.
4. Cut grooves into the sashes where new gaskets will be installed.
5. Prime and paint the window frames and sashes
6. Install new gaskets around the perimeter of the sashes. V-groove type gaskets will likely work the best at the jambs and meeting rails, while bubble gaskets work well at the head and sill interface.
7. Reinstall the sashes, meeting rails, and interior stops.



Clean frame and seal in the following locations indicated

Figure 27: Recommended sealant location as part of window frame rehabilitation

As part of the work, if the weight pockets are to be retained, then cleaning and lubrication of the pulleys, replacement of the sash cords or chains, and balancing of the weights should be completed as part of the work.

The weight and balance system could also be abandoned and replaced with a spring-loaded tape balance. The weight pockets can then be be insulated and sealed, improving the overall thermal performance of the window frame-to-rough opening interface.

Windows requiring more extensive rehabilitation such as reglazing, replacement of rotten wood, or rebuilding of sashes are outside the scope of this document. Work of this nature should be completed by a qualified restoration contractor. Alternately other retrofit measures, including sash replacement, window insert replacement, or complete window replacement should be considered for severely deteriorated windows.

3.2 Measure 2: Exterior storm

The addition of exterior storm windows to the exterior of the existing window is a common, commercially available off-the-shelf technology, and is for the most part straight forward. This work should be completed in conjunction with the window rehabilitation work outlined in the above section. The existing window sill must be in good condition, as it will still be exposed to the elements (though exposure will be significantly reduced).

The exterior storm window is fastened to the outer window casing, or in some cases directly to the window trim. The storms should be sealed with an exterior grade paintable sealant at the jambs and heads, but left unsealed at the sill. Most storm windows have an adjustable bottom leg to account for variations in the sill height. This leg should not be caulked, to allow for drainage at the bottom. Some systems even provide small weep holes or notches in the bottom leg to promote drainage. Systems with enhanced drainage are recommended.

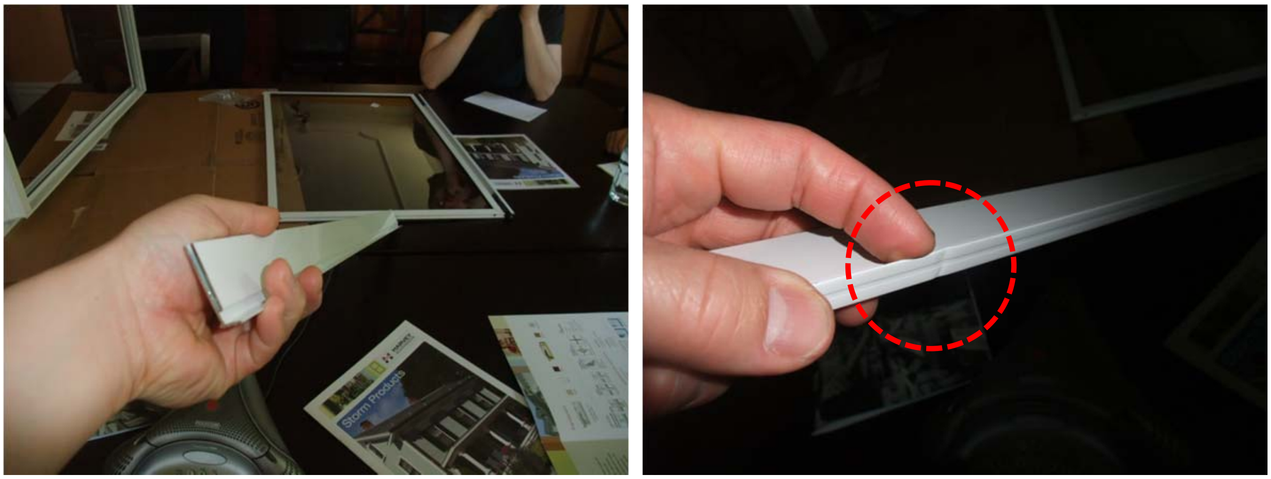


Figure 28: Exterior aluminum storm windows, showing weep channel

In order to minimize the potential for interstitial condensation, the original window must be made as air tight as possible (Wilson 1960). Slight ventilation of the exterior storm is typically provided by the weep holes provided at the sill. If the interior window is made sufficiently air tight, then the slight ventilation of the weep holes of the storm should provide adequate air change to prevent condensation. If condensation does form, slightly increasing the gap to allow for additional ventilation of the space is recommended.

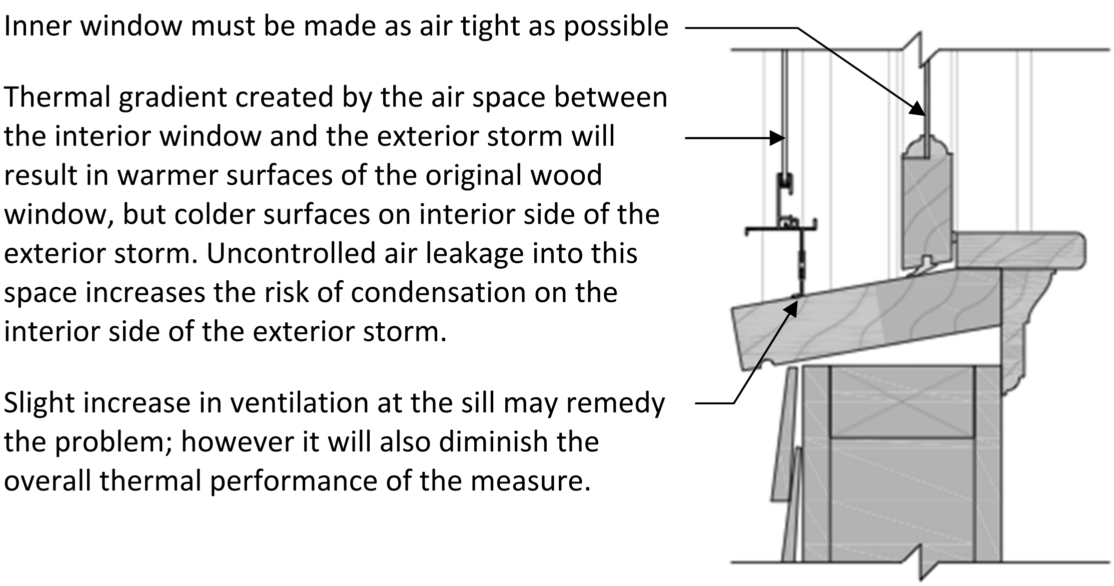


Figure 29: Condensation potential for exterior storm retrofits

3.3 Measure 3: Removable Interior Storm

The addition of interior storm windows is done solely for the purpose of improving the thermal performance of the window systems. Interior storms do not provide any upgrade to the water management of the assembly.

The installation of removable interior storms relies on the original window to still perform the primary water management of the assembly. In fact, these windows do not provide any additional water management performance at all. Because of this, the original window should be rehabilitated as outline above necessary to enhance its water management performance.

An interior storm creates the potential for condensation on the interior surface of the original exterior window. It is important that the interface between the interior storm and the window frame be as air tight as possible. Also, the placement of the units is such that other air leakage paths (such as through the pulleys for the sash weights) could bypass the storm window, leading to interior air infiltration into this space. These bypasses can lead to problems even if the interface between the storm and window frame is perfectly air tight. Condensation potential can be reduced by increasing the ventilation of the space to the outside. This needs to be done carefully, as increased ventilation to the exterior will result in diminished energy performance of the window, and could render the strategy ineffective. It is recommended that the original window be rehabilitated (as per Measure 1) along with this strategy. If condensation problems develop, then the exterior window can be made incrementally slightly leakier until the problem is resolved. This could be done through strategies such as slightly gapping the lower sash at the sill with a shim, or removing the lower sash sill gasket if it exists (though this will have a detrimental effect on airtightness in the summer when the interior storm is removed).

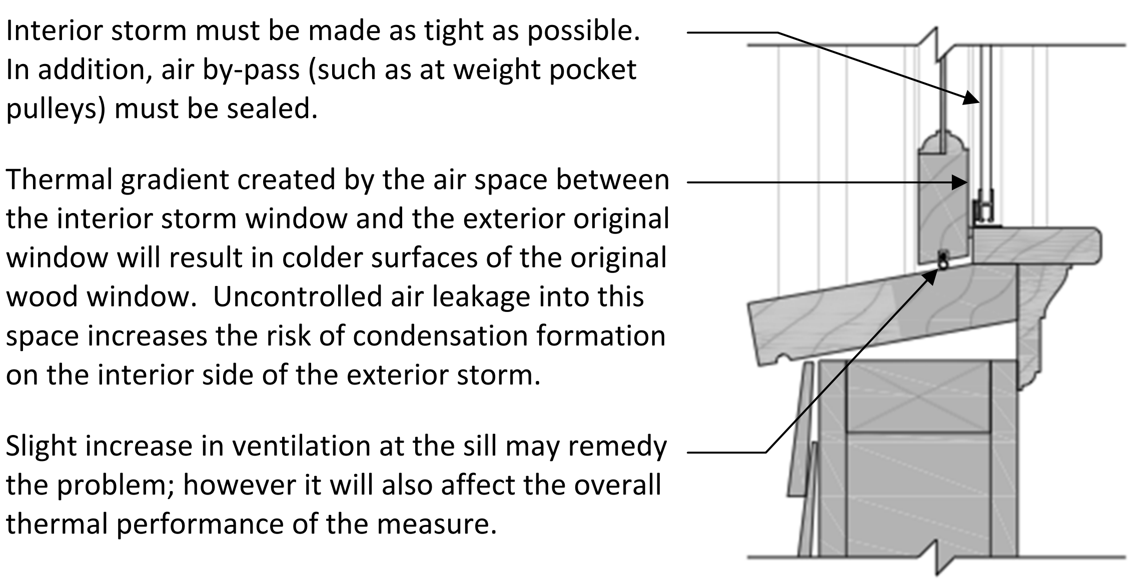


Figure 30: Condensation potential for interior storm retrofits

3.4 Measure 4: Permanent Interior Storm

The addition of interior storm windows is done solely for the purpose of improving the thermal performance of the window systems. Interior storms do not provide any upgrade to the water management of the assembly.

The installation of removable interior storms relies on the original window to still perform the primary water management of the assembly. In fact, these windows do not provide any additional water management performance at all. Because of this, the original window should be rehabilitated as outline above necessary to enhance its water management performance.

An interior storm creates the potential for condensation on the interior surface of the original exterior window. It is important that the interface between the interior storm and the window frame be as air tight as possible. Also, the placement of the units is such that other air leakage paths (such as through the pulleys for the sash weights) could bypass the storm window, leading to interior air infiltration into this space. These bypasses can lead to problems even if the interface between the storm and window frame is perfectly air tight. Condensation potential can be reduced by increasing the ventilation of the space to the outside. This needs to be done carefully, as increased ventilation to the exterior will result in diminished energy performance of the window, and could render the strategy ineffective. It is recommended that the original window be rehabilitated (as per Measure 1) along with this strategy. If condensation problems develop, then the exterior window can be made incrementally slightly leakier until the problem is resolved. This could be done through strategies such as slightly gapping the lower sash at the sill with a shim, or removing the lower sash sill gasket if it exists.

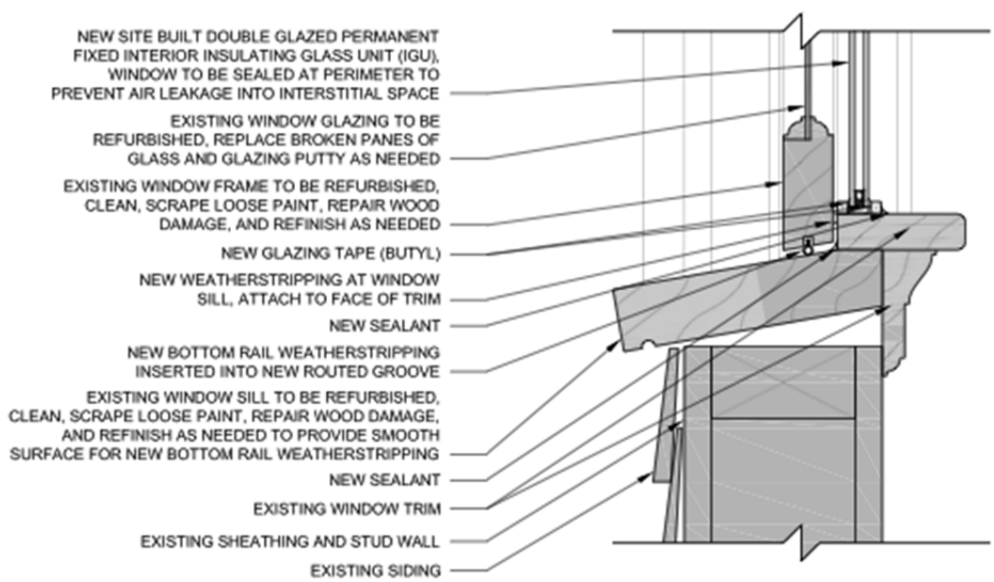


Figure 31. Example sill detail for a permanent interior storm window

3.5 Measure 5: Window sash retrofit

This work is most likely to be completed by a specialized window restoration contractor as it requires the disassembly of the existing window frames, routing of the frame elements to create a larger glazing pocket to accommodate the thicker IGU, and the reconstruction and re-glazing of the frames.

A key element to ensure if this approach is taken is that the IGU must be installed on setting blocks, and the new glazing pocket be weeped and drained to the exterior. IGU seal failure (identified by condensation or "fogging" of the space between the two layers of glass) is commonly a result of the IGU seals being in direct contact with water for extended periods of time.

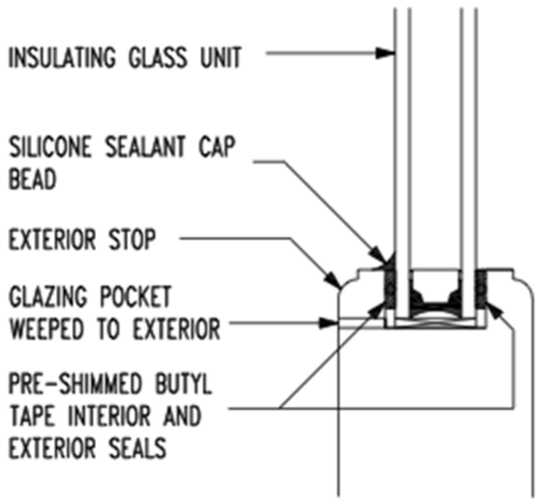


Figure 32: Integration of an IGU into a wood sash

This measure must also incorporate improvements to the airtightness of the sashes in the opening, since this work will only address the conductance through the window sashes only and not the surrounding window frame. This is typically accomplished by the use of retrofit sash liners in commercially available products, and the addition of gaskets. If this method is not used, methods outlined in Measure 1 should be implemented.

3.6 Measure 6: Window sash replacement

In this measure, the window frames are typically retrofitted with new jamb liners that provide the tracks for the sashes to ride in, and eliminate the need for sash weights. Prior to the installation of the jamb liners, it is recommended the frame should be cleaned and the corner interfaces between the head, jambs and sill caulked. It is recommended that the jambs be coated with a liquid applied waterproof membrane, or at minimum, a high quality paint (such as an elastomeric paint). The membrane should extend down onto the sill. Where exposed it can be painted to match the rest of the sill and trim color. These measures are water control improvements, which increase the water resistance of the existing sloped wood sill, and allow any incidental leakage to drain to the exterior.

It is recommended that the space between the jamb liners be sealed at the jambs and head on both the interior and exterior, for air barrier continuity. Where the jamb liners interface with the sill, they should be left unsealed to allow the space to weep out at the bottom.

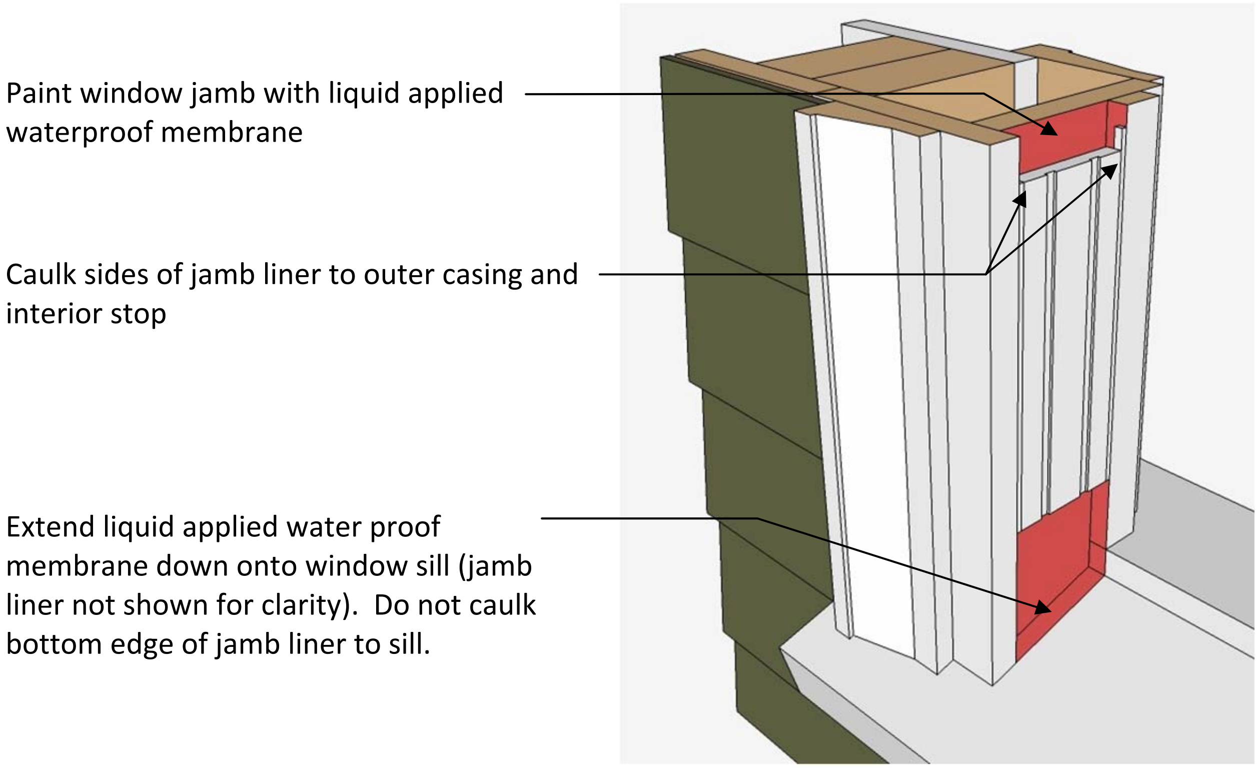
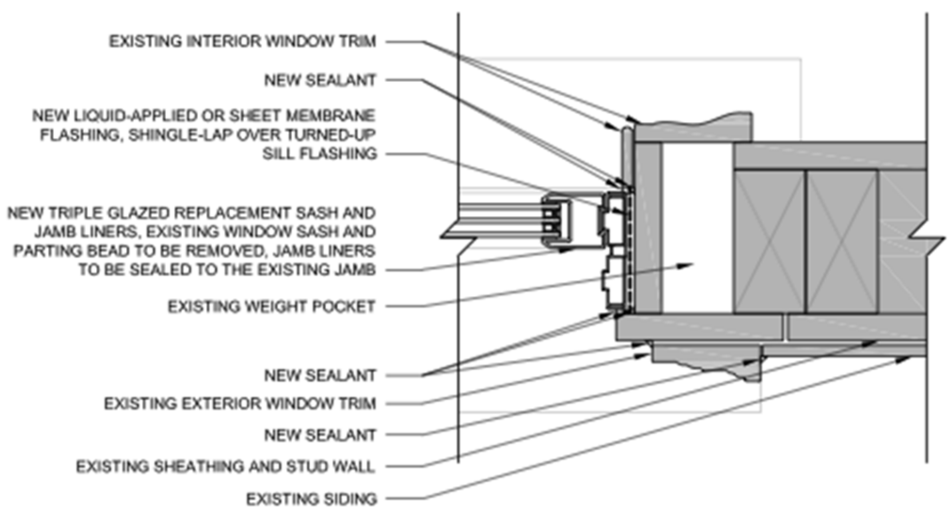


Figure 33. Frame preparation for replacement window sashes



3.7 Measure 7: Insert Replacement Window

In this measure, the existing wood window frame should be to be the new window rough opening, and treated in a similar manner following current industry recommended practice for waterproofing and draining. The window frame should be cleaned of any dirt and loose paint. The parting beads and interior stops at the head and jambs should be removed from the frame. The weight pocket pulleys should be removed and the openings in-filled. All corners between head, jambs, sill, and exterior casings should be sealed with caulking. This is recommended from both a water management performance as well as for air tightness performance. The rough opening should then be coated on all sides with a liquid applied waterproof membrane. A membrane product is recommended in this application, because the area will no longer be accessible for maintenance once the replacement window is installed.

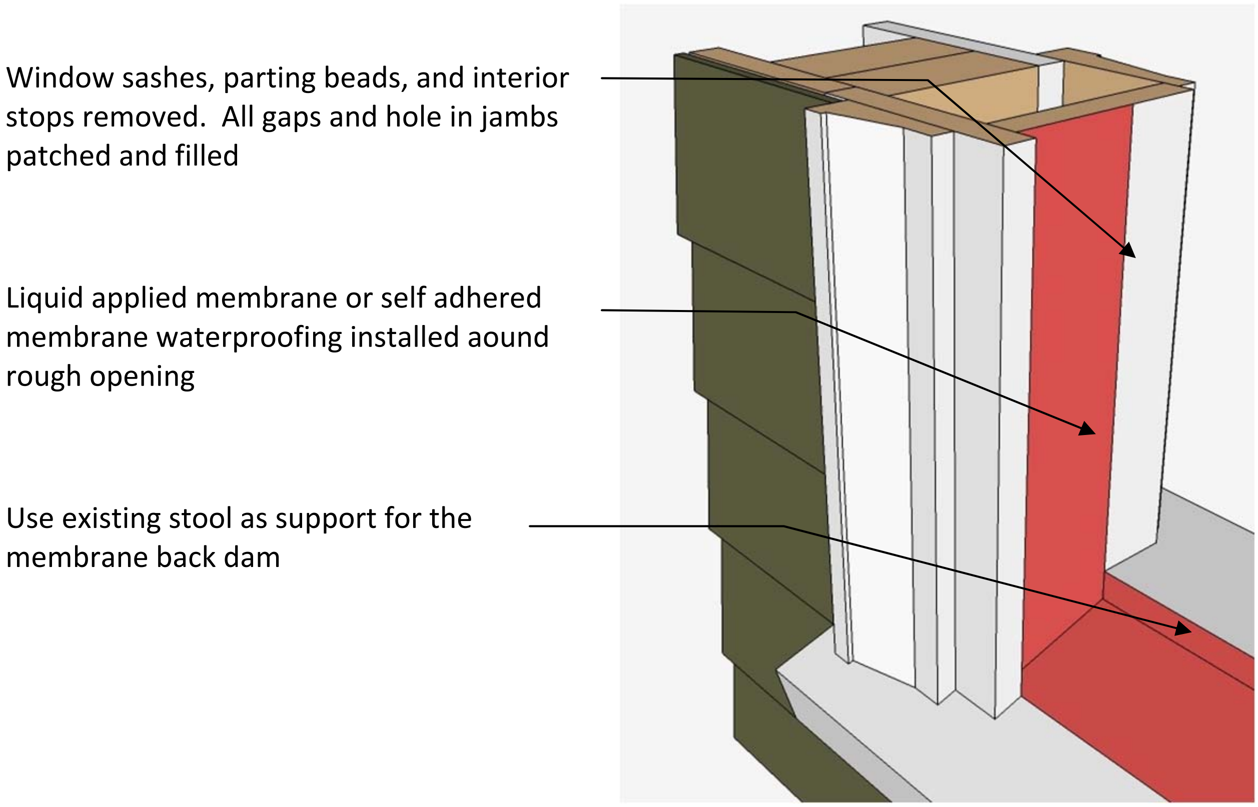


Figure 34. Frame preparation for insert replacement window

Figure 35. Examples of membrane installation in a wood window frame

The replacement window is typically installed from the interior: it is normally set on the sill, tilted up into the rough opening, and pushed up against the exterior casing of the window. An interior backer rod and sealant joint should be installed around the interior perimeter of the rough opening. New interior stops are then installed (or the originals could be re-installed if still in a usable condition). The joint between the window and stops is caulked for aesthetics.

On the exterior the window should be caulked to the casing on the head and jambs. The sill however should be left to drain to the exterior.

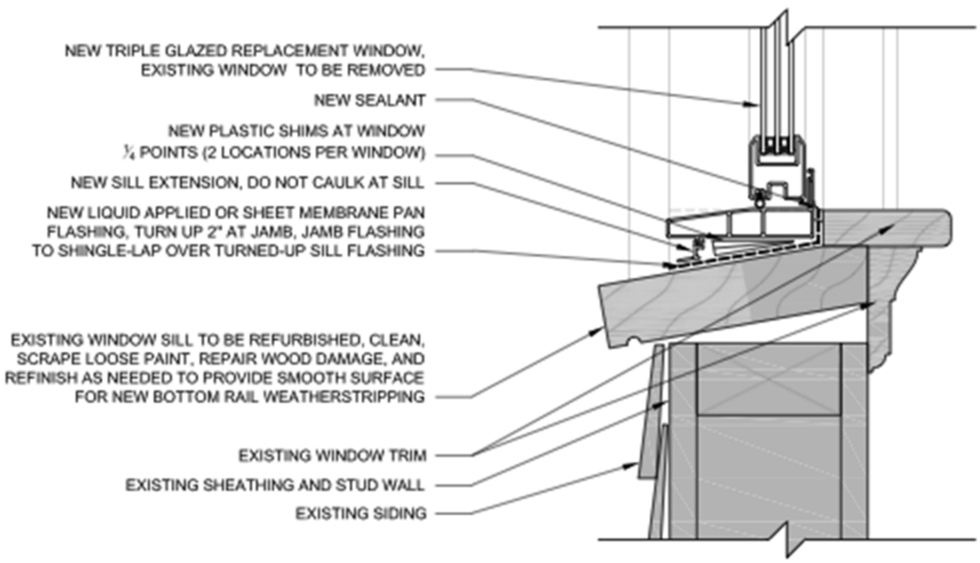


Figure 36. Example sill detail of insert replacement window

3.8 Measure 8: Complete window replacement

As discussed above, the highest performance but most intrusive and expensive option is a complete window replacement. This measure includes not only removal of the existing window sashes, but the entire window frame (back to the rough framing). This often includes the interior and exterior casing and trim as well.

A complete window replacement would most commonly be done in conjunction with a more extensive building renovation project. Other work such as cladding replacement, insulation upgrades or other work would most likely be completed at the same time.

3.8.1 Window replacement as sole scope of work

If this work is being done as the sole scope of work (ie. no other enclosure retrofit work being done in conjunction with the window replacement), then a termination location for the work must be chosen. The details provided here, are designed so that a future cladding replacement or exterior insulation upgrade can be integrated with the window replacement with only minimal disruption to the window installation details.

Often the existing rough opening size is not the desired final dimension and additional blocking is added to frame out the rough opening to the correct dimension. The new rough opening is lined on all sides with a liquid applied or self adhered waterproof membrane. The membrane should extend out a minimum of 4" onto the pane of the wall. The membrane will ultimately be covered with exterior window trim. Should a future upgrade to the wall occur at a later date, only the window trim would need to be removed to allow for a tie-in between a new WRB (and potentially an air barrier).

Typically, a certain amount of siding will need to be removed to accommodate the window installation. Trimming back of the siding should be done with care so that damage to underlying elements such as building paper can be avoided if possible. Connecting the window membrane flashings to a building paper or some other WRB is recommended. It may be the case that the wall does not have an existing WRB to connect to. In this case, sealing the membrane flashing directly to the wood sheathing, and providing a metal flashing below the sill to shed water back out over the cladding would be recommended, however it should be recognized that in doing so a certain amount of risk is accepted by the home owner as to the remainder of the wall does not conform to recommended enclosure water management design. In these situations, it may be warranted to examine a full cladding replacement at the same time in order to retrofit the building with a proper WRB.

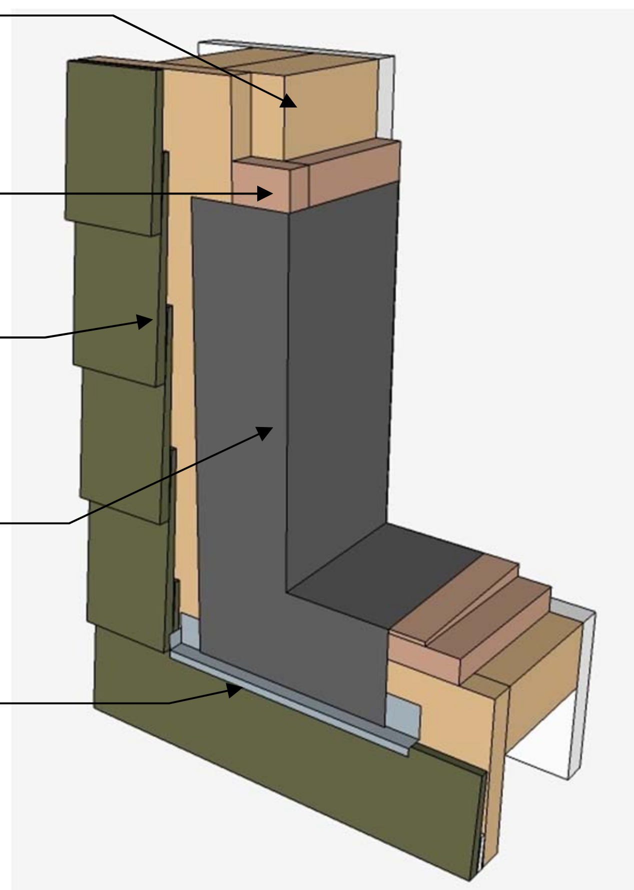


Figure 37. Replacement window rough opening preparation

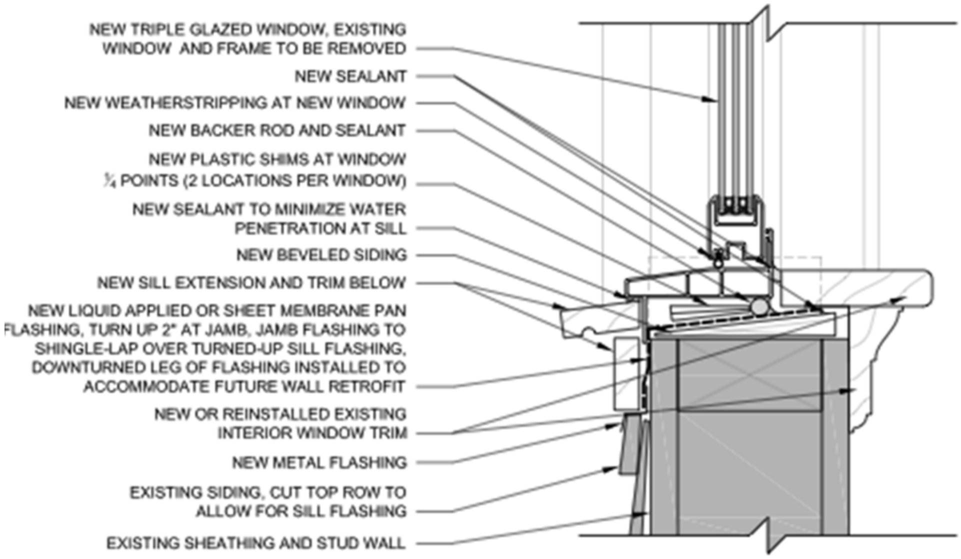


Figure 38. Example sill detail for window replacement without siding replacement

3.8.2 Window replacement in conjunction with a siding replacement

If the siding is replaced and a new wall WRB is installed at the same time as the windows, the re-installation details would be the same as current recommended new construction practice. The details would change slightly in that a complete wrapping of the rough opening with a membrane would no longer be needed. Instead, the wall WRB could be wrapped into the rough opening on the sill and jambs, a pan flashing installed at the sill. After the window was installed, the jambs and head would be sealed with a self adhere membrane flashing and the WRB would be shingle lapped over top of the membrane head flashings.

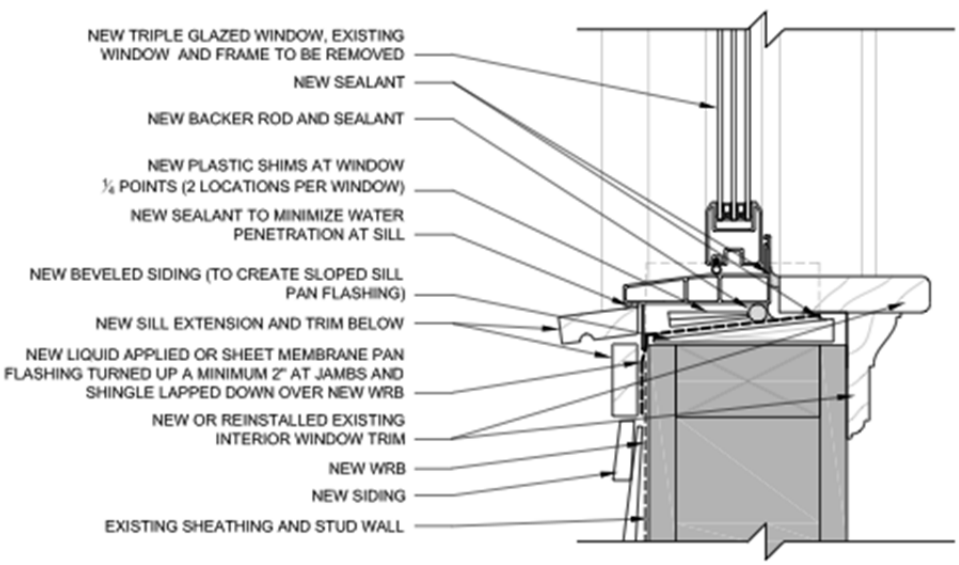


Figure 39. Example sill detail of replacemetn window in conjuntion with siding replacement

3.8.3 Window replacement in conjunction with an exterior insulation retrofit

Window replacement done in conjunction with an exterior insulation retrofit of the building requires some additional consideration for the window installation details. The window can be placed either inboard of the insulation layer ("innie" window) or at the front face of the insulation ("outie" window). The choice of the window placement is often governed by the location of the WRB (or the placement of the WRB may be governed by the desired window placement location).

"Innie" windows are most easily integrated with a WRB that is placed behind the insulation at the plane of the exterior wall sheathing. By contrast, "outie" windows are most easily integrated with a WRB that is placed at the face of the exterior insulation. In either case, the integration of the window flashing with the WRB remains the same.

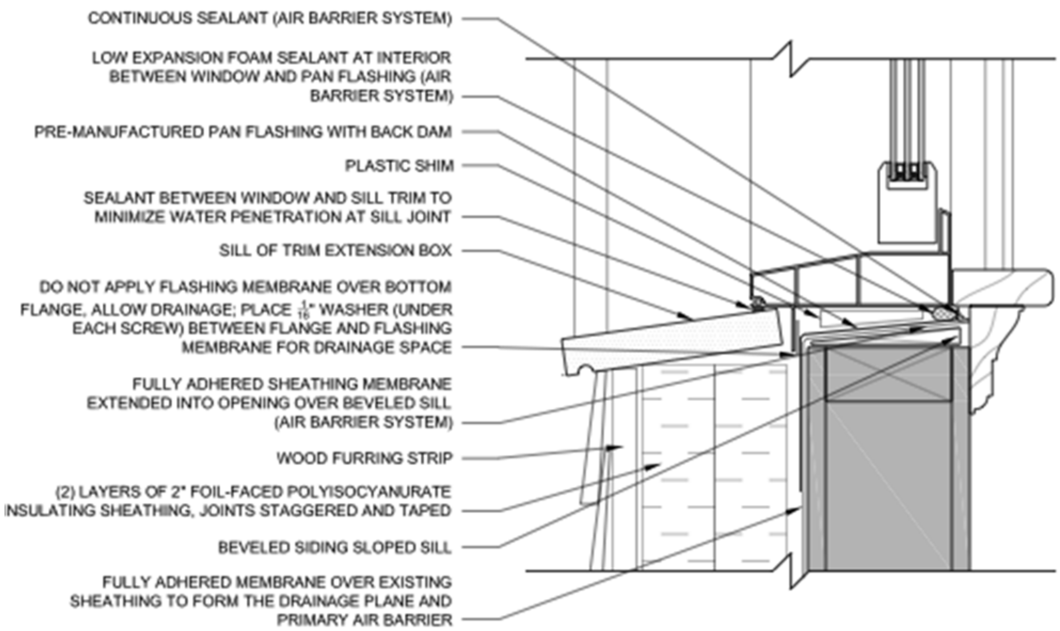


Figure 40. Example sill detail of "innie" window

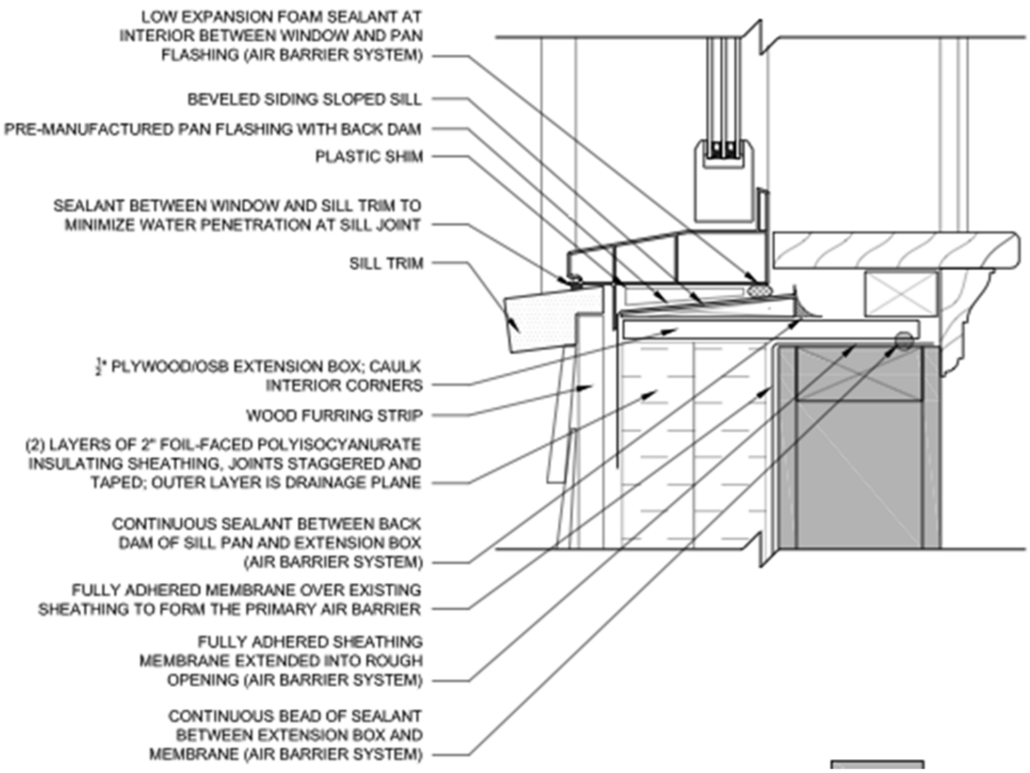
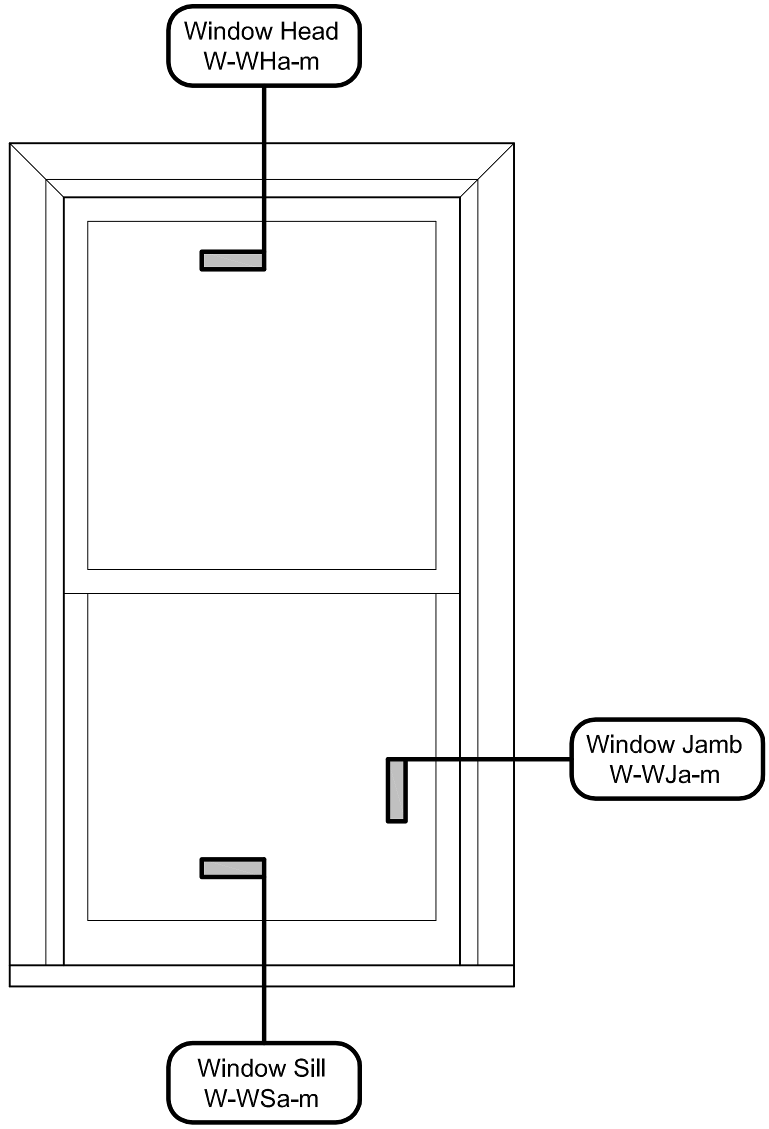


Figure 41. Example sill detail of "outie" window

Appendix A: Window Repair, Rehabilitation, and Replacement Details

Wood Frame Wall
Window Retrofit Options

Window Detail Key



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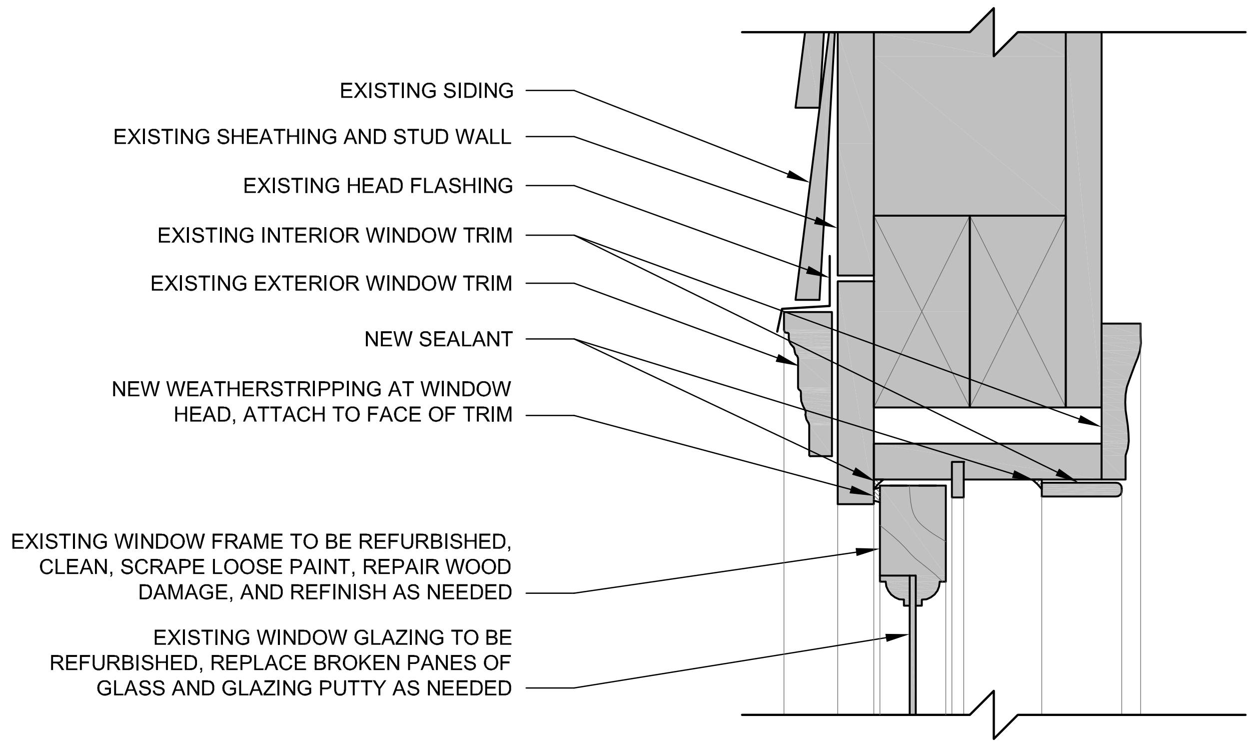

GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW HEAD AT WOOD FRAME WALL - A

SCALE: 3" = 1'-0"

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Wood Frame Wall
Window Retrofit Options

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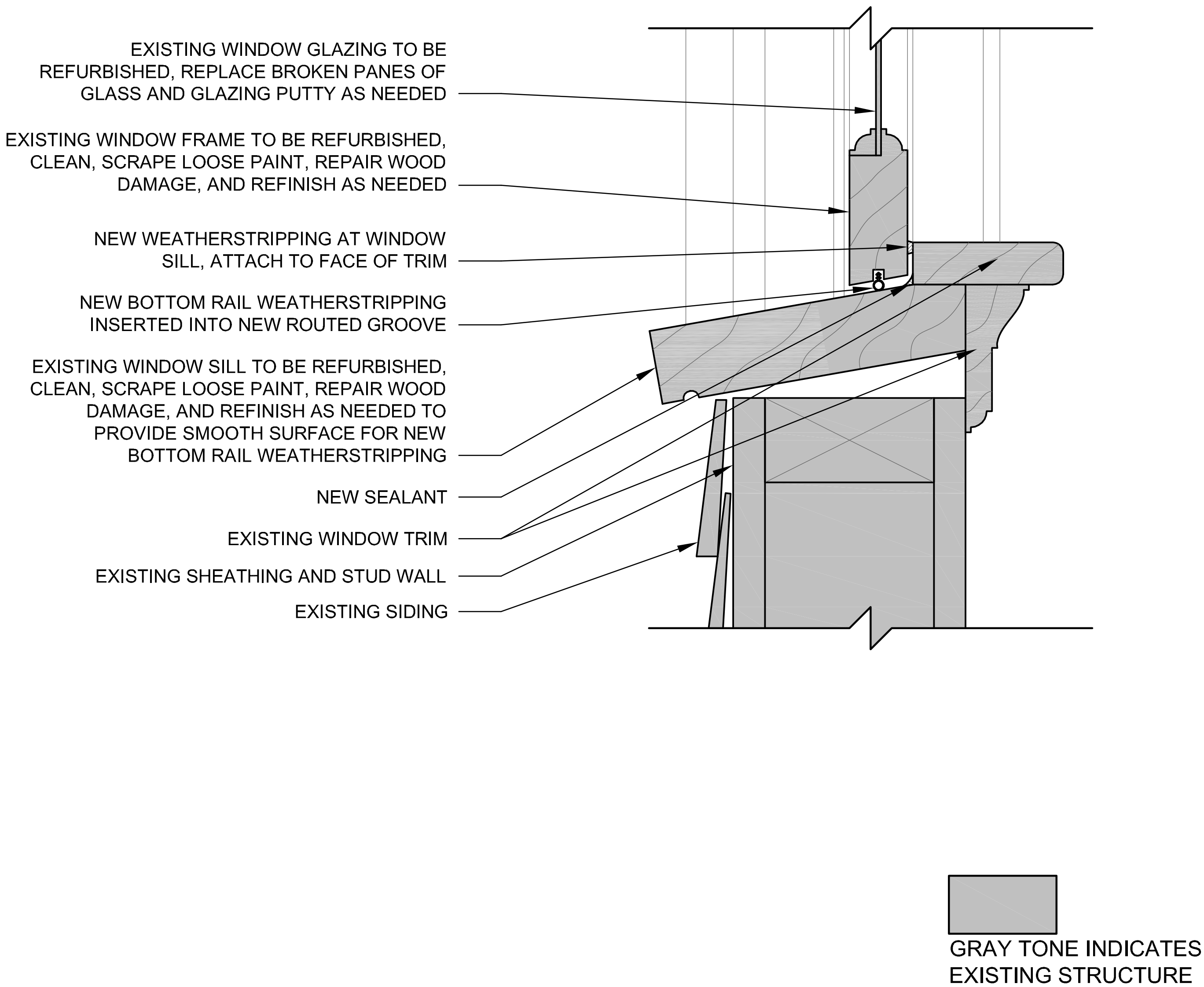
Sheet Title:

W-WHa



WINDOW SILL AT WOOD FRAME WALL - A

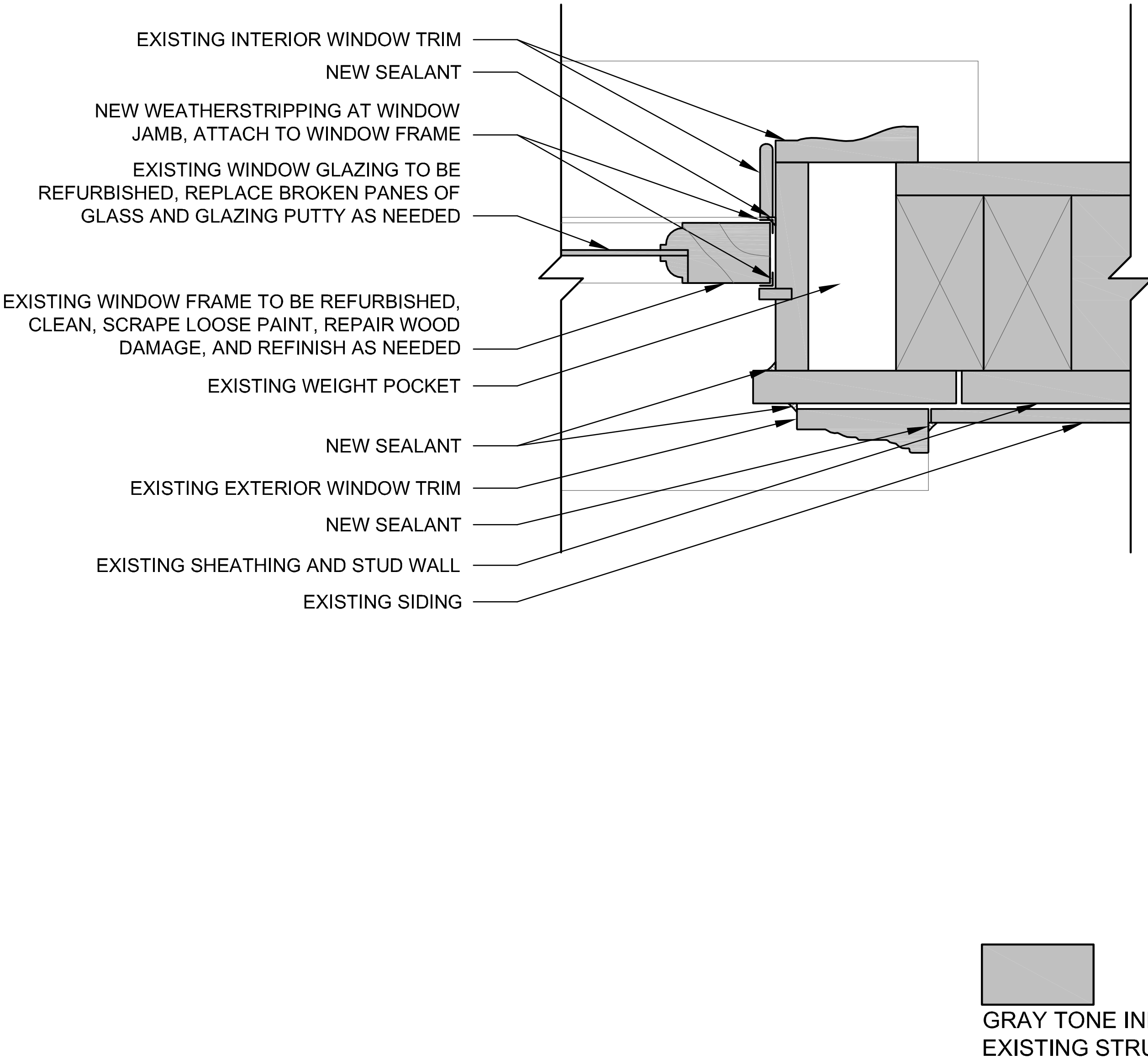
SCALE: 3" = 1'-0"

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WSa



WINDOW JAMB AT WOOD FRAME WALL - A

SCALE: 3" = 1'-0"

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U.S. Department of Energy

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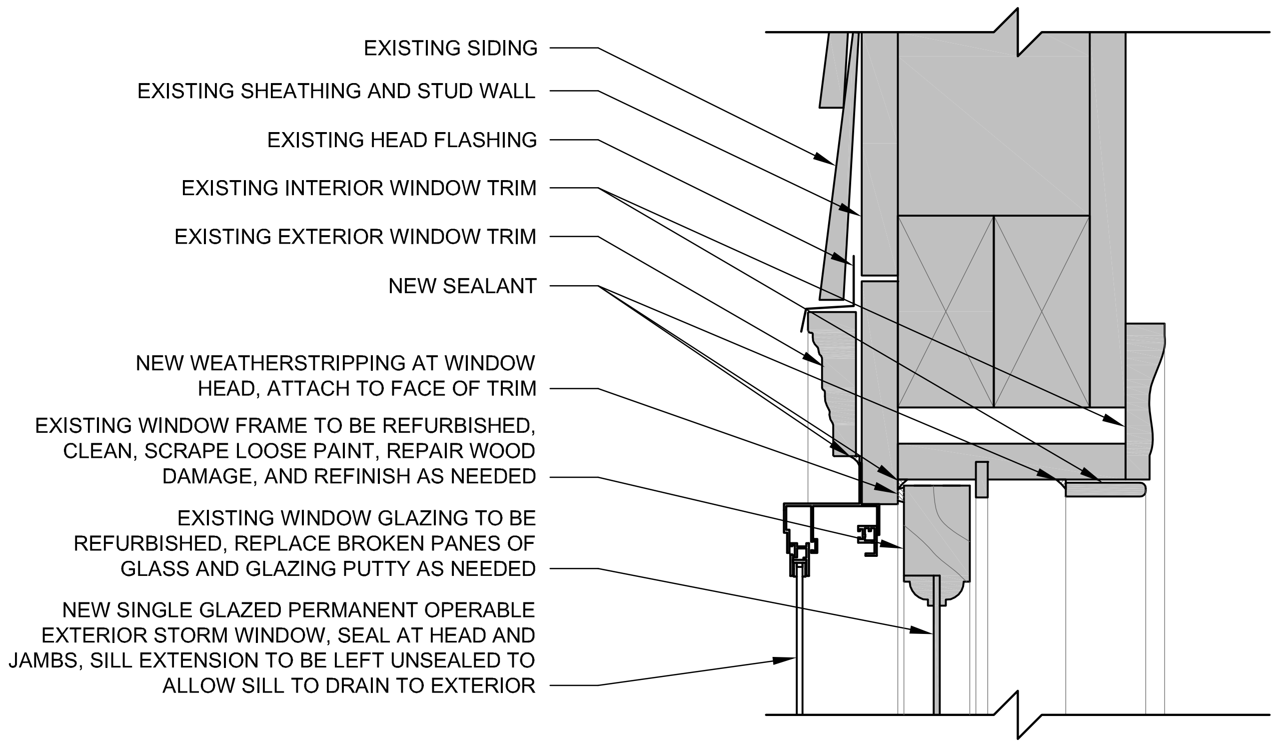
Date: 2011-11-03

Sheet Title:

W-WJa



WINDOW HEAD AT WOOD FRAME WALL - B

SCALE: 3" = 1'-0"

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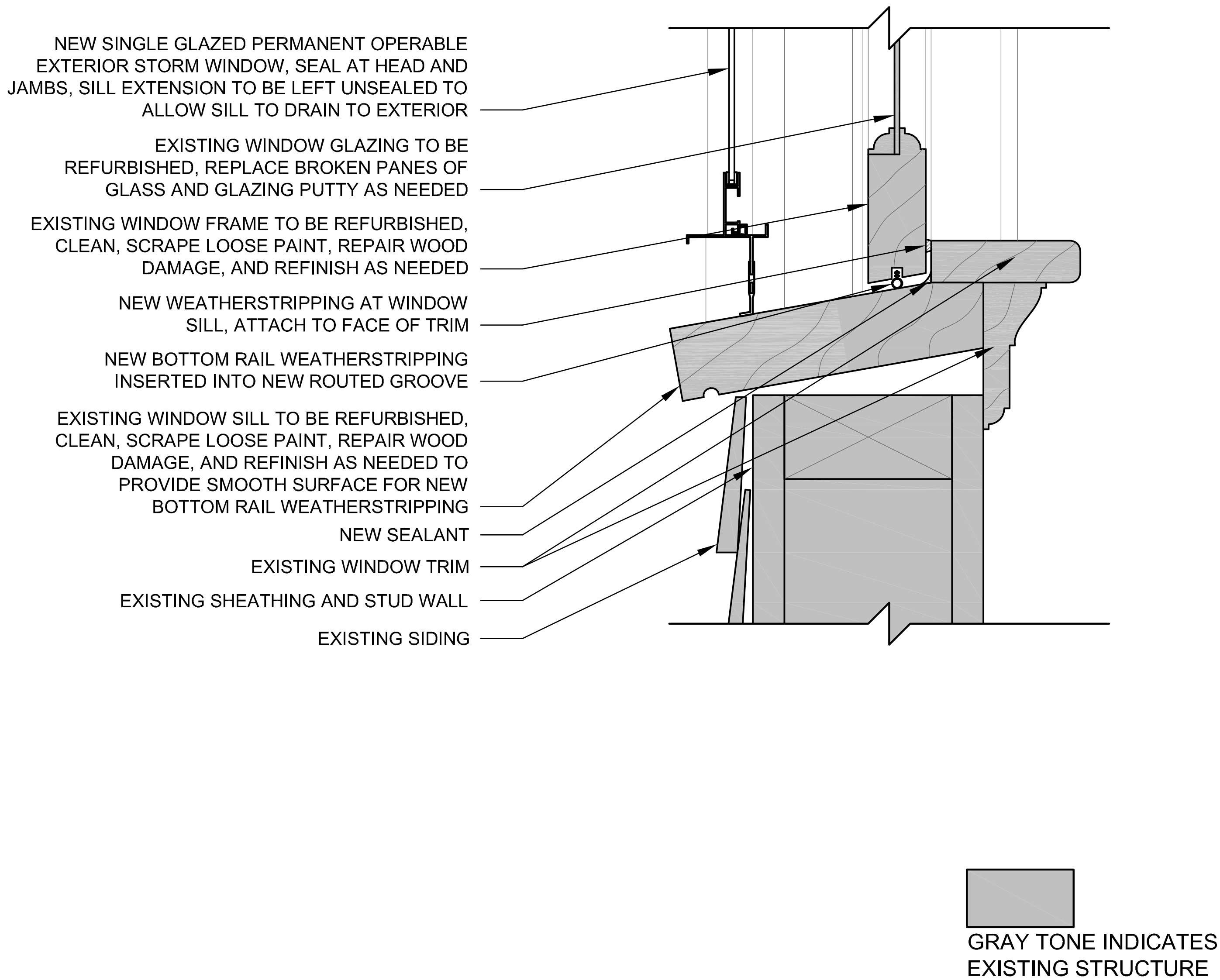
Sheet Title:

W-WHb



WINDOW SILL AT WOOD FRAME WALL - B

SCALE: 3" = 1'-0"

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Wood Frame Wall
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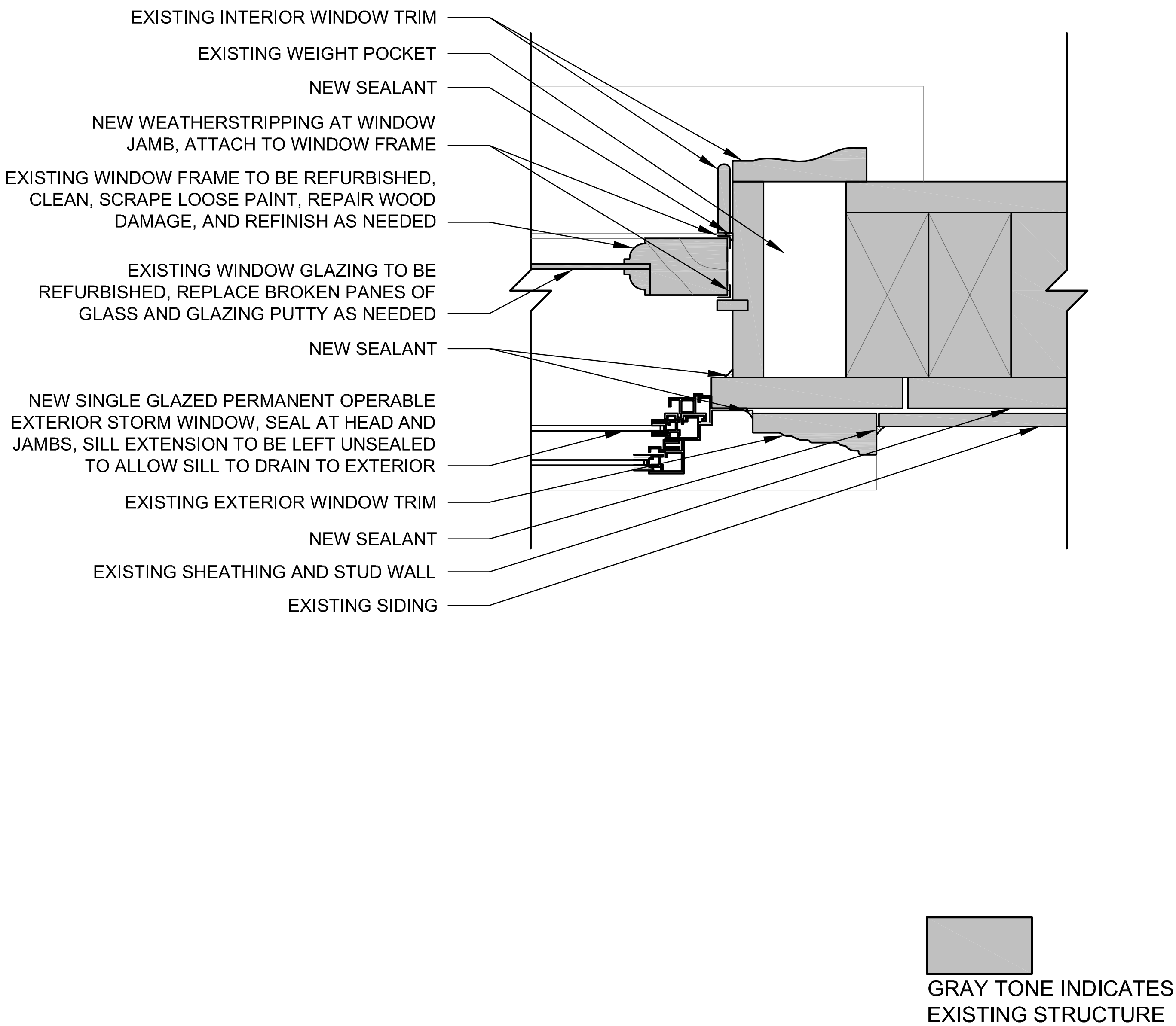
Date: 2011-11-03

Sheet Title:

W-WSb



WINDOW JAMB AT WOOD FRAME WALL - B

SCALE: 3" = 1'-0"

with

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U.S. Department of Energy
Research Toward Zero Energy Homes

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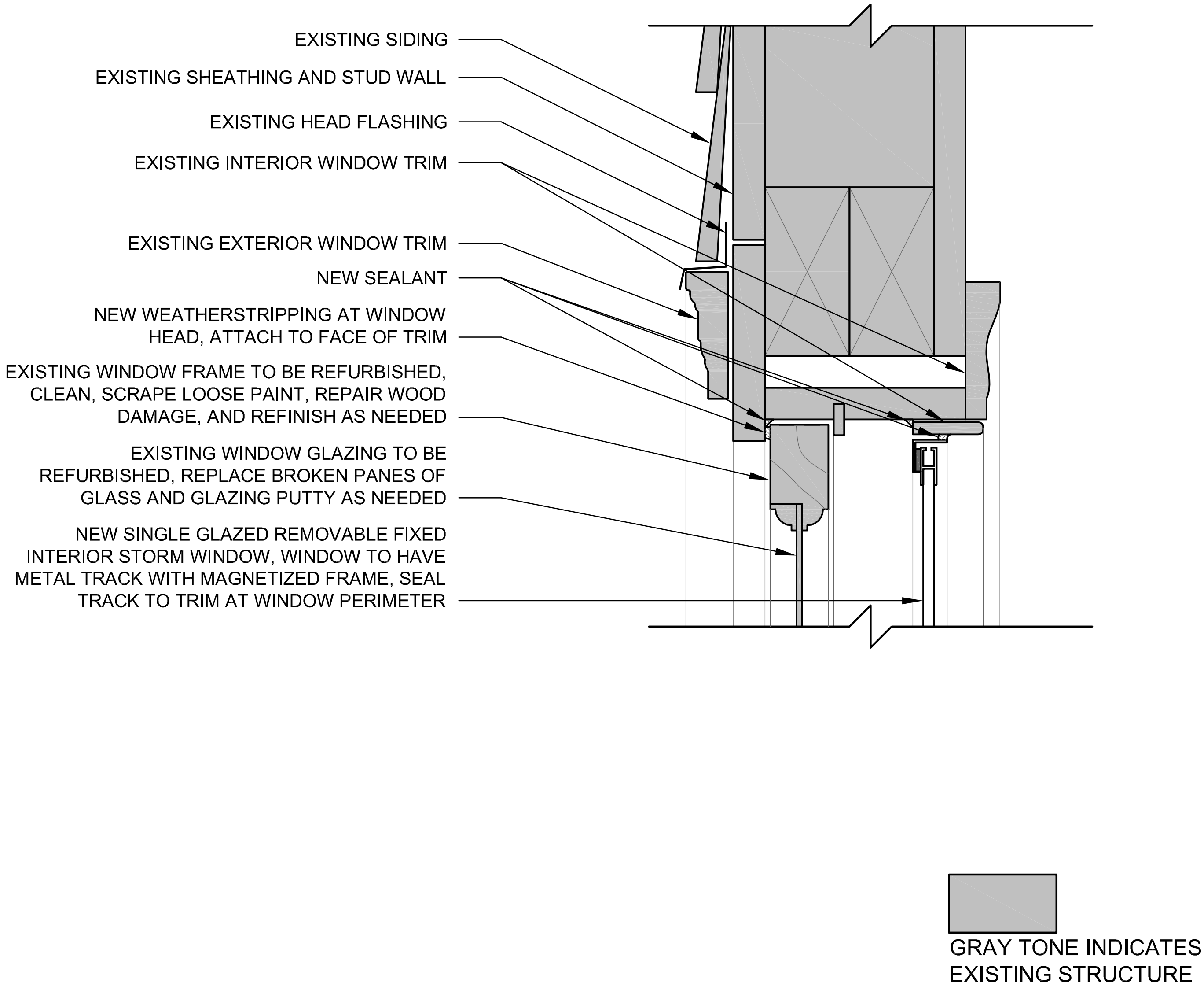
Sheet Title:

W-WJb



WINDOW HEAD AT WOOD FRAME WALL - C

SCALE: 3" = 1'-0"

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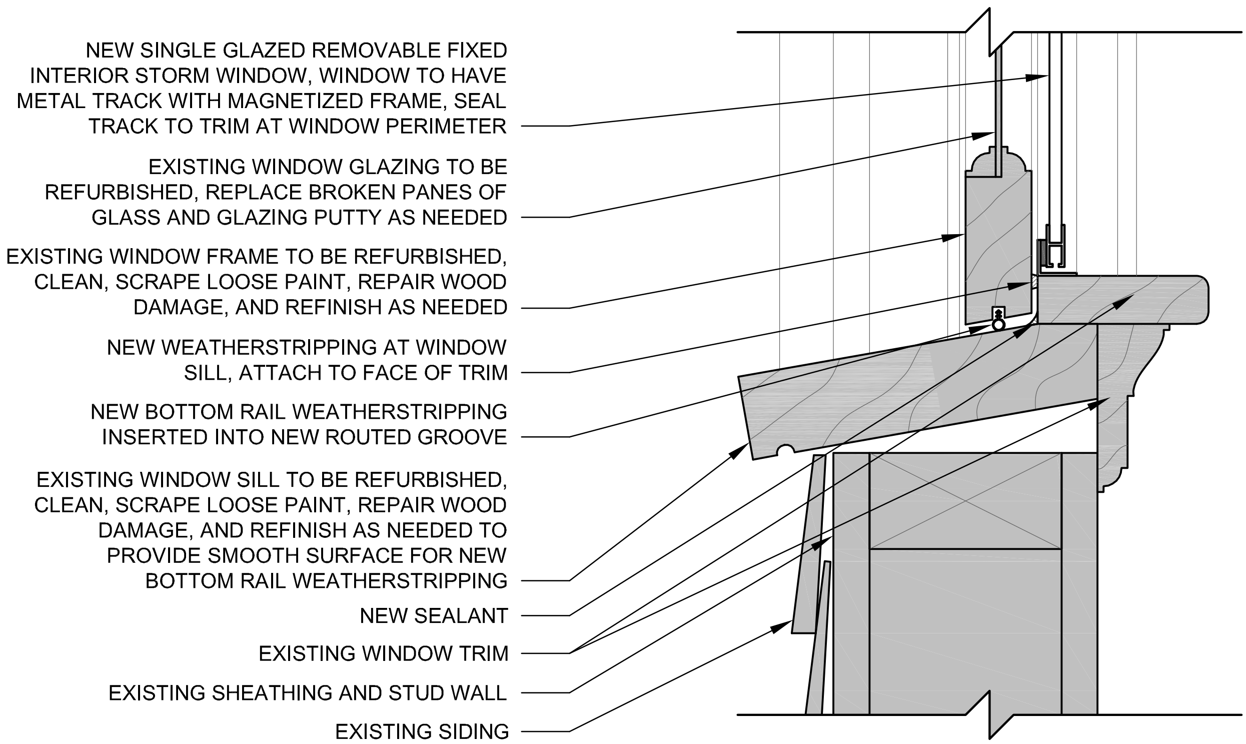
Sheet Title:

W-WHc



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW SILL AT WOOD FRAME WALL - C

SCALE: 3" = 1'-0"

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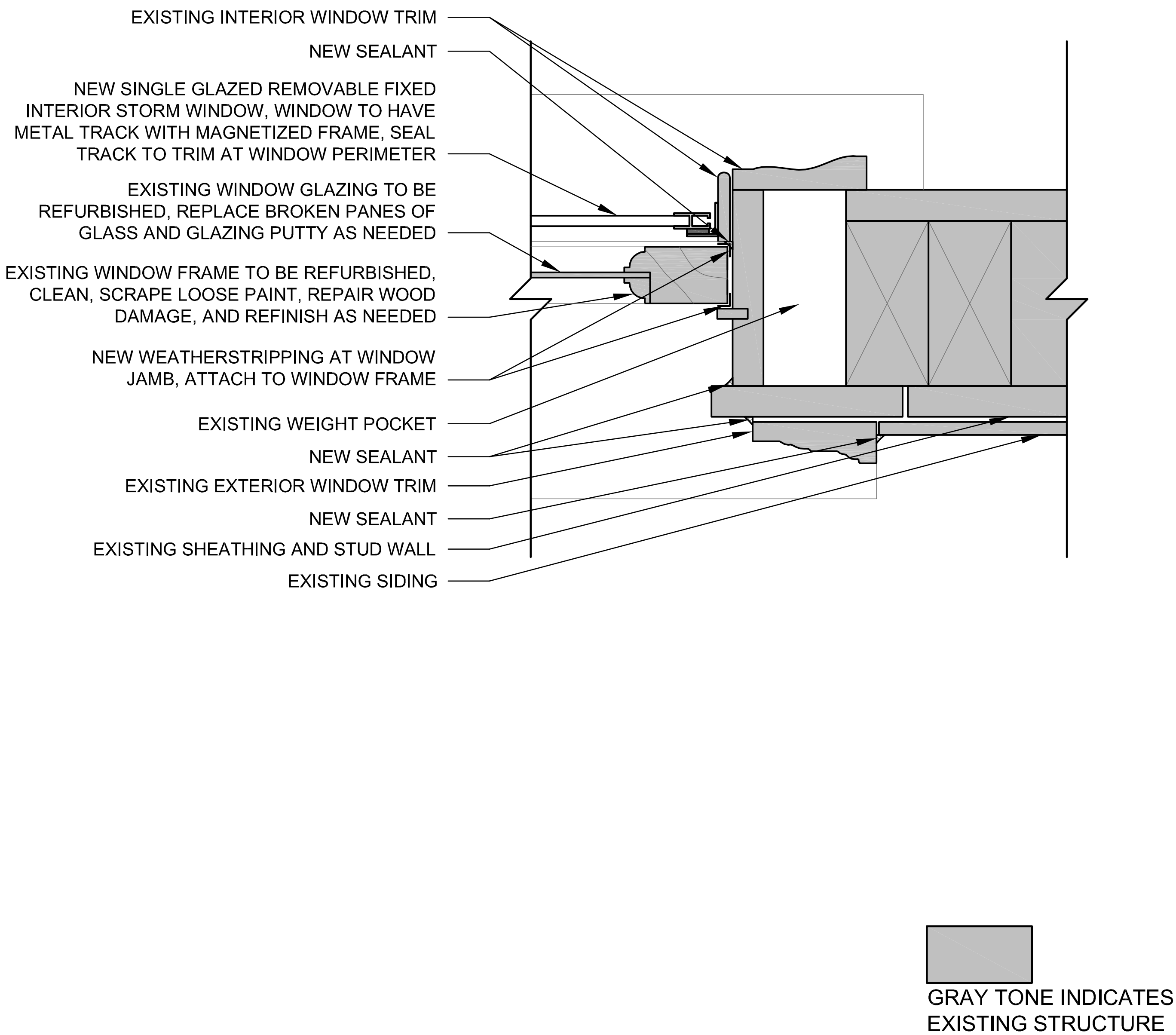
W-WSc



WINDOW JAMB AT WOOD FRAME WALL - C

SCALE: 3" = 1'-0"

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Research Toward Zero Energy Homes

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Window Retrofit Options

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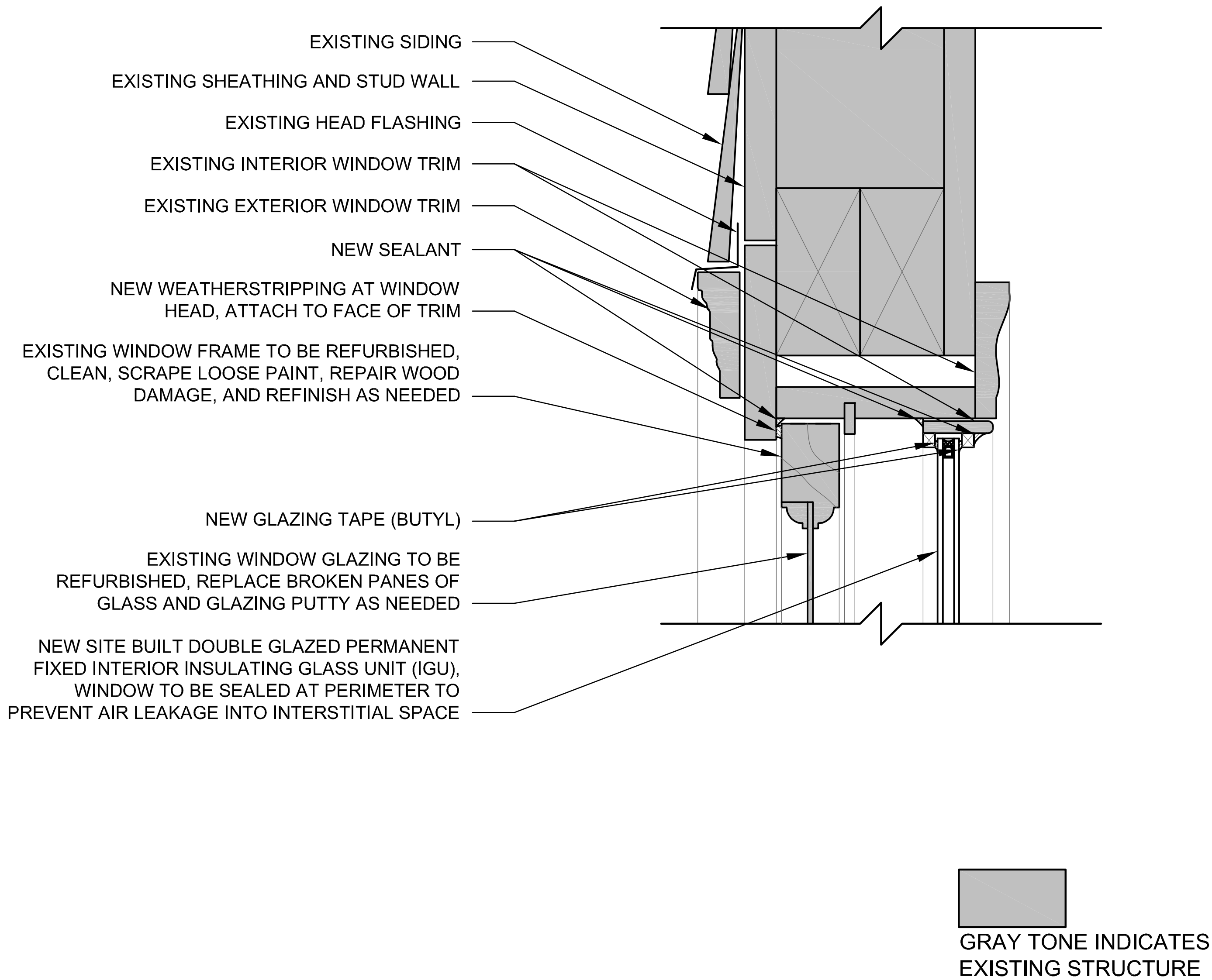
Sheet Title:

W-WJc



WINDOW HEAD AT WOOD FRAME WALL - D

SCALE: 3" = 1'-0"

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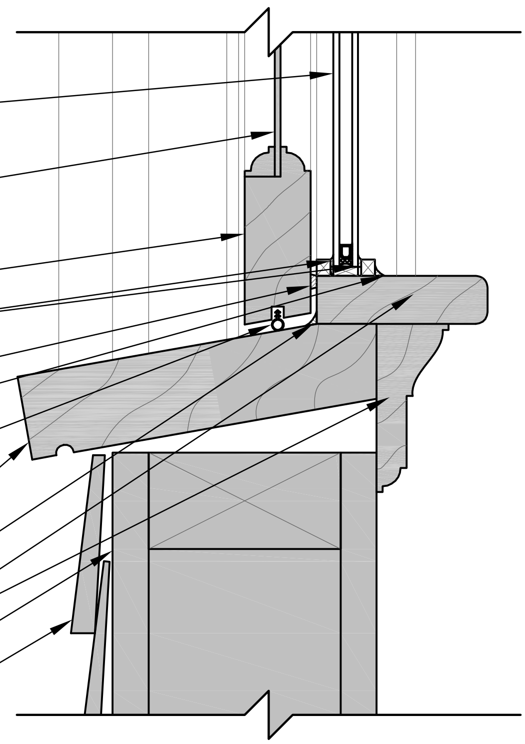
Sheet Title:

W-WHd



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW SILL AT WOOD FRAME WALL - D

SCALE: 3" = 1'-0"

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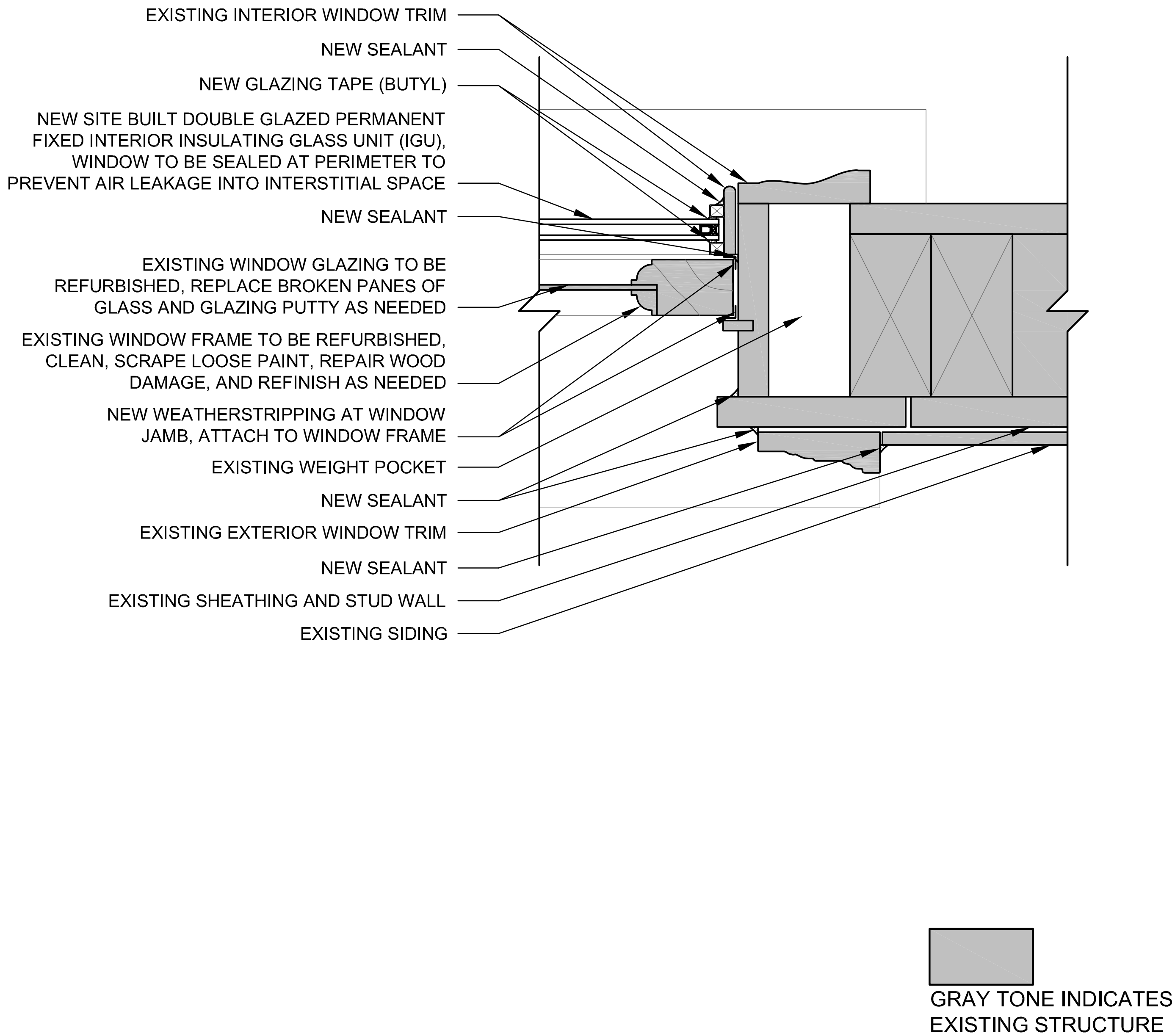
Sheet Title:

W-WSd



WINDOW JAMB AT WOOD FRAME WALL - D

SCALE: 3" = 1'-0"

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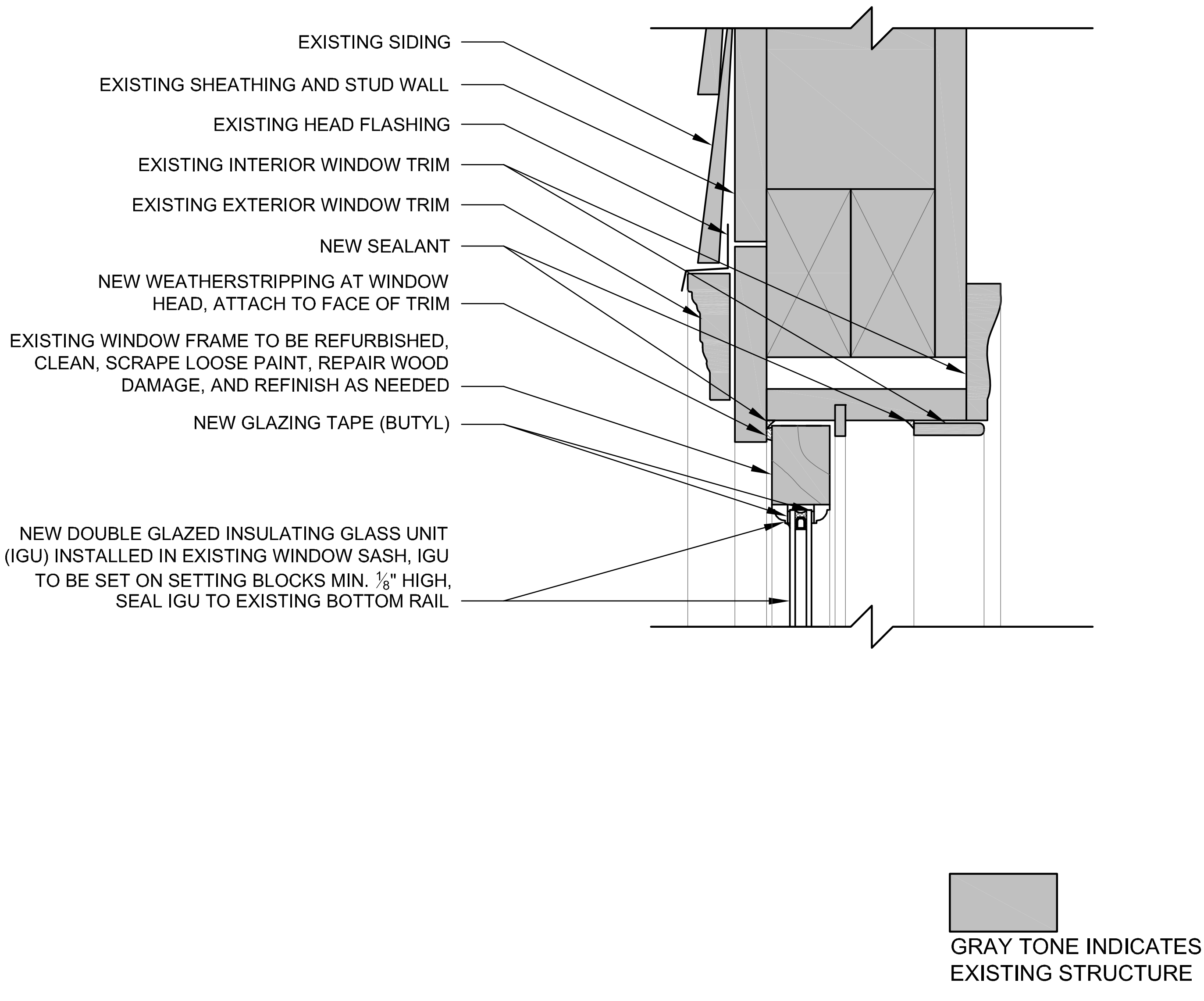
Sheet Title: W-WJd



WINDOW HEAD AT WOOD FRAME WALL - E

SCALE: 3" = 1'-0"

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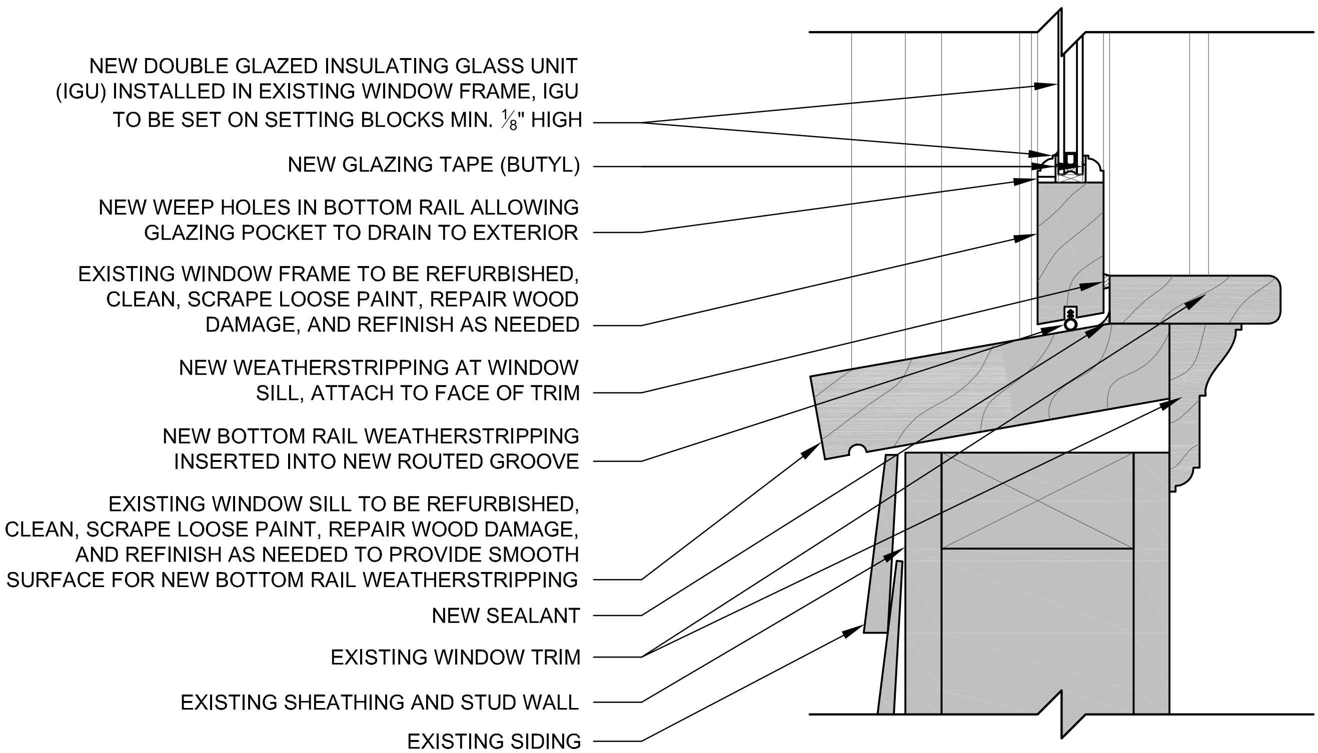
Sheet Title:

W-WHe



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW SILL AT WOOD FRAME WALL - E

SCALE: 3" = 1'-0"

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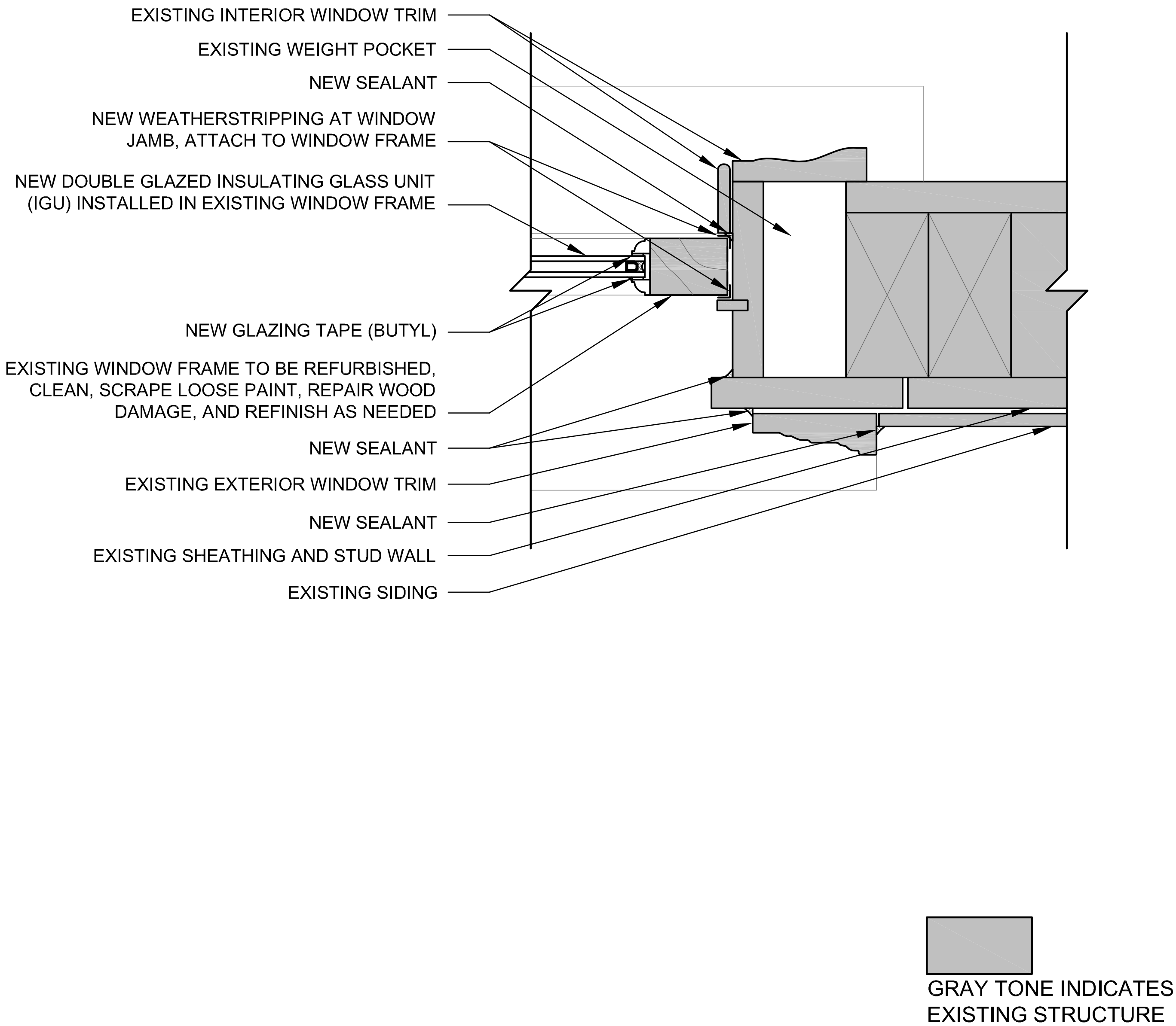
Sheet Title:

W-WSe



WINDOW JAMB AT WOOD FRAME WALL - E

SCALE: 3" = 1'-0"

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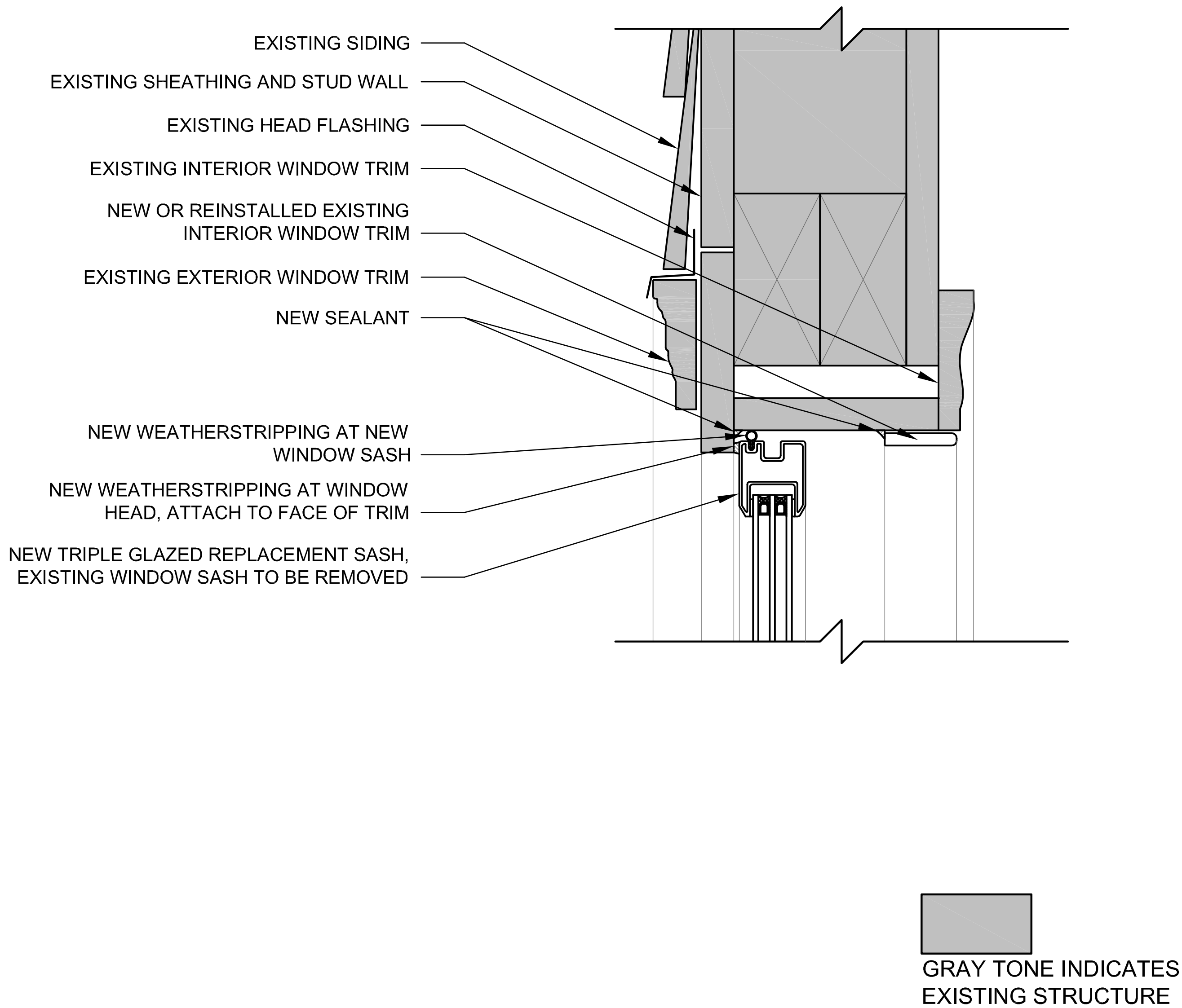
Sheet Title:

W-WJe



WINDOW HEAD AT WOOD FRAME WALL - F

SCALE: 3" = 1'-0"

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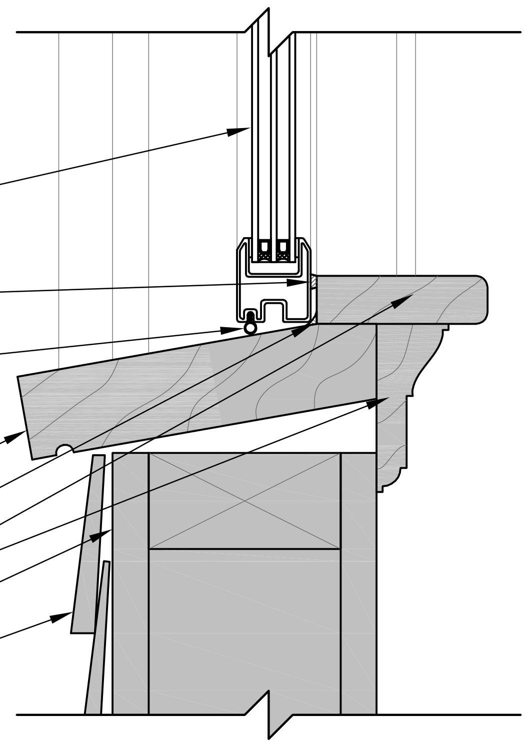
Date: 2011-11-03

Sheet Title:

W-WHf



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW SILL AT WOOD FRAME WALL - F

SCALE: 3" = 1'-0"

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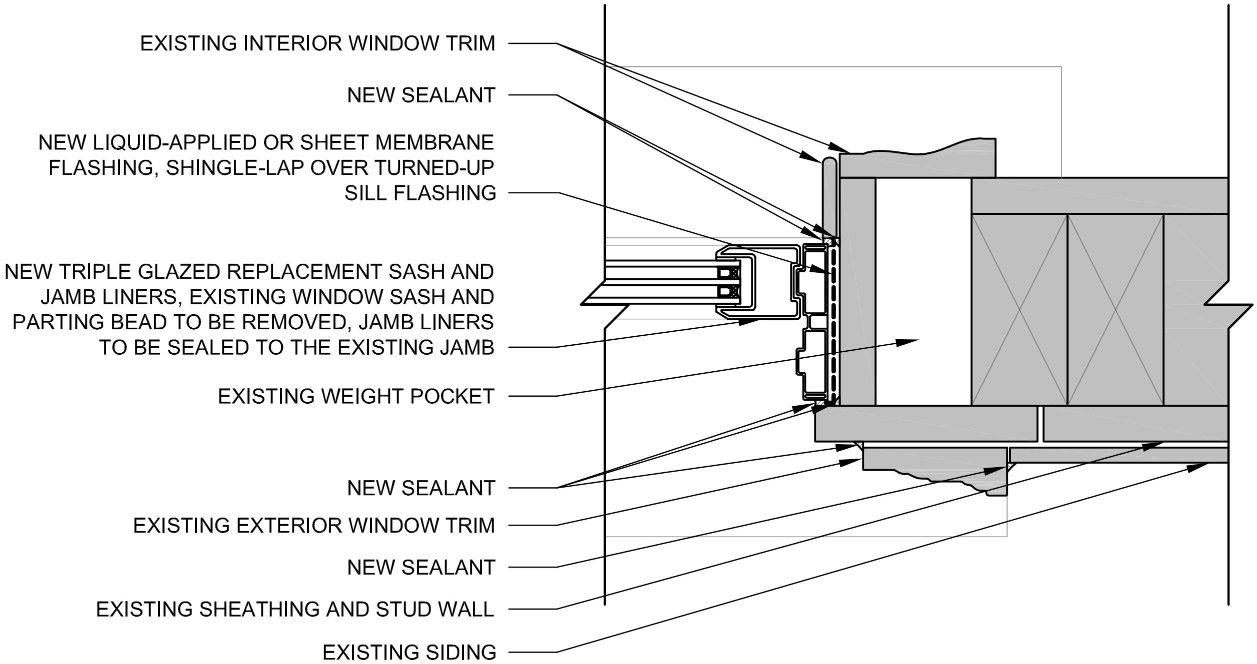
Sheet Title:

W-WSf



WINDOW JAMB AT WOOD FRAME WALL - F

SCALE: 3" = 1'-0"

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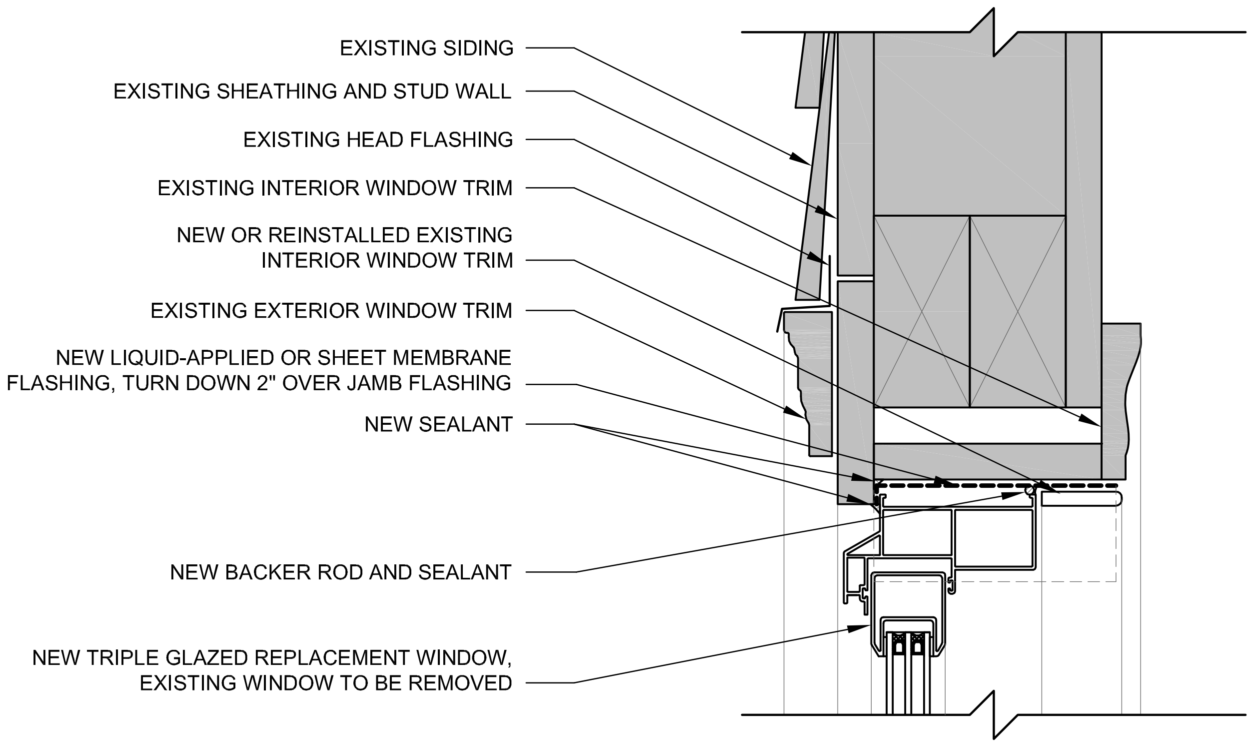
Sheet Title: W-WJf



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW HEAD AT WOOD FRAME WALL - G

SCALE: 3" = 1'-0"

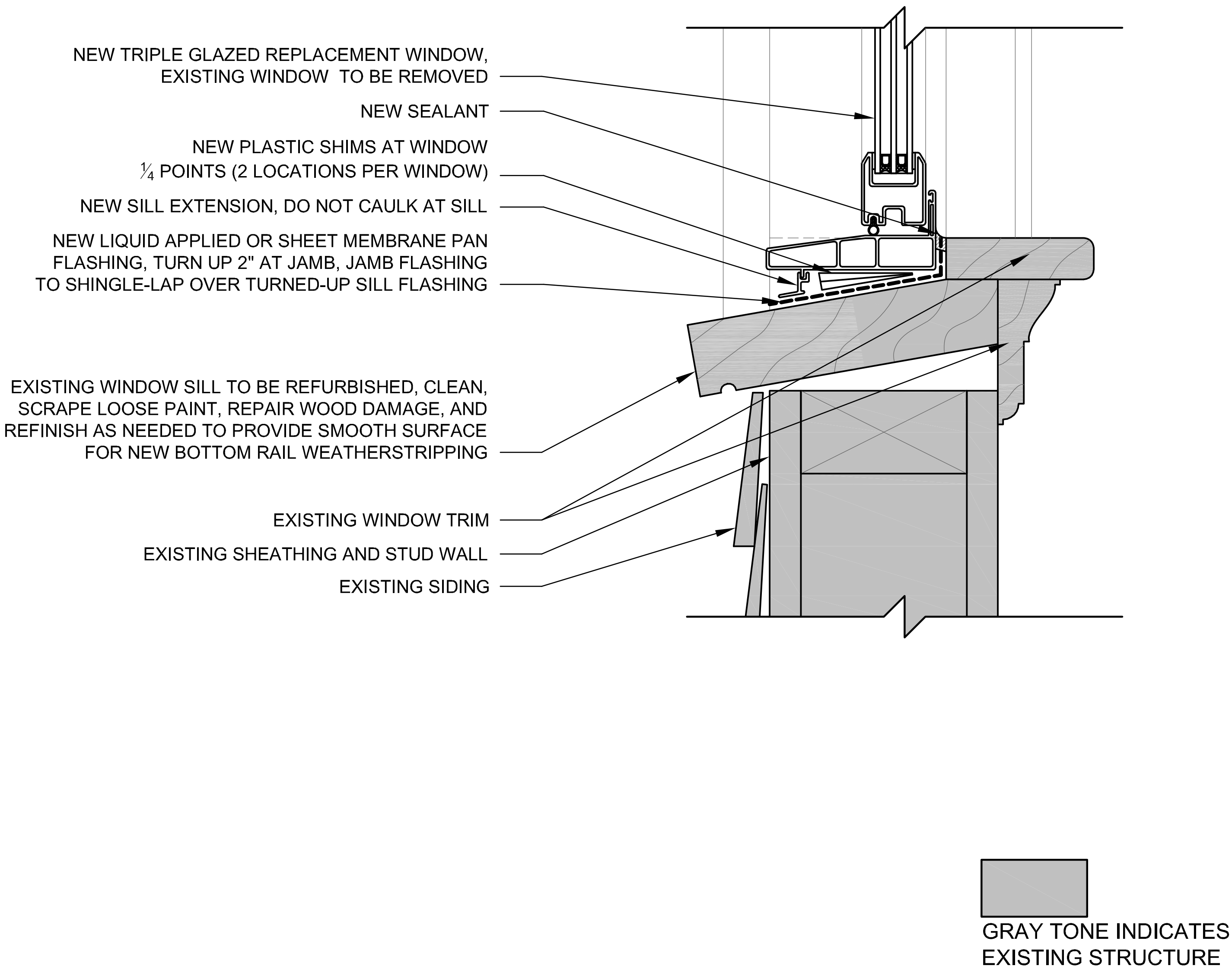
with

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WHg



WINDOW SILL AT WOOD FRAME WALL - G

SCALE: 3" = 1'-0"

with

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

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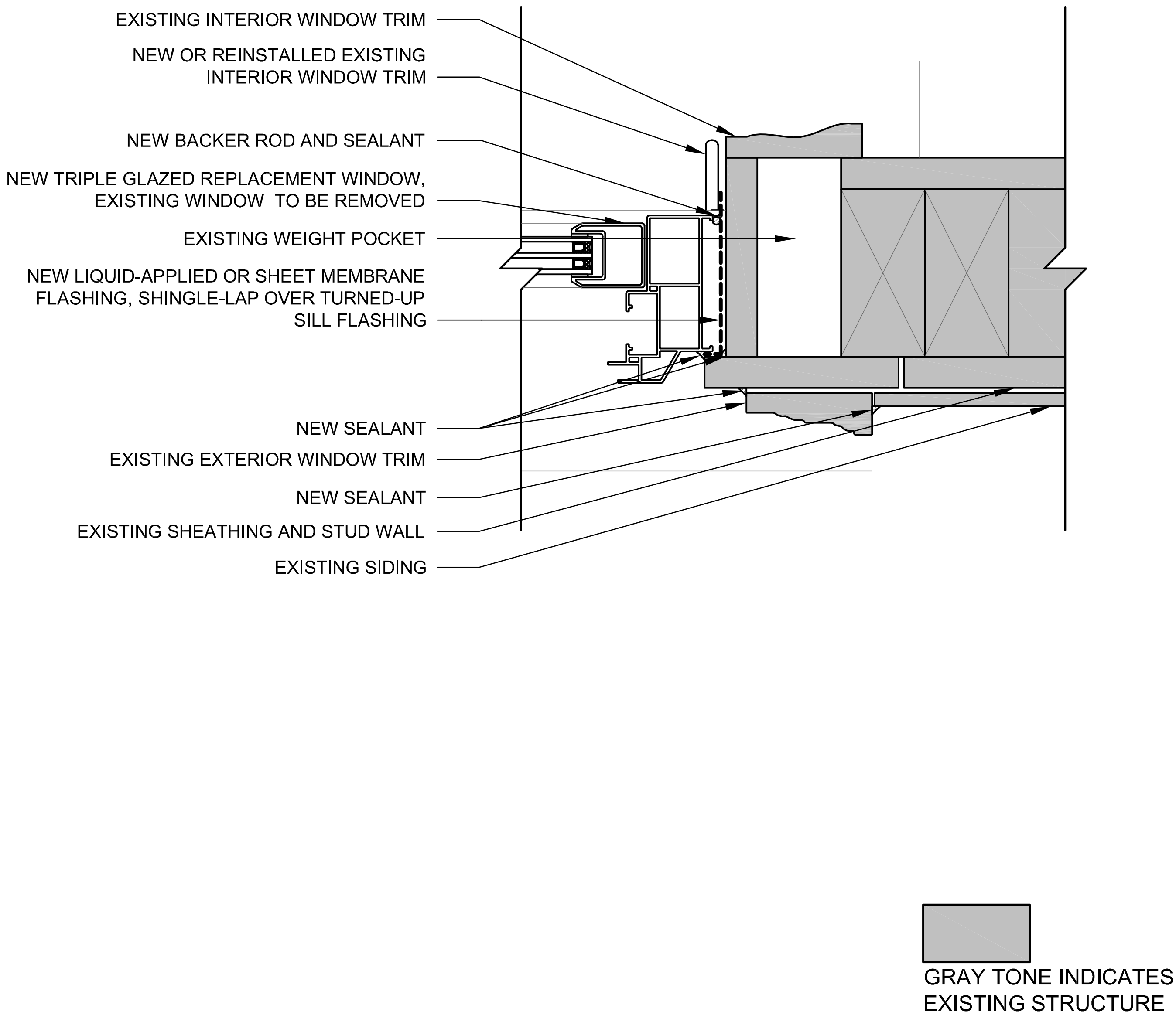

WINDOW JAMB AT WOOD FRAME WALL - G

SCALE: 3" = 1'-0"

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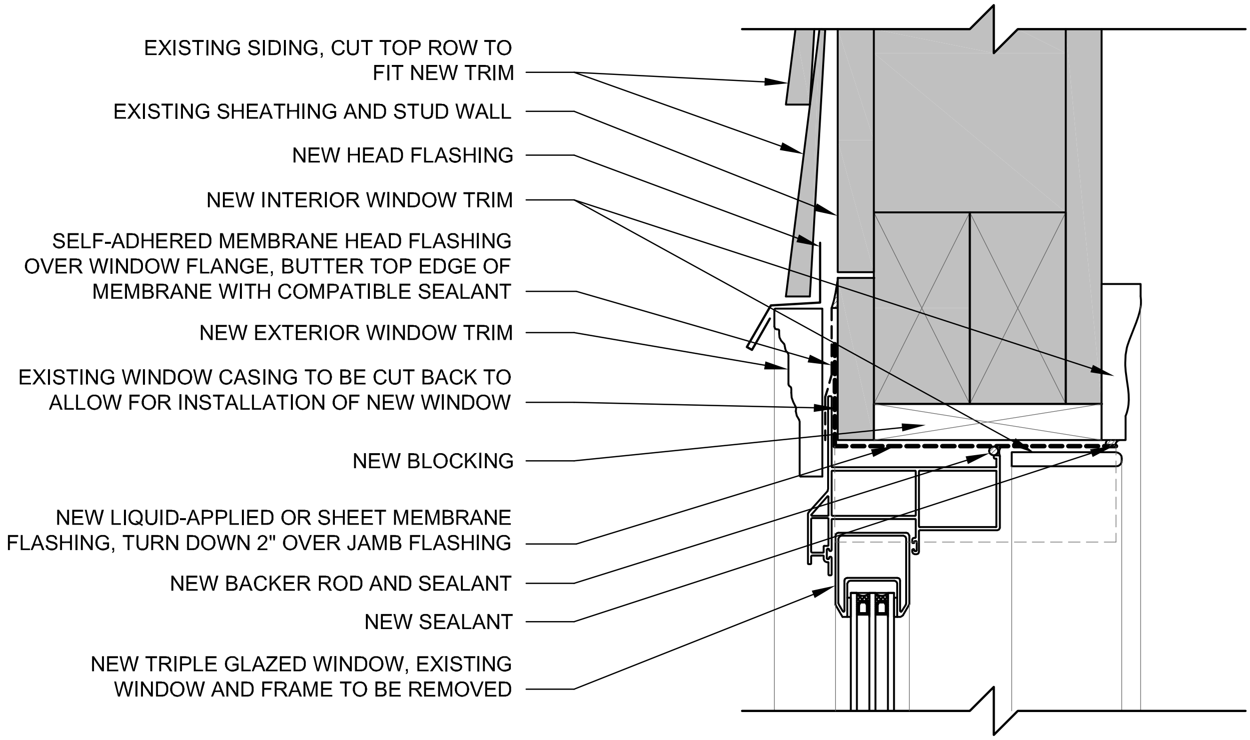
Sheet Title:

W-WJg



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW HEAD AT WOOD FRAME WALL - H

SCALE: 3" = 1'-0"

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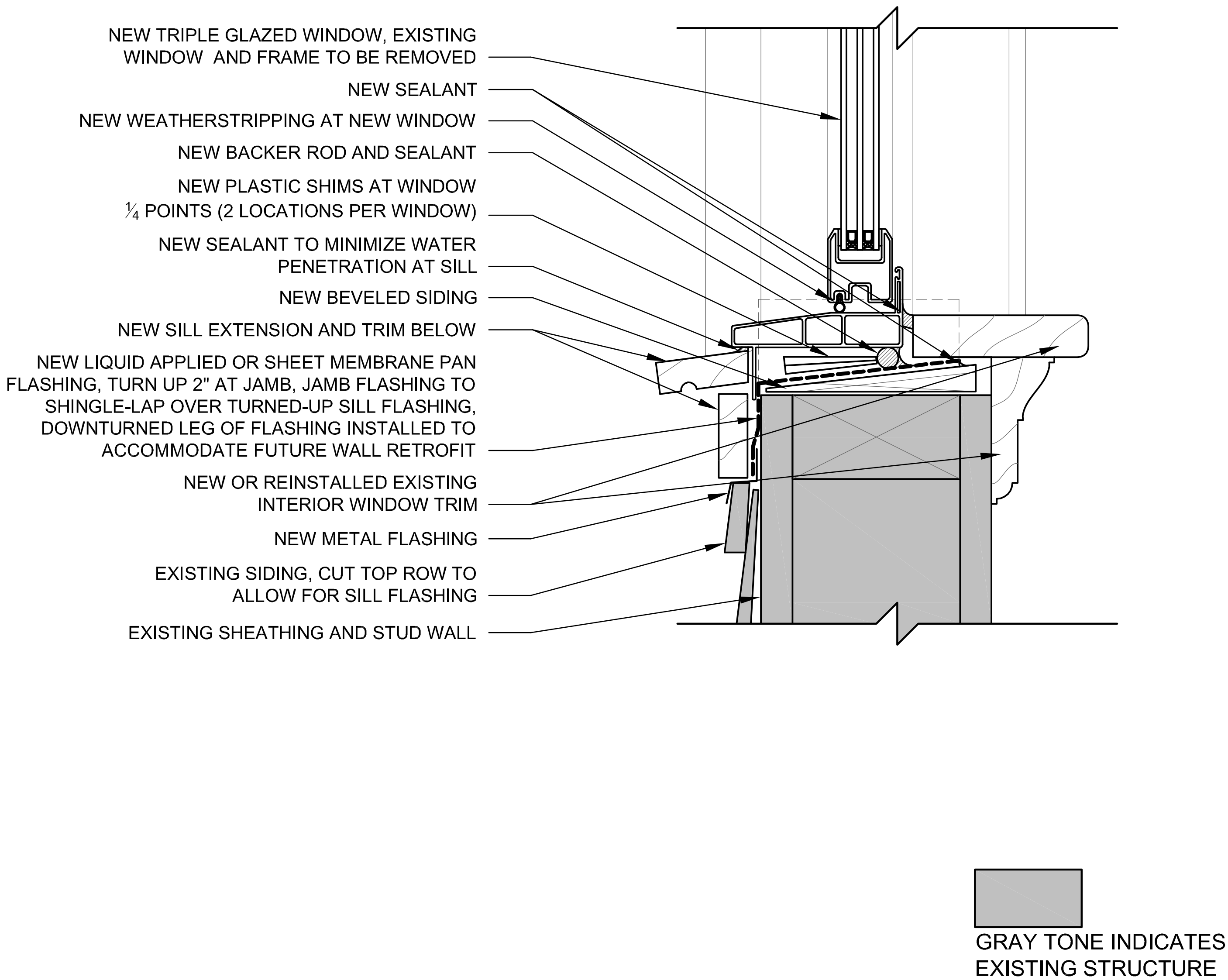
Sheet Title:

W-WHh



WINDOW SILL AT WOOD FRAME WALL - H

SCALE: 3" = 1'-0"

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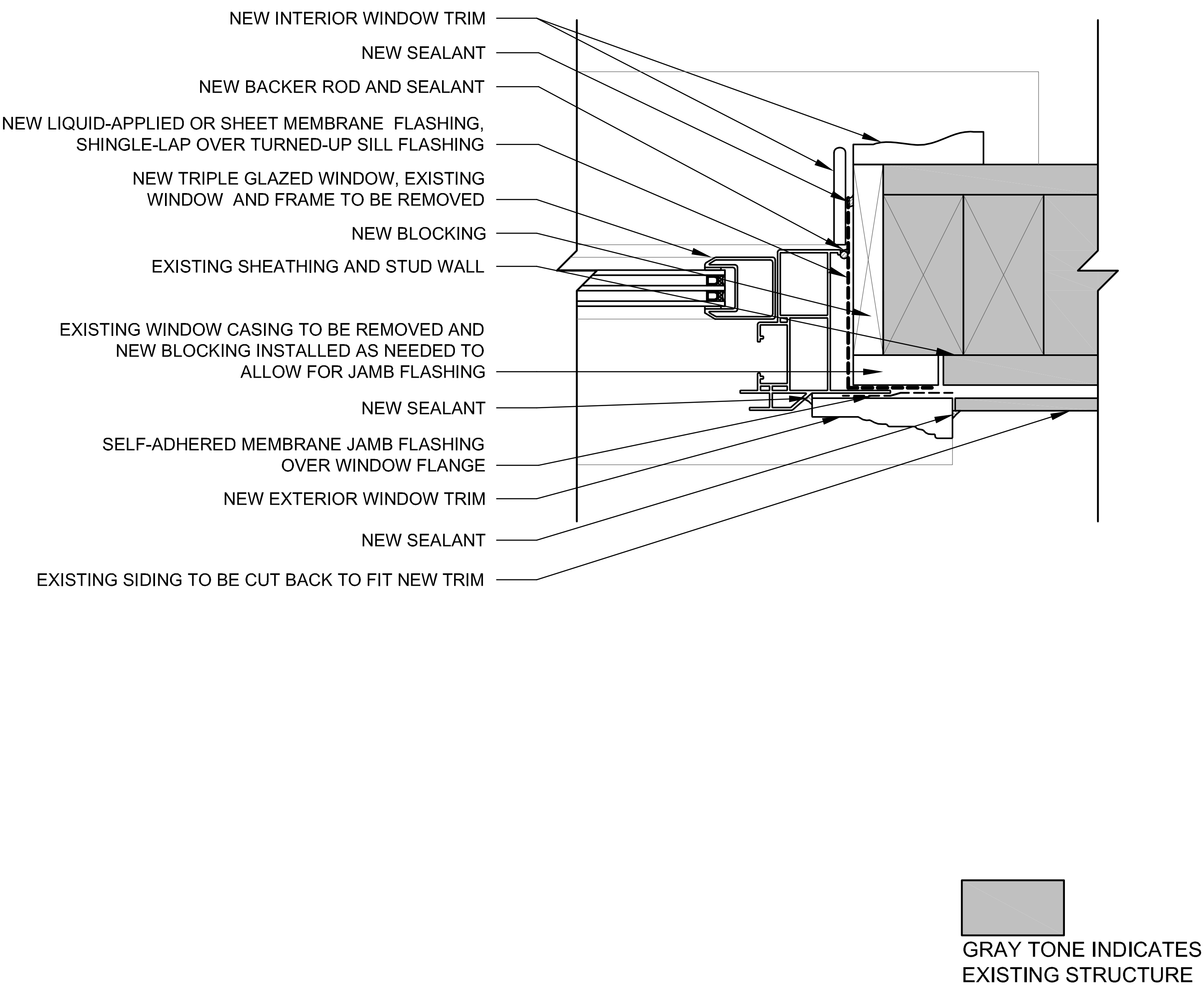
Sheet Title:

W-WSh



WINDOW JAMB AT WOOD FRAME WALL - H

SCALE: 3" = 1'-0"

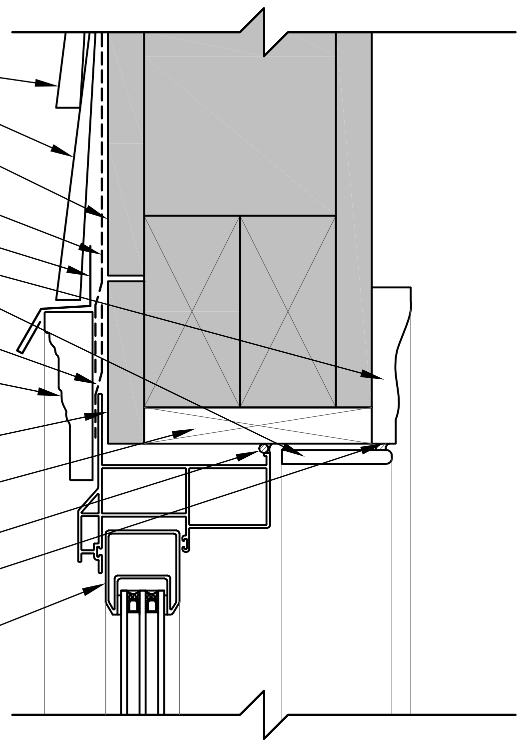
with

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WJh



GRAY TONE INDICATES EXISTING STRUCTURE

WINDOW HEAD AT WOOD FRAME WALL - J

SCALE: 3" = 1'-0"

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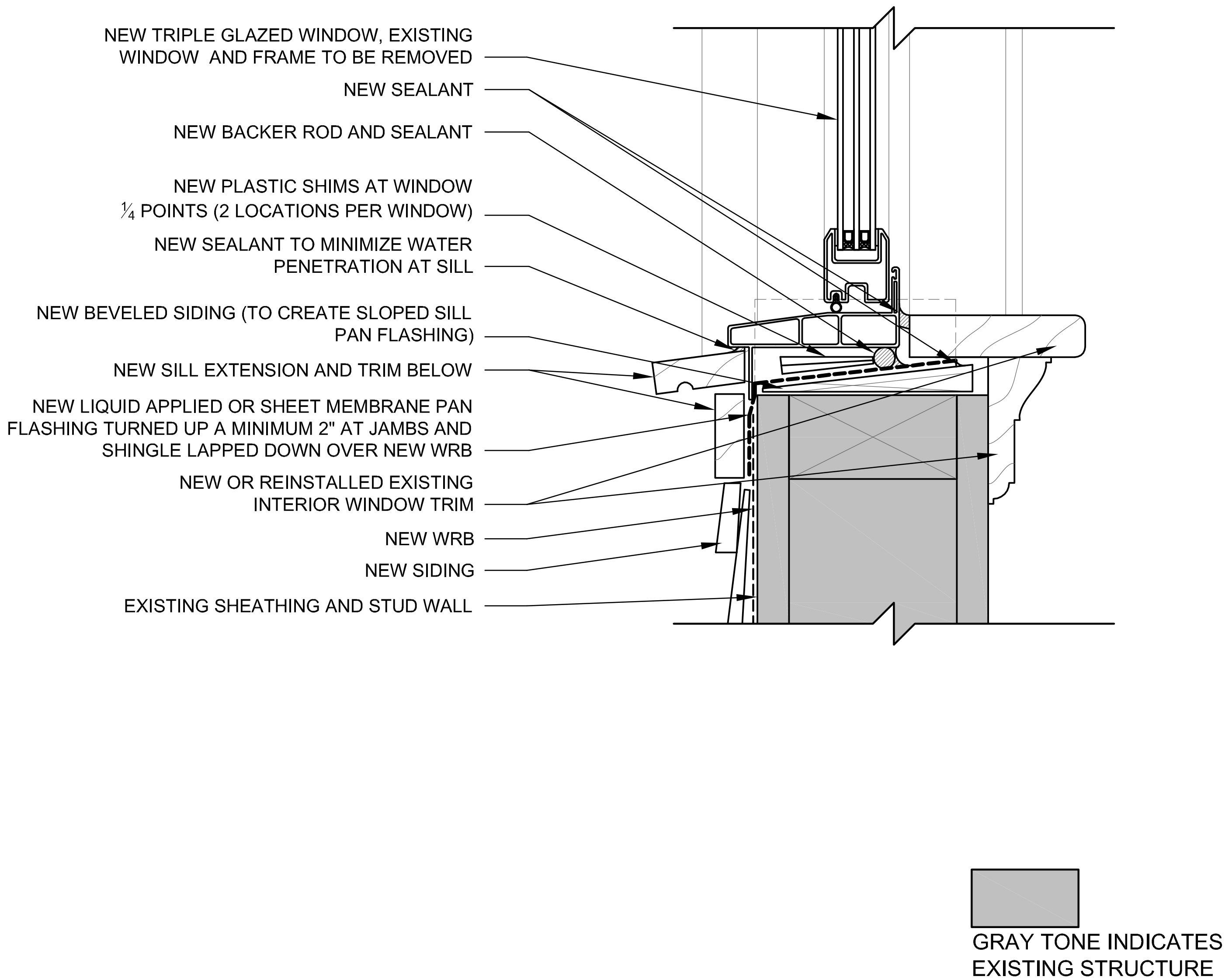
Sheet Title:
W-WHj



WINDOW SILL AT WOOD FRAME WALL - J

SCALE: 3" = 1'-0"

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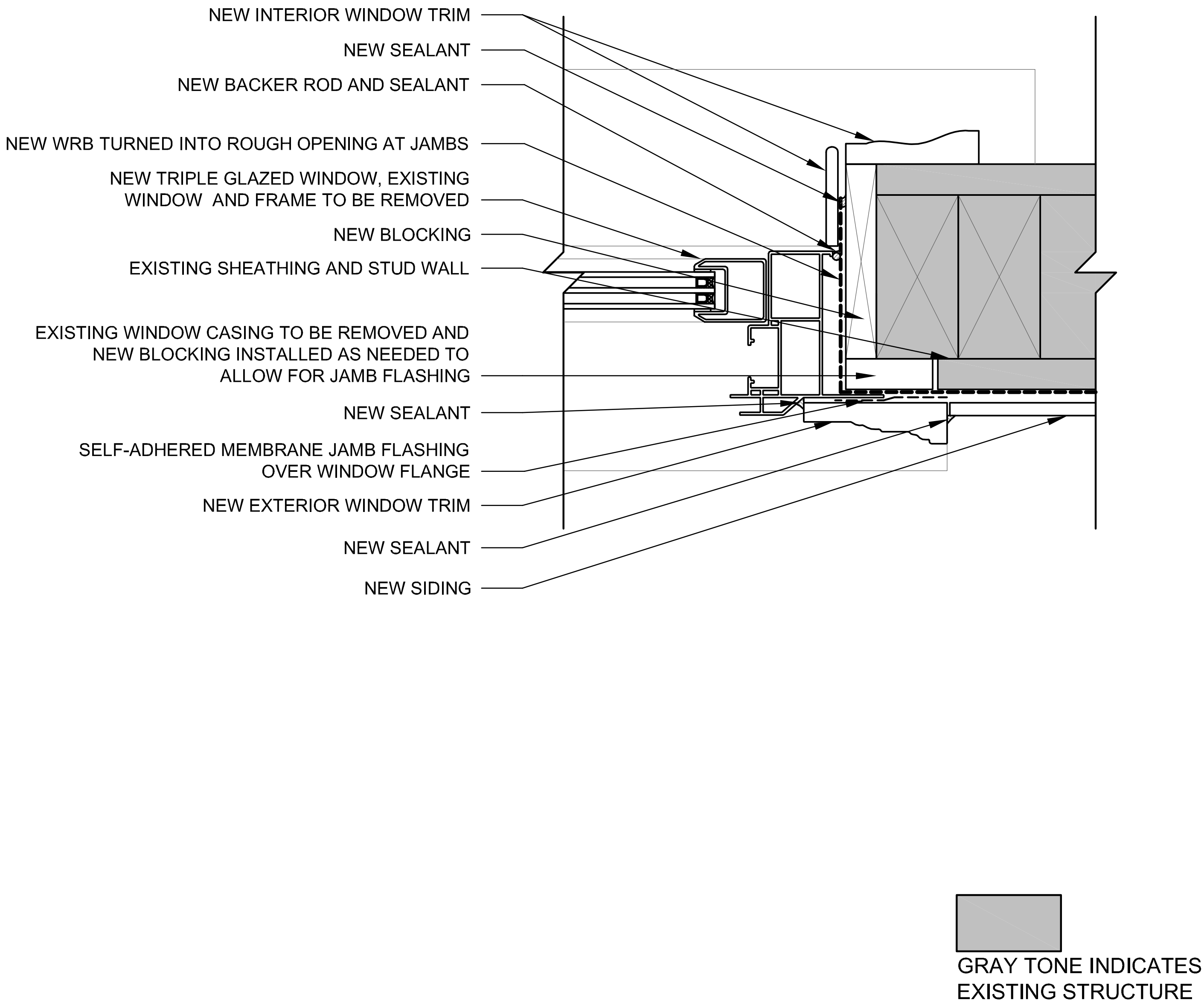
Date: 2011-11-03

Sheet Title:

W-WSj



WINDOW JAMB AT WOOD FRAME WALL - J

SCALE: 3" = 1'-0"

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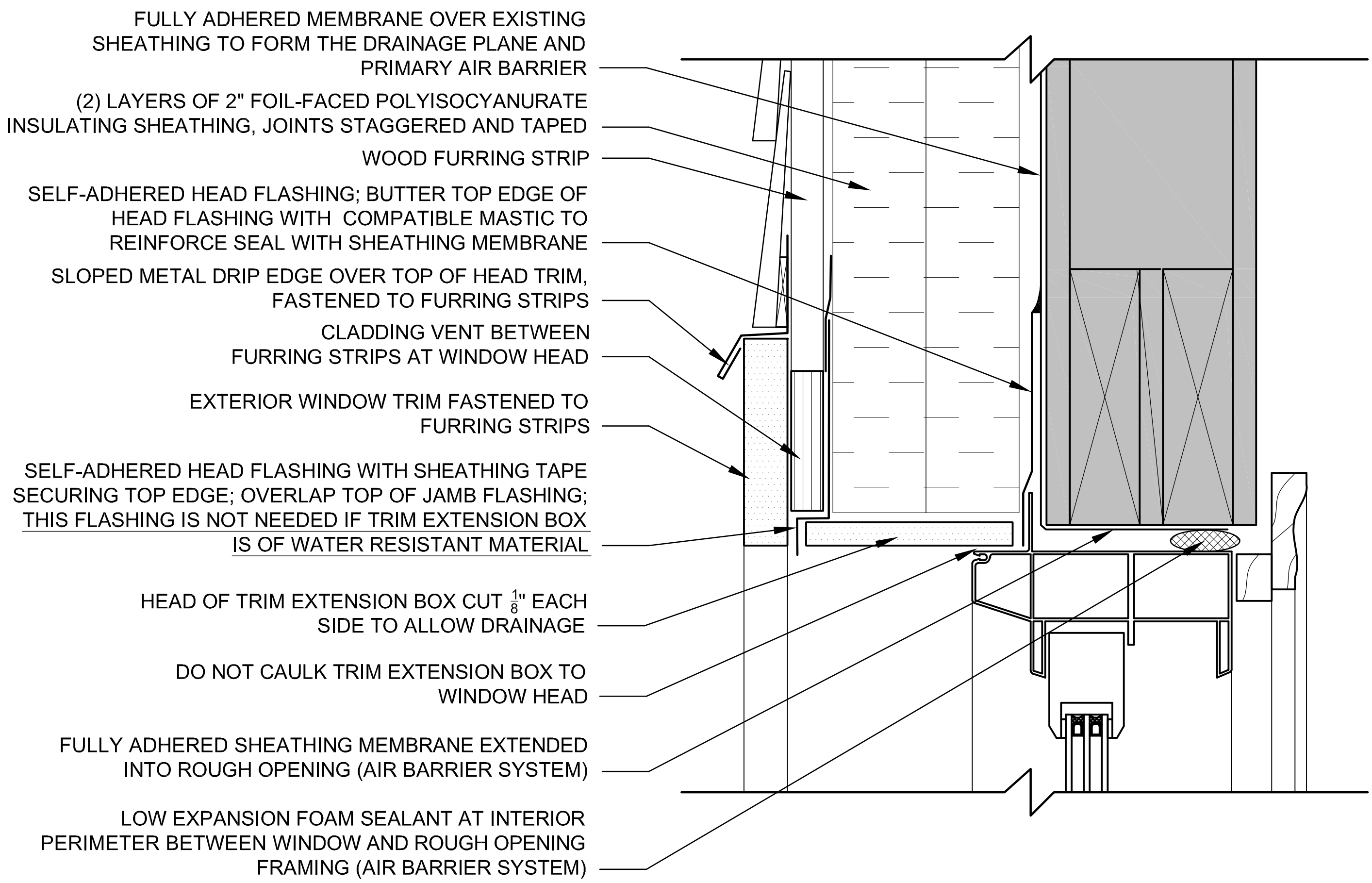
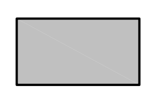
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WJj





WINDOW HEAD AT WOOD FRAME WALL "INNIE" - K

SCALE: 3" = 1'-0"

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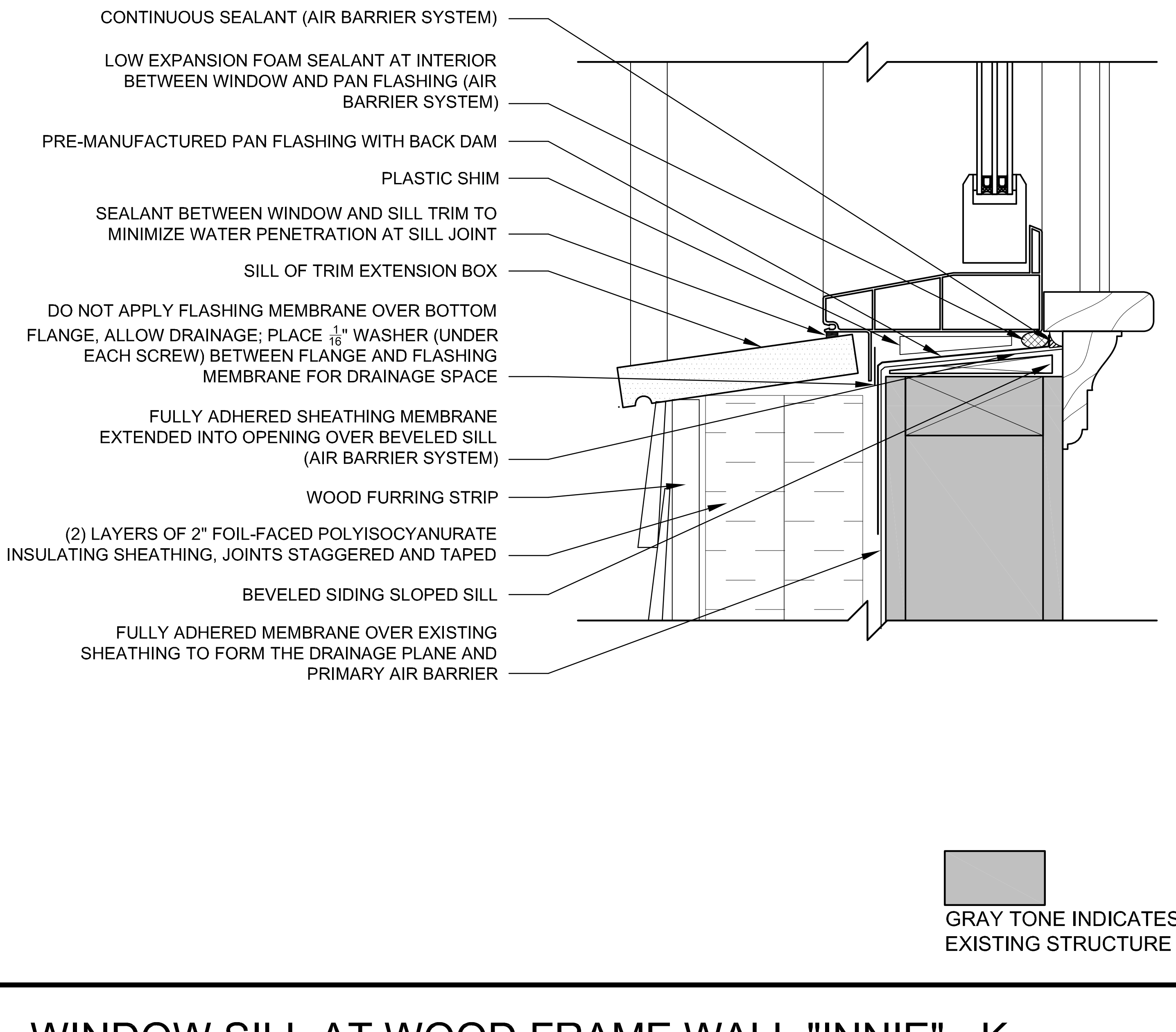
Sheet Title:

W-WHk



WINDOW SILL AT WOOD FRAME WALL "INNIE" - K

SCALE: 3" = 1'-0"

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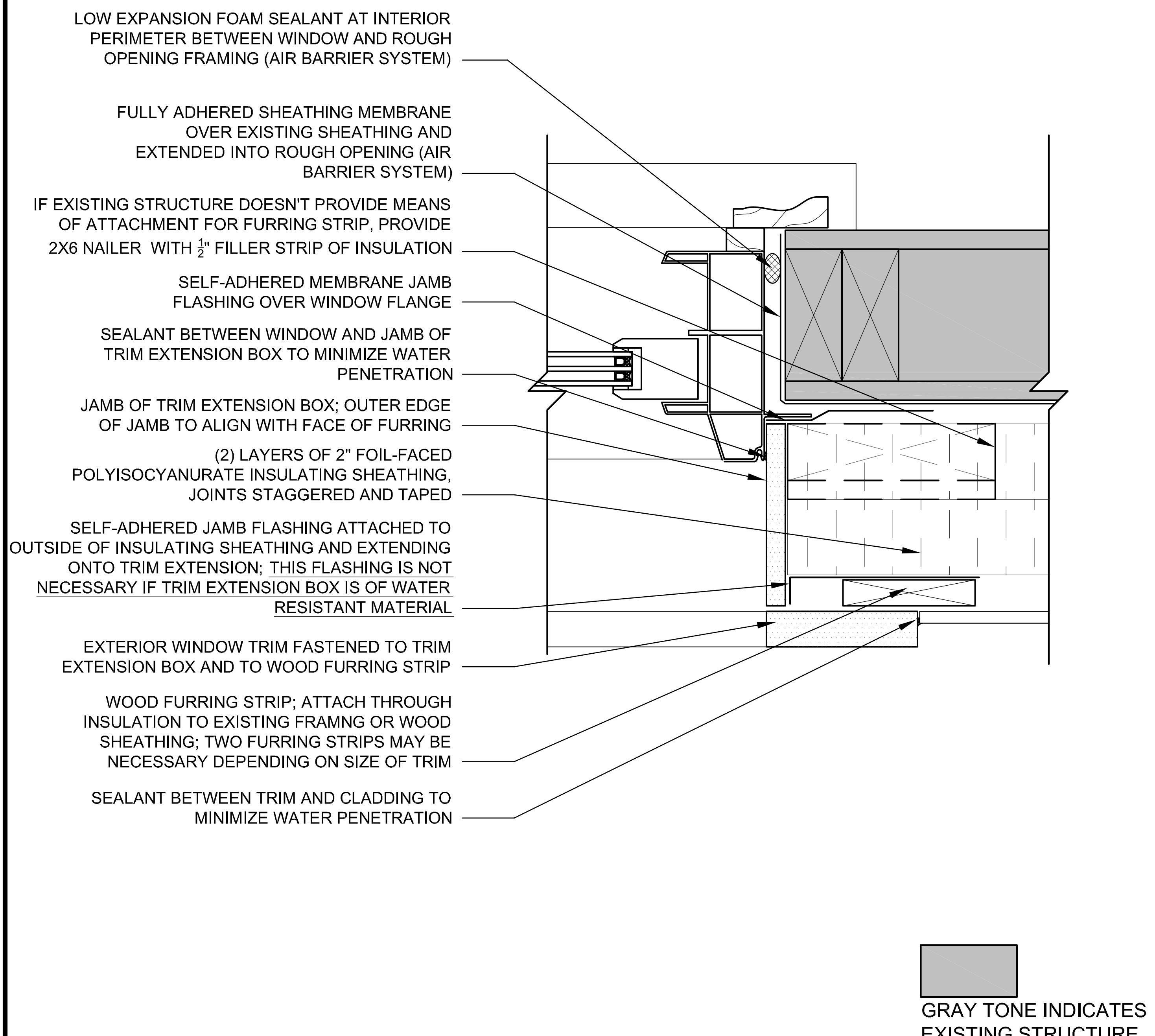
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WSk



WINDOW JAMB AT WOOD FRAME WALL "INNIE" - K

SCALE: 3" = 1'-0"

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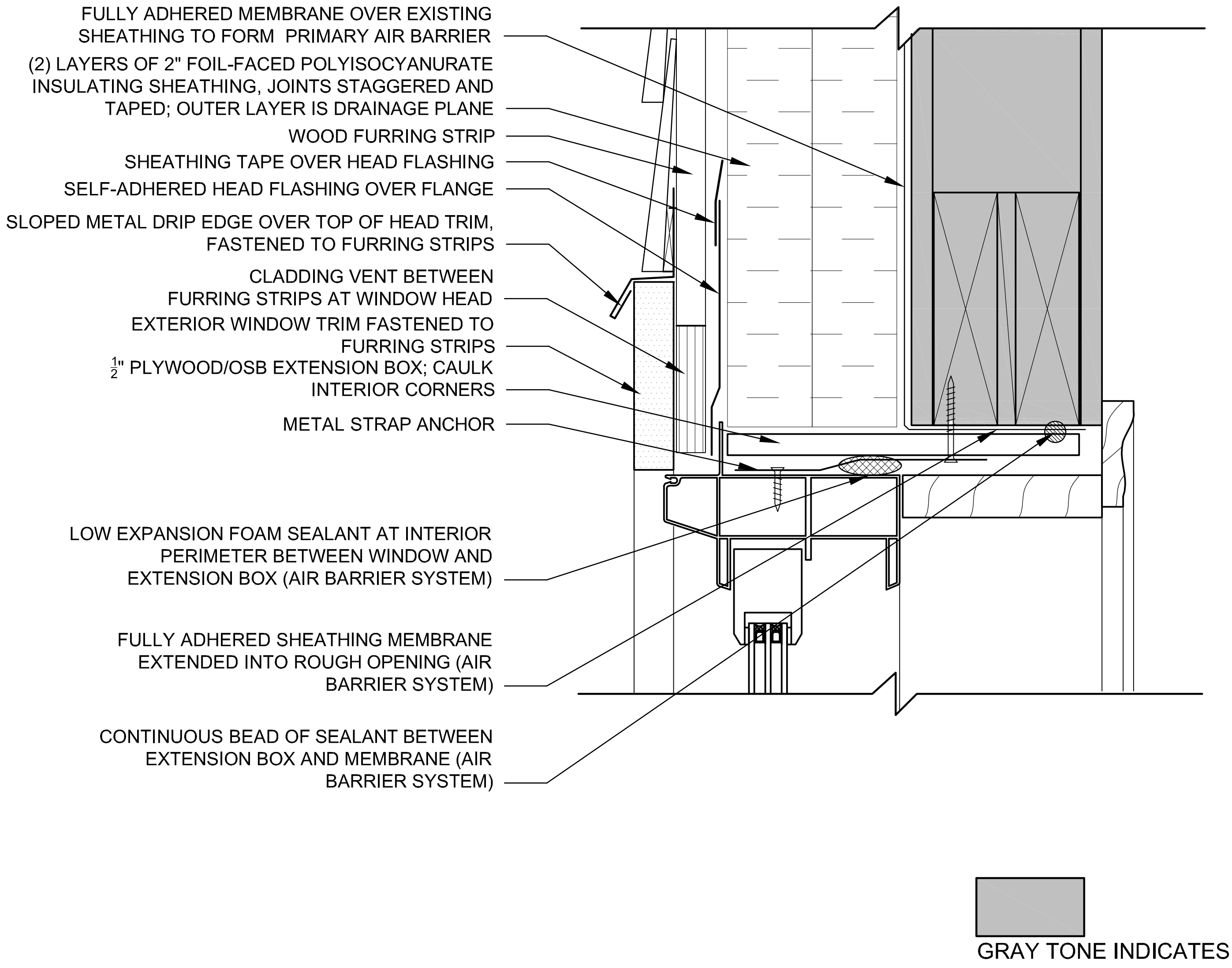
Sheet Title:

W-WJk



WINDOW HEAD AT WOOD FRAME WALL "OUTIE" - M

SCALE: 3" = 1'-0"

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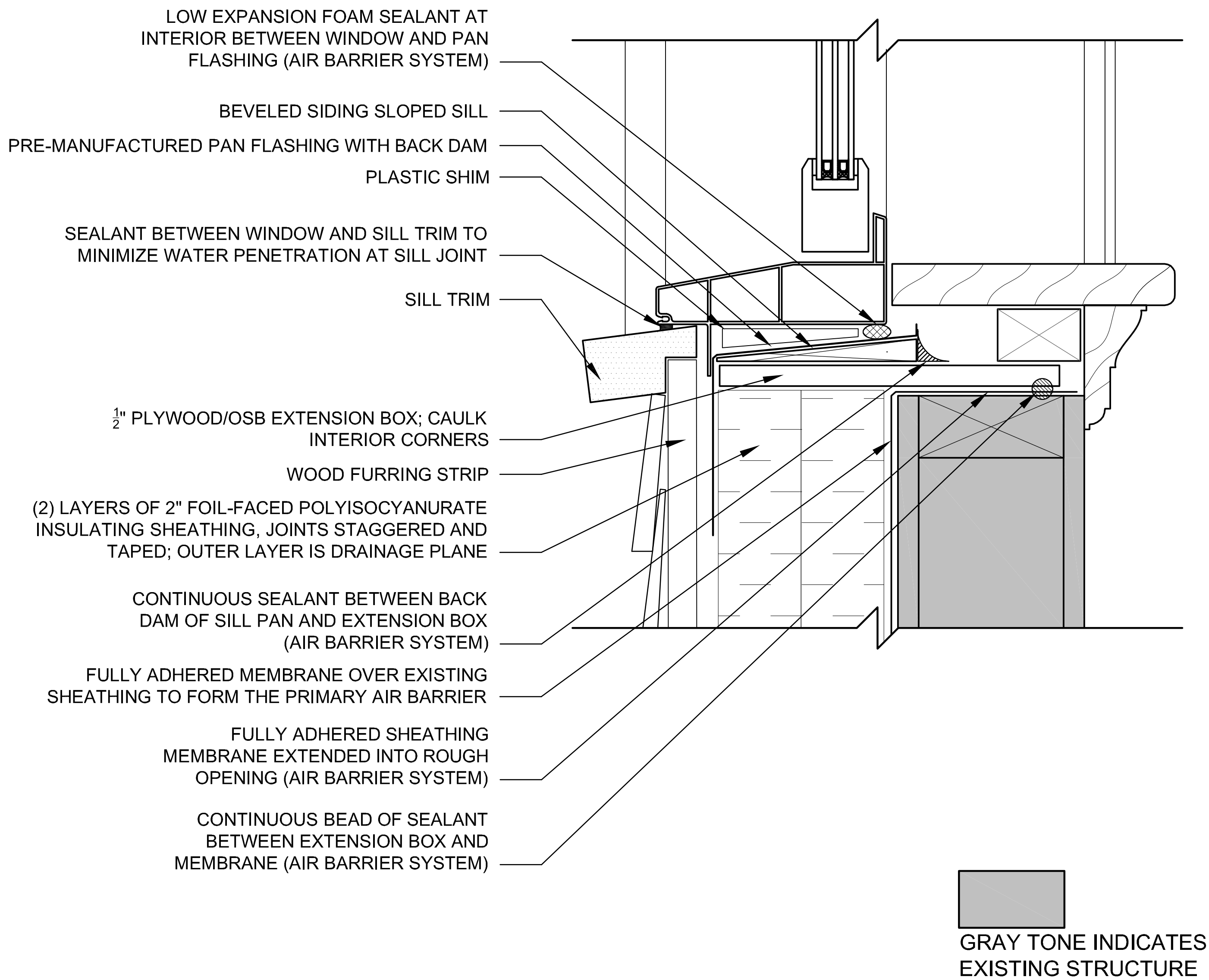
Sheet Title:

W-WHm



WINDOW SILL AT WOOD FRAME WALL "OUTIE" - M

SCALE: 3" = 1'-0"

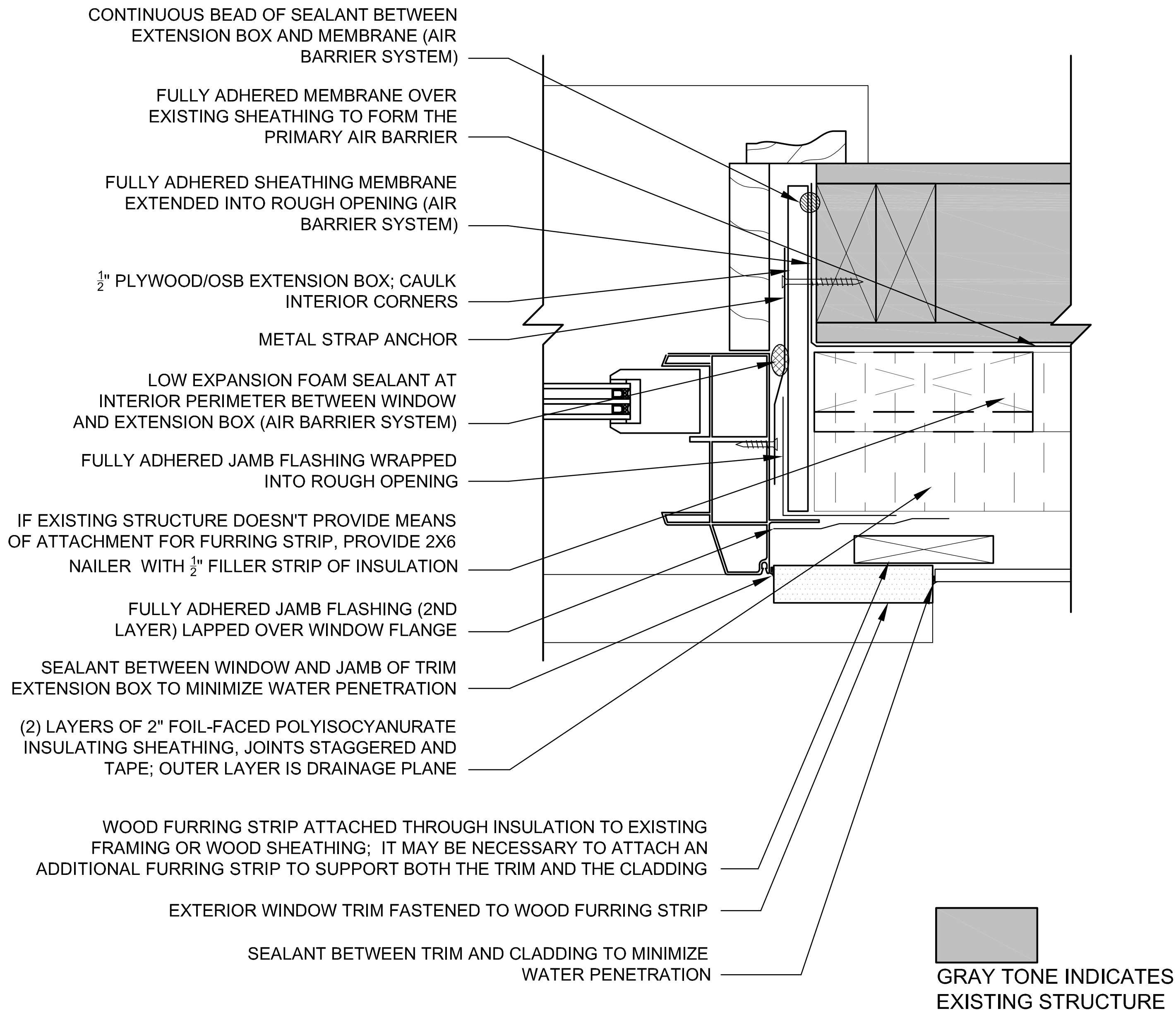
bsc with Building America U.S. Department of Energy Research Toward Zero Energy Homes

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WSm



WINDOW JAMB AT WOOD FRAME WALL "OUTIE" - M

SCALE: 3" = 1'-0"

with Building America U.S. Department of Energy *Research Toward Zero Energy Homes*

Wood Frame Wall
Window Retrofit Options

Date: 2011-11-03

Sheet Title:

W-WJm

Appendix B: BEOPT Analysis Graphs

Dallas, TX

Utility Rates: $0.13/kWh
$1.09/therm

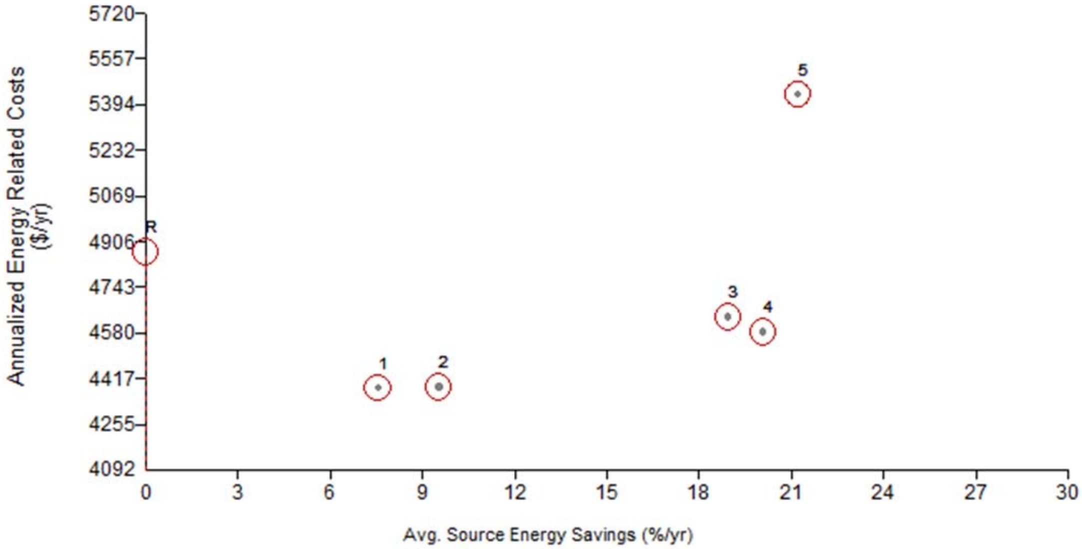


Figure 8. Annualized Energy Related Costs vs. Avg. Source Energy Savings for Dallas, TX

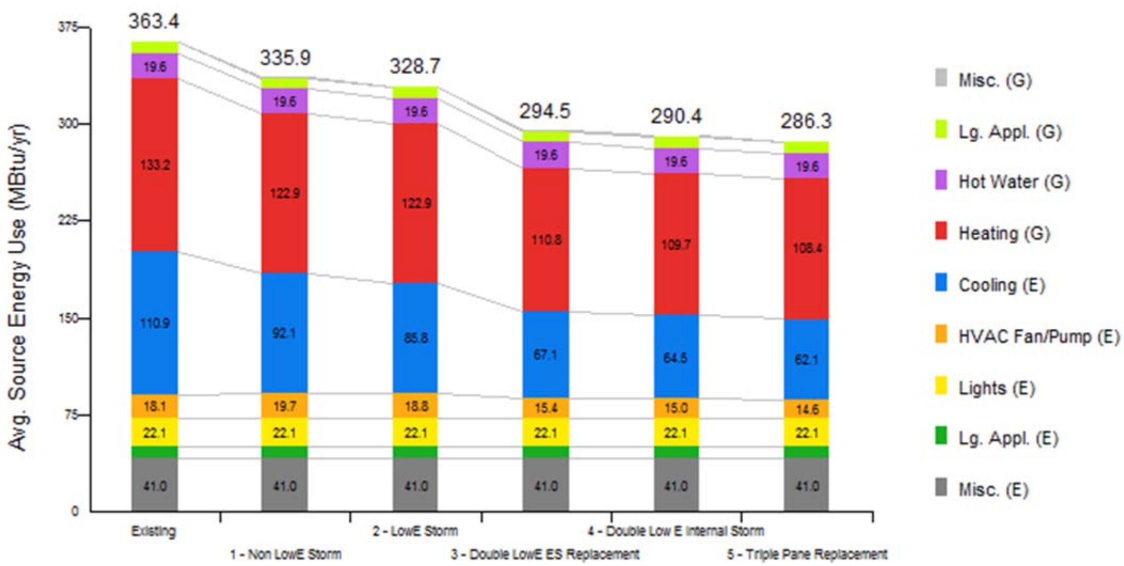


Figure 9. Average Source Energy Savings Reduction for Dallas, TX

Kansas City, MO

Utility Rates: $0.08/kWh
$1.23/therm

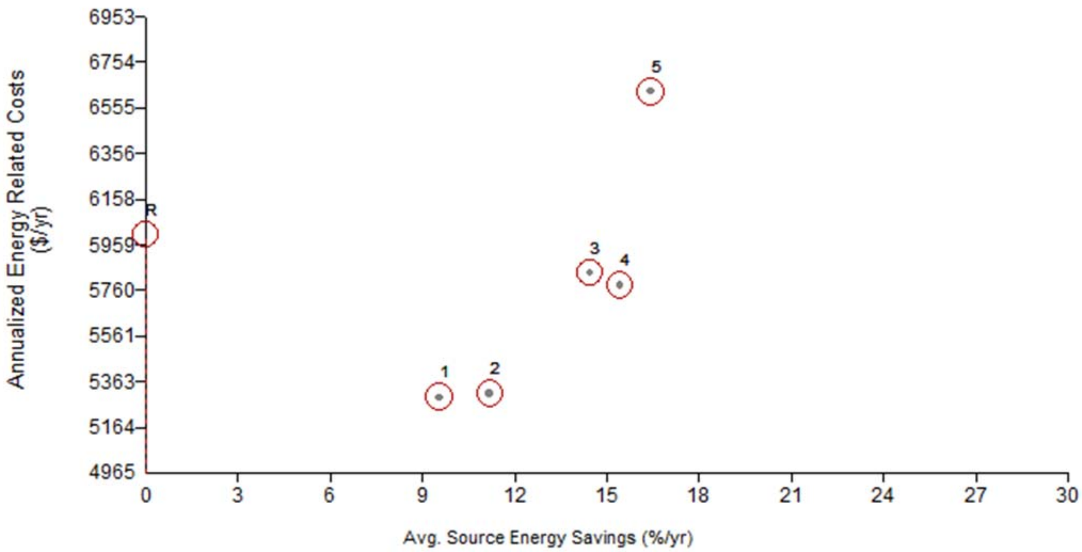


Figure 10. Annualized Energy Related Costs vs. Avg. Source Energy Savings for Kansas City, MO

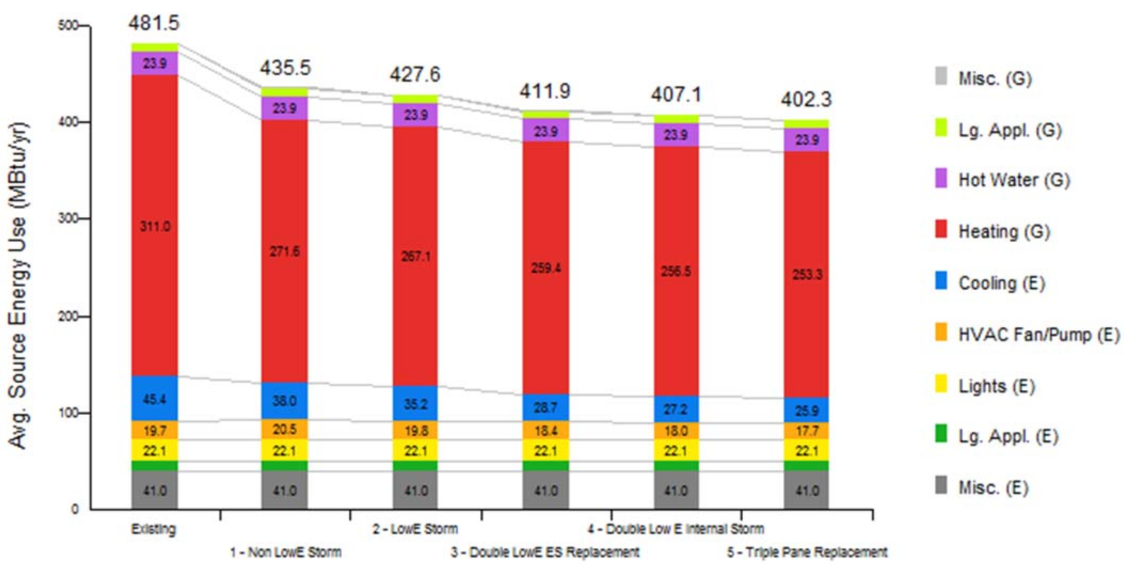


Figure 11. Average Source Energy Savings Reduction for Kansas City, MO

Boston, MA

Utility Rates: $0.18/kWh
$1.70/therm

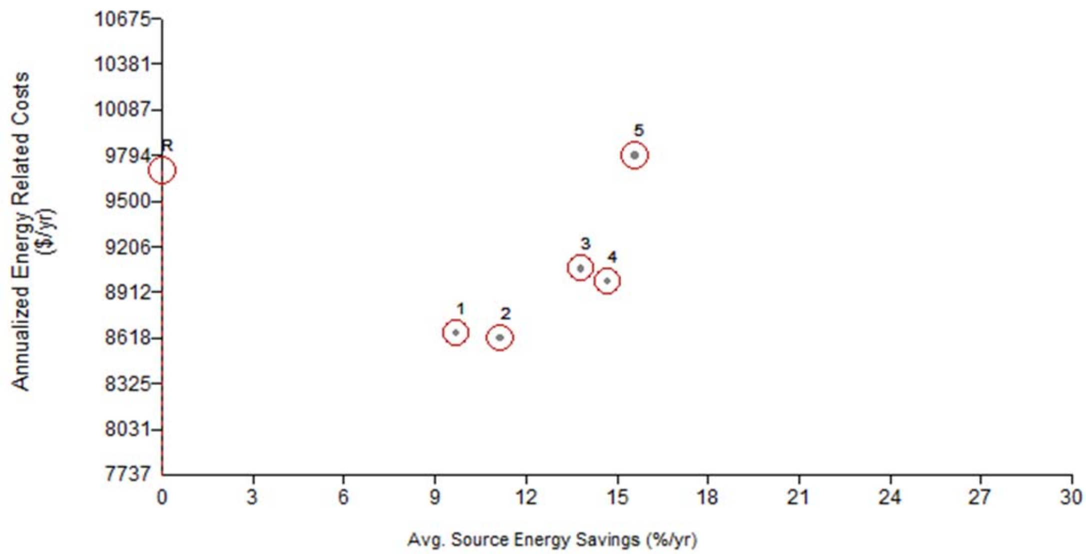


Figure 12. Annualized Energy Related Costs vs. Avg. Source Energy Savings for Boston, MA

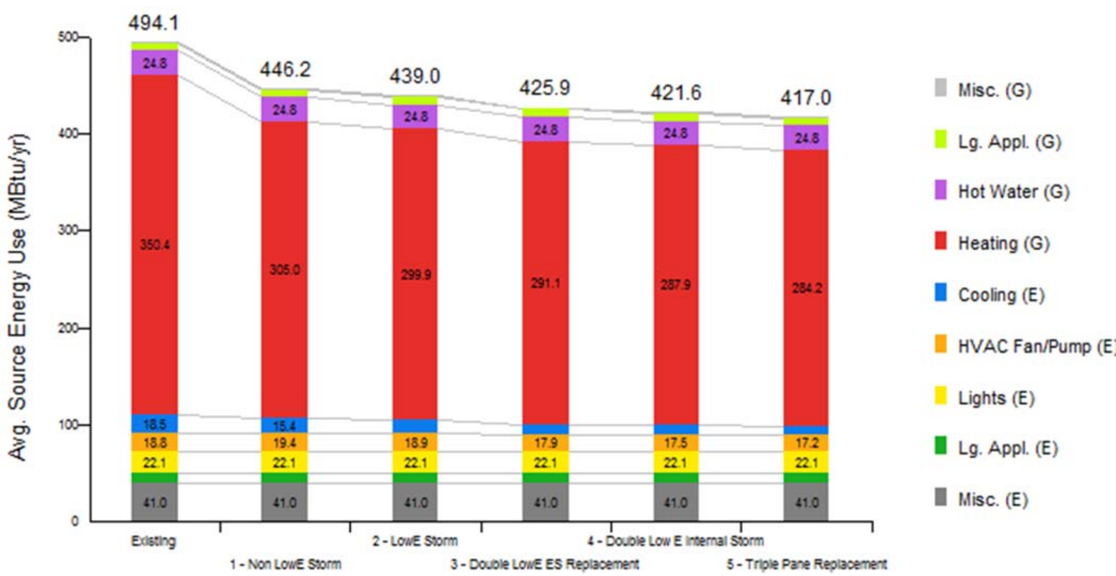


Figure 13. Average Source Energy Savings Reduction for Boston, MA

Duluth, MN

Utility Rates: $0.10/kWh
$0.87/therm

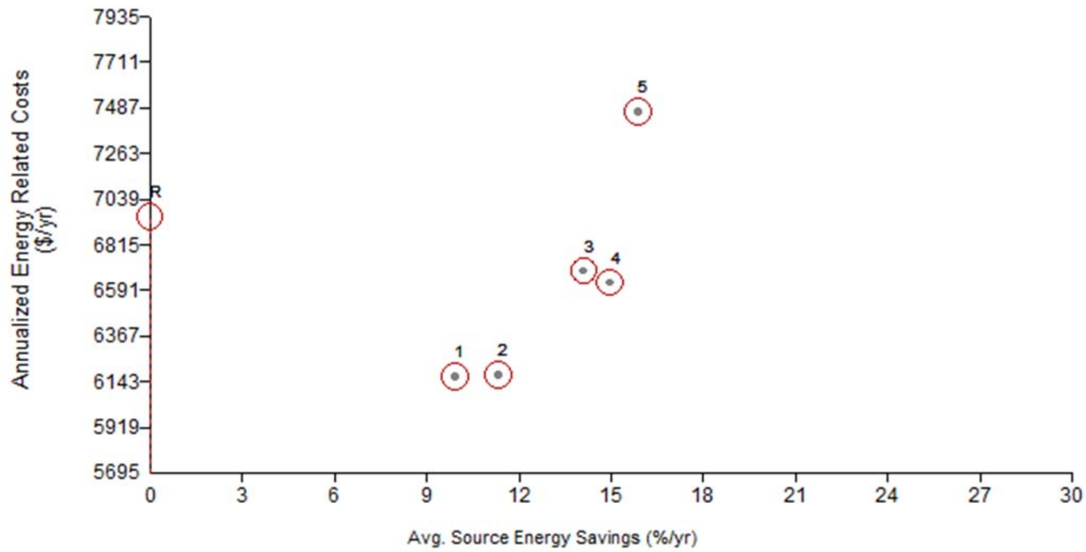


Figure 14. Annualized Energy Related Costs vs. Avg. Source Energy Savings for Duluth, MN

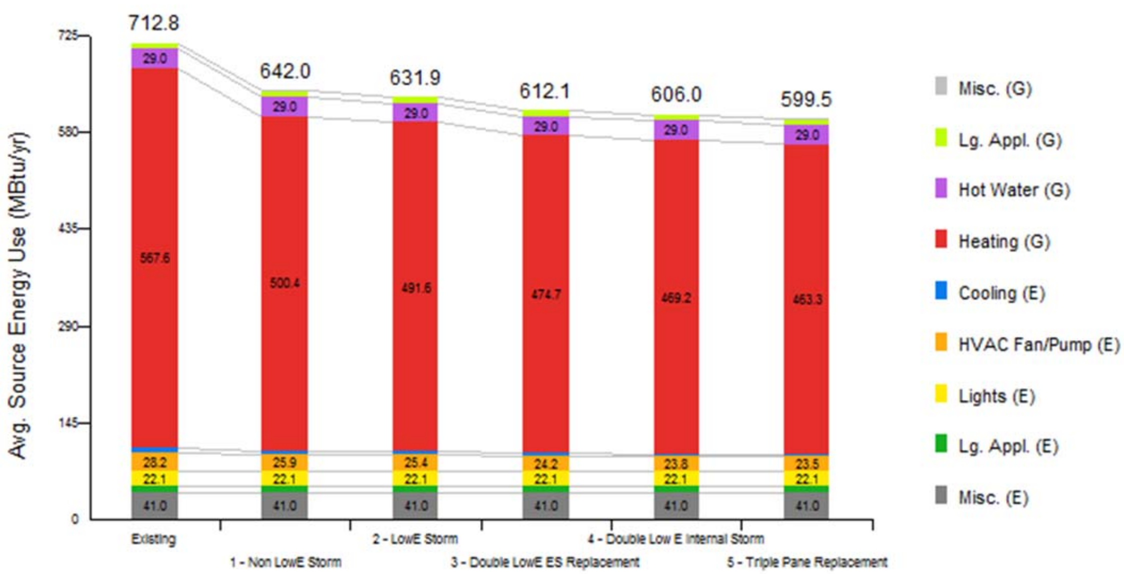


Figure 15. Average Source Energy Savings Reduction for Duluth, MN

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