

# Measure Guideline: Wood Window Repair, Rehabilitation, and Replacement

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December 2012

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## **Measure Guideline: Window Repair, Rehabilitation, and Replacement**

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

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Prepared under Subcontract No. KNDJ-0-40337-00

December 2012

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*Unless otherwise indicated, all tables were created by BSC.*

## Definitions

|         |   |
|---------|---|
| ASHRAE  | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| BA      | Building America Program  |
| BSC     | Building Science Corporation  |
| DOE     | U.S. Department of Energy   |
| IGU     | Insulated glazing unit  |
| NFRC    | National Fenestration Rating Council                                      |
| SHGC    | Solar heat gain coefficient   |
| U-Value | Window Thermal Transmittance Value  |
| UA      | U-Value multiplied by assembly area                                       |
| WRB     | Water resistive barrier   |

## Executive Summary

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

This measure guideline provides information and guidance about rehabilitating, retrofitting, and replacing wood window assemblies in residential construction. It is intended primarily to help contractors and homeowners understand the options for safely improving the performance of their wood windows.

Deciding which window measure will be most appropriate for the retrofit project depends on several factors, including current conditions, desired appearance or aesthetic goals, energy performance goals, cost, disruption to occupants, durability risks, historic requirements, and any other project goals or requirements.

Table 1 lists the f most common approaches to improve the performance of wood windows:

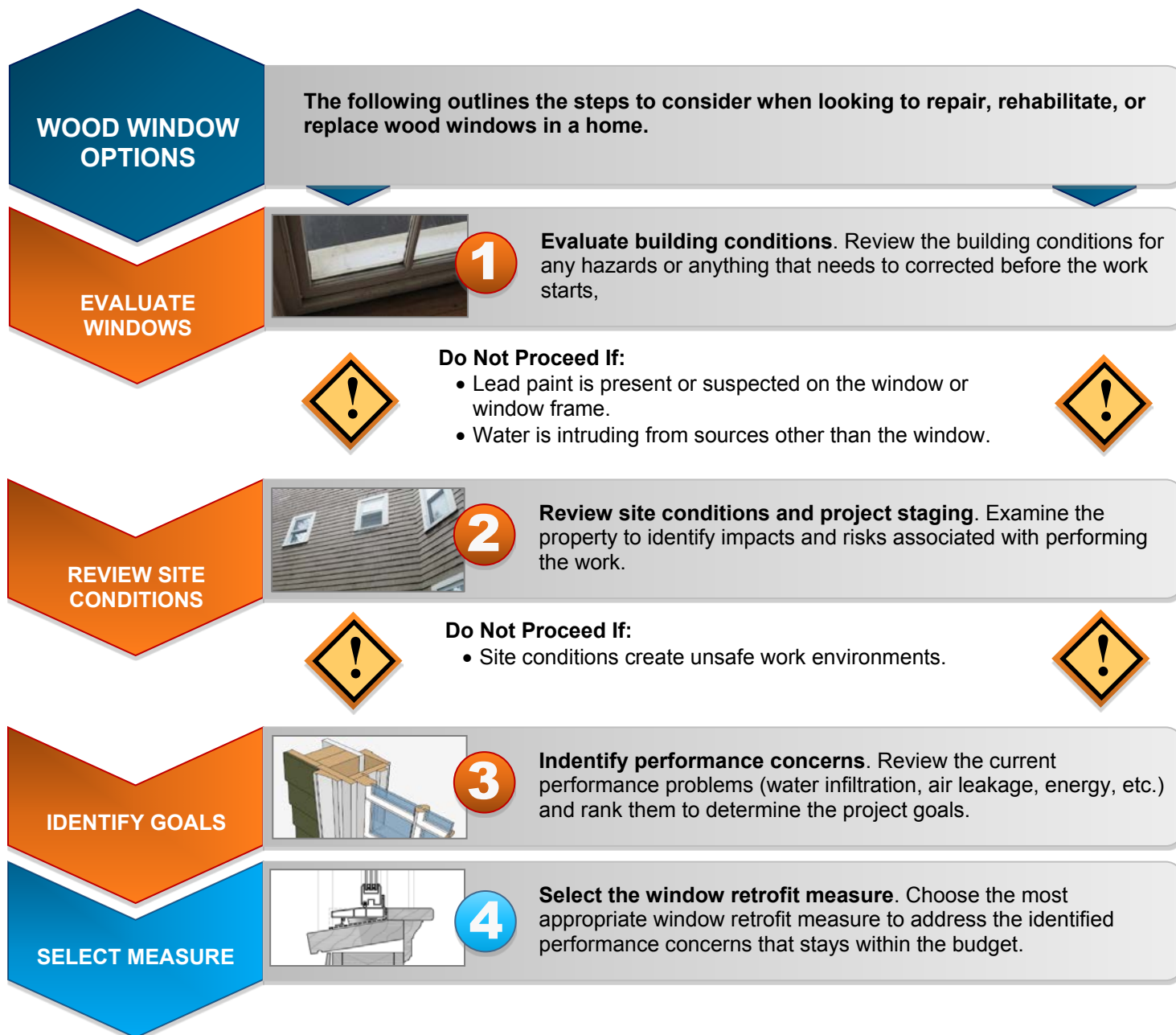
**Table 1. Window Retrofit Measures**

|   | 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. 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 windows to accommodate storm windows. Improves the air infiltration performance, conductance, and solar gain. Additional benefits can be achieved with hard coat low-e glazing. Cost is relatively low.   |
| 3 | Interior removable storm windows | Recommended installation practice for removable interior storm windows, including preparation of windows to accommodate storm windows. Improves the air infiltration performance, conductance, and solar gain. Condensation potential on outer prime window could be a durability concern. Cost is relatively low.   |
| 4 | Interior permanent storm windows | Recommended installation practice for permanent interior storm windows, including preparation of windows to accommodate storm windows. 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. |

|   | Measure                     | Description   |
|---|-----------------------------|---|
| 5 | Window sash modification    | Modification of the old window sashes, leaving the original wood window frames in place. Frame preparation to accommodate original sashes to accept high performance insulating glass units. Improves the air infiltration performance, conductance, and solar gain and maintains 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 frames in place. Frame preparation to accommodate high performance replacement sashes and tracks. Improves the air infiltration performance, conductance, and solar gain and maintains 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 wood window frame. Improves the air infiltration performance, conductance, and solar gain. Work can be done quickly with little disruption to the 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. Improves the air infiltration performance, conductance, and solar gain. 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 is typically a significant disruption to the building occupant. |

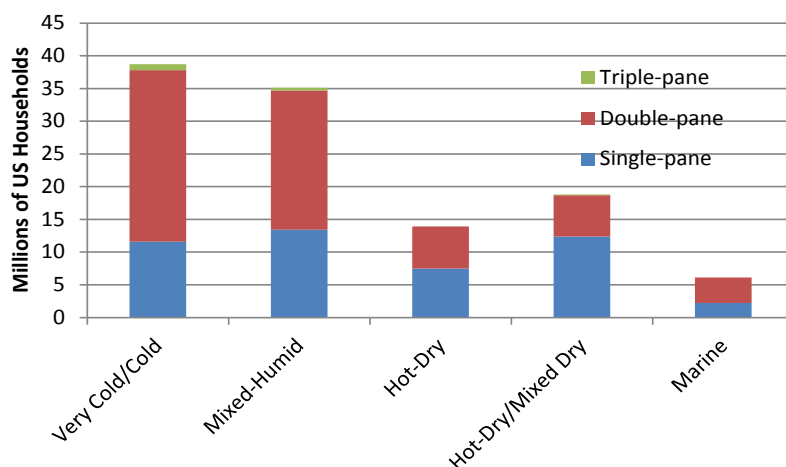
Complementary information about a variety of energy upgrades can also be found in the National Renewable Energy Laboratory's Standard Work Specifications, currently under development through U.S. Department of Energy's Guidelines for Homes Energy Professionals project.

## Progression Summary

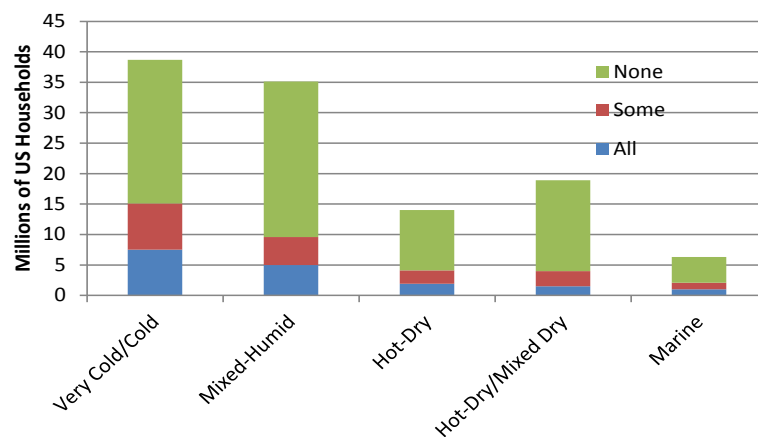


# 1 Introduction

There is a significant push for energy performance upgrades to existing homes. An important target is often the windows. Poor window performance can have significant impacts on the overall thermal resistance and airtightness of the home. The existing U.S. housing stock has a wide range of window types (Figure 1), ages, and conditions. All are factors in the overall energy performance and comfort performance of the home. Most windows are still original to the homes; however, it is not uncommon for windows to be replaced (Figure 2). Possibly more common than window replacement are attempts at lower cost window retrofits. These retrofits have often been done (with varying degrees of success) by homeowners trying to address problems without adequate knowledge about how to safely, effectively, and economically address the problems.



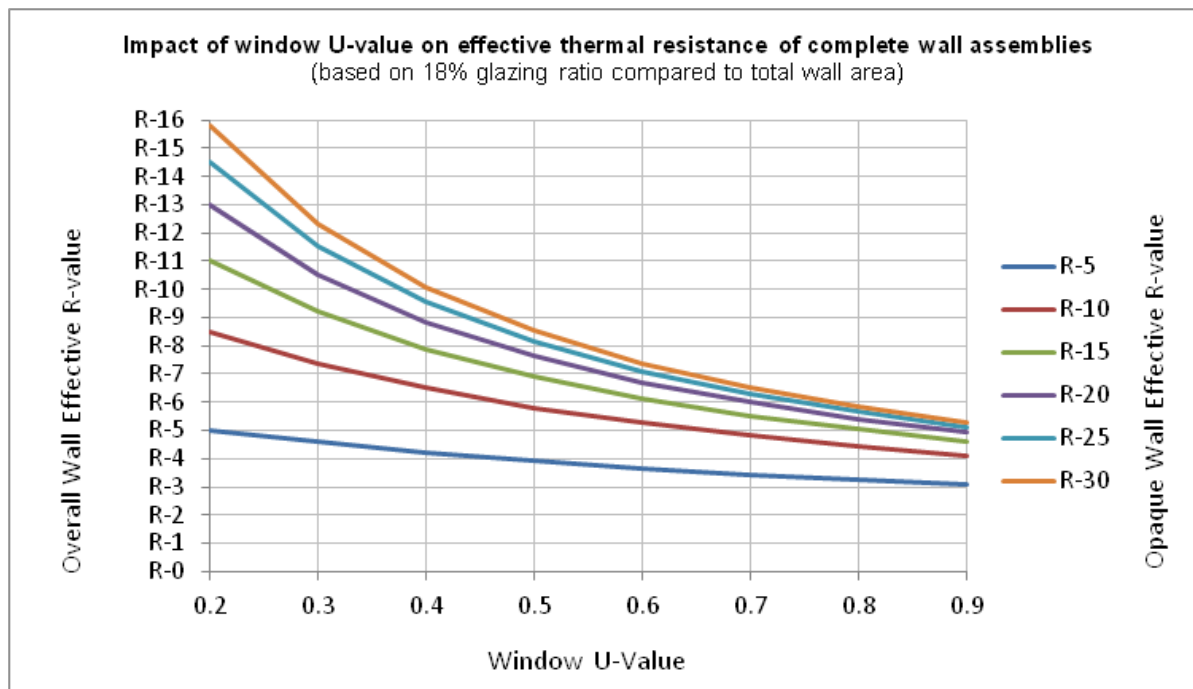
**Figure 1. Glazing type (single, double, triple) by climate region**  
(EIA 2009)



**Figure 2. Window replacement history by climate region**  
(EIA 2009)



Old single-glazed windows have such low thermal resistance that their effect on the overall thermal resistance of the walls can be staggering. A simple UA<sup>1</sup> analysis that compares the total wall effective R-value to the window U-value for opaque wall assemblies of varying effective R-values shows how significant this impact can be (Figure 3).



**Figure 3. Impact of window U-value on effective thermal resistance of complete wall assemblies**

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 being a major component to total energy use. Improving the performance of the window stock is therefore central to the goal of reducing the energy consumption of the existing building stock.

Table 2 provides information and guidance about rehabilitating, retrofitting, and replacing wood window assemblies in residential construction. The intent is to provide information about means and methods to improve the energy and comfort performance of wood window assemblies in a way that considers component durability, in-service operation, and long-term performance. This guideline focuses on proper detailing of strategies to provide a visual reference for how to properly implement these recommendations.

This measure guideline is primarily intended to help contractors and homeowners understand the options for safely improving the performance of their wood windows. The details are simple, clear, and provide specific information about building condition review, material preparation, installation, and other considerations that would not normally be explained in a general retrofit recommendation.

<sup>1</sup> The UA analysis multiplies an individual component U-value by its associated area to create an area weighted thermal transmittance value.

**Table 2. Window Performance Improvement Measures**

|   | Measure                          | Description  |
|---|----------------------------------|--|
| 1 | Window Rehabilitation            | Repair/rehabilitation of the old window sashes, leaving the original wood window frames 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 windows to accommodate storm windows.   |
| 3 | Interior removable storm windows | Recommended installation practice for removable interior storm windows, including preparation of windows to accommodate storm windows.   |
| 4 | Interior permanent storm windows | Recommended installation practice for permanent interior storm windows, including preparation of windows to accommodate storm windows.   |
| 5 | Window sash modification         | Modification of the old window sashes, leaving the original wood window frames in place. Frame preparation to accommodate original sashes to accept high performance insulating glass units (IGUs).        |
| 6 | Window sash replacement          | Removal of the old window sashes, leaving the original wood window frames 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 frames to accommodate replacement windows installed in the wood window frames   |
| 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. |

Do-it-yourself homeowners (as opposed to professional contractors) are likely to use this information: therefore, it is important that clear information about 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.

Complementary information about a variety of energy upgrades can also be found in the National Renewable Energy Laboratory's (NREL) Standard Work Specifications, currently under development through the U.S. Department of Energy's (DOE) Guidelines for Homes Energy Professionals project.

## 2 Decision-Making Criteria

### 2.1 Risk Identification

Before any retrofit work is conducted, the conditions of the building systems must be reviewed.

#### 2.1.1 Lead and Other Hazardous Materials

Lead is commonly located on old wood windows and trim. Any work being completed on the window systems should follow all state and federal laws for handling hazardous materials.

Contractor/Homeowner Safety

U.S. Environmental Protection Agency:  
Lead in Paint, Dust, and Soil:  
Renovation, Repair and Painting  
[www.epa.gov/lead/pubs/renovation.htm](http://www.epa.gov/lead/pubs/renovation.htm)

Occupational Safety and Health  
Administration: Fall Protection (if window  
work is to be done at height, from the  
exterior) [www.osha.gov/  
SLTC/fallprotection/index.html](http://www.osha.gov/SLTC/fallprotection/index.html)

#### 2.1.2 Site Conditions and Project Staging

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

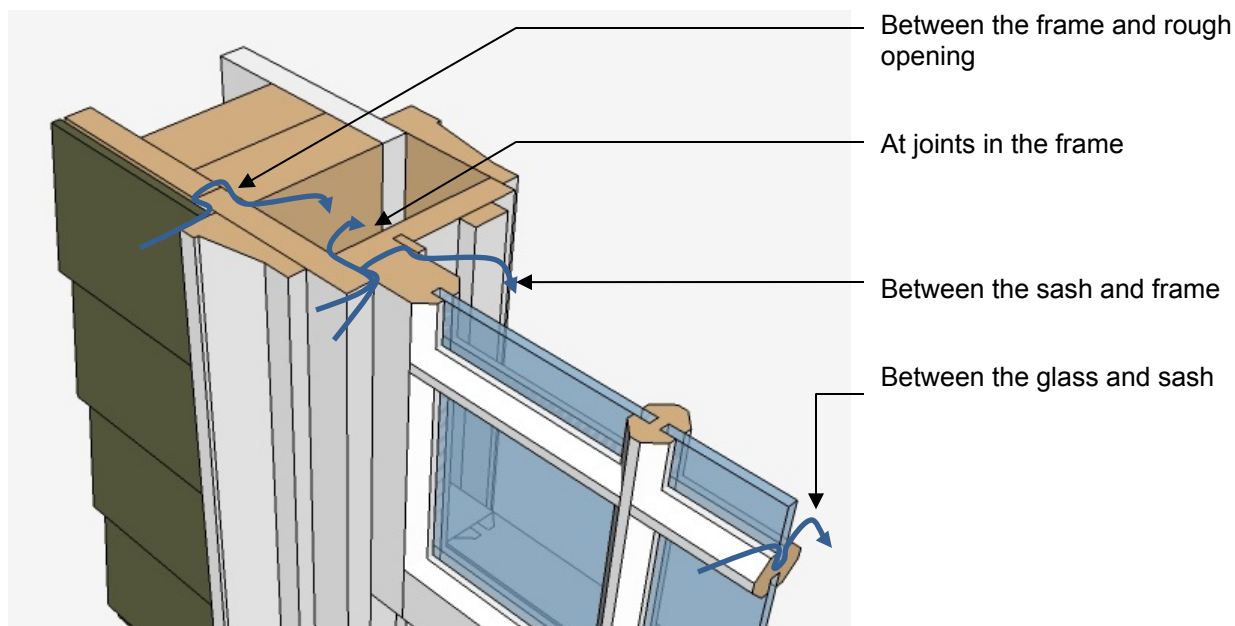
Scaffolding, lifts, ladders, or other means to access work areas may be needed if the work is to be done on the exterior. Work done at height may require fall protection. Proximity to adjacent property or vegetation may limit access or create unsafe work areas. Exterior staged work may also damage landscaping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

If the work will be done from the interior, consideration should be given to disruptions to the occupants and clearances for moving equipment and materials into and out of the space. Interior work always poses a risk of damage to interior finishes. Planning and protection are required.

#### 2.1.3 Identification of Water Infiltration Concerns

Windows are the most common location of water infiltration issues. It is important to understand the various pathways for potential water infiltration, and identify current water leakage problems. Although the details presented in this guideline are all intended to improve the moisture performance of the window assemblies, the guideline is not intended to address all possibilities, and is not a replacement for inspection and evaluation of the performance of an individual window. 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 (Figure 4):

- Between the window frame and rough opening
- Through the joints in the window frame
- Between the window frame and the operable sashes
- Through the joints between the glass and the sash frames.



**Figure 4. Common window water infiltration pathways**

Interior and exterior inspection and monitoring of the building conditions should be completed before any work is started. Water staining, peeling paint or wall paper, and staining on trim or floor assemblies below window systems indicate 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. 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.

Leakage between the window and the rough opening or through the joints in the window are typically contained within the wall assembly and may go unnoticed, or could manifest 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, other problems not associated with the window system may cause the water infiltration. Care must be taken to properly diagnose the infiltration pathway.

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

If there are no obvious signs of water infiltration problems and the window elements and connection wall components are in good condition, no additional work may be needed. However, water infiltration problems are often concealed within wall cavities. This becomes a greater concern if the window retrofit work is being done in conjunction with the addition of cavity fill insulation, because a cavity that may have had sufficient drying ability may now have prolonged moisture accumulation that can lead to material deterioration. If leakage is suspected, further investigation, including thermal scans, moisture content measurements, and cutting of

investigation holes below window assemblies to look for signs of moisture problems are recommended.

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

#### **2.1.4 Identification of Deteriorated or Damaged Materials**

Damaged 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 guideline (except complete window replacement), the condition of the sill is critical to the performance of the measure. Cracked or rotting sills need to be replaced before any work is done (see Figure 5).



**Figure 5. Failed window sill with replacement window installed**

The window frame, including the exterior casings, is 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. For window rehabilitation, sash retrofit, or interior storm window retrofit, the condition of the sashes is critical to the performance of the window. For exterior storm windows, 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 will be removed. Thus, windows with severely deteriorated sashes may be better candidates for the latter retrofit measures.

### **2.1.5 Identification of User Comfort Concerns**

As part of the initial review, comfort concerns related 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.

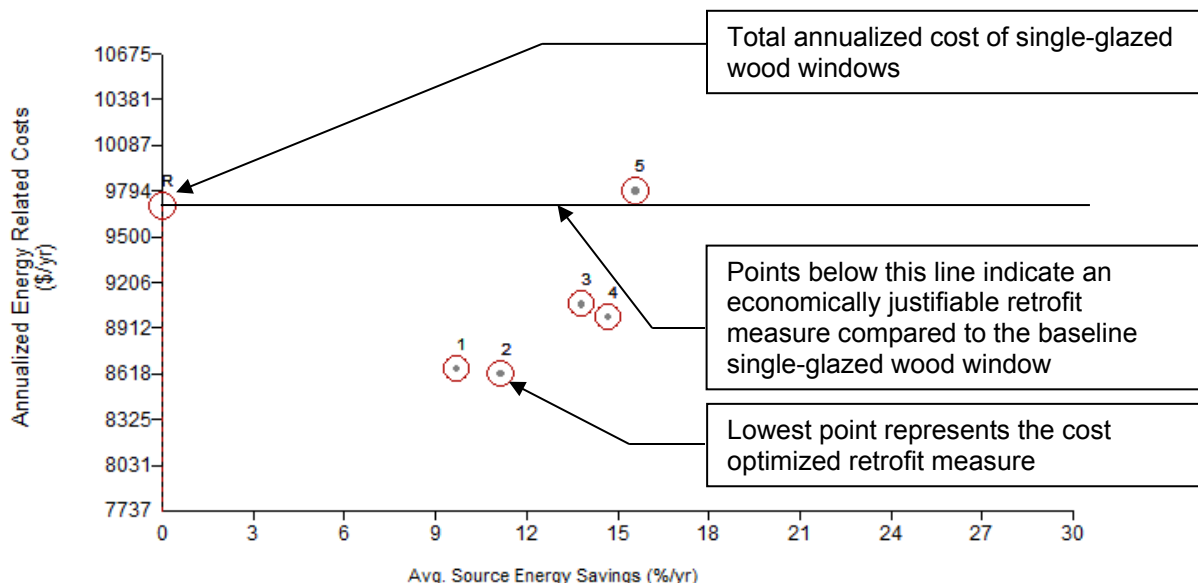
Radiation effects from cool glass surfaces are another common comfort problem. This is more difficult to identify, as many people assume that the discomfort felt when near a window is from air leakage or drafts. This results in some misdiagnosis of the dominant function. A general recommendation is to increase the interior surface temperature of the window system to reduce the radiant heat transfer 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.

## **2.2 Cost and Performance**

The cost effectiveness of a window retrofit will depend on numerous factors, though possibly most critical is the existing window performance. Single-glazed wood windows have proportionally very poor performance compared to other glazing systems ( $U = 0.87$ , solar heat gain coefficient [SHGC] = 0.62). If the baseline begins from this point, almost any window retrofit strategy will provide a cost justifiable improvement to the current conditions.

A preliminary evaluation was completed looking at the cost versus energy performance of several wood window retrofit measures. Cost data for the windows were 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). Product costs vary widely, so estimated averages were used to develop a representative sample. For each project, specific cost analysis will be required to ensure the cost effectiveness.

Simulations were run using BEopt simulation software developed by NREL (see Figure 6). The analysis examines the cost effectiveness of the window system upgrades by comparing the annualized cost of each measure over the analysis period (assumed at 30 years for this analysis) compared to the estimated annualized utility savings. The costs displayed in the cost/energy graphs (Appendix B) are full annualized utility bills plus incremental annualized values for other cash flows such as mortgage/loan payments, replacement costs, and residual values of the measure being implemented. A measure is determined to be economically justifiable if its total annualized cost is less than the total annualized cost of the baseline (in this case, the original wood windows). The cost optimized solutions have the lowest total annualized cost.



**Figure 6: Example of BEopt analysis graph**

An example home was used as the baseline to help demonstrate the benefits of using exterior insulation as part of a house energy retrofit (see Table 3). This benchmark home was assumed to be a 1950s era two-story slab-on-grade construction.

**Table 3. Benchmark House Characteristics**

| House Characteristics | Square Feet               |
|-----------------------|---------------------------|
| 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. The baseline window was chosen to be a double-hung, single-glazed wood window. In addition to the performance changes in both the U-value and the SHGC, increases in airtightness were also included as part of the analysis. Levels of increased airtightness were estimated because measured data relating specifically to window airtightness increases were lacking.

The following parametrics were run to see the effectiveness of the various window retrofit strategies to the energy performance and utility cost (Table 4).



Based on general assumptions, most measures chosen (other than triple-glazed replacement windows) in all climate zones were economically justifiable when the baseline windows were single-glazed wood. However, costs vary widely, so project-specific costs and analysis will be required to determine the cost effectiveness of the measure for each project.

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

| Parametric Step   | Cost/ft <sup>2</sup> |
|---|----------------------|
| <b>Benchmark = single glazed wood</b><br>(U = 0.87, SHGC = 0.62)  | N/A                  |
| <b>Single-glazed wood + clear exterior storm</b><br>(U = 0.49, SHGC = 0.60)   | \$7.81               |
| <b>Single-glazed wood + low-e exterior storm</b><br>(U = 0.40, SHGC = 0.52)   | \$12.14              |
| <b>Double-glazed low-e ENERGY STAR<sup>®</sup> window</b><br>(U = 0.30, SHGC = 0.30)                                | \$40.73              |
| <b>Single-glazed wood + interior double-glazed low-e ENERGY STAR window</b><br>(U = 0.25, SHGC = 0.25) <sup>2</sup> | \$40.73              |
| <b>Triple-glazed low-e window</b><br>(U = 0.20, SHGC = 0.20)  | \$77.76              |

Simulations were run for the following cities (Table 5):

**Table 5. Reference Cities**

| City                         | Climate Zone |
|------------------------------|--------------|
| <b>Dallas, Texas</b>         | 3A           |
| <b>Kansas City, Missouri</b> | 4A           |
| <b>Boston, Massachusetts</b> | 5A           |
| <b>Duluth, Minnesota</b>     | 7A           |

Results indicated that most strategies chosen in all climate zones were economically justifiable when the baseline windows were single-glazed wood. The exterior clear storms and low-e storm windows provided the cost optimized solutions for colder climates. However, in Dallas a much narrower gap between the storm windows and the window replacements was noted. This is partly because the overall storm window performance has a lesser effect on the single-glazed wood framed window, and partly because Dallas is in a cooling-dominated climate that is affected predominantly from SHGC and not U-value. In none of the analyses were triple-glazed windows demonstrated to be economically justifiable.

<sup>2</sup> Values were assumed due to unavailability of actual modeled or measured values for this configuration



## 3 Technical Description

### 3.1 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, to properly apply the various measure recommendations (see Figure 7).

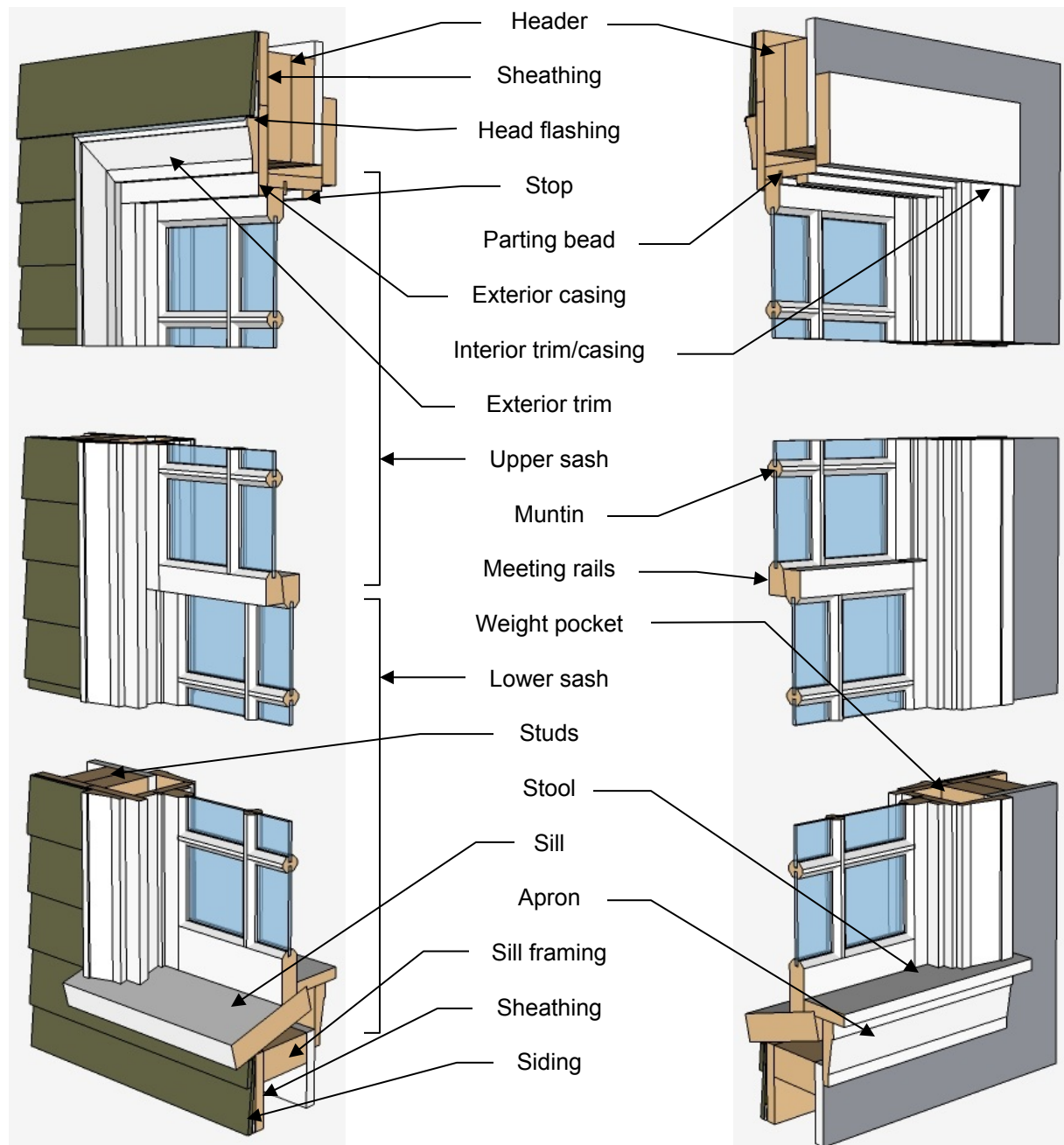
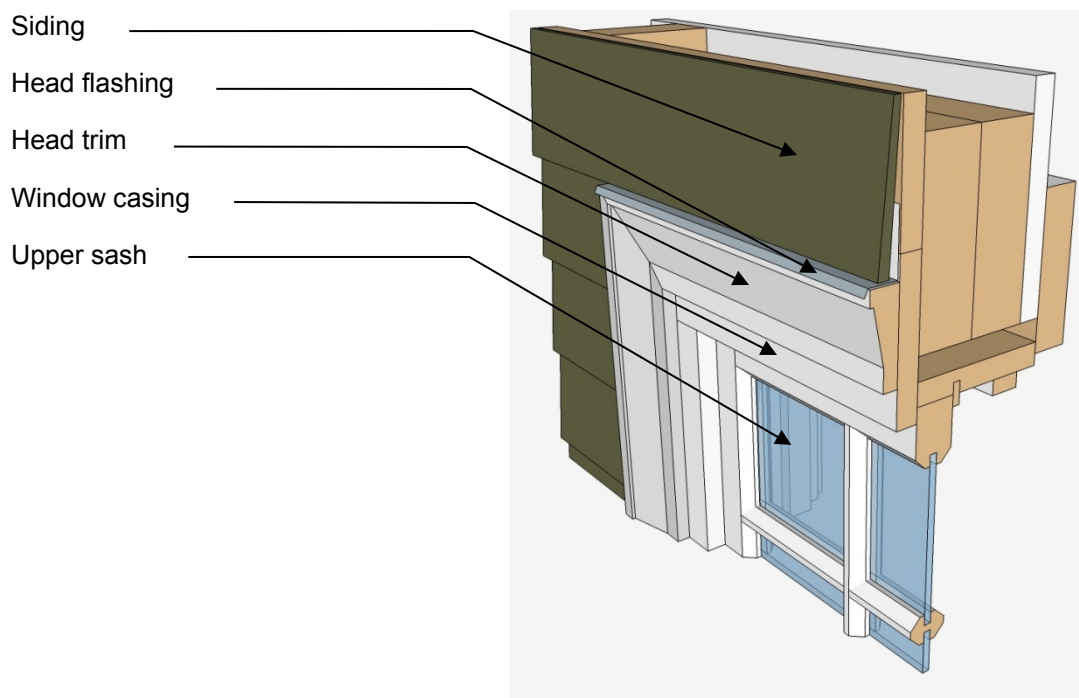


Figure 7. Window components

### 3.1.1 Window Water Management Functions

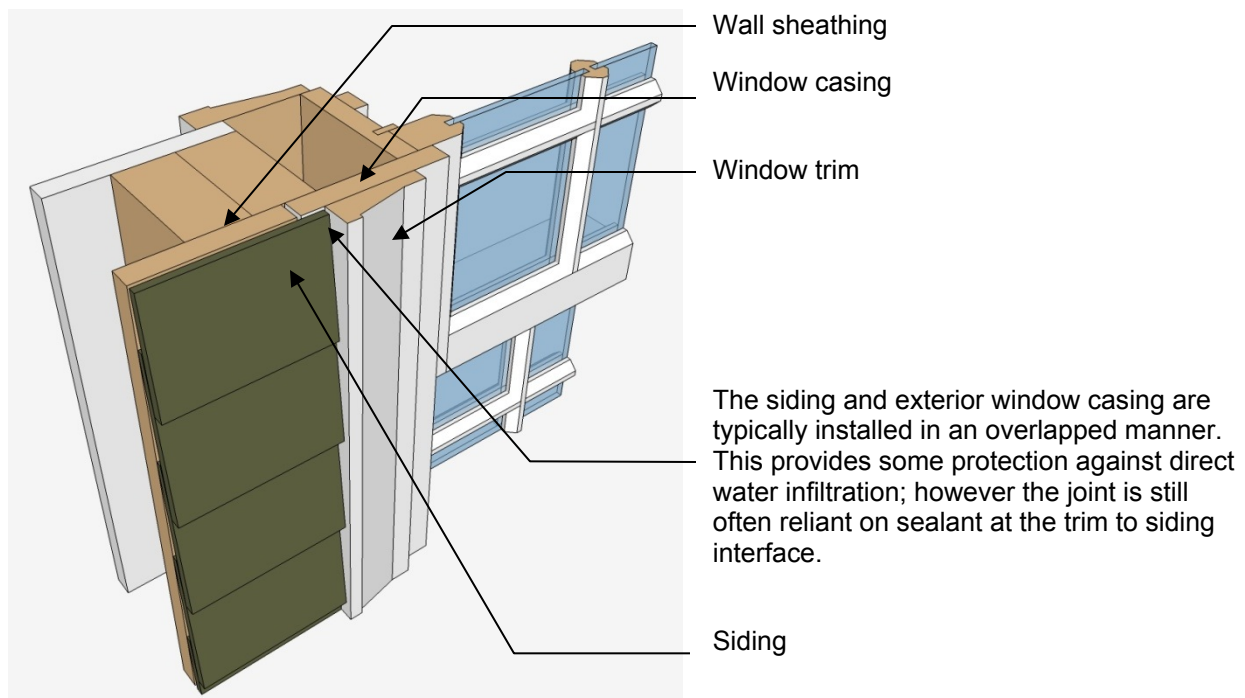
Traditional double-hung wood windows function by shingle lapping the various components of the window assembly (including its surrounding trim components).

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 8).



**Figure 8. 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. The lapping at the jambs cannot wholly rely on gravity to prevent water from infiltrating into the enclosure, so sealants are often used between the siding and the window trim to limit the potential for infiltration.



**Figure 9. Window jamb component lapping**

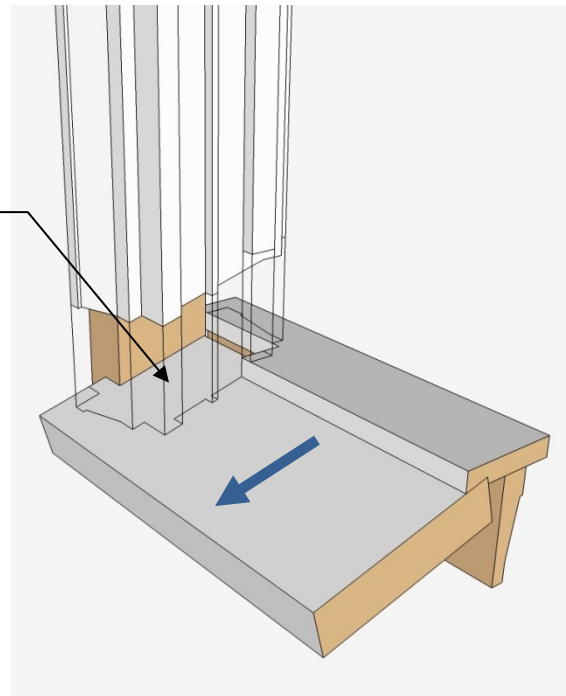
Similar approaches are used in mass masonry walls with a few slight changes to the concept. At the window head, the window frame is set back from the face of the masonry (approximately one layer of brick), so the head flashing is traditionally eliminated. At the jambs, the window casing either butts directly up against the brick, or is overlapped by the outer layer of brick with the joint caulked (Figure 10). The sill is shingle lapped over a stone, concrete, or brick sill. The masonry sill is usually sloped to the exterior.



**Figure 10. Wood window sill on top of masonry sill**

Wood sills are traditionally continuous with the jamb framing, casing and trim all installed over top of the sill

This configuration promotes drainage to the exterior even if there is a failure in a seal at the sill to jamb interface or higher up in the window frame



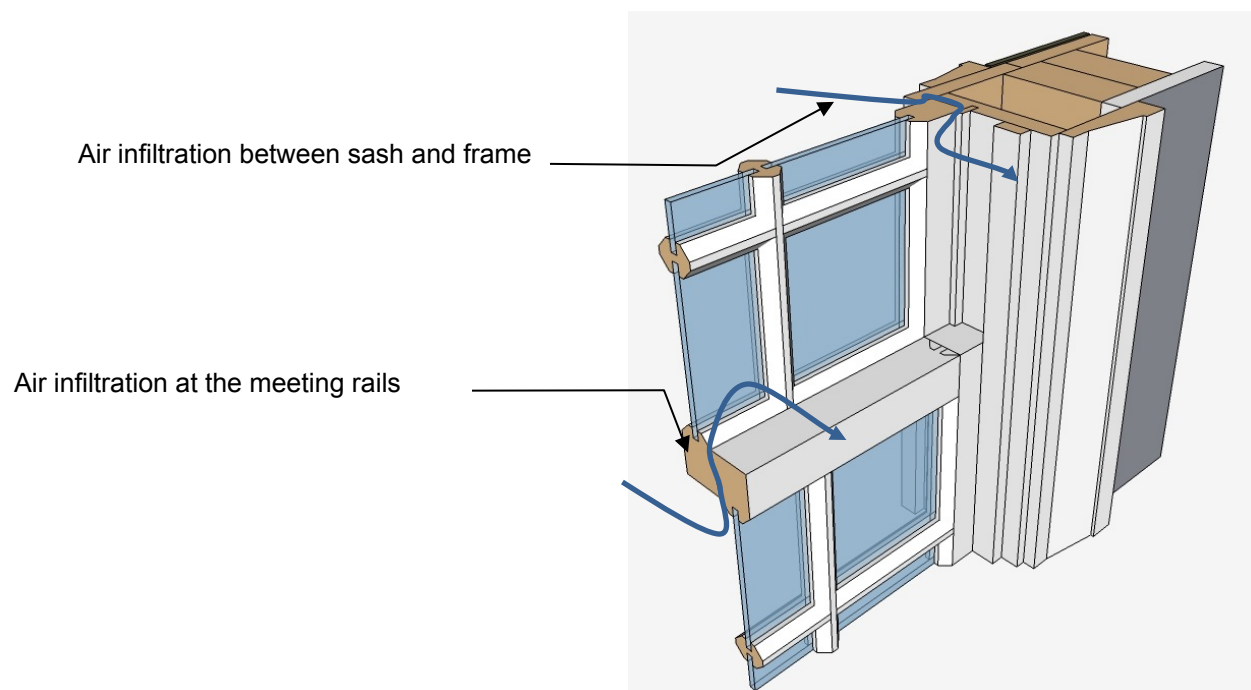
**Figure 11. Window sill component lapping**

The continuous sloped wood sill is a critical element to the performance of wood windows. The sill significantly protects the wall assemblies below. In essence, the wood sill acts similarly to a sloped pan flashing that is part of current recommended new construction practice (Figure 11). 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 than for wood-framed buildings. Unfortunately, these subsill flashings often deteriorate over time and lose their effectiveness.

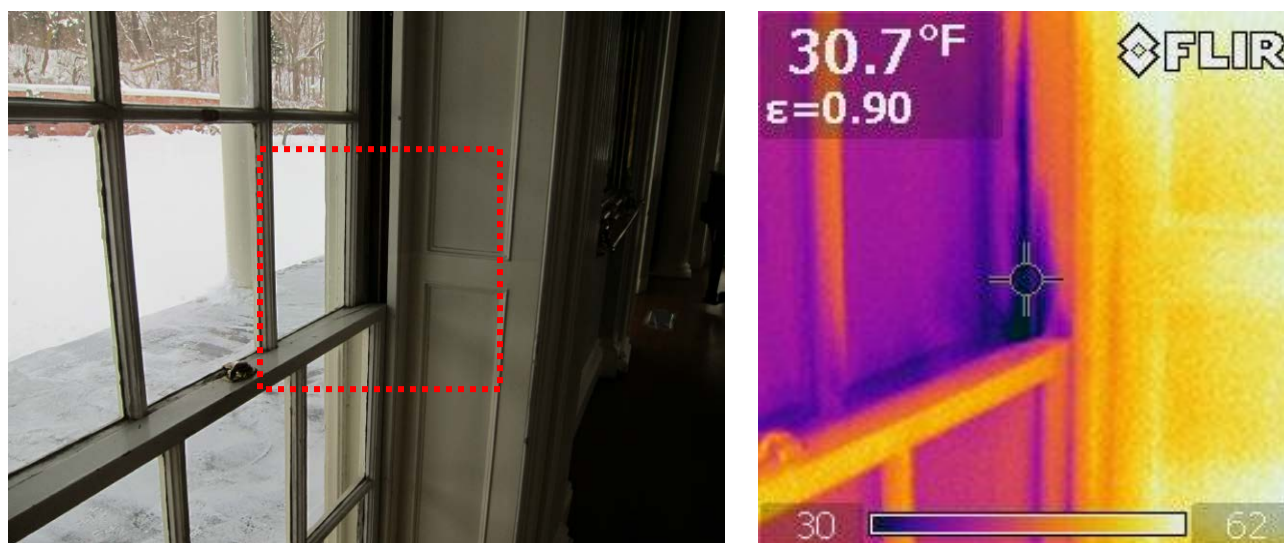
The condition of the wood window frame is critical to the water management performance for all proposed measures except complete window replacement. Damaged or deteriorating window sills must be repaired or replaced.

### **3.1.2 Window Air Leakage**

There are multiple pathways for air leakage through a window frame. The most common are between the meeting rails (where the upper and lower sashes interface), and between the sashes and the frame (Figure 12 through Figure 14). These are the operable elements of the window, so 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. In addition to the meeting rail and jamb air leakage, leaks can also be found at the head and sill.

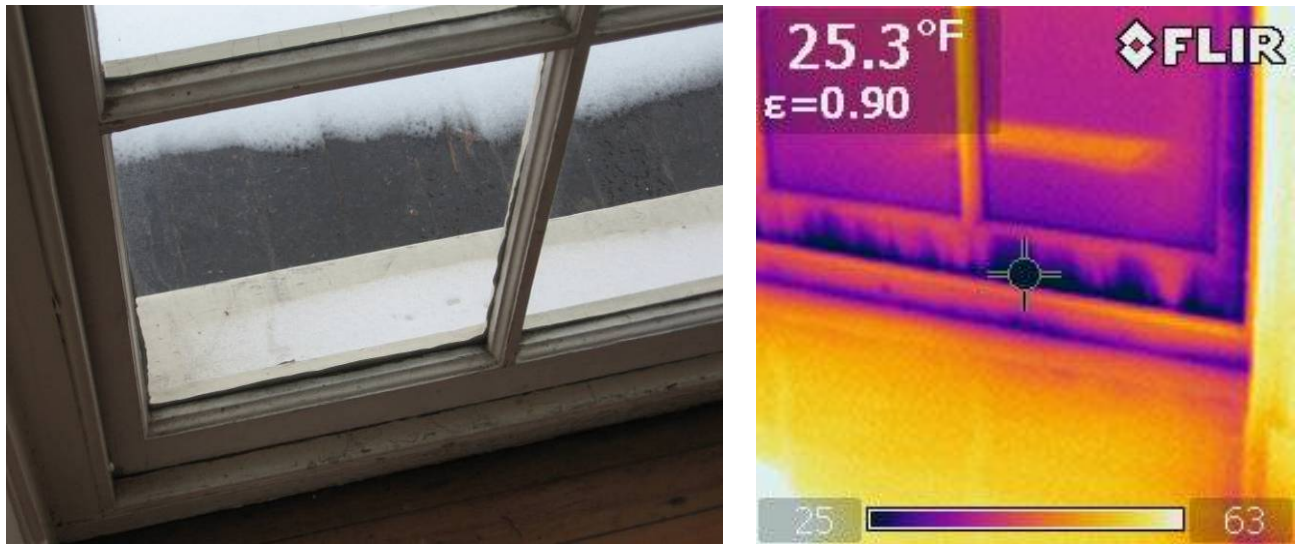


**Figure 12. Window air leakage pathways**



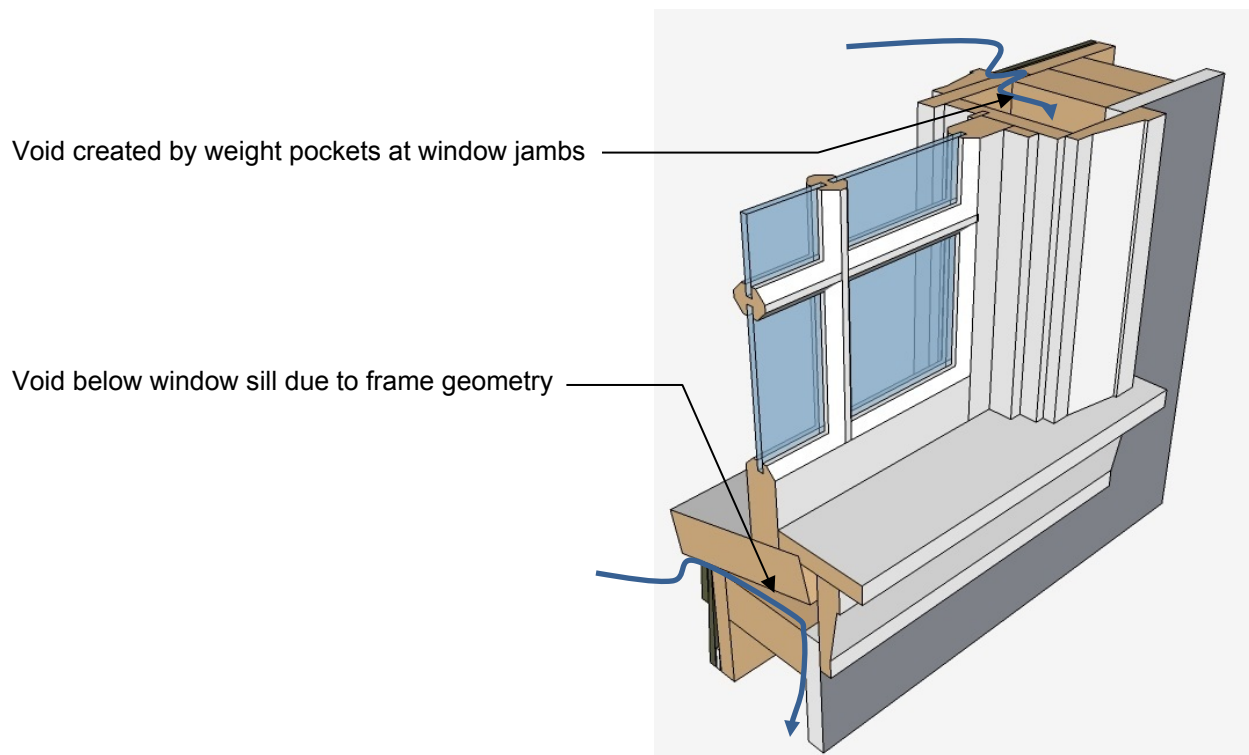
**Figure 13. Infrared images of window air leakage (depressurization test). Dark colored areas indicate cold surface temperatures from cold outdoor air leaking into the building.**





**Figure 14. Infrared images of window air leakage (depressurization test). Dark colored areas indicate cold surface temperatures from cold outdoor air leaking into the building.**

A typical window installation has void spaces between the frame and the rough opening. The gaps are also common areas of uncontrolled air leakage; however, the pathway is less direct, and therefore less significant from a user comfort perspective (Figure 15 and Figure 16).



**Figure 15. 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 16. Infrared images of window air leakage at window interior apron trim. Dark colored areas indicate cold surface temperatures from cold outdoor air leaking into the building.**

The largest of the voids are typically at the weight pockets created to house the sash counterweights (see Figure 17 and Figure 18). 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 in Section 3.1.3), as they are a pathway for movement of interior air into the space between the old 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 permit energy loss from conductance and 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 17. Sash weight pockets**



**Figure 18. Abandoned sash weight and insulation installation**

The spaces should be filled with spray polyurethane foam to address these concerns. The weights should be removed before the void is filled. In addition to the weight pockets, there are typically gaps between the window frame and the rough opening at the head and sill. These voids should also be filled.

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.

### **3.1.3 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 can infiltrate the space.



**Figure 19. Examples of condensation problems with interior storm window retrofits**





**Figure 20. Examples of condensation problems with interior storm window retrofits**

Condensation at exterior storm windows is typically not a durability concern, but mostly an operational and aesthetic concern, as it disrupts clear vision to the outside. The exterior storm windows are typically made of moisture-insensitive materials (aluminum extrusions).

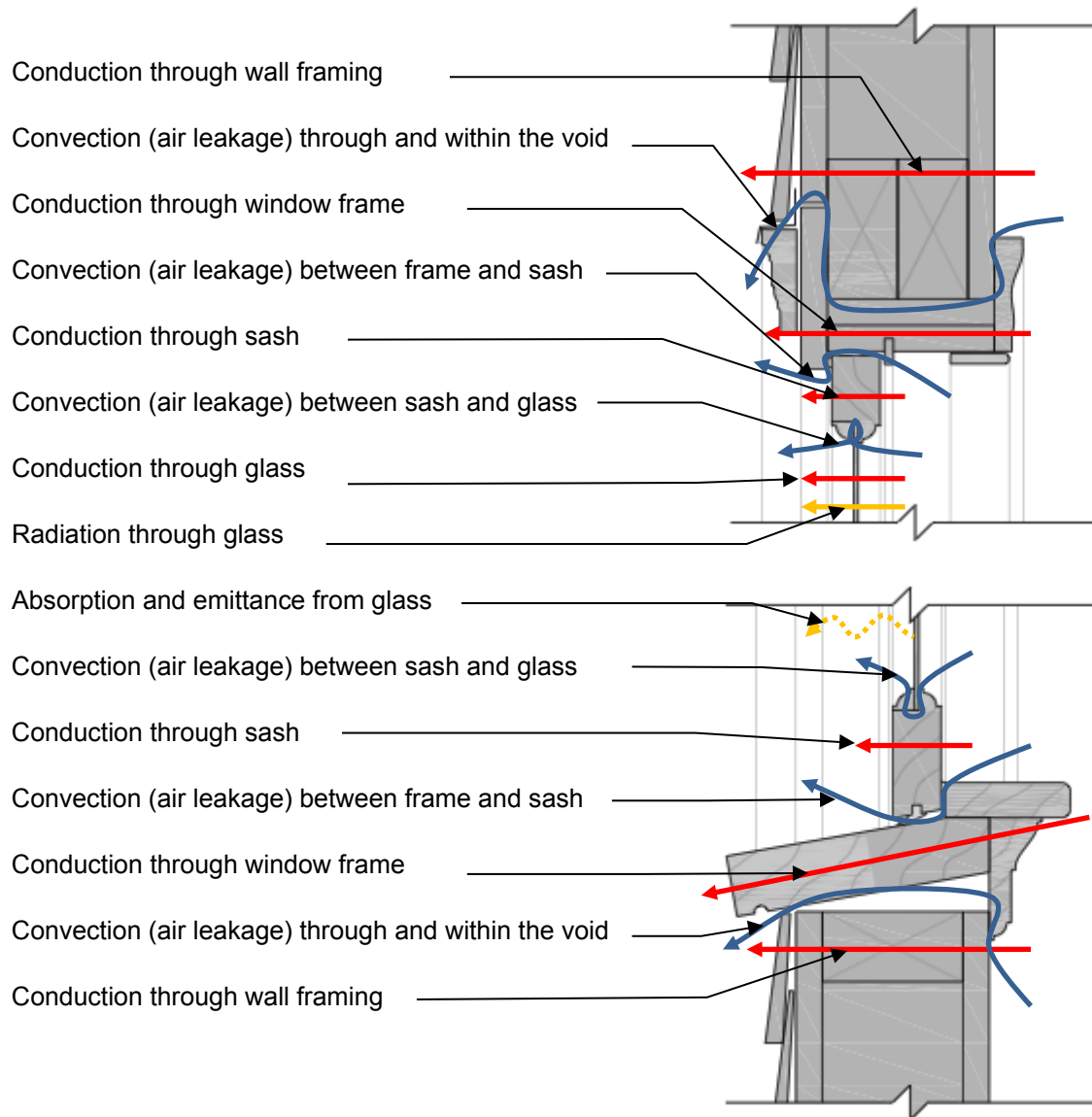
Retrofit of interior storm windows can pose a durability risk: if there is air leakage, the condensation will occur on the “prime” window, which is often part of the historical fabric of the house, and is made of moisture-sensitive materials such as wood (Brown 1997). Therefore, airtightness of interior storm windows is crucial in cold climate installations.

Research shows 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 airtight as possible to reduce air infiltration into the void space. Air bypass of the glazing elements must also be considered and addressed.

Airtightness of interior storm windows 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.

### **3.1.4 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 performance. With so many materials (wood, polymers, glass, metal) being combined to create a window system, the interactions between all these elements are not necessarily simple or straightforward (see Figure 21).



**Figure 21. Window energy transfer components**

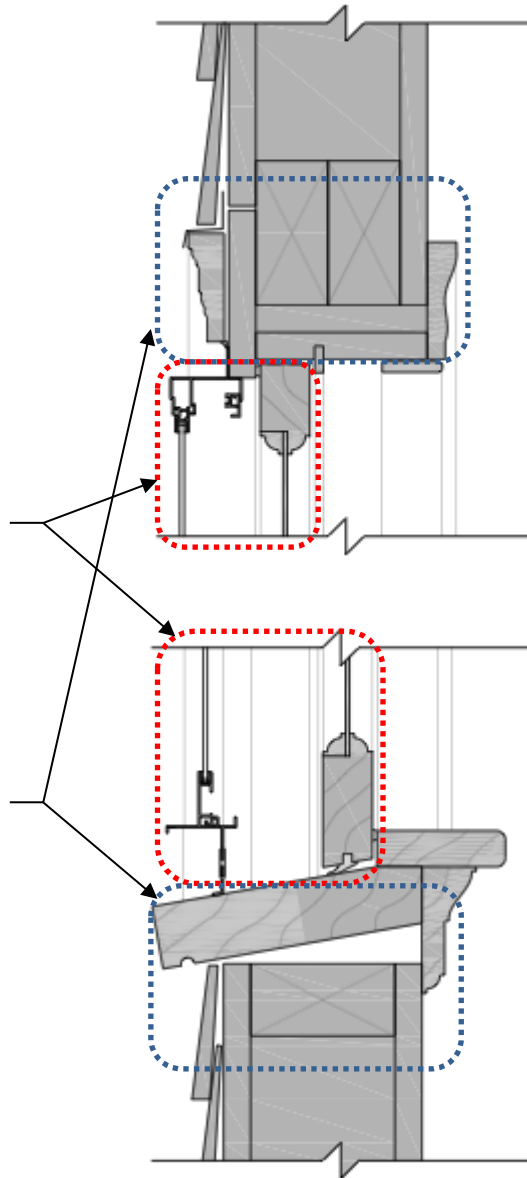
Figure 21 is a simplification of the energy transfer through a window and its surrounding enclosure elements. The actual energy transfer mechanisms are three dimensional, with all of the mechanisms interacting and impacting the actual performance. To more closely quantify window performance, extensive laboratory testing (or at minimum two-dimensional heat flow computer simulation modeling) is generally required.

Knowing the general mechanisms can help a person understand 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 22).

The exterior storm window creates a buffer of still air between the original window and the new storm window.

The exterior storm window will reduce the radiation transfer, conductance transfer, and air leakage of the sashes and sash-to-frame interface.

The storm window does not significantly affect conductance and air leakage through the window frame (though flanking effects will have some impact) or at the window-to-wall interface.



**Figure 22. Areas of energy transfer affected by the addition of exterior storms**

Until recently, information was available only about the energy performance of the window system. However, new standards for rating fenestration attachment products have recently been introduced by the National Fenestration Rating Council (NFRC 2010a, 2010b), to help quantify the effects of various window coverings. 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, some information is available to help in the determination. Some work coordinated 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 storm windows (Figure 23).

| 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 23. Window U-value and SHGC for various windows systems and exterior storm configurations (Windows Energy Savings Estimator (2011))**

Although some general ranking of the expected performance improvements can be made, each project should make its own evaluation of the expected performance to determine the best approach.

### 3.2 Measure Selection Criteria

The energy performance of the window system involves all three modes of energy transfer (conduction, convection, and radiation). Understanding the general mechanisms can help understanding of how a certain measure will modify the performance. To more closely quantify window performance, extensive laboratory testing (or at minimum two-dimensional heat flow computer simulation modeling) is generally required.

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

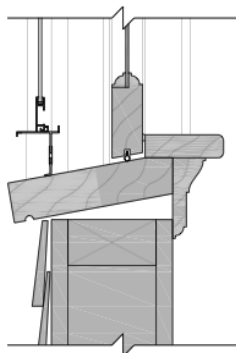
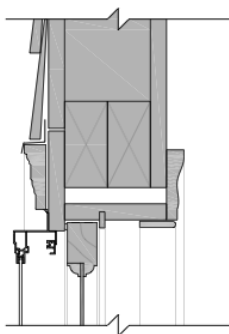
### 3.2.1 Measure 1—Window Rehabilitation

The first measure looks to improve the window performance without significant modification or addition. 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 airtightness 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 (This is an 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.

### 3.2.2 Measure 2—Exterior Storm Windows



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

**Figure 24. Interior removable storm window sample**



Key points:

1. Maintains interior appearance of the window; however, the exterior appearance will change. The addition of exterior storm windows 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.

### 3.2.3 Measure 3—Interior Removable Storm Windows



**Figure 25. Interior removable storm window sample**

An alternative 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 premanufactured fixed or operable glass or acrylic lites in a thin metal frame. The premanufactured versions are often installed via a metal angle and magnetic track fastened to the window frame.

These systems are typically less permanent, and intended to be installed seasonally (usually during the winter in cold climates), as most limit opening and closing.



**Figure 26. Installed interior removable storm window**

Key points:

1. Maintain the exterior appearance of the window; however, the interior appearance will change. Removable interior storms are 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 and thermal conductance through the assembly.
5. This work will reduce the potential for interior condensation problems on the window system, though it poses a risk of interstitial condensation between the interior storm and original window (both an aesthetic and an operational concern, and may pose 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.

### 3.4.4 Measure 4—Interior Permanent Fixed Storm Windows



**Figure 28. Interior storm window on double-hung original window**

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

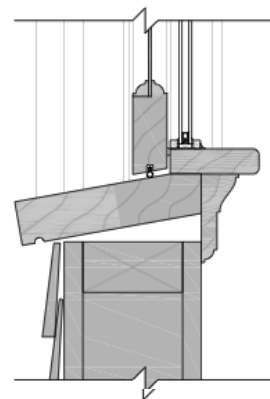
Fixed glazing units meet requirements if the window no longer needs to operate. Fixed units can typically be made more airtight, and will have thinner frame profiles so that the vision area is not impacted. Also, they can often be installed to have minimal impact on the interior appearance of the



**Figure 27. Interior storm window on double-hung original window**

window so that interior aesthetics can be more closely maintained. An operational concern with this approach is that the windows can no longer be cleaned from the interior, and may be difficult from the exterior as well. Although the more common approach has been to use single-glazed lights (often clear acrylic for retrofits by homeowners), double- and triple-glazed IGUs can be used to increase energy performance.

Alternatively, if an operable window is required, a new window frame and sash could be installed on the interior of the original window. The window is not required to address the water management needs of the system, so lower standards may be acceptable for the frame. The ideal frame would have a thin profile frame for minimal disruption to the vision area of the rough opening, and have excellent airtightness. 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), 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. 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 become a concern, and should be studied in more detail.

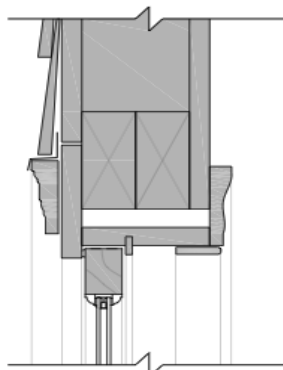


**Figure 29. Interior storm detail**

**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.
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).

### 3.2.5 Measure 5—Window Sash Modification



Wood window sashes can sometimes be retrofitted 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 30. Window sash modification**



### 3.2.6 Measure 6—Window Sash Replacement

Window sashes may be replaced without replacing the frame. This is a good option if there is a desire to maintain the original appearance, but the old 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 the sash. If the replacement sashes are made from wood, the windows can be out of square to a certain degree, as the top and bottom of the sashes can be cut to match the angles.

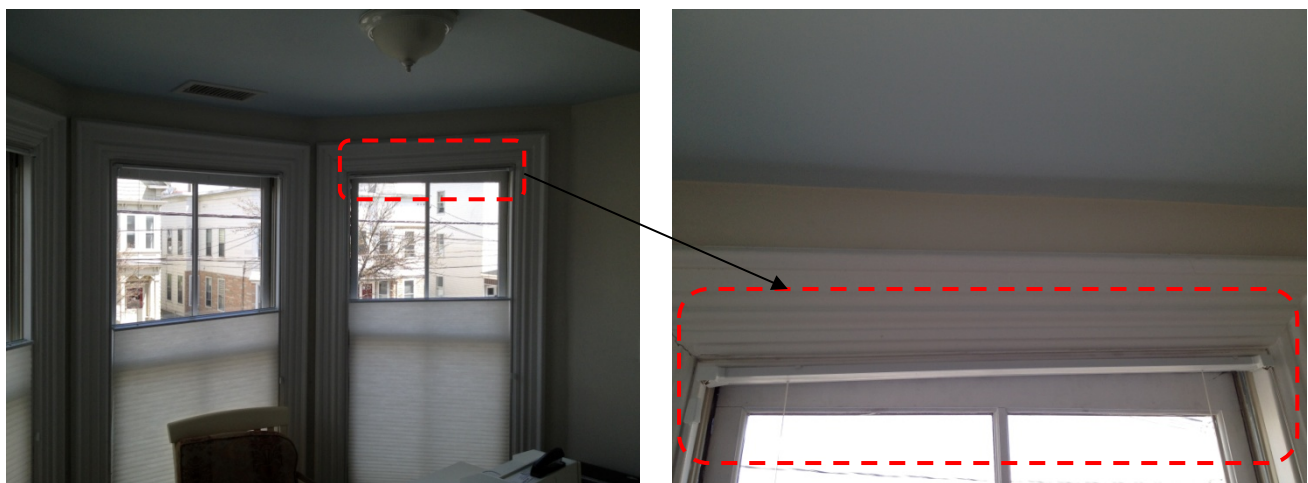


Figure 31. Sash replacement, showing out of square opening and requirement for sash extension

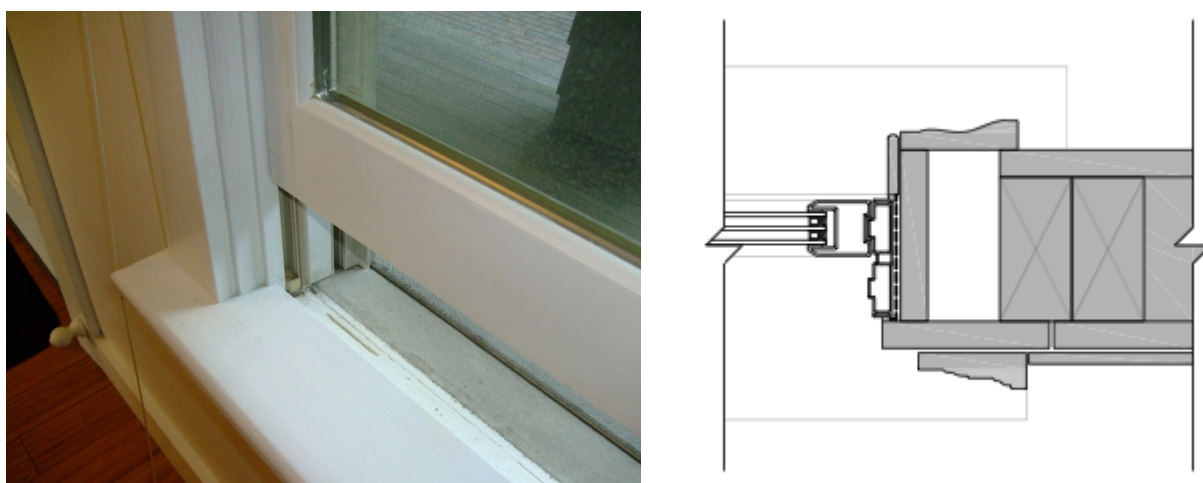
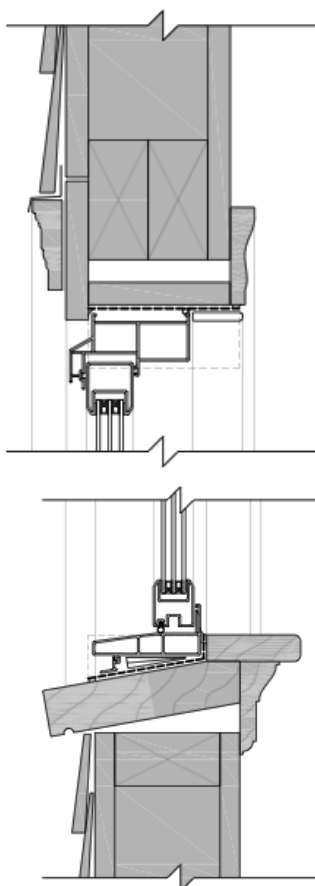


Figure 32. Window sash replacement jamb liners

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).

### 3.2.7 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. The benefit to this is the speed of installation (very little rehabilitation of the frame is needed), low disruption to the homeowner (the installation does not overly affect interior or exterior trim and finishes), and adjustment ability (although the windows need to be custom ordered to fit the 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 downside to this approach is that the vision area is reduced by an additional window frame with sashes. For

**Figure 33. Insert replacement vinyl frame window**

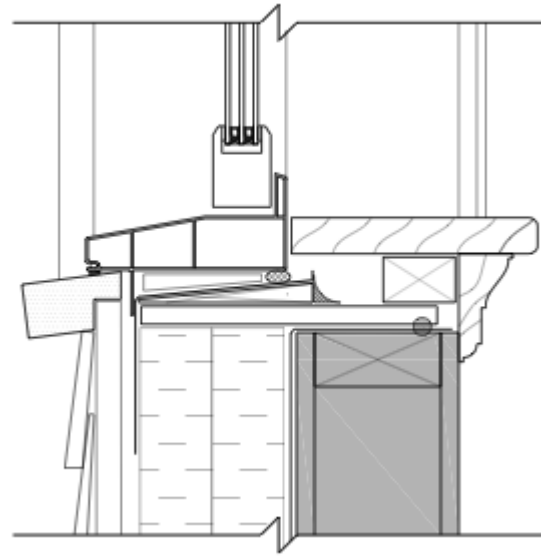
already small window openings, this may be significant and undesirable. For larger windows, the impact will be less noticeable.

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.

### **3.2.8 Measure 8—Complete Window Replacement**

Ultimately the old window can be completely removed and replaced with a new window. The benefit of this measure is that the installation details can be brought up to current 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, it provides the most freedom for designing and placing the windows. The windows can be installed in plane with the framing or be pushed toward the exterior to line up more traditionally with the plane of the siding.



**Figure 34. 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 this is 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.

## 4 Measure Implementation

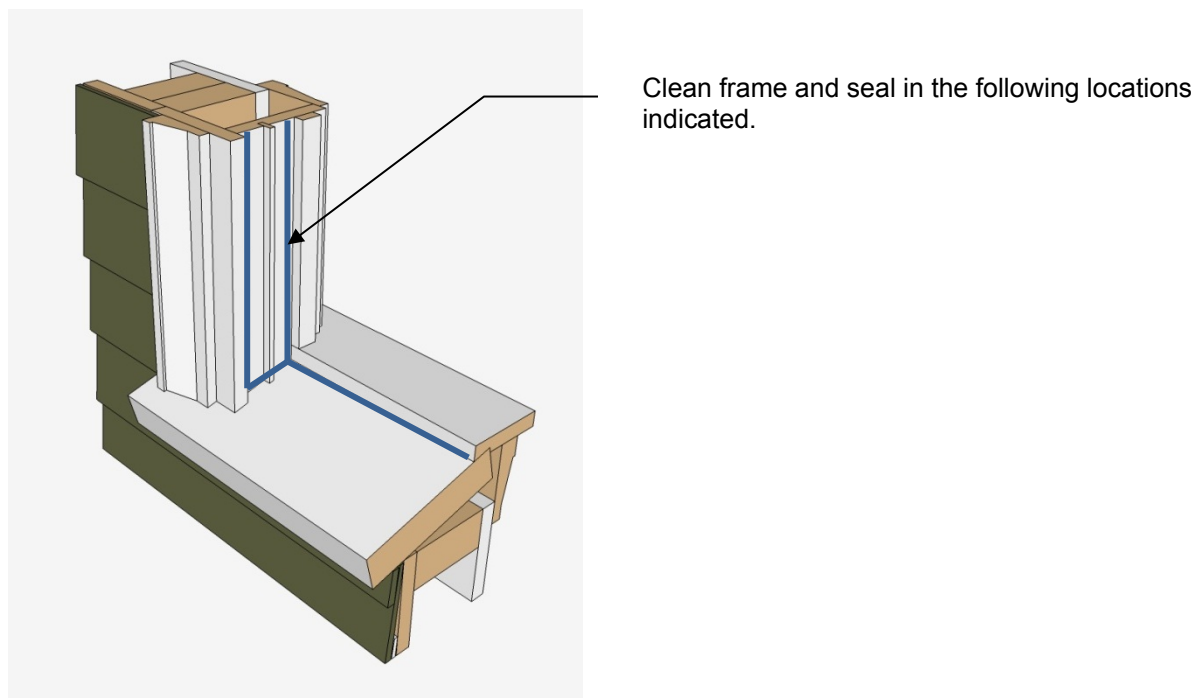
This section steps through eight options for improving wood window systems (see Appendix A for details). The order of the measures is generally from least improvement to the most. The intent is not to determine specific incremental performance improvement; however, the focus is on the detailing the implementation of the strategies.

### 4.1 Measure 1—Window Rehabilitation

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

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 (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.



**Figure 35. Recommended sealant location as part of window frame rehabilitation**

As part of the work, if the weight pockets are to be retained, clean and lubricate the pulleys, replace the sash cords or chains, and balance the weights 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 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 guideline. Work of this nature should be completed by a qualified restoration contractor. Alternatively, other retrofit measures, including sash replacement, window insert replacement, or complete window replacement should be considered for severely deteriorated windows.

## **4.2 Measure 2—Exterior Storm Windows**

Adding exterior storm windows to the exterior of the window is a common, commercially available, off-the-shelf technology, and is for the most part straightforward. This work should be completed in conjunction with the window rehabilitation work outlined in Section 4.1. The 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 storm windows 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.



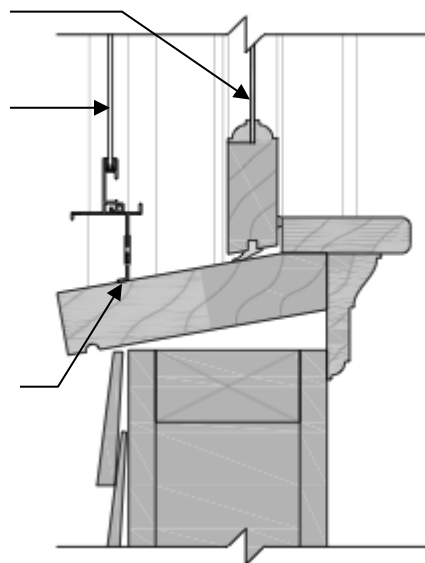
**Figure 36. Exterior aluminum storm windows, showing weep channel**

To minimize the potential for interstitial condensation, the original window must be made as airtight 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 airtight, 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.

Inner window must be made as airtight as possible.

Thermal gradient created by the air space between the interior window and the exterior storm will result in warmer surfaces of the original wood window, but colder surfaces on interior side of the exterior storm. Uncontrolled air leakage into this space increases the risk of condensation on the interior side of the exterior storm.

Slight increase in ventilation at the sill may remedy the problem; however it will also diminish the overall thermal performance of the measure.



**Figure 37. Condensation potential for exterior storm retrofits**



### 4.3 Measure 3—Removable Interior Storm Windows

Interior storm windows are added solely to improve the thermal performance of the window system. They do not upgrade the water management of the assembly.

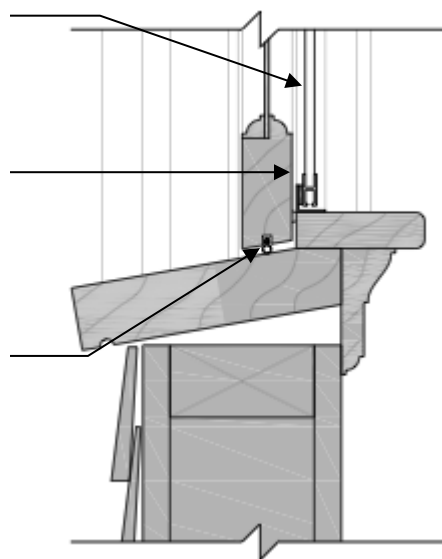
The installation relies on the original window to primarily manage the water. Thus, the original window should be rehabilitated to enhance its water management performance.

An interior storm window creates the potential for condensation on the interior surface of the original exterior window, so the interface between the interior storm and the window frame must be as airtight 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 window and the frame is perfectly airtight. 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. The original window should be rehabilitated (per Measure 1) along with this strategy. If condensation problems develop, the exterior window can be made incrementally slightly leakier until the problem is resolved. This could be done by slightly gapping the lower sash at the sill with a shim, or removing the lower sash sill gasket (if there is one), although this will have a detrimental effect on airtightness in the summer when the interior storm is removed.

Interior storm window must be made as tight as possible. Air bypass (such as at weight pocket pulleys) must be sealed.

Thermal gradient created by the air space between the interior storm window and the exterior original window will result in colder surfaces of the original wood window. Uncontrolled air leakage into this space increases the risk of condensation formation on the interior side of the exterior storm.

Slight increase in ventilation at the sill may remedy the problem; however, it will also affect the overall thermal performance of the measure.



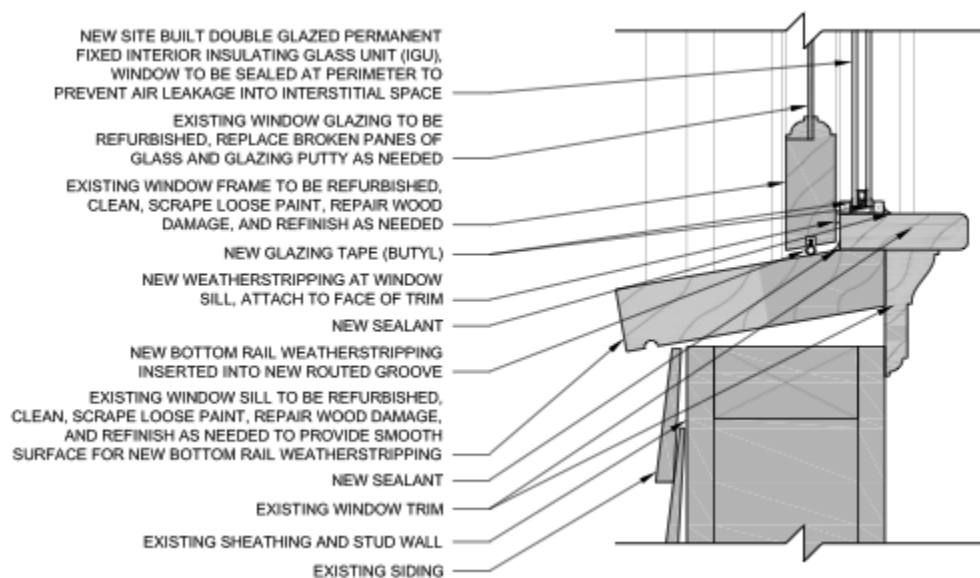
**Figure 38. Condensation potential for interior storm retrofits**

### 4.4 Measure 4—Permanent Interior Storm Windows

Interior storm windows are added solely to improve the thermal performance of the window system. They do not upgrade the water management of the assembly.

The installation relies on the original window to primarily manage the water. Thus, the original window should be rehabilitated to enhance its water management performance.

An interior storm window creates the potential for condensation on the interior surface of the original exterior window, so the interface between the interior storm and the window frame must be as airtight 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 window and the frame is perfectly airtight. 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. The original window should be rehabilitated (per Measure 1) along with this strategy. If condensation problems develop, the exterior window can be made incrementally slightly leakier until the problem is resolved. This could be done by slightly gapping the lower sash at the sill with a shim, or removing the lower sash sill gasket (if there is one).

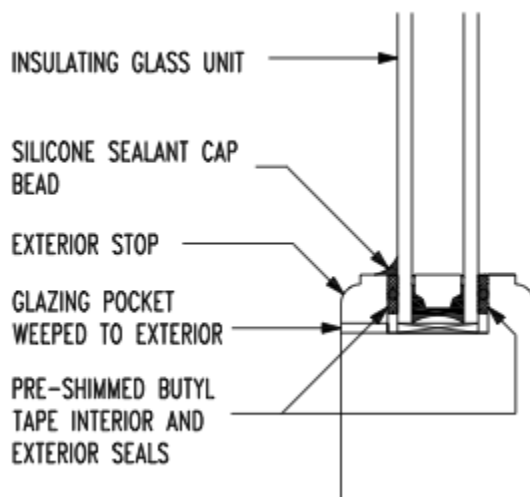


**Figure 39. Example sill detail for a permanent interior storm window**

#### **4.5 Measure 5—Window Sash Retrofit**

This work must most likely be completed by a specialized window restoration contractor who can disassemble the window frames, route the frame elements to create a larger glazing pocket to accommodate the thicker IGU, and reconstruct and reglaze 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 must 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.



**Figure 40. Integration of an IGU into a wood sash**

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

#### **4.6 Measure 6—Window Sash Replacement**

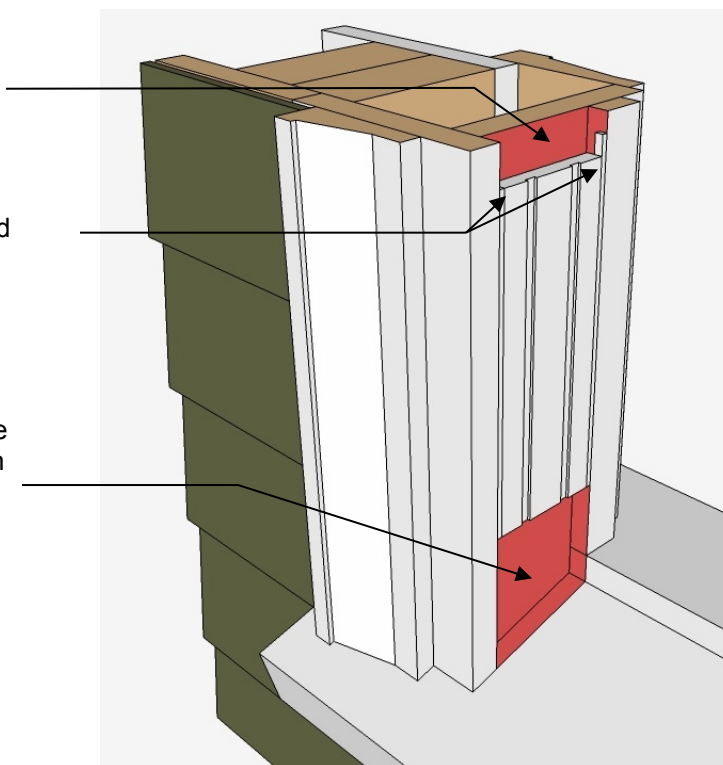
In this measure, the window frames are typically retrofitted with new jamb liners that provide the tracks for the sashes to ride in, and eliminate the need for sash weights. Before the jamb liners are installed, the frame should be cleaned and the corner interfaces between the head, jambs and sill caulked. The jambs should 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 sloped wood sill, and allow any incidental leakage to drain to the exterior.

The space between the jamb liners and window frame should 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.

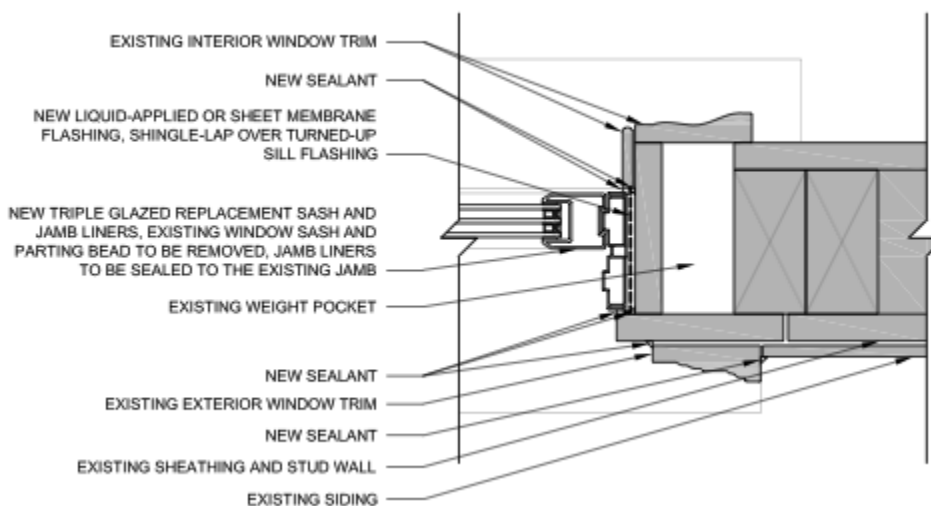
Paint window jamb with liquid applied waterproof membrane

Caulk sides of jamb liner to outer casing and interior stop

Extend liquid applied water proof membrane down onto window sill (jamb liner not shown for clarity). Do not caulk bottom edge of jamb liner to sill.



**Figure 41. Frame preparation for replacement window sashes**



**Figure 42. Example jamb detail for a replacement window sash**

#### **4.7 Measure 7—Insert Replacement Window**

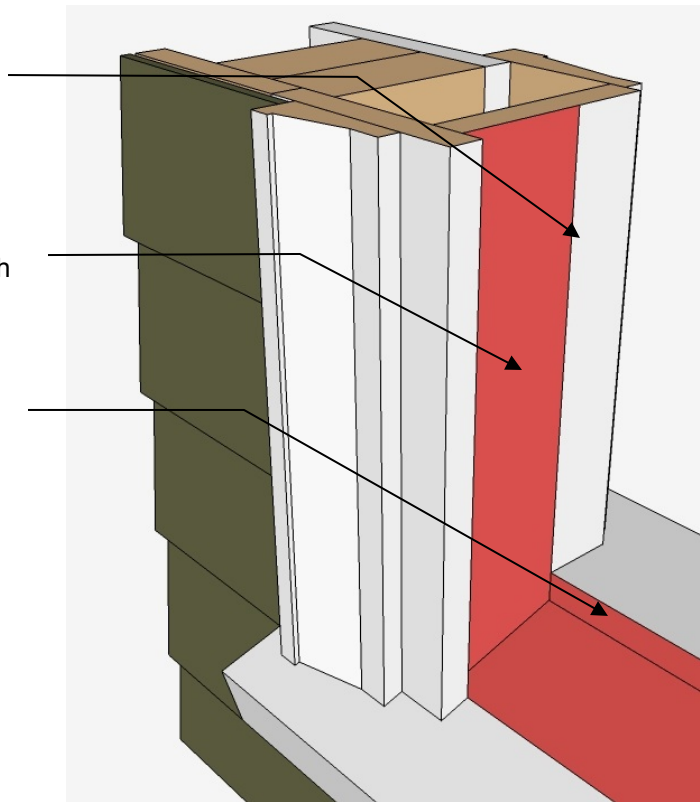
In this measure, the wood window frame should be considered to be the new window rough opening and treated in a similar manner following current industry recommended practice for waterproofing and draining. It should be cleaned of any dirt and loose paint. The parting beads

and interior stops at the head and jambs should be removed. The weight pocket pulleys should be removed and the openings left by the pulleys in-filled. All corners between head, jambs, sill, and exterior casings should be sealed with caulking. This is recommended for water management and airtightness. 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.

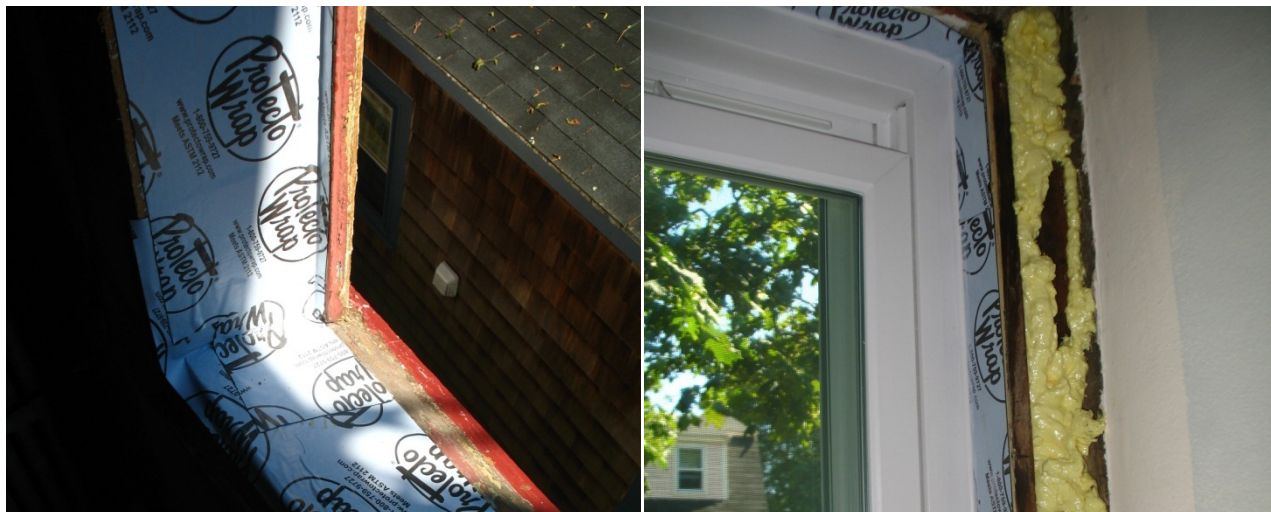
Window sashes, parting beads, and interior stops removed. All gaps and holes in jambs patched and filled.

Liquid applied membrane or self-adhered membrane waterproofing installed around rough opening.

Use stool as support for the membrane back dam.



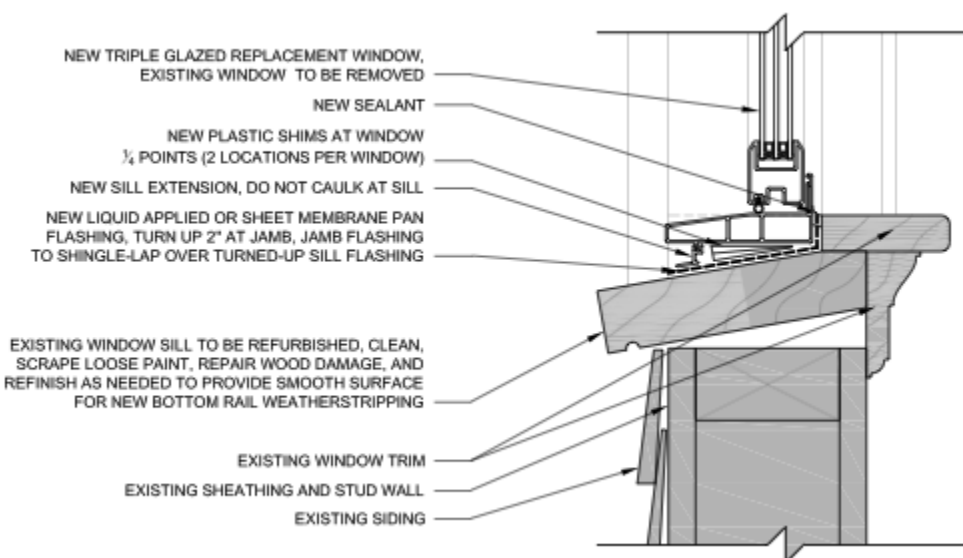
**Figure 43. Frame preparation for insert replacement window**



**Figure 44. 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 reinstalled if usable). 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 45. Example sill detail of insert replacement window**



## **4.8 Measure 8—Complete Window Replacement**

As discussed earlier, the highest performance but most intrusive and expensive option is a complete window replacement. This measure includes removing the entire window frame (back to the rough framing). This often includes the interior and exterior casing and trim.

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

### **4.8.1 Window Replacement as Sole Scope of Work**

If this work is being done as the sole scope of work (no other enclosure retrofit work being done in conjunction with the window replacement), 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 rough opening size is not the desired final dimension and additional blocking is added to frame it out 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 in. onto the plane of the wall. The membrane will ultimately be covered with exterior window trim. Should the wall be upgraded later, only the window trim would need to be removed to allow for a tie-in between a new water resistive barrier (WRB) and potentially an air barrier.

Typically, some siding will need to be removed to accommodate the window. The siding should be trimmed back 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. The wall may not have a 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 is recommended; however, the homeowner must accept some risk, because the remainder of the wall may not conform to recommended enclosure water management design. In these situations, examining a full cladding replacement at the same time may be warranted to retrofit the house with a proper WRB.



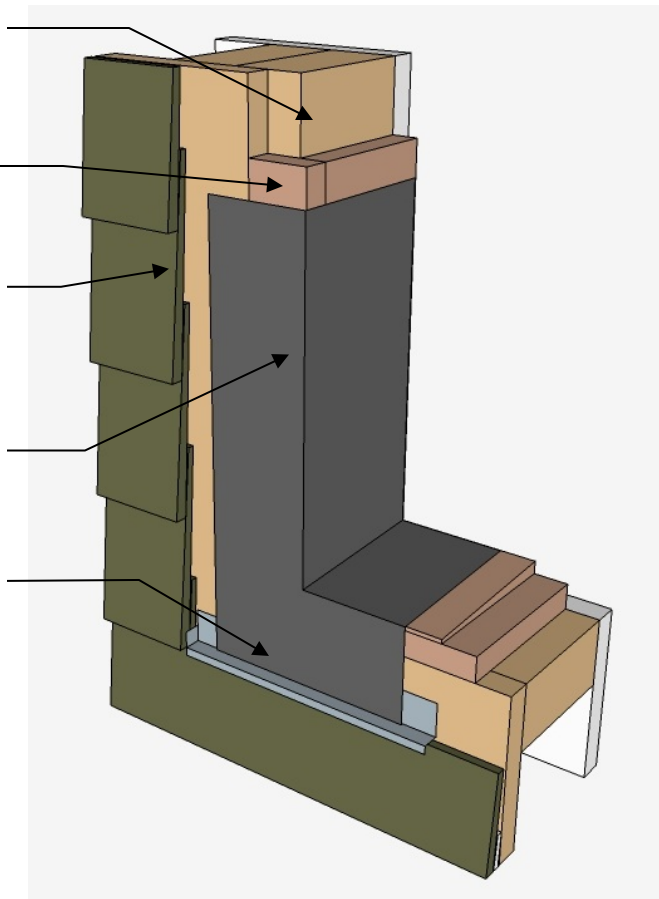
Remove sashes and window frame back to wall framing

New blocking as needed

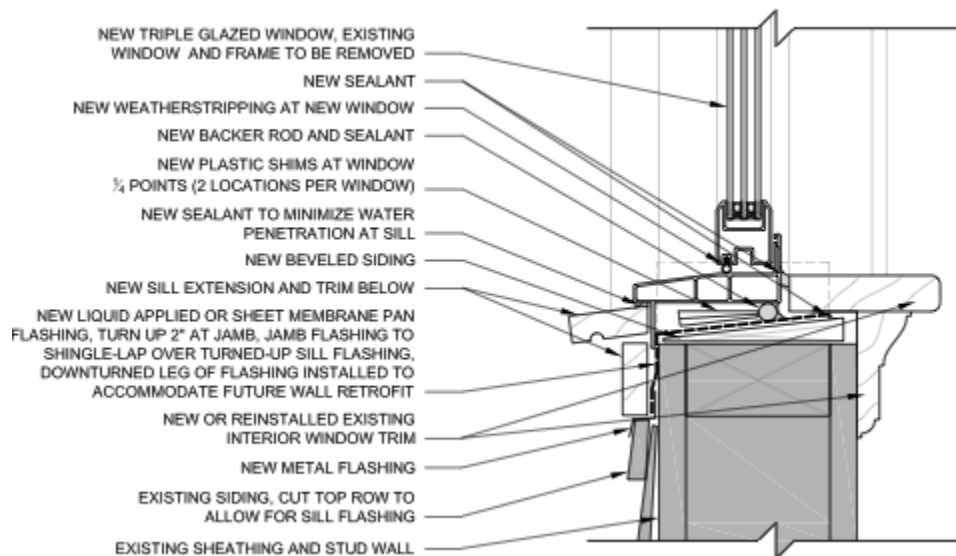
Cut back siding as required to account for new replacement window dimensions

Wrap rough opening with liquid applied or self-adhered membrane flashing

Lap bottom edge of membrane pan flashing over sheet metal flashing to shed water back out over the siding



**Figure 46. Replacement window rough opening preparation**



**Figure 47. Example sill detail for window replacement without siding replacement**

#### 4.8.2 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 reinstallation 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 is installed, the jambs and head need to be sealed with a self-adhered membrane flashing and the WRB would need to be shingle lapped over top of the membrane head flashings.

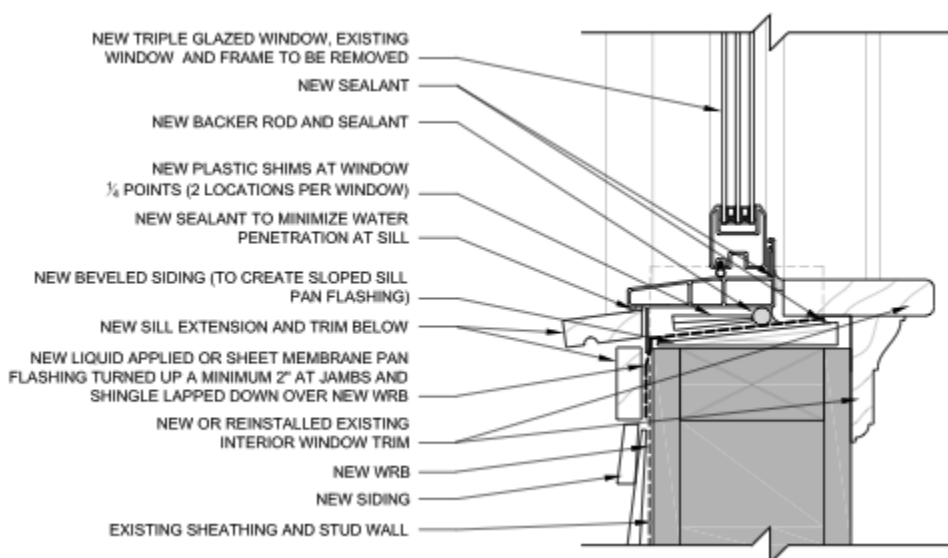
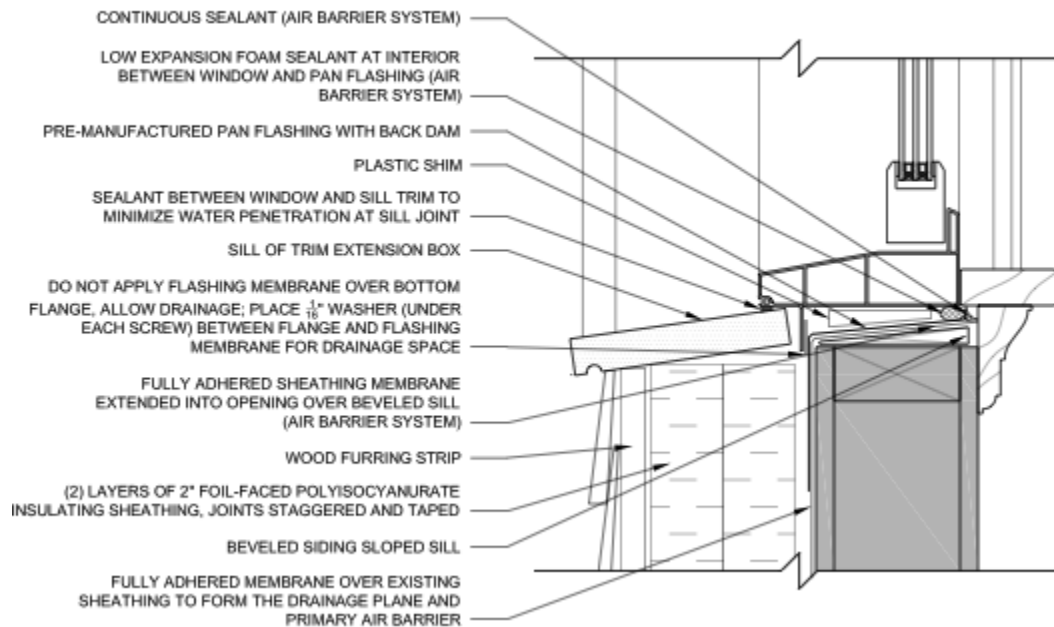


Figure 48. Example sill detail of replacement window in conjunction with siding replacement

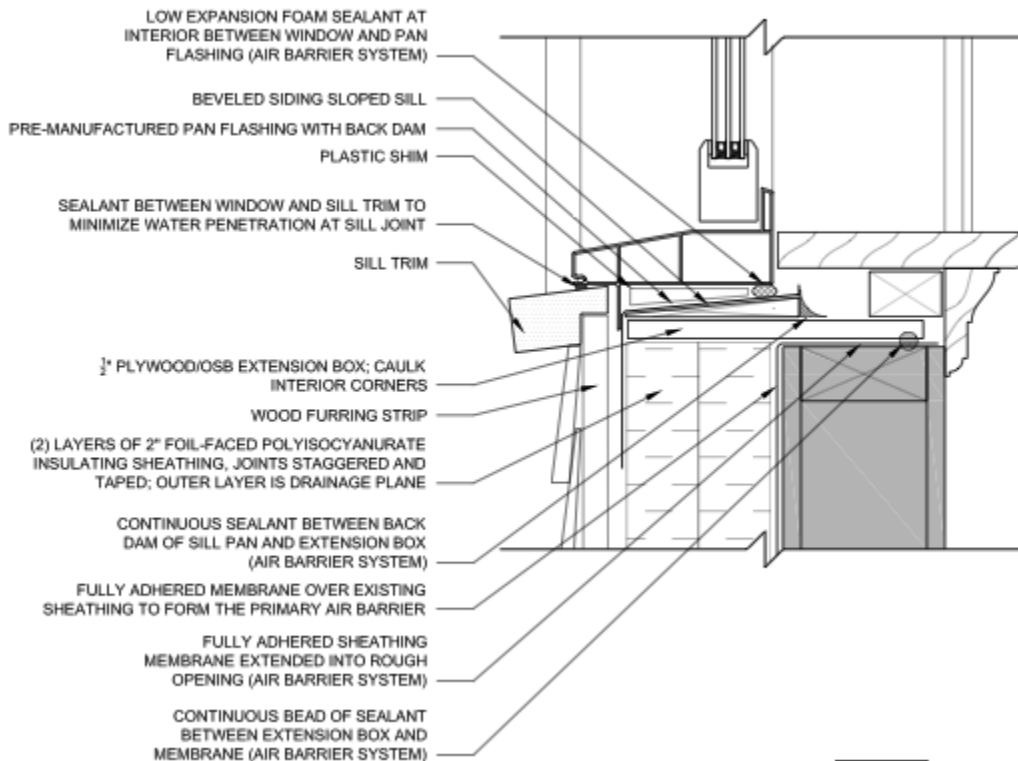
#### 4.8.3 Window Replacement in Conjunction With an Exterior Insulation Retrofit

Window replacement in conjunction with an exterior insulation retrofit 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 49. Example sill detail of "innie" window**



**Figure 50. Example sill detail of "outie" window**

## References

Brown, W.C. (1997). NRC-IRC (Institute for Research in Construction) Construction Technology Update No. 5. “Window Condensation in Historic Buildings That Have Been Adapted for New Uses.”

[EIA] 2009 Energy Information Administration – EIA Residential Energy Consumption Survey 2009.

Highly Insulating or Low-E Storm Windows Energy Savings Estimator (2011), Retrieved August 8, 2011, from [http://www.windowvolumepurchase.org/docs/Window\\_Savings\\_Estimator\\_Manual.pdf](http://www.windowvolumepurchase.org/docs/Window_Savings_Estimator_Manual.pdf)

Davis, J.M. (December 2007) “New Life for Old Double Hung Windows.” *Fine Homebuilding Magazine*. Newtown, CT: Taunton Press.

NFRC (2010a). NFRC 100A-2010 Procedure for Determining Fenestration Attachment Product U-factors, Greenbelt, MD: National Fenestration Rating Council.

NFRC (2010b). NFRC 200A-2010 Procedure for Determining Fenestration Attachment Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence, Greenbelt, MD: National Fenestration Rating Council.

Wilson, A.G. (1960). NRC-IRC (Institute for Research in Construction) Canadian Building Digest CBD 5. “Condensation Between Panes of Double Windows.” Ottawa, ON: National Research Council of Canada.

## **Appendix A: Window Repair, Rehabilitation, and Replacement Details**

## Wood Frame Wall Window Retrofit Options

M1: WINDOW REHABILITATION - HEAD DETAIL  
M1: WINDOW REHABILITATION - SILL DETAIL  
M1: WINDOW REHABILITATION - JAMB DETAIL

M2: EXTERIOR STORM - HEAD DETAIL  
M2: EXTERIOR STORM - SILL DETAIL  
M2: EXTERIOR STORM - JAMB DETAIL

M3: INTERIOR REMOVABLE STORM - HEAD DETAIL  
M3: INTERIOR REMOVABLE STORM - SILL DETAIL  
M3: INTERIOR REMOVABLE STORM - JAMB DETAIL

M4: INTERIOR PERMANENT FIXED STORM - HEAD DETAIL  
M4: INTERIOR PERMANENT FIXED STORM - SILL DETAIL  
M4: INTERIOR PERMANENT FIXED STORM - JAMB DETAIL

M5: WINDOW SASH RETROFIT - HEAD DETAIL  
M5: WINDOW SASH RETROFIT - SILL DETAIL  
M5: WINDOW SASH RETROFIT - JAMB DETAIL

M6: WINDOW SASH REPLACEMENT - HEAD DETAIL  
M6: WINDOW SASH REPLACEMENT - SILL DETAIL  
M6: WINDOW SASH REPLACEMENT - JAMB DETAIL

M7: INSERT REPLACEMENT WINDOW - HEAD DETAIL  
M7: INSERT REPLACEMENT WINDOW - SILL DETAIL  
M7: INSERT REPLACEMENT WINDOW - JAMB DETAIL

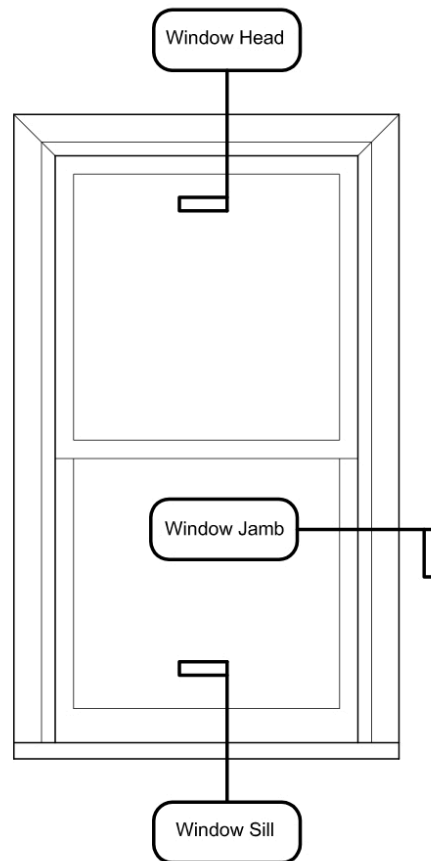
M8A: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL  
M8A: COMPLETE REPLACEMENT WINDOW - SILL DETAIL  
M8A: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

M8B: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL  
M8B: COMPLETE REPLACEMENT WINDOW - SILL DETAIL  
M8B: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

M8C: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL  
M8C: COMPLETE REPLACEMENT WINDOW - SILL DETAIL  
M8C: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

M8D: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL  
M8D: COMPLETE REPLACEMENT WINDOW - SILL DETAIL  
M8D: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

## Window Detail Key



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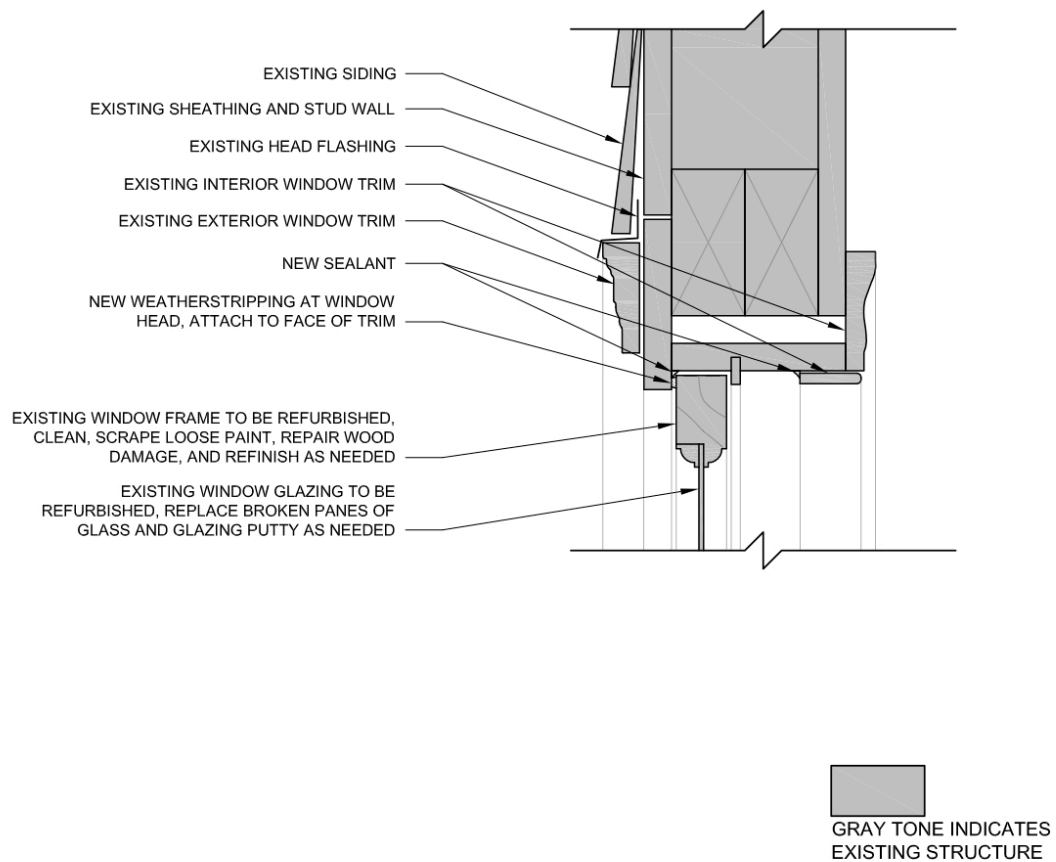
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## M1: WINDOW REHABILITATION - HEAD DETAIL

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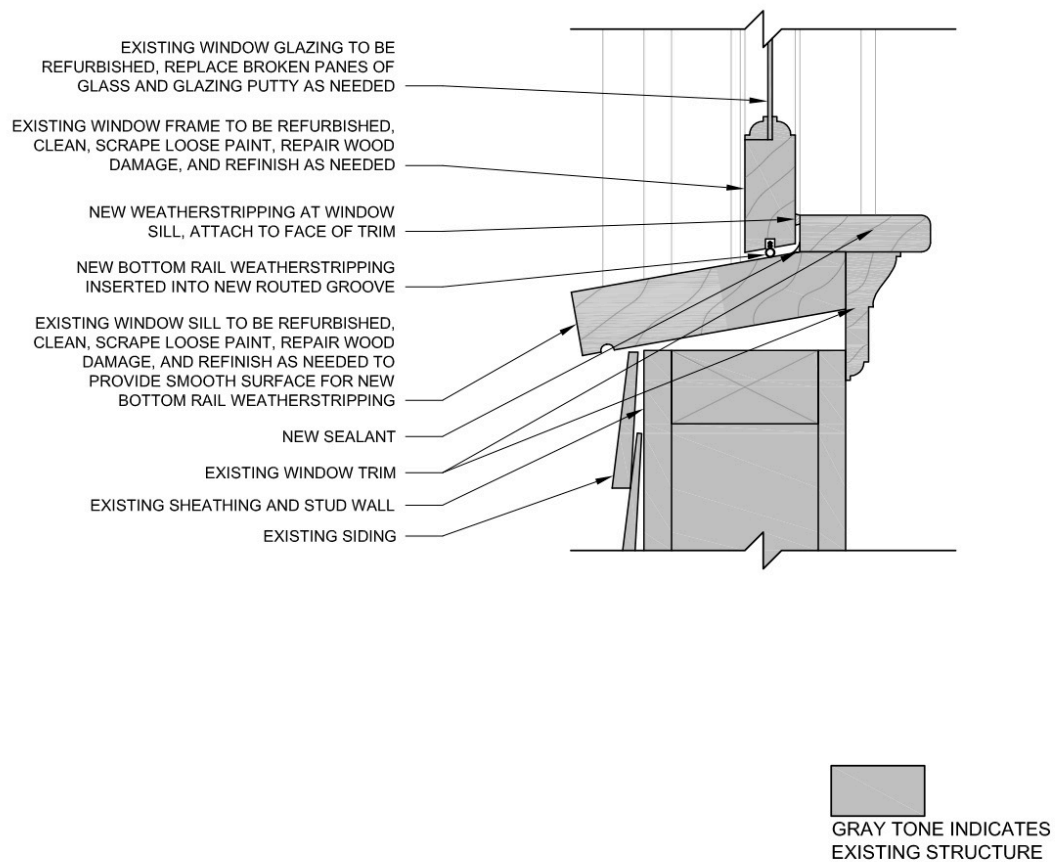
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## M1: WINDOW REHABILITATION - SILL DETAIL

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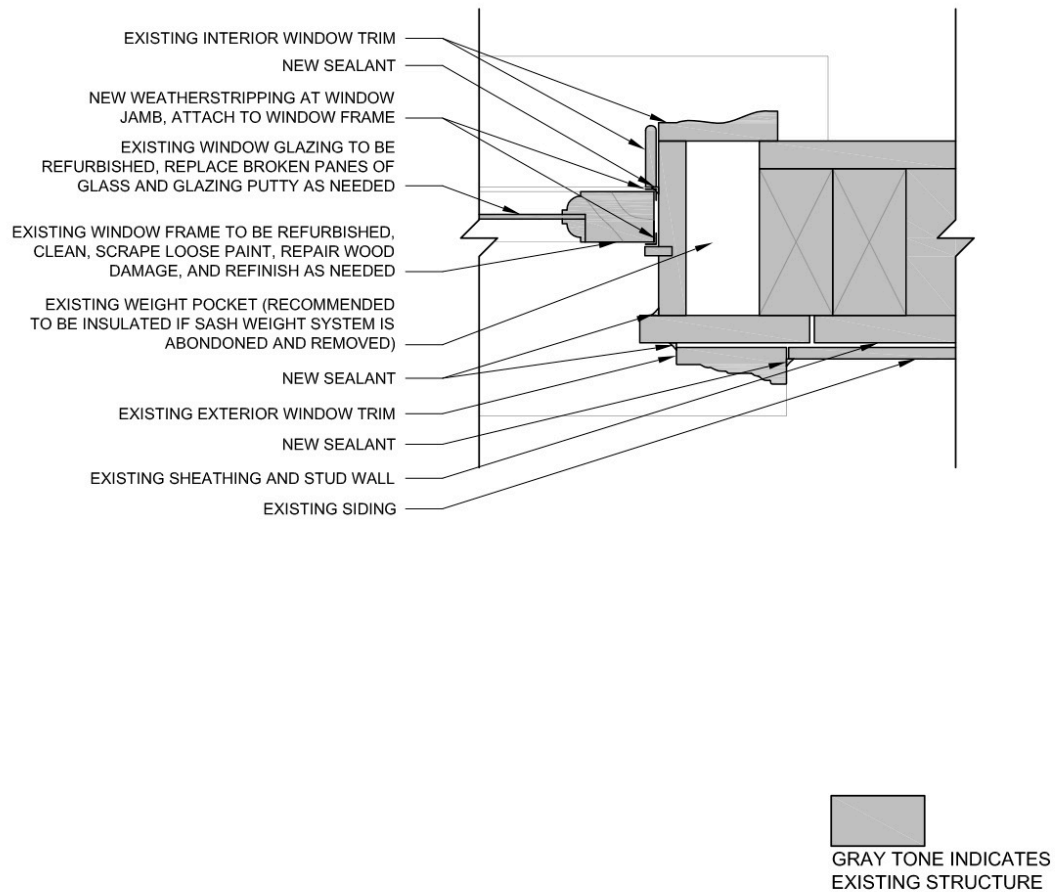
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**M1-S**



## M1: WINDOW REHABILITATION - JAMB DETAIL

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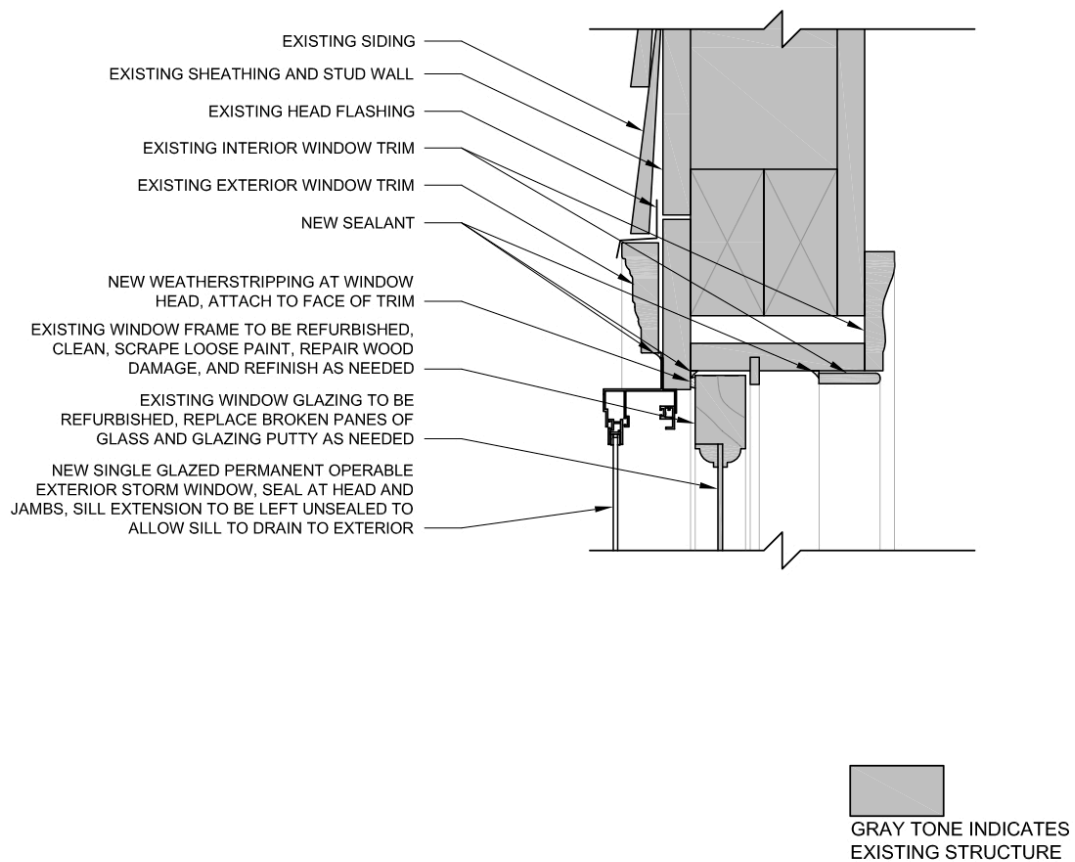
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## M2: EXTERIOR STORM - HEAD DETAIL

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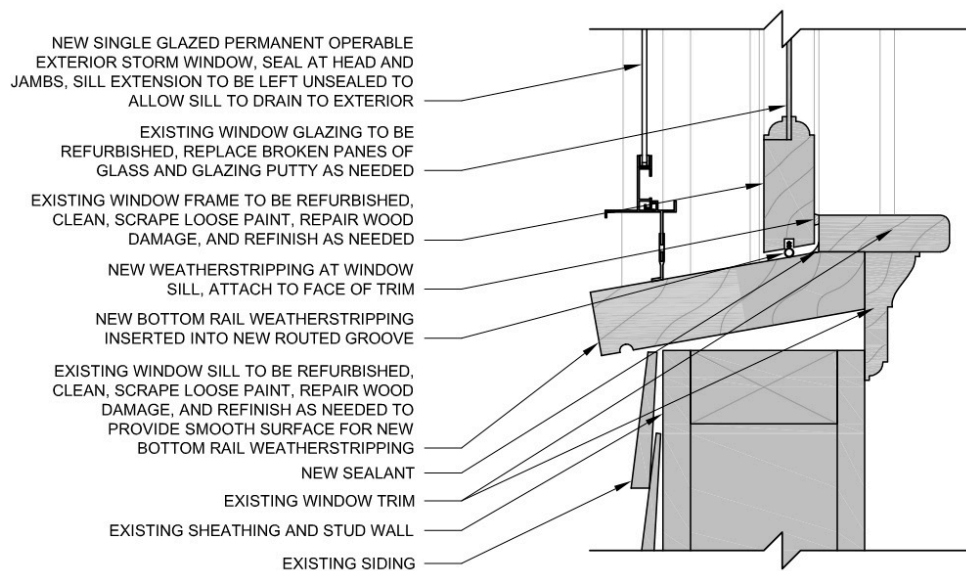
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**M2-H**



 GRAY TONE INDICATES EXISTING STRUCTURE

## M2: EXTERIOR STORM - SILL DETAIL

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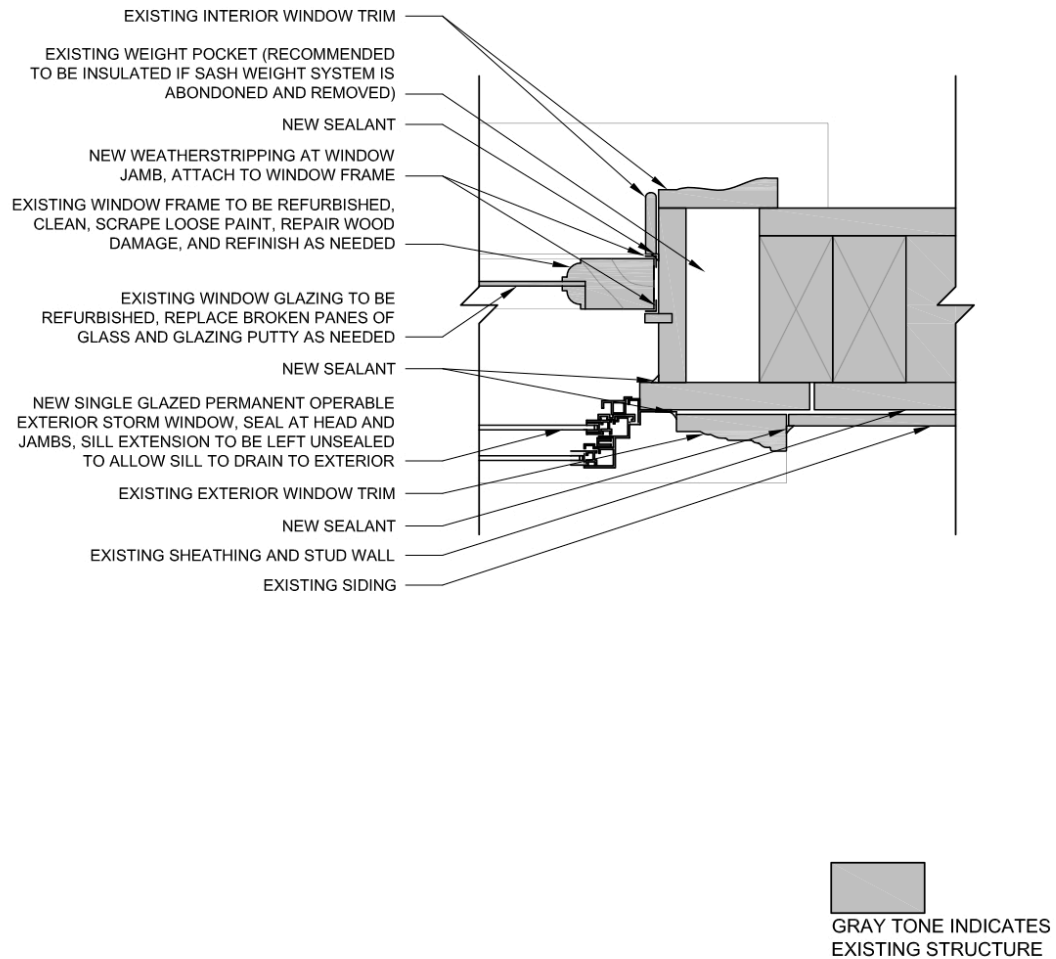
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## M2: EXTERIOR STORM - JAMB DETAIL

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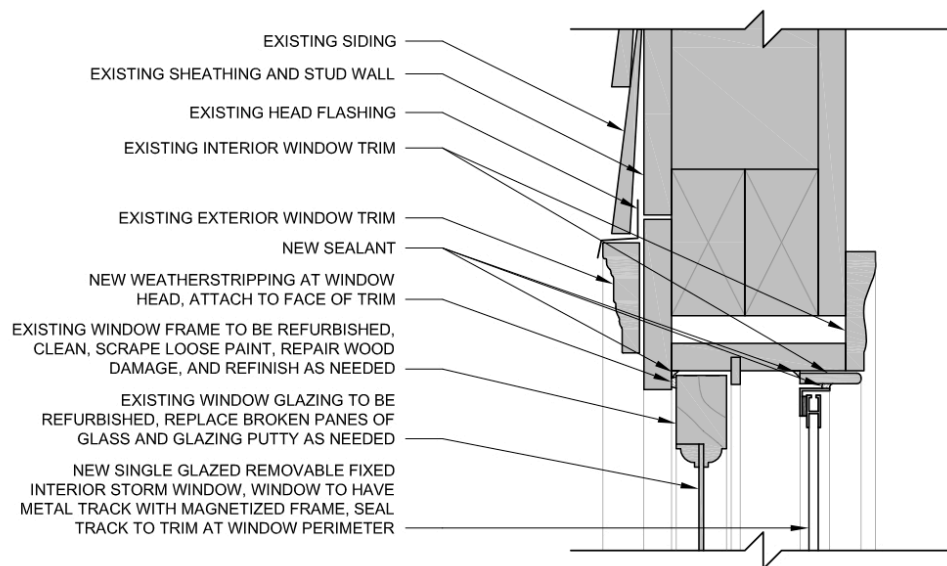
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**M2-J**





GRAY TONE INDICATES  
EXISTING STRUCTURE

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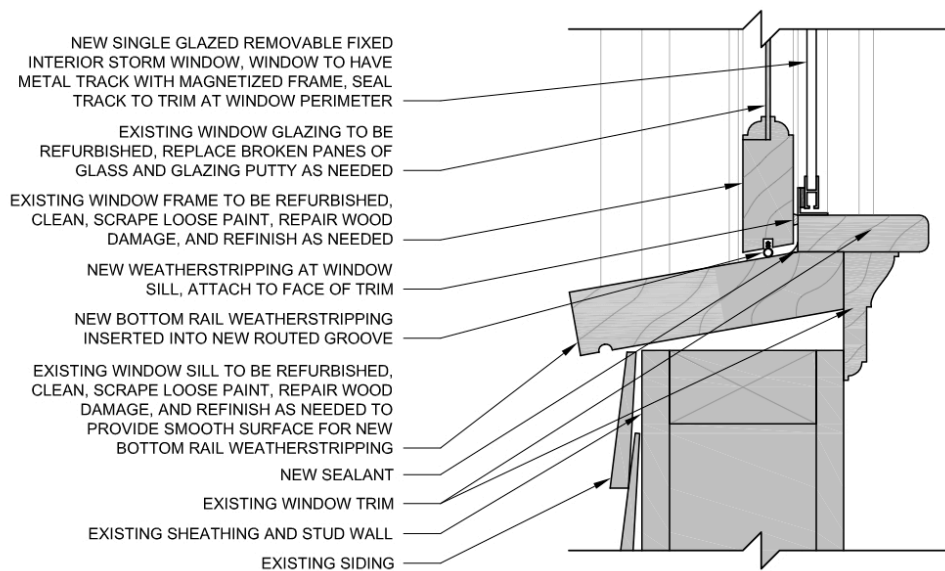
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**M3-H**



GRAY TONE INDICATES  
EXISTING STRUCTURE

## M3: INTERIOR REMOVABLE STORM - SILL DETAIL

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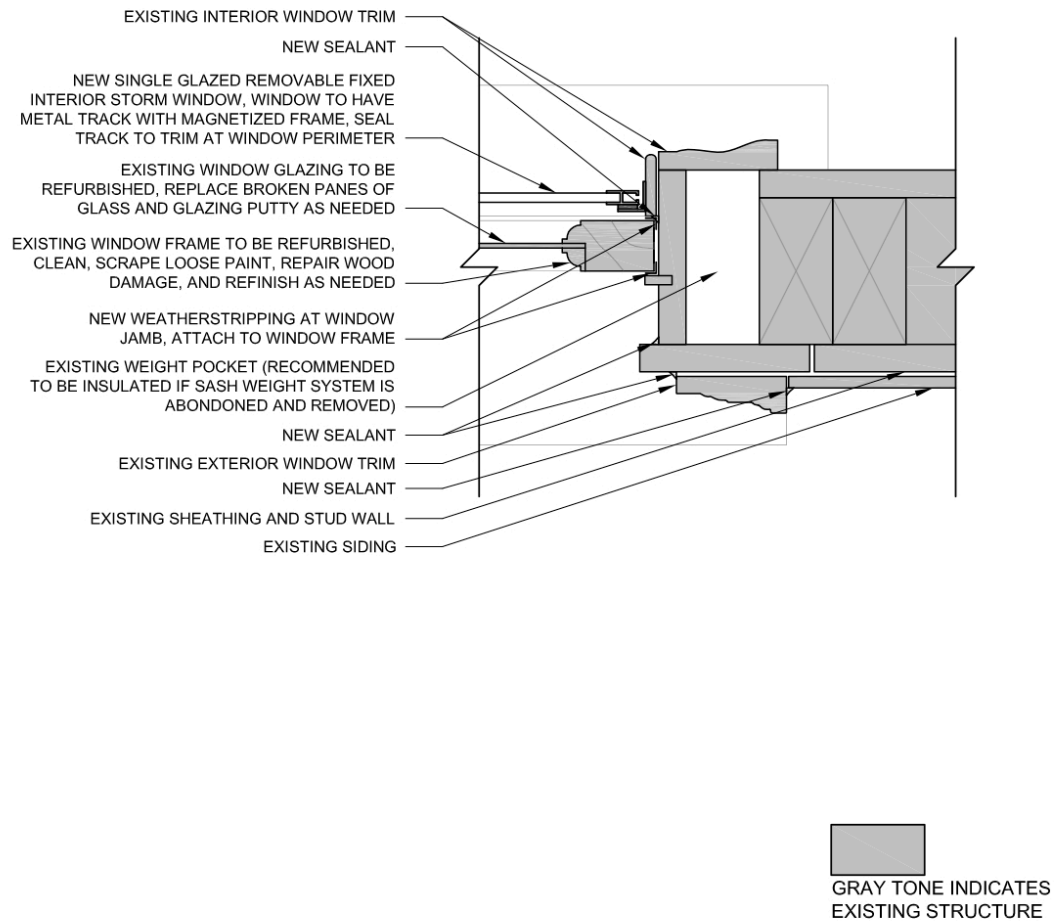
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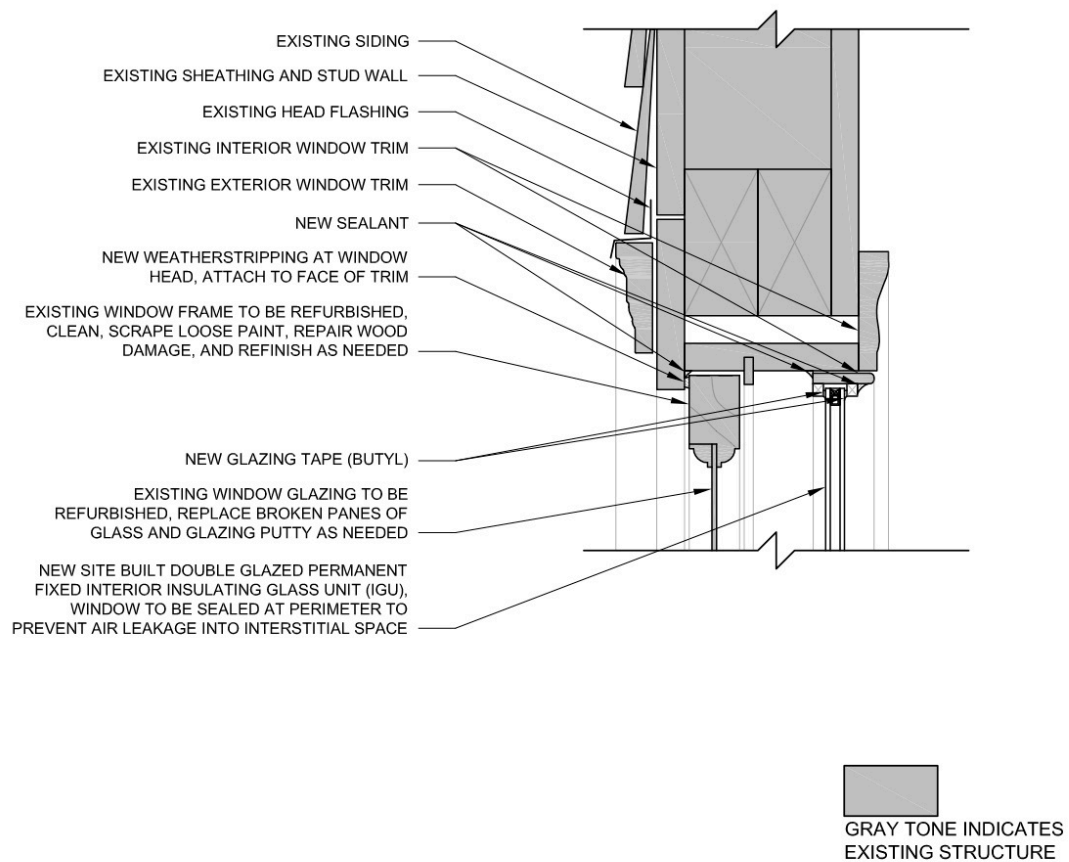
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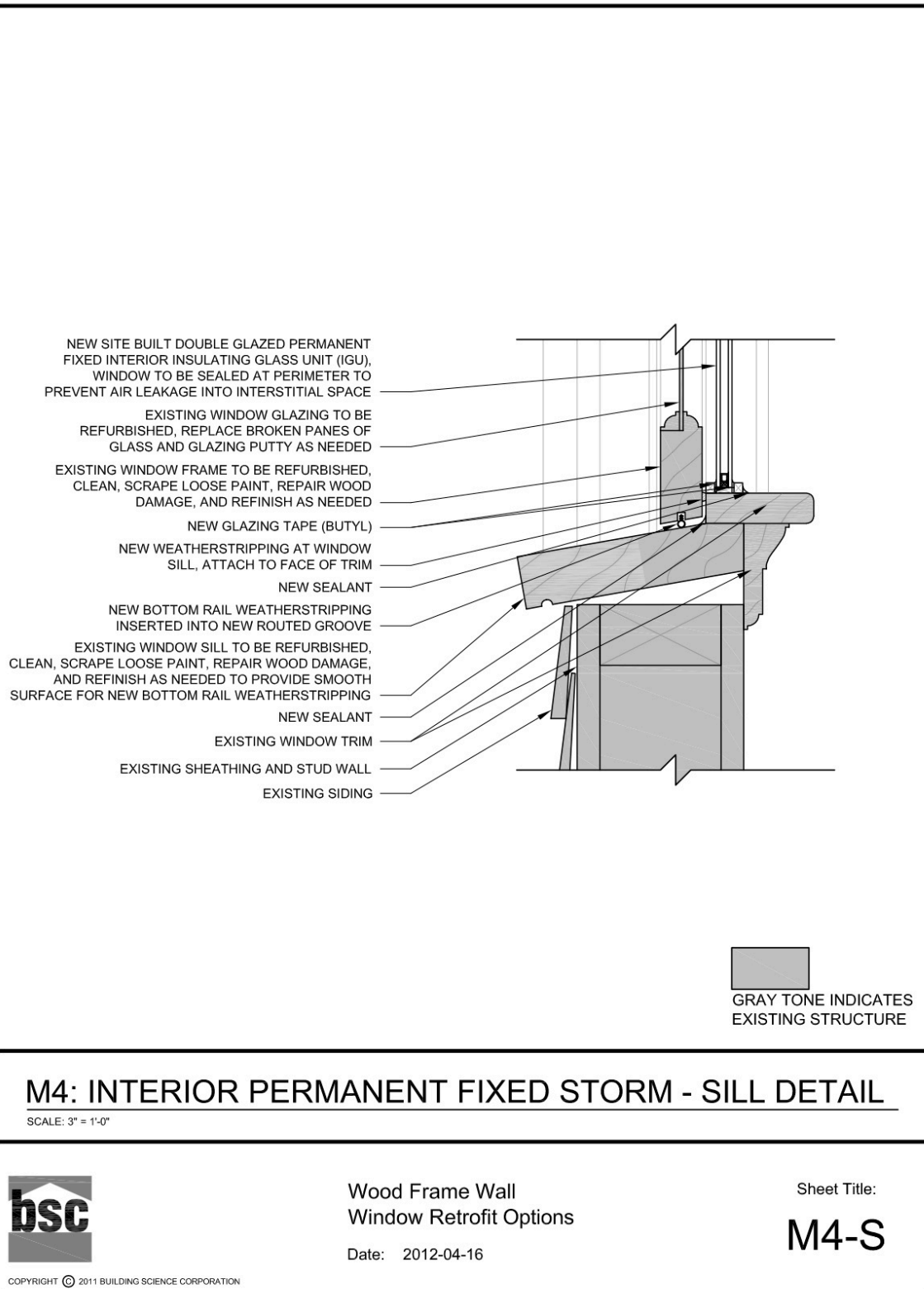
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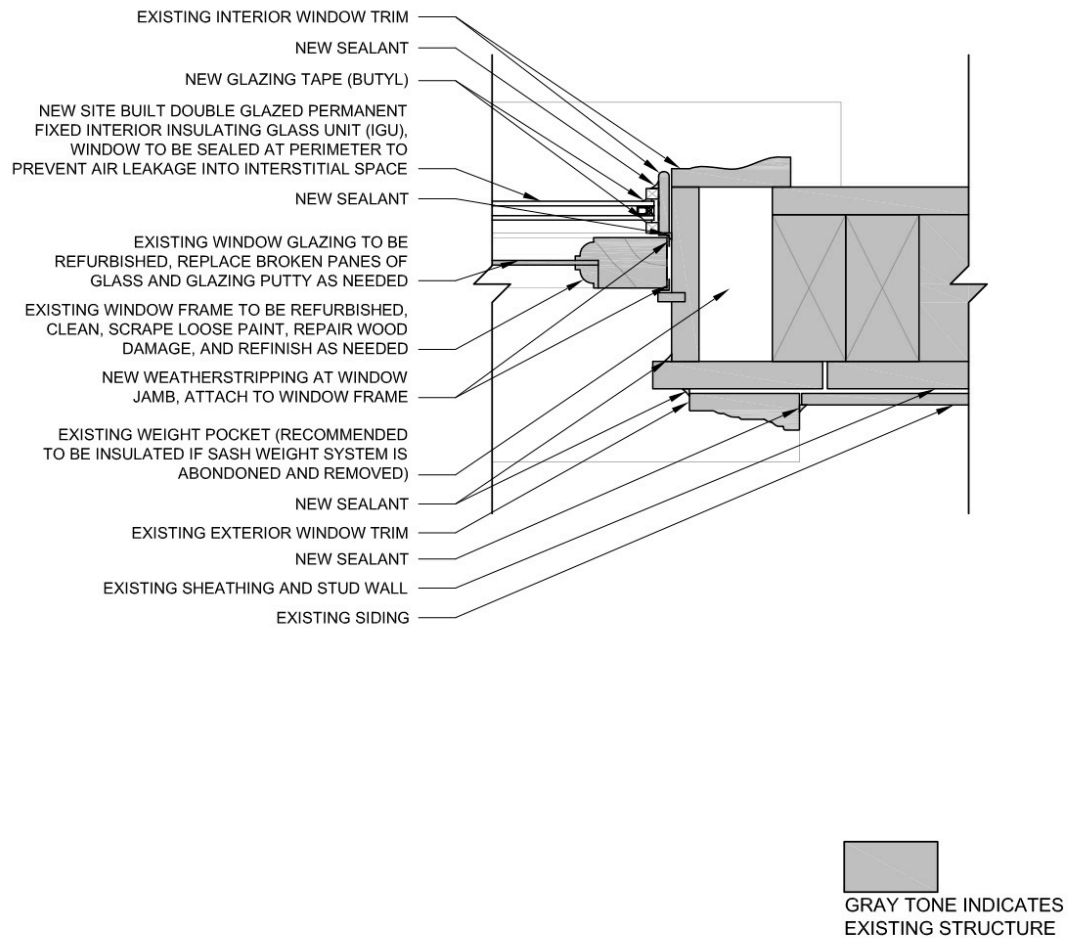
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## M4: INTERIOR PERMANENT FIXED STORM - JAMB DETAIL

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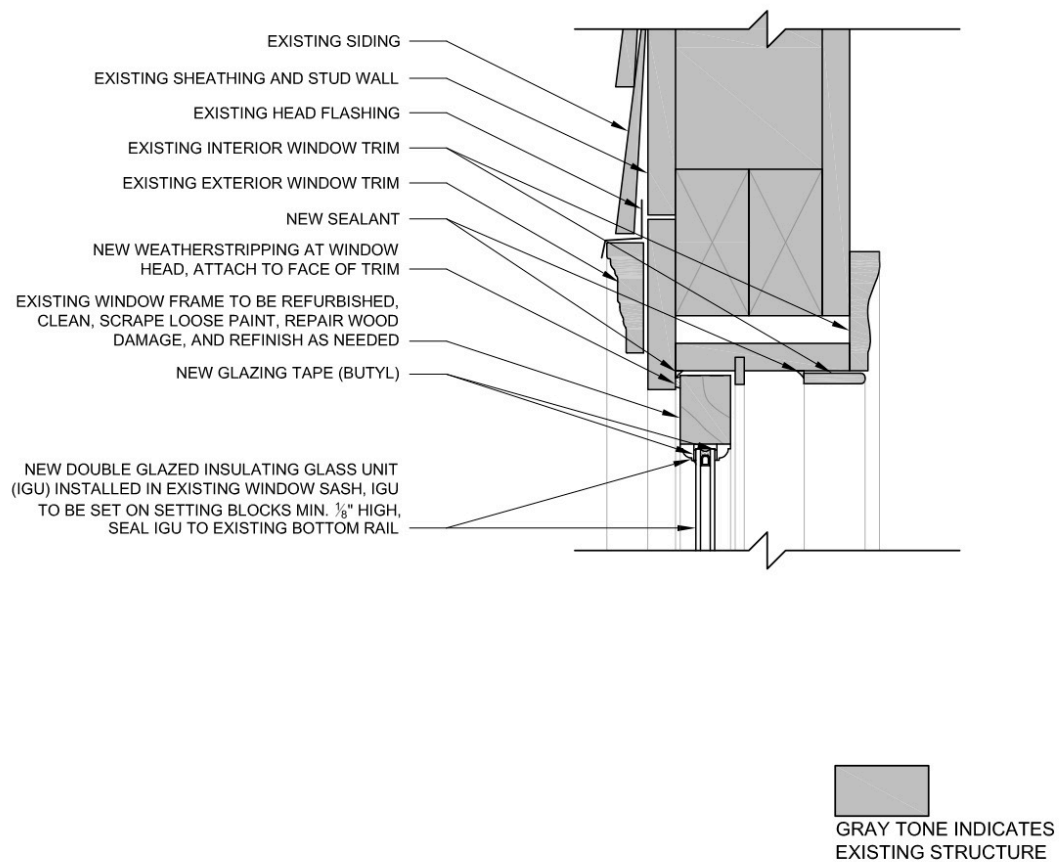
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## M5: WINDOW SASH RETROFIT - HEAD DETAIL

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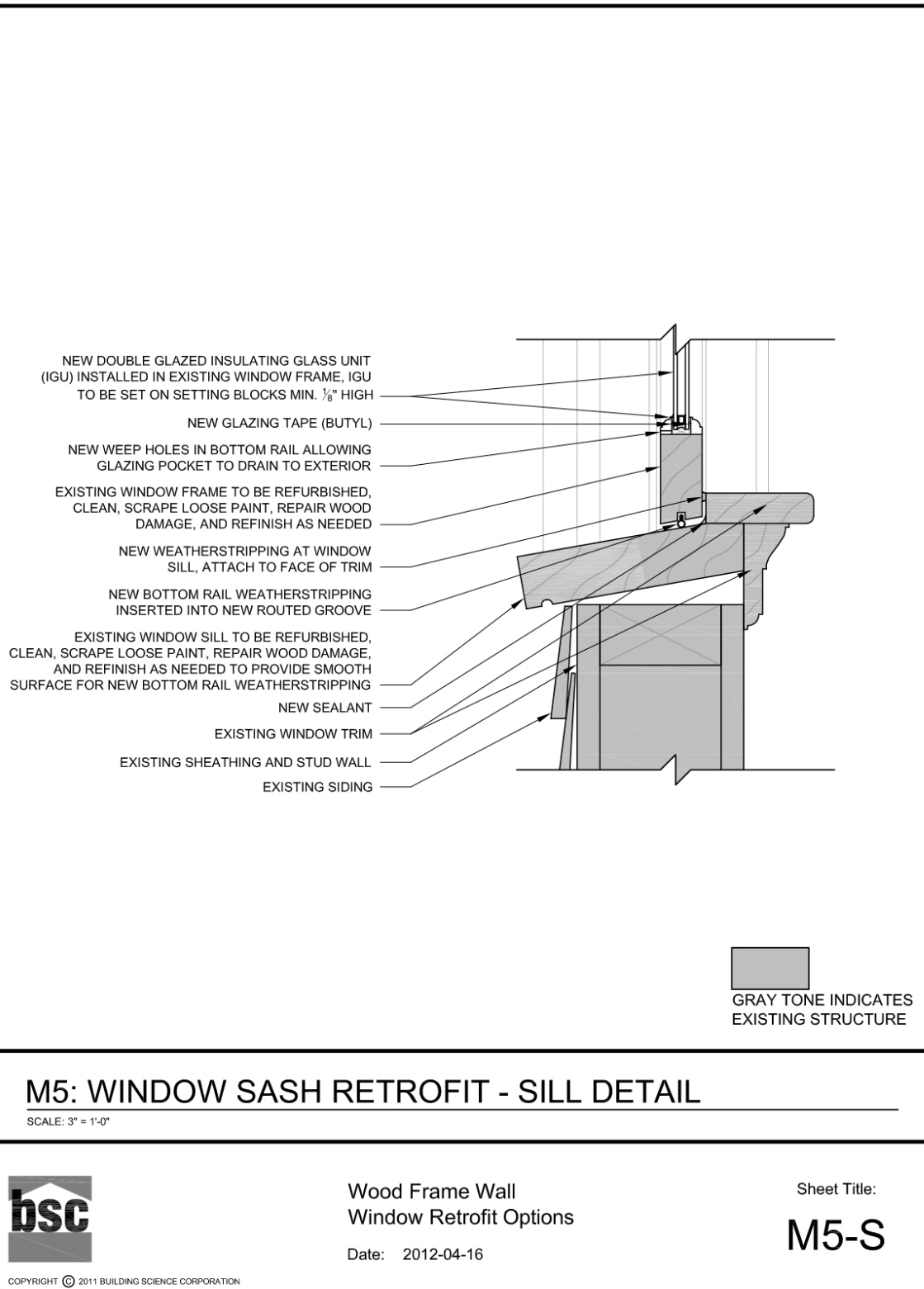
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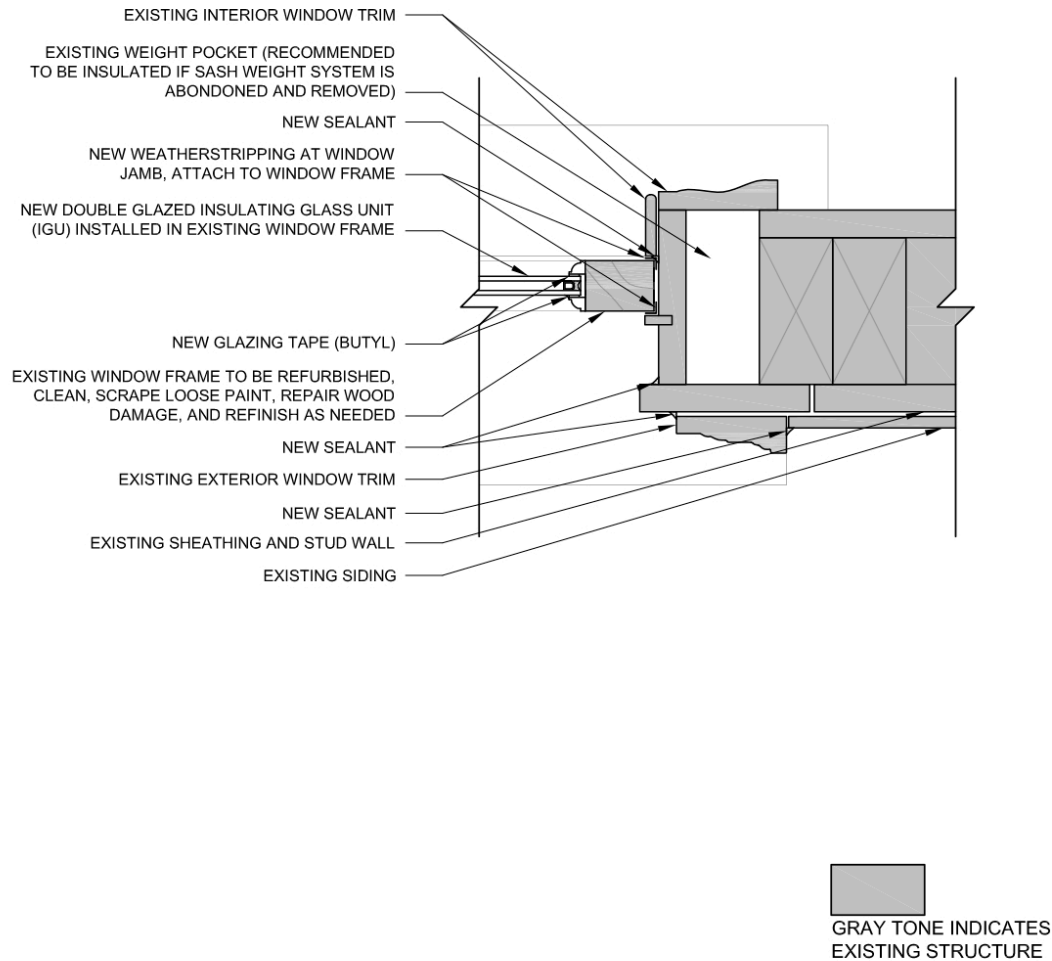
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## M5: WINDOW SASH RETROFIT - JAMB DETAIL

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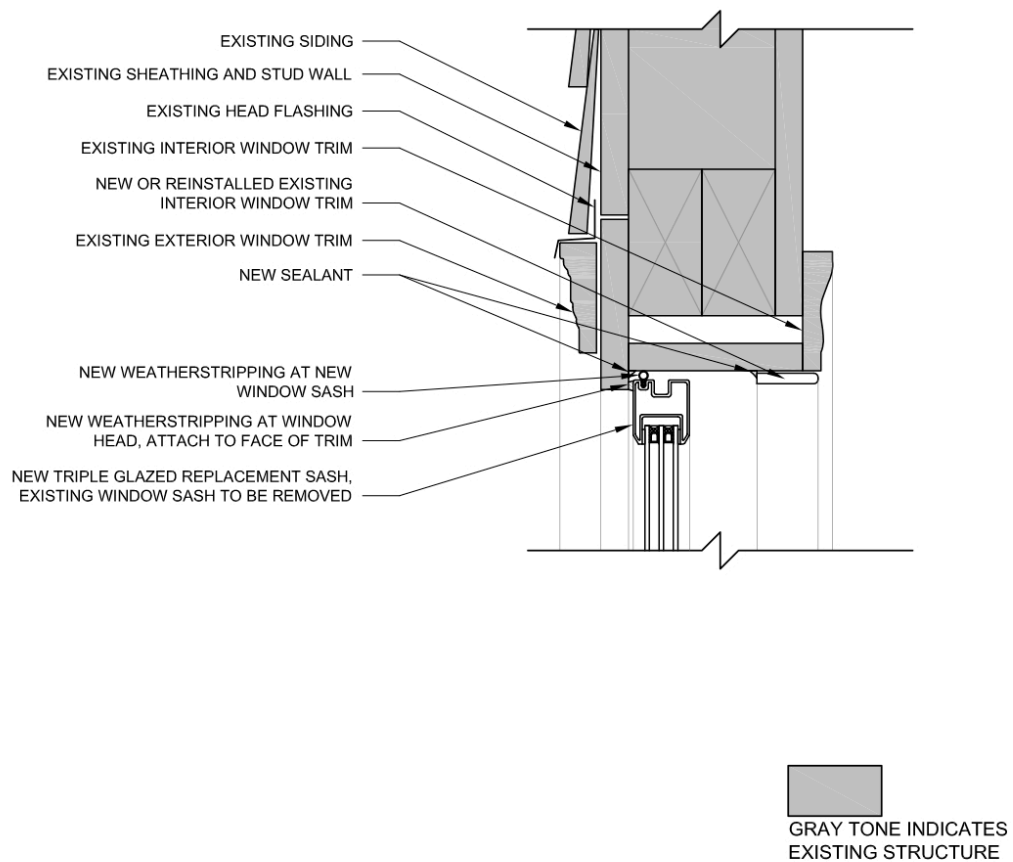
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## M6: WINDOW SASH REPLACEMENT - HEAD DETAIL

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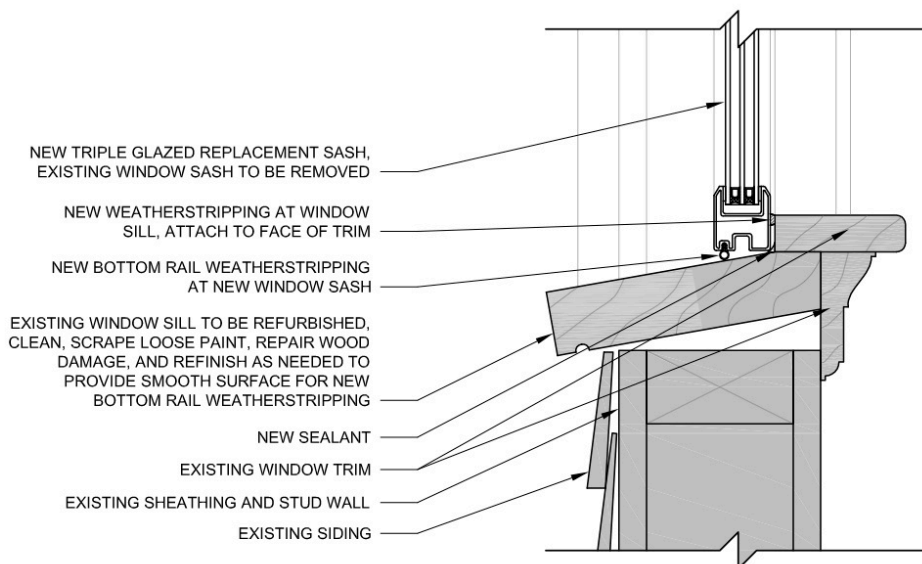
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Window Retrofit Options

Date: 2012-04-16

Sheet Title:

**M6-H**



## M6: WINDOW SASH REPLACEMENT - SILL DETAIL

SCALE: 3" = 1'-0"



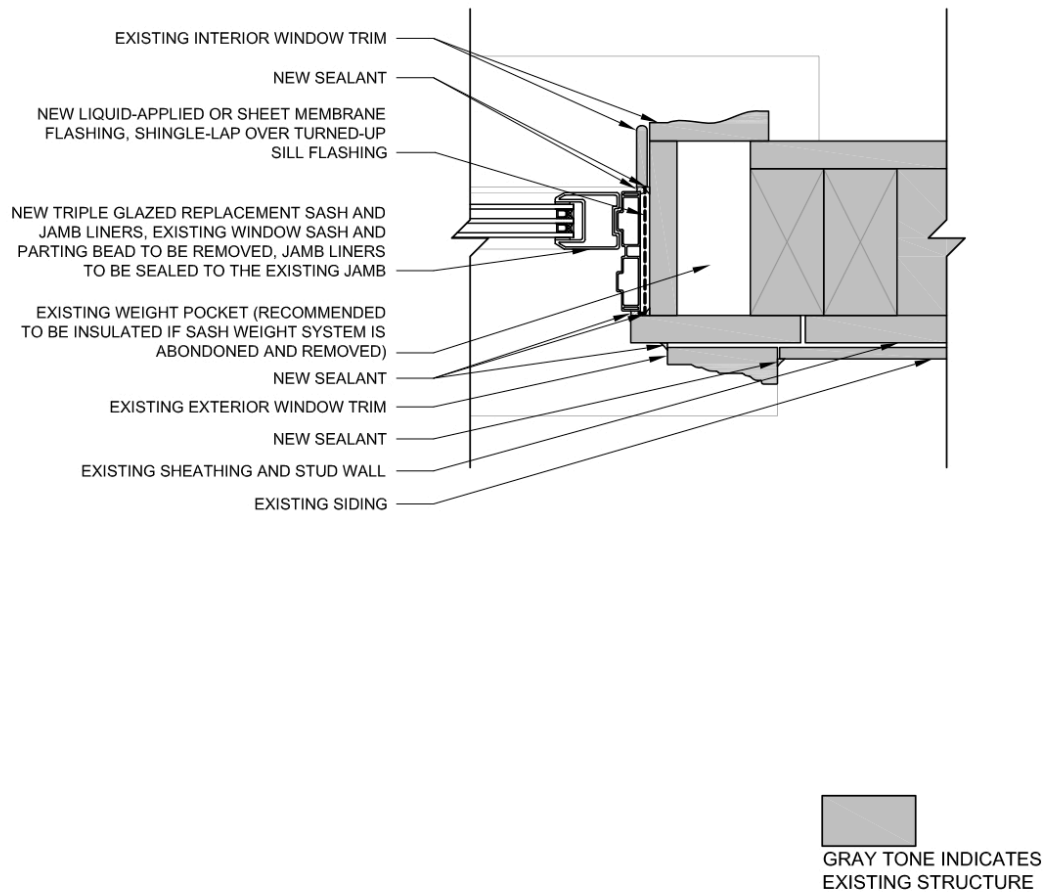
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**M6-S**



## M6: WINDOW SASH REPLACEMENT - JAMB DETAIL

SCALE: 3" = 1'-0"



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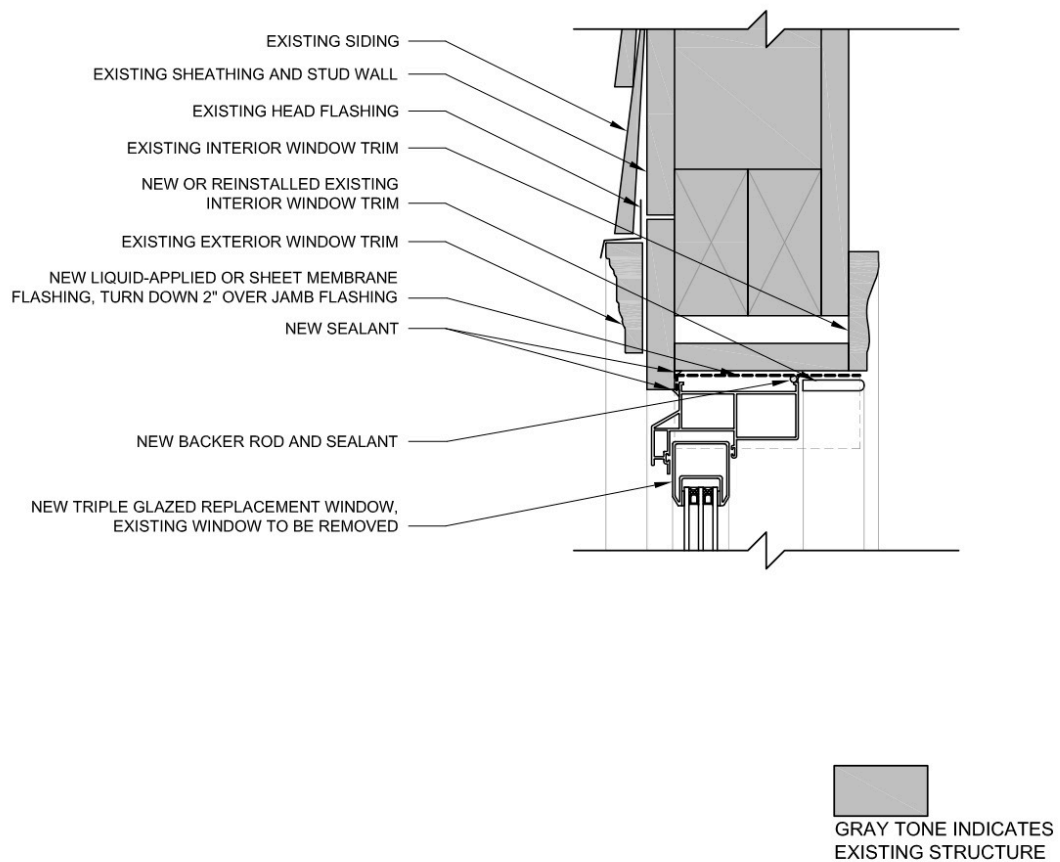
Wood Frame Wall  
Window Retrofit Options

Date: 2012-04-16

Sheet Title:

**M6-J**





## M7: INSERT REPLACEMENT WINDOW - HEAD DETAIL

SCALE: 3" = 1'-0"



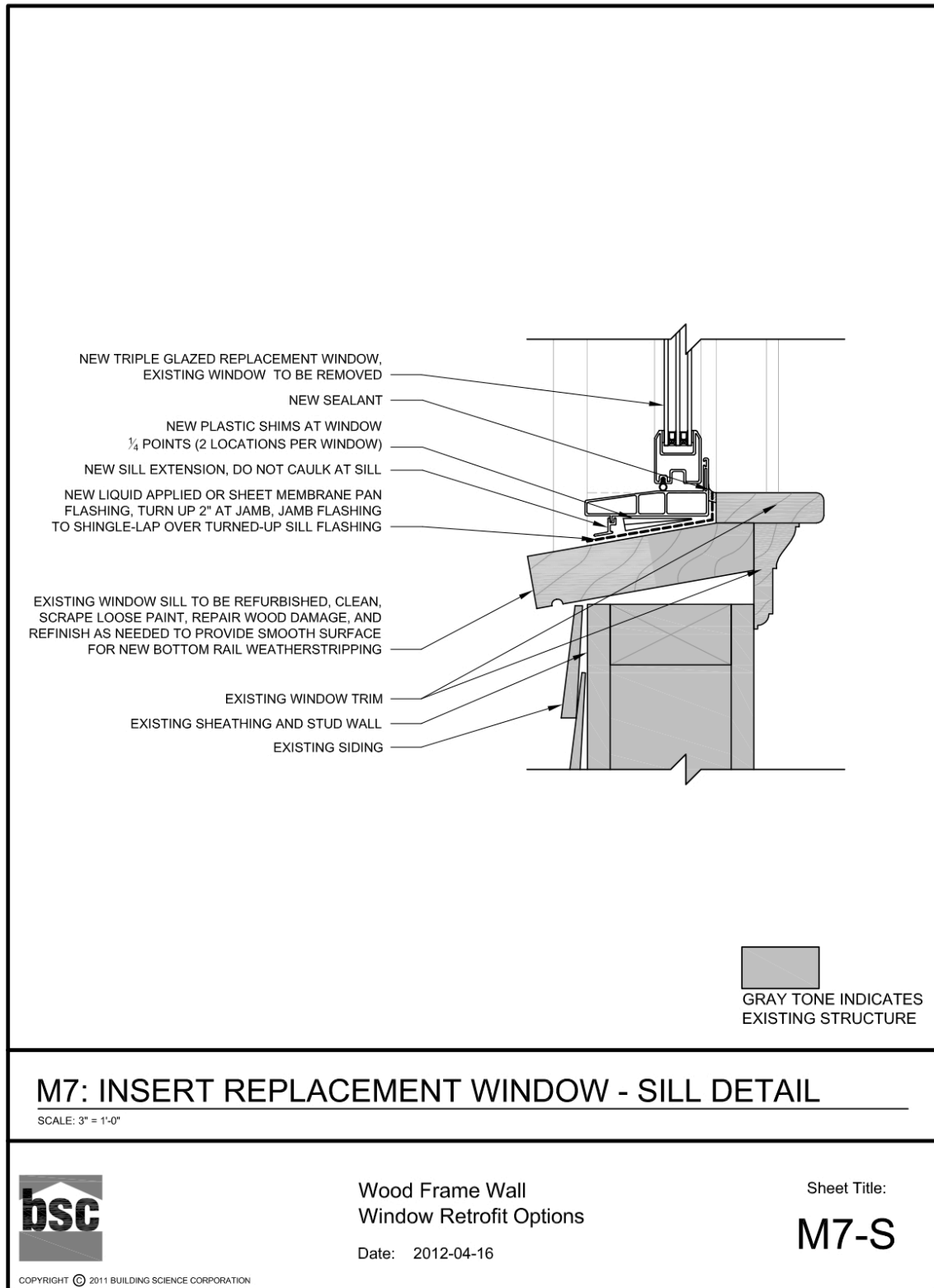
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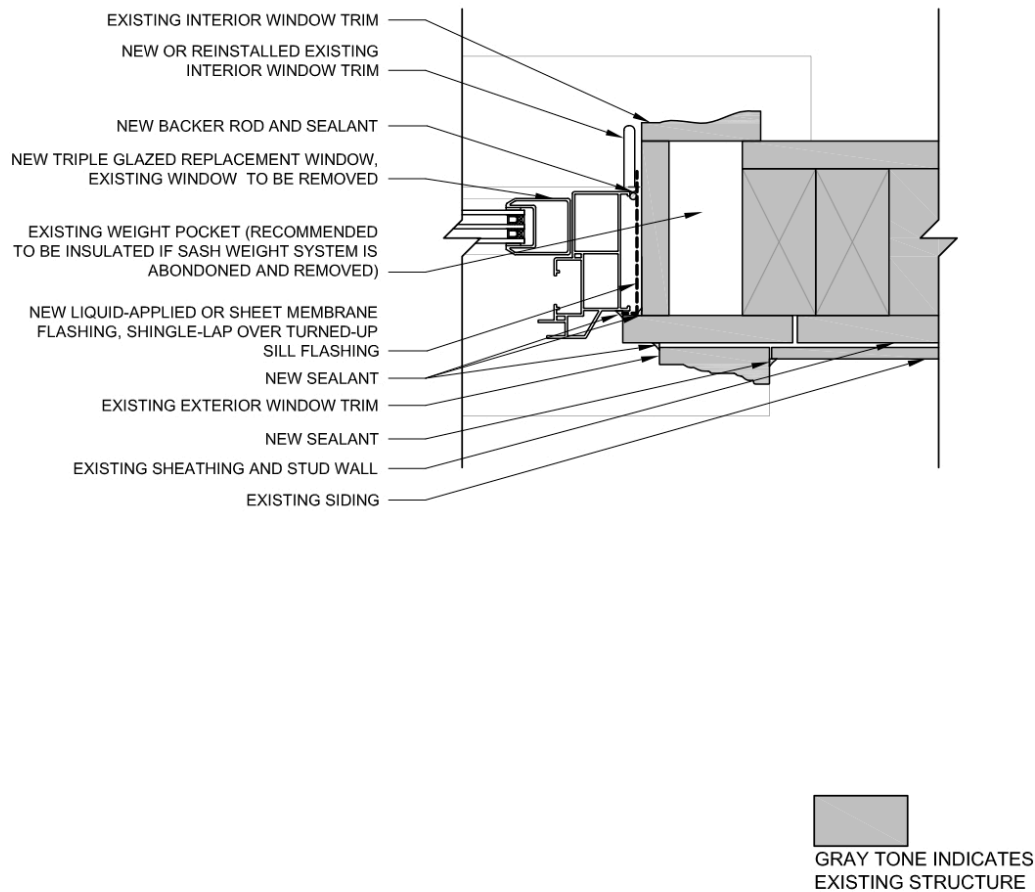
Wood Frame Wall  
Window Retrofit Options

Date: 2012-04-16

Sheet Title:

**M7-H**





## M7: INSERT REPLACEMENT WINDOW - JAMB DETAIL

SCALE: 3" = 1'-0"



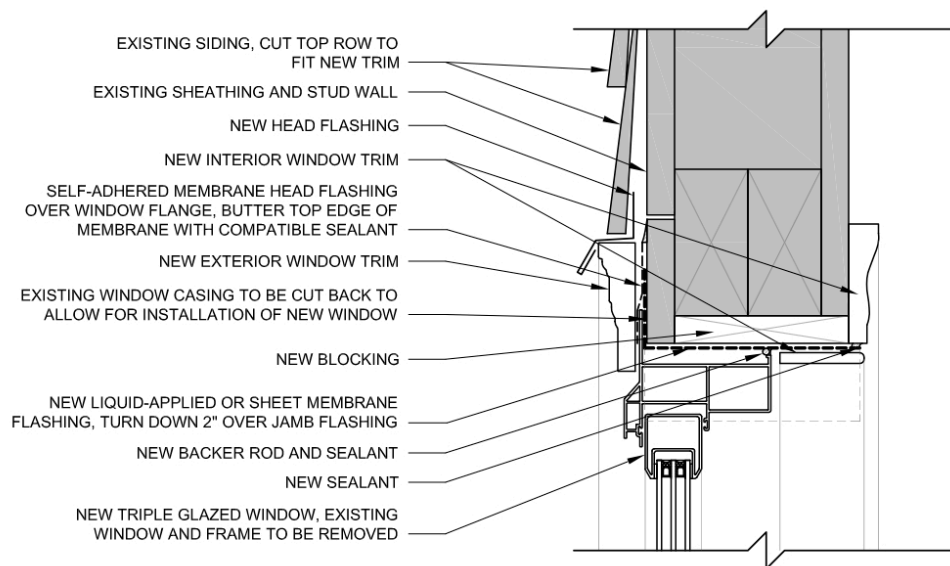
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**M7-J**



GRAY TONE INDICATES  
EXISTING STRUCTURE

## M8-A: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL

SCALE: 3" = 1'-0"



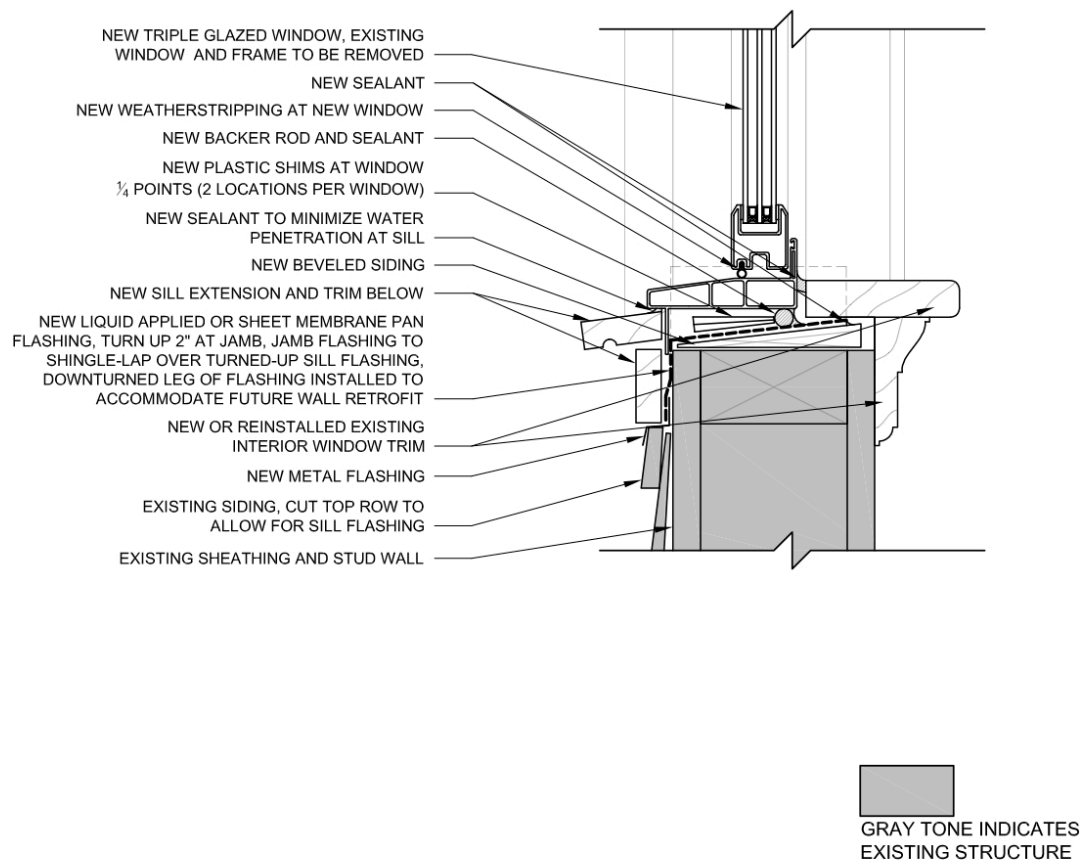
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Sheet Title:

**M8A-H**



## M8-A: COMPLETE REPLACEMENT WINDOW - SILL DETAIL

SCALE: 3" = 1'-0"



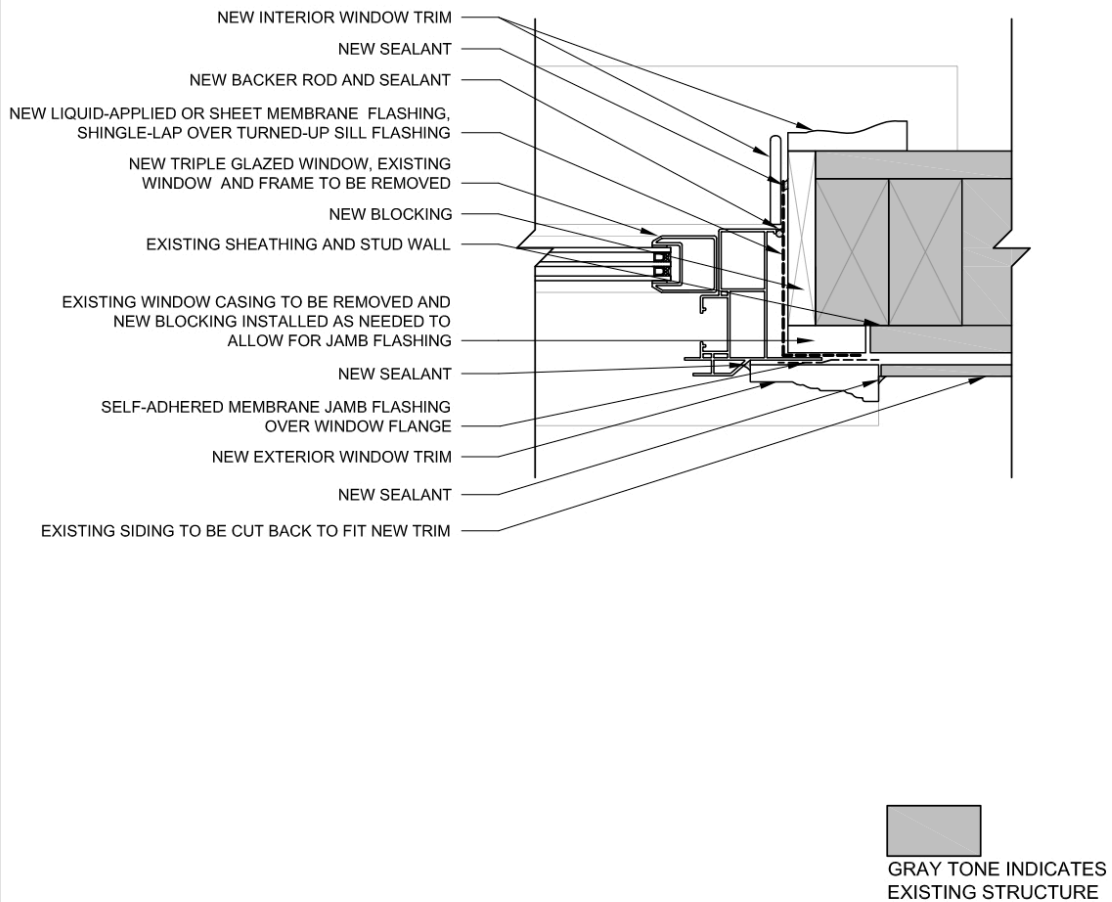
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Sheet Title:

**M8A-S**



## M8-A: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

SCALE: 3" = 1'-0"



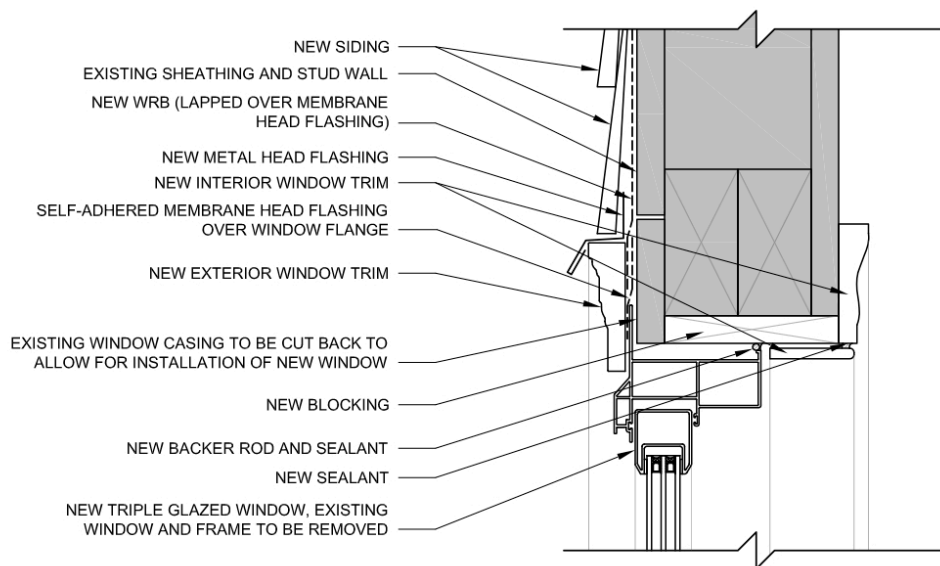
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**M8A-J**



## M8-B: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL

SCALE: 3" = 1'-0"



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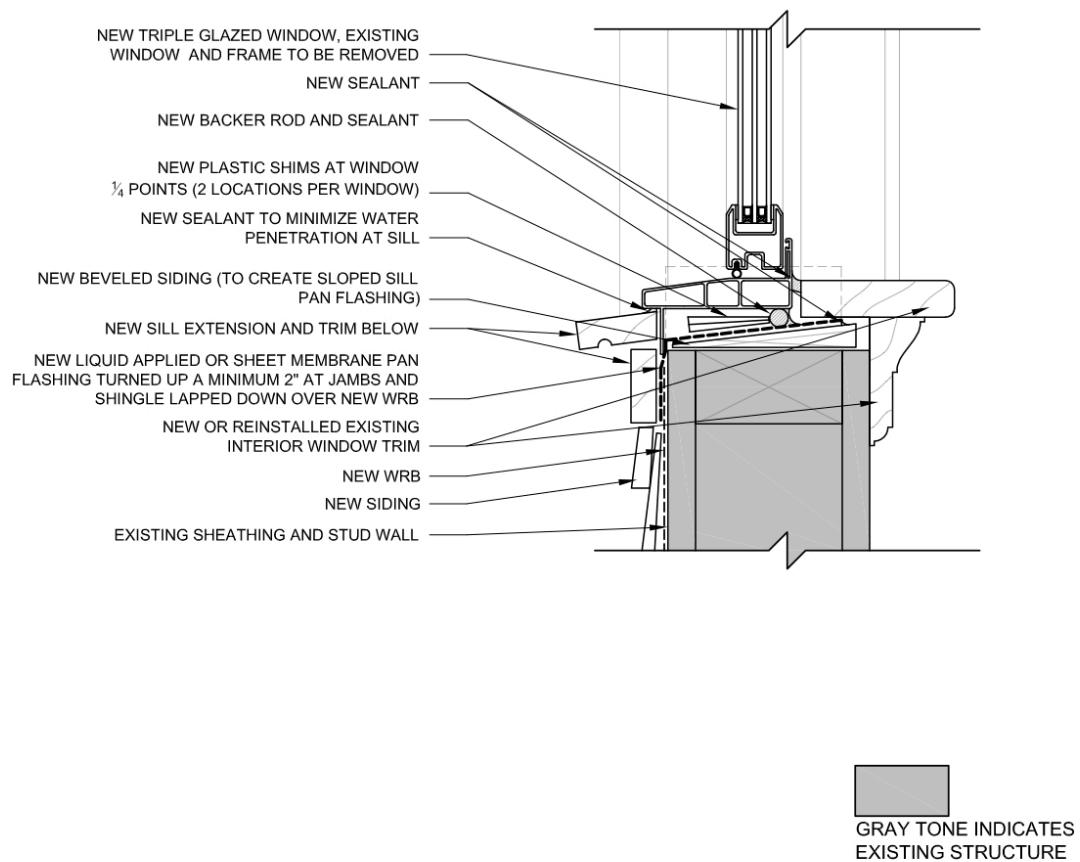
Wood Frame Wall  
Window Retrofit Options

Date: 2012-04-16

Sheet Title:

**M8B-H**





## M8-B: COMPLETE REPLACEMENT WINDOW - SILL DETAIL

SCALE: 3" = 1'-0"



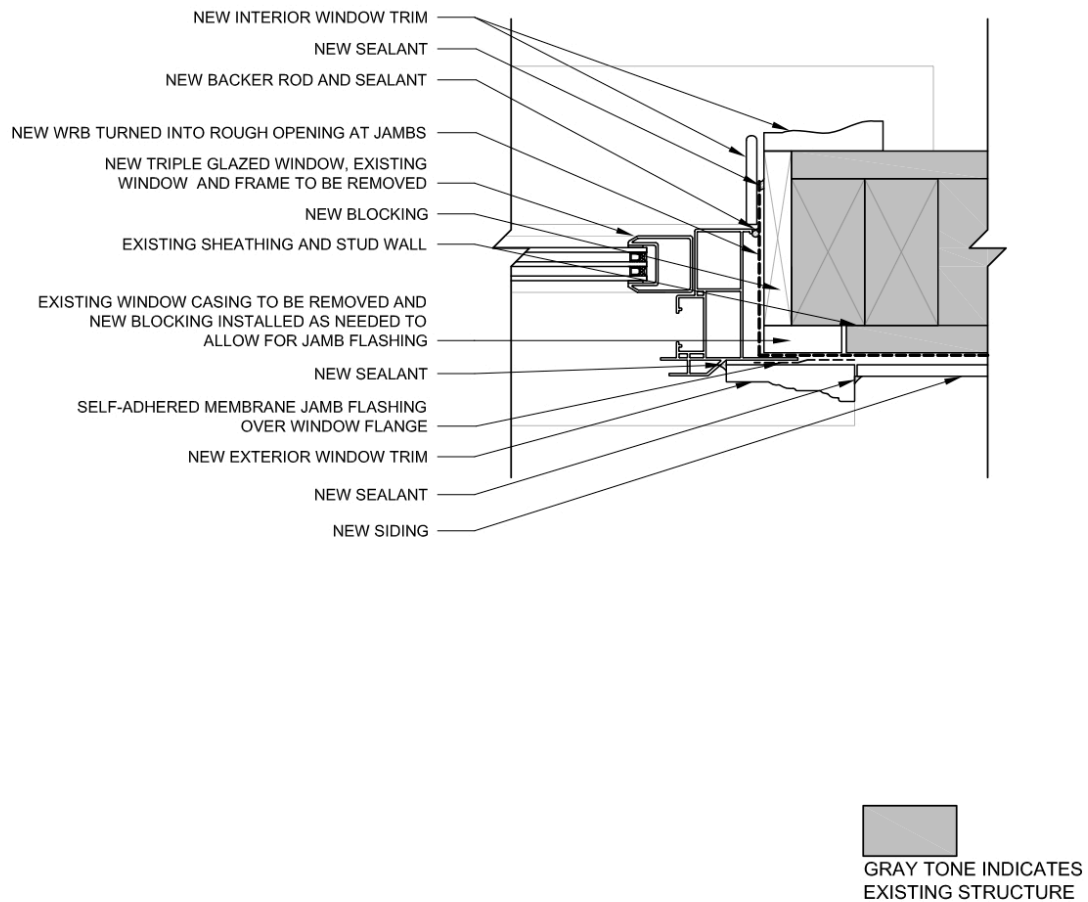
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Sheet Title:

**M8B-S**



## M8-B: COMPLETE REPLACEMENT WINDOW - JAMB DETAIL

SCALE: 3" = 1'-0"



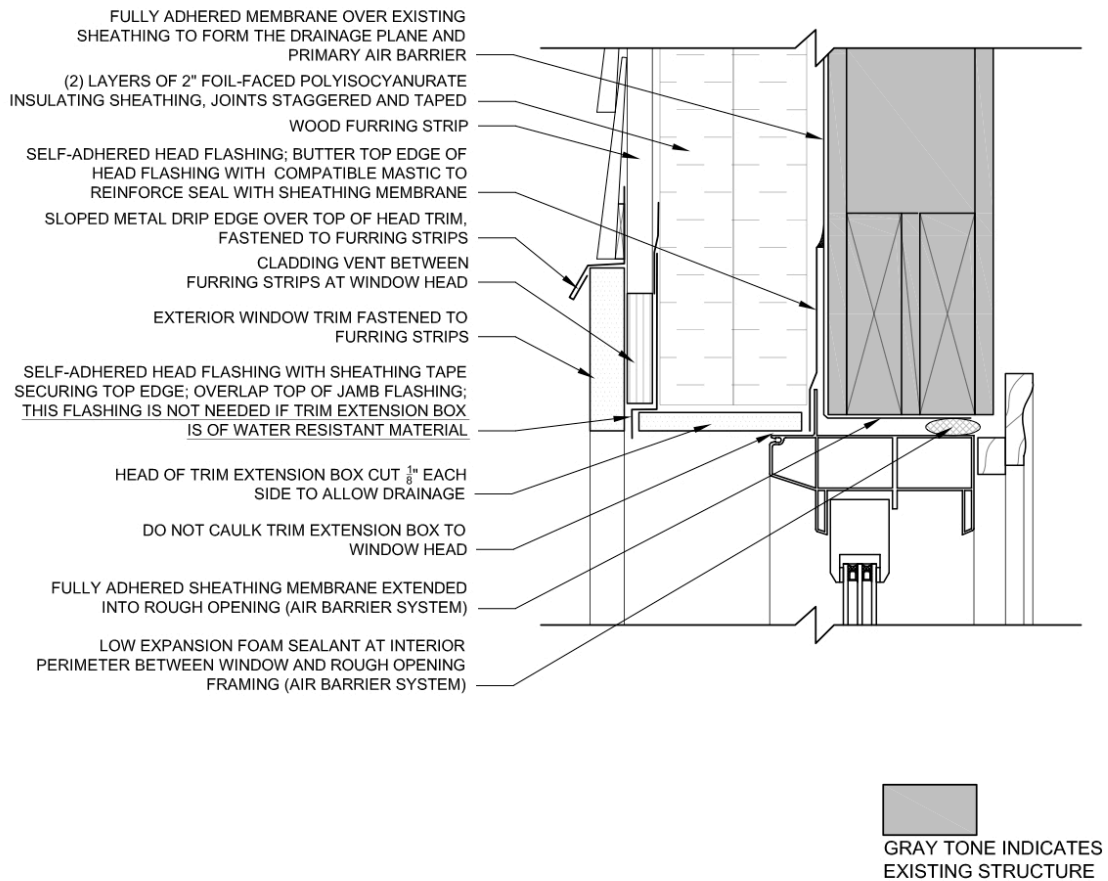
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Sheet Title:

**M8B-J**



## M8-C: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL

SCALE: 3" = 1'-0"



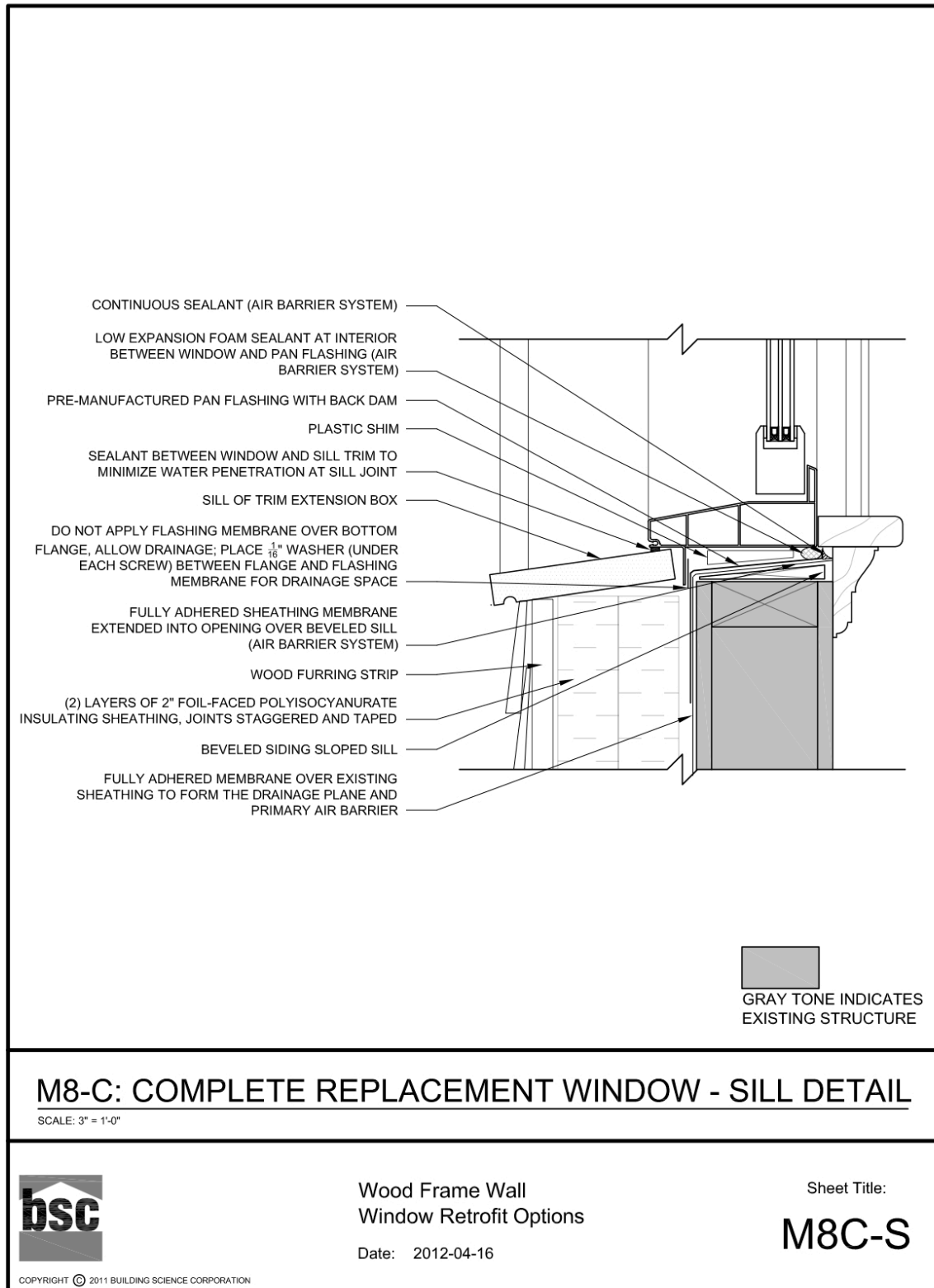
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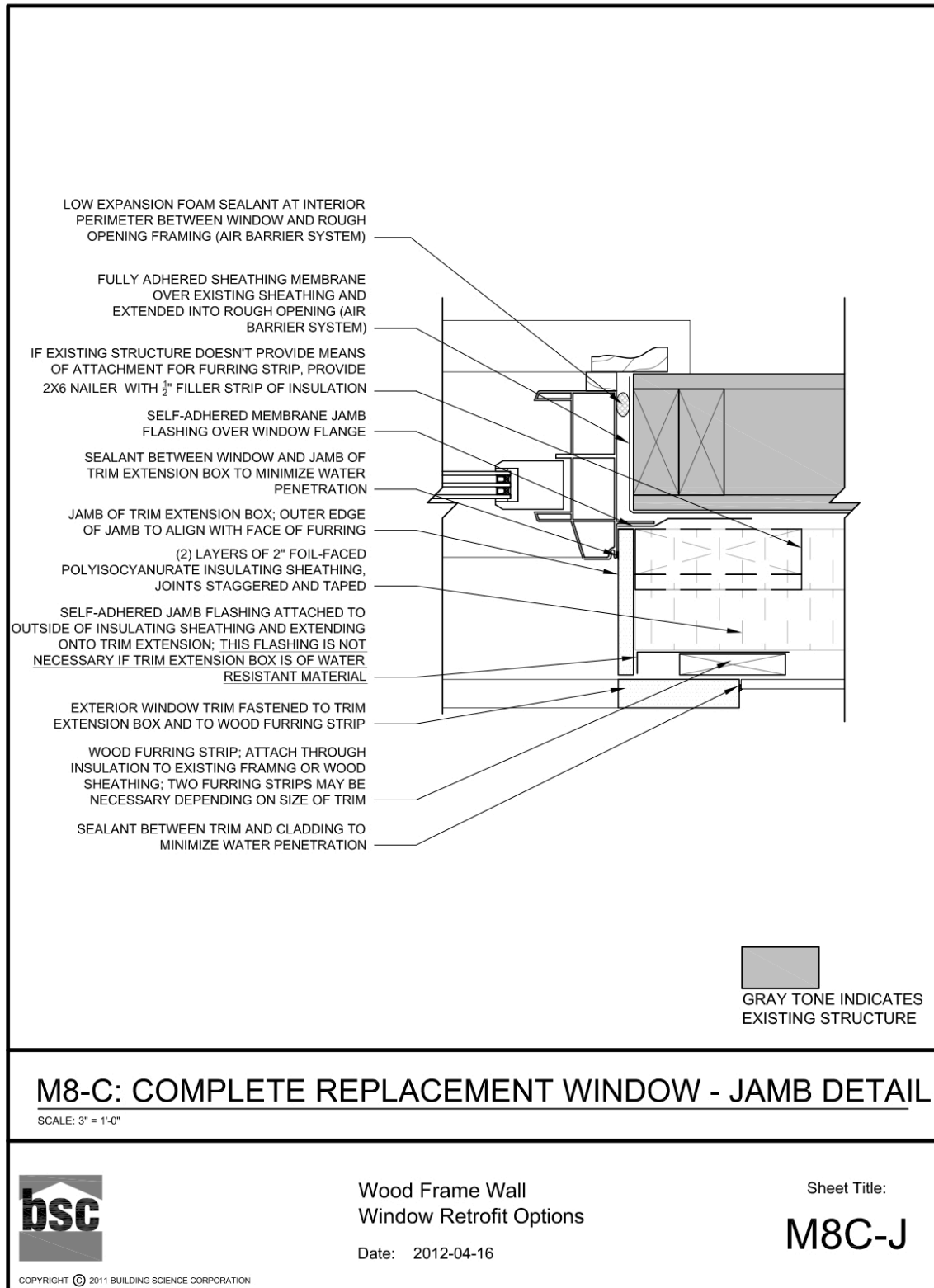
Wood Frame Wall  
Window Retrofit Options

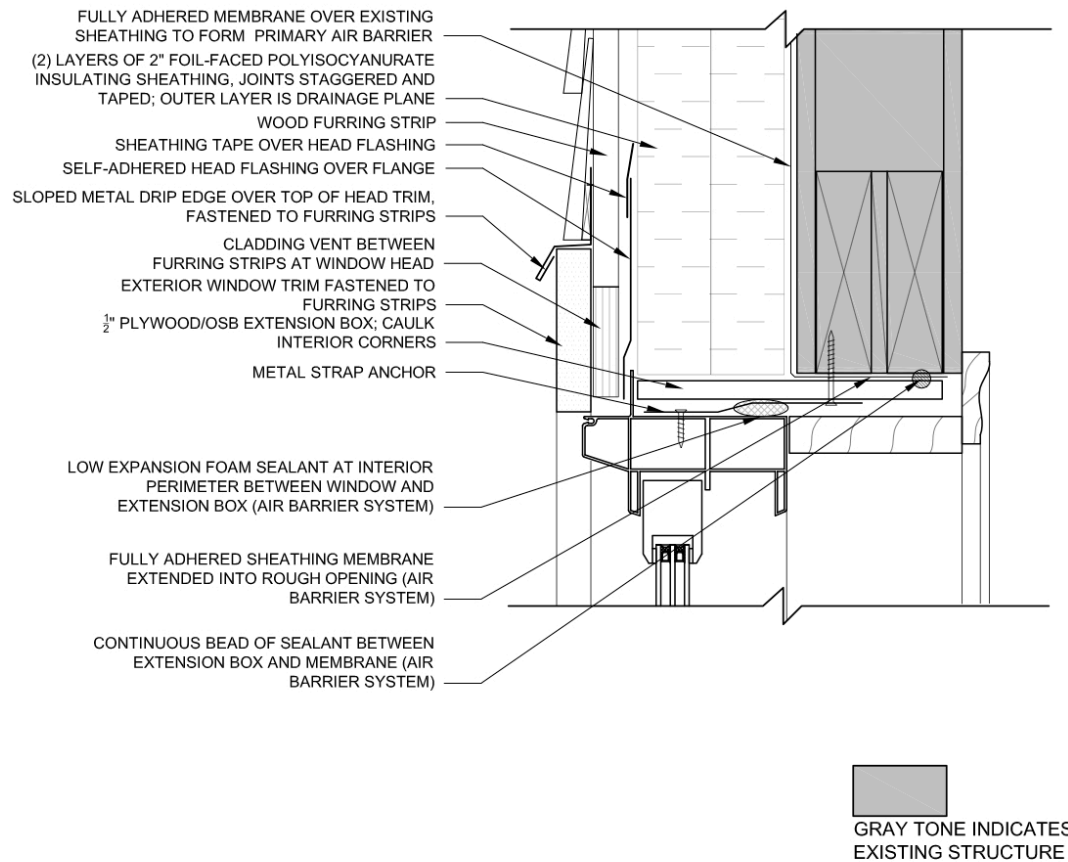
Date: 2012-04-16

Sheet Title:

**M8C-H**







## M8-D: COMPLETE REPLACEMENT WINDOW - HEAD DETAIL

SCALE: 3" = 1'-0"



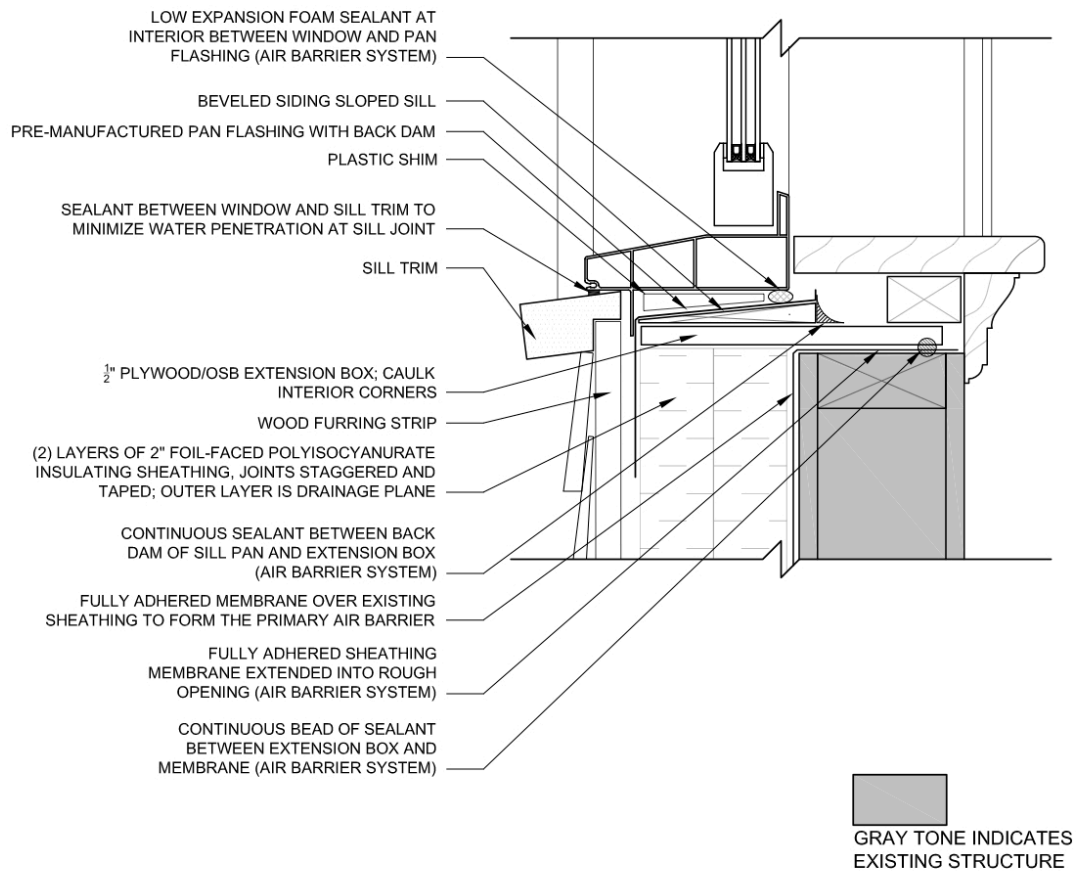
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**M8D-H**



## M8-D: COMPLETE REPLACEMENT WINDOW - SILL DETAIL

SCALE: 3" = 1'-0"



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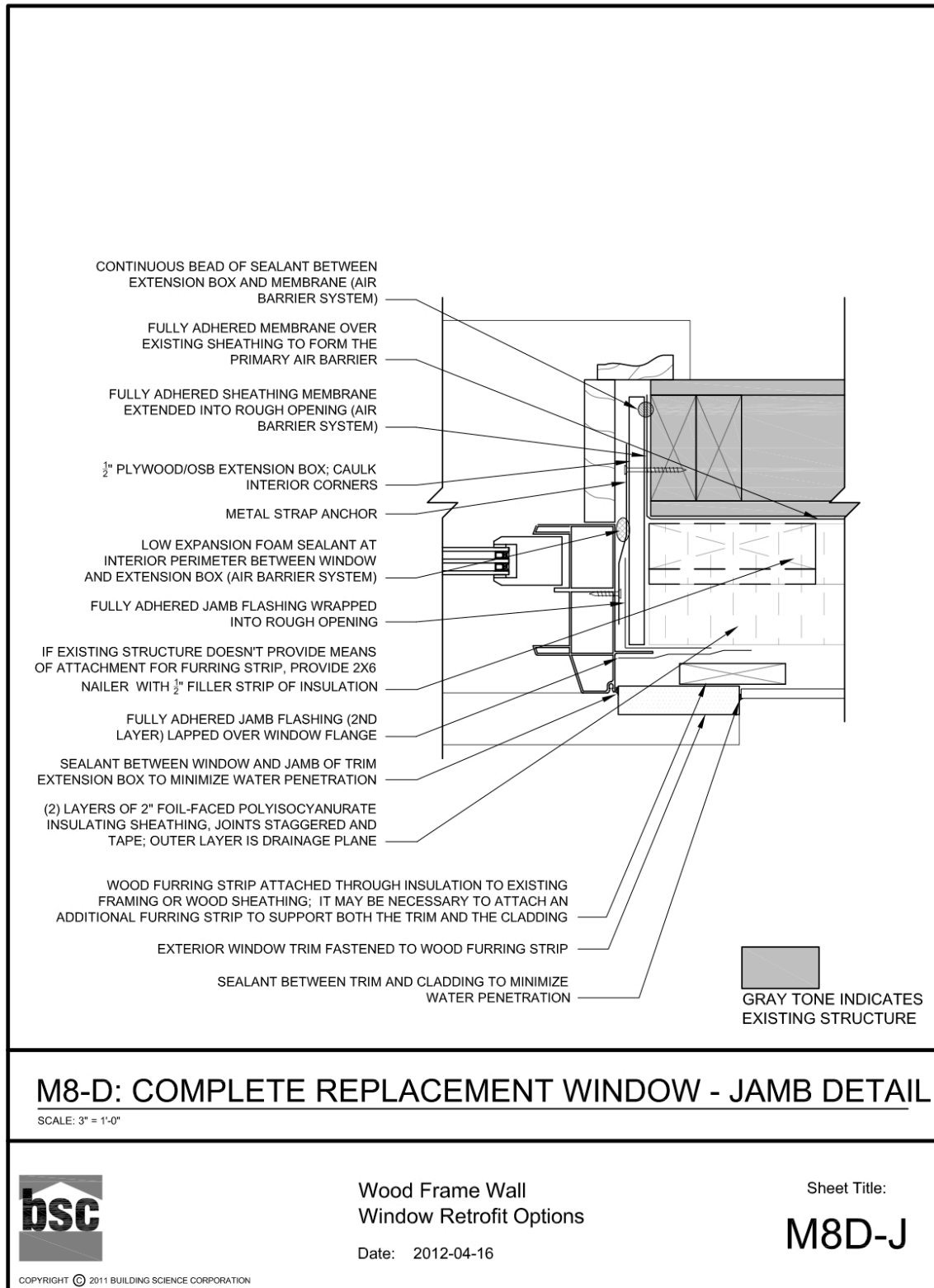
Wood Frame Wall  
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**M8D-S**



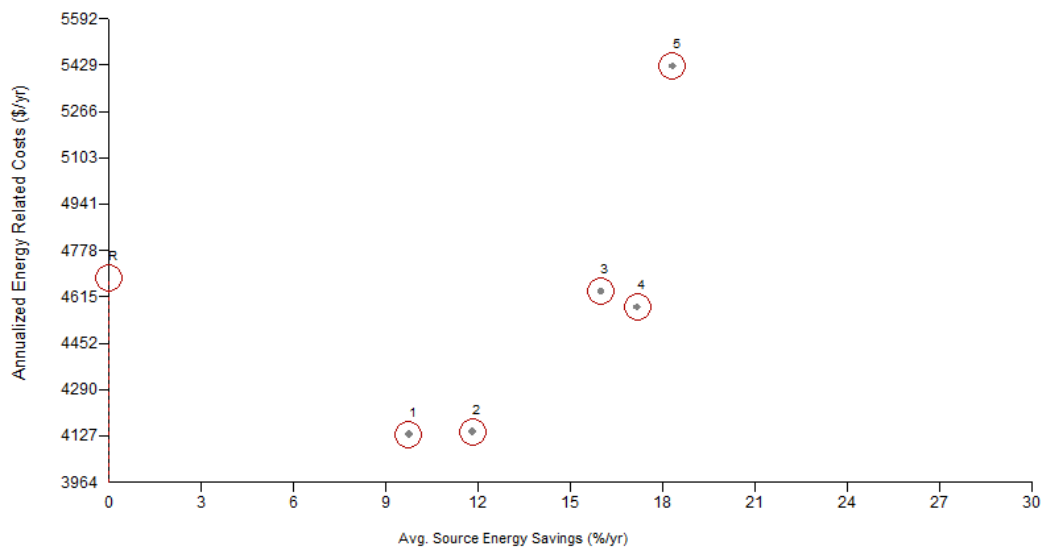


## Appendix B: BEOPT Analysis Graphs

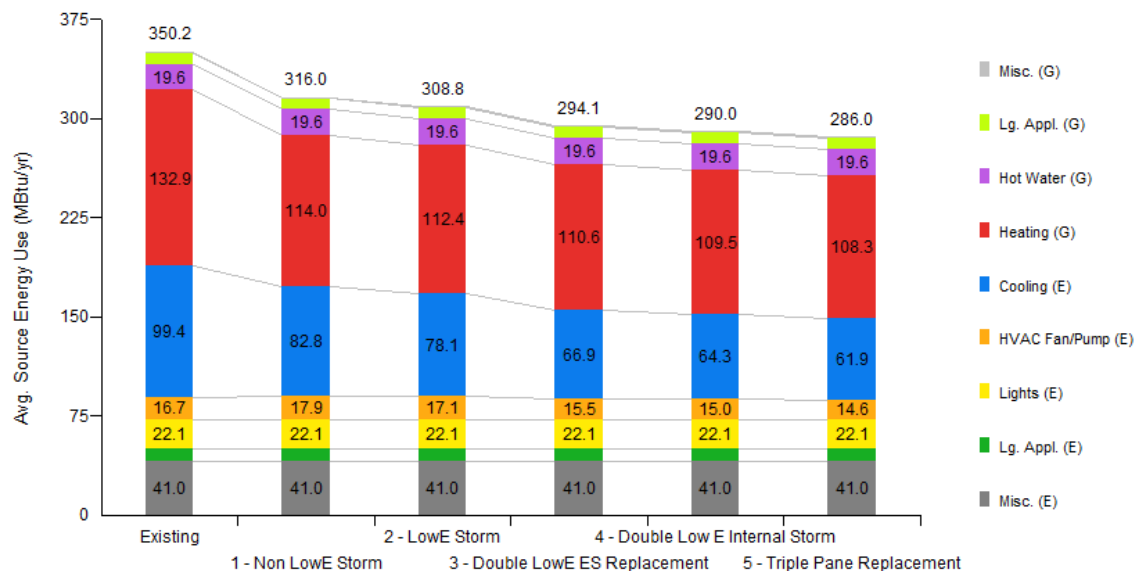
Dallas, Texas

Utility Rates: \$0.13/kWh

\$1.09/therm



**Figure 51. Annualized energy related costs versus average source energy savings for Dallas**

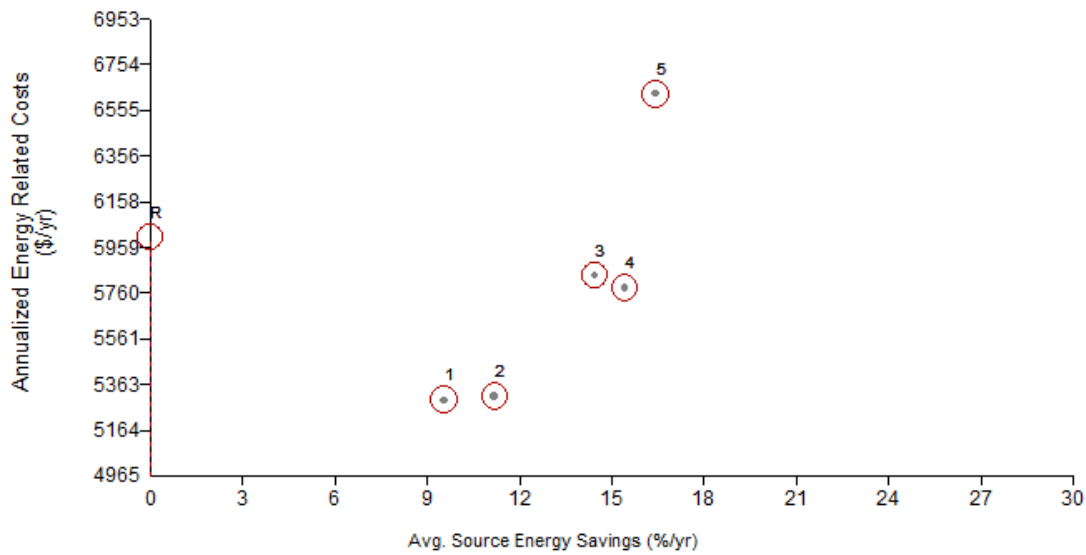


**Figure 52. Average source energy savings reduction for Dallas**

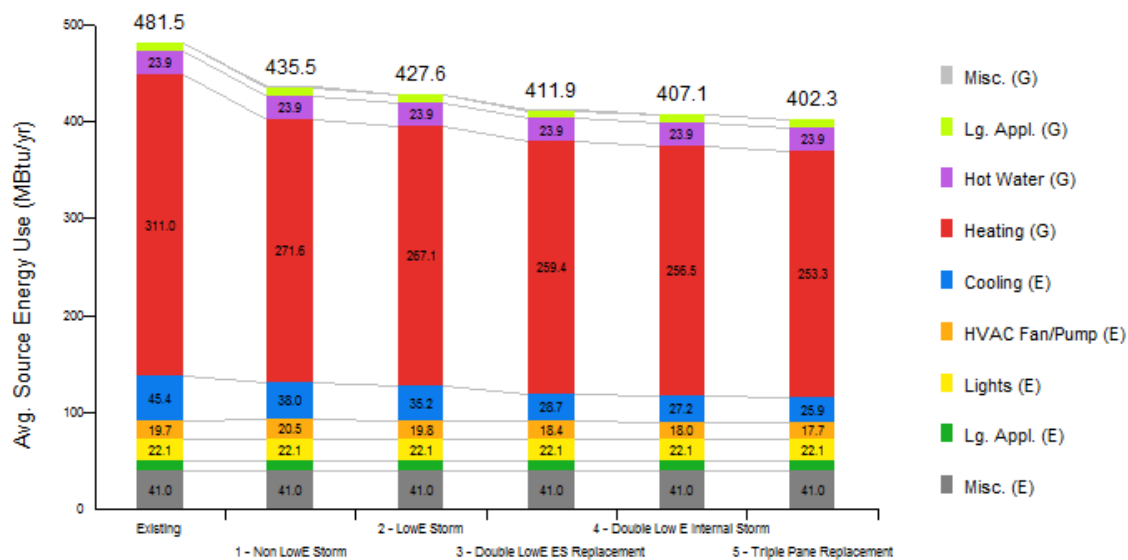
Kansas City, Missouri

Utility Rates: \$0.08/kWh

\$1.23/therm



**Figure 53. Annualized energy related costs versus average source energy savings for Kansas City**

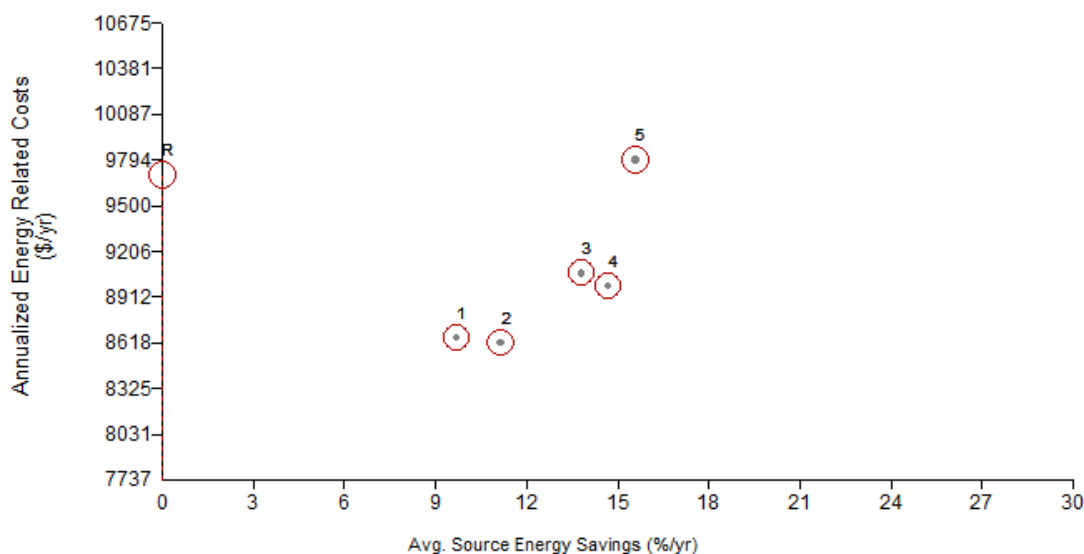


**Figure 54. Average source energy savings reduction for Kansas City**

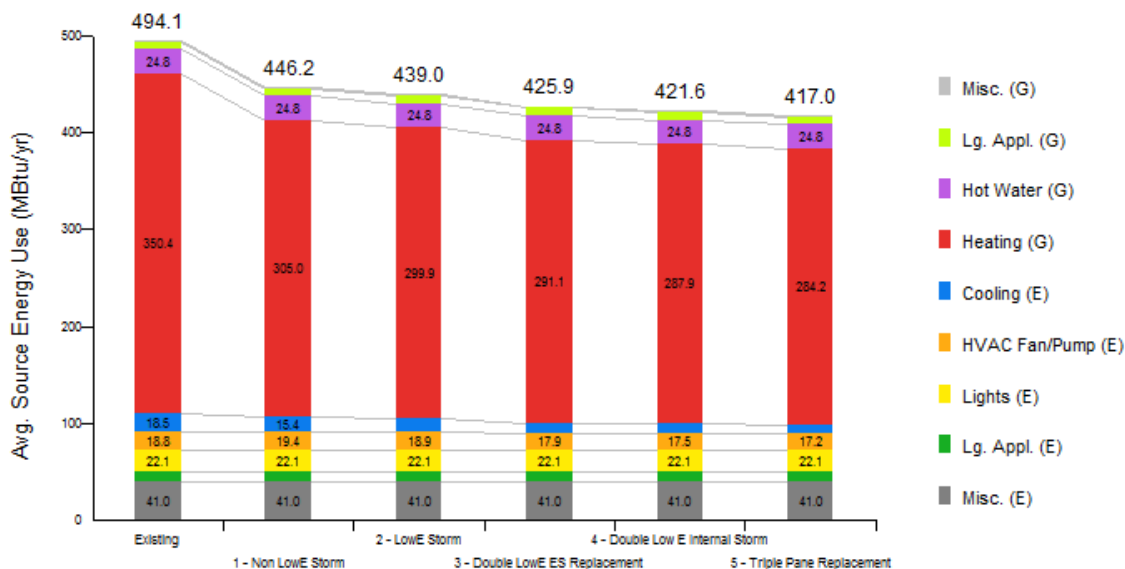
Boston, Massachusetts

Utility Rates: \$0.18/kWh

\$1.70/therm



**Figure 55. Annualized energy related costs versus average source energy savings for Boston**

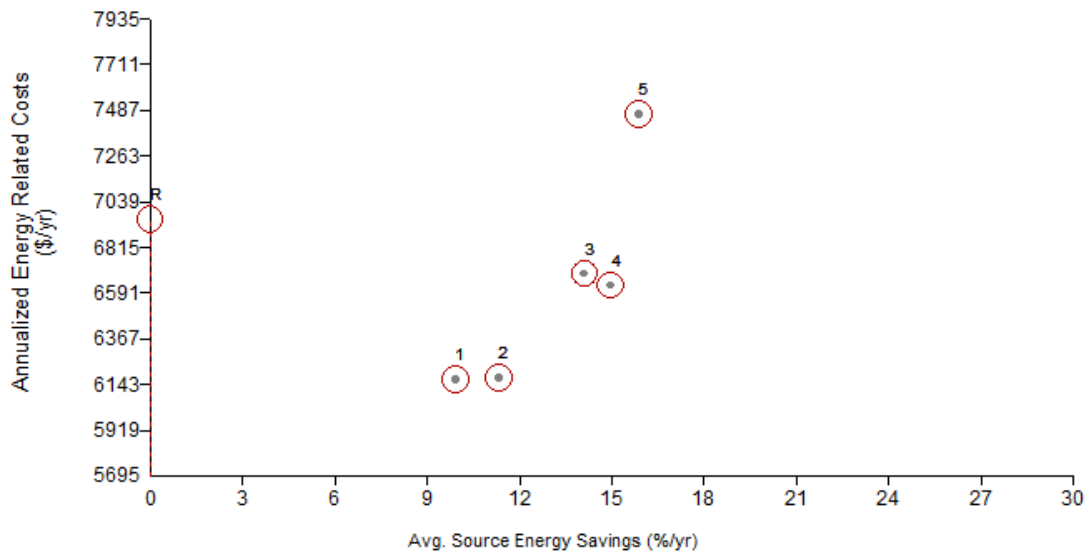


**Figure 56. Average source energy savings reduction for Boston**

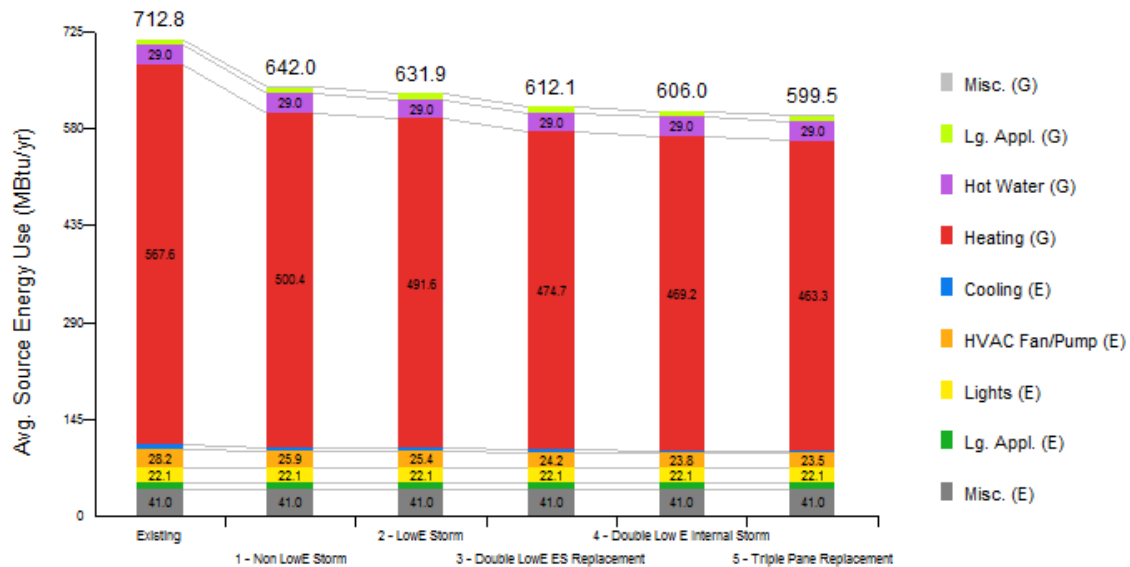
Duluth, Minnesota

Utility Rates: \$0.10/kWh

\$0.87/therm



**Figure 57. Annualized energy related costs versus average source energy savings for Duluth**



**Figure 58. Average source energy savings reduction for Duluth**

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