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Thermal and Optical Properties of Low-E Storm Windows and Panels

July 2015

TD Culp
SH Widder, Technical Lead
KA Cort, Project Manager

U.S. DEPARTMENT OF
ENERGY

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Thermal and Optical Properties of Low-E Storm Windows and Panels

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July 2015

Prepared for the Northwest Power and Conservation Council
under Contract 67698

Pacific Northwest National Laboratory
Richland, Washington 99352

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[1] Birch Point Consulting, LLC, La Crosse, Wisconsin.

Summary

Installing low-emissivity (low-E) storm windows and panels over existing windows has been identified as a cost-effective new approach for improving the energy efficiency of existing buildings where window replacement is impractical or too expensive. As such, it is desirable to characterize the key energy performance properties of low-E storm windows and panels when installed over different types of existing primary windows. This paper presents the representative U-factors, solar heat gain coefficients (SHGCs), and visible light transmittance (VT) properties of the combined assemblies of various storm windows and panel types installed over different primary windows. Both exterior and interior panels with clear glass and low-E glass were analyzed, installed over single-pane and double-pane primary windows with nonmetal and metal framing. Both fixed and operable windows and panels were evaluated.

Detailed thermal and optical simulations were conducted using WINDOW and THERM software in accordance with National Fenestration Ratings Council procedures, but accounting for how exterior and interior storm windows and panels are realistically attached over existing primary windows (e.g., onto the brickmold, trim pieces, and/or window sill). Over single-pane windows, the U-factor can be reduced by 47 to 53% with clear glass panels and by 59 to 64% with low-E panels. Over double-pane windows, the U-factor can be reduced by 32 to 45% with clear glass panels and by 43 to 57% with low-E panels. The SHGC can be reduced by 8 to 17% with clear glass panels, and by 17 to 28% with low-E panels.

In addition, storm windows and panels help to reduce air leakage (AL) through existing windows, particularly older windows. Although the amount of air leakage through existing windows can vary significantly, estimates of typical air leakage before and after installation of storm windows and panels are also provided.

Acknowledgments and Author Information

The authors would like to thank Joseph Petersen who assisted in the preparation of this document by providing input, comments, and suggestions.

- Thomas Culp, Ph.D. is the owner of Birch Point Consulting, LLC which provides consulting services in the areas of energy-efficient window performance, building code development, glass performance, and glass coatings. He also works directly with low-E storm window and glass manufacturers on this new technology.
- Sarah Widder is an engineer with PNNL. Her work focuses on sustainable design, energy efficiency, and greenhouse gas management. She is currently involved in using whole building performance metrics to analyze the impact and effectiveness of current sustainable design trends.
- Katherine Cort is an economist with the Pacific Northwest National Laboratory (PNNL) and the team lead for Building America's Window Attachments program. She has over 15 years of experience analyzing energy-efficiency programs, technologies, and research and provides technical support for the U.S. Department of Energy (DOE) Building Technologies Program.

Acronyms and Abbreviations

AL	air leakage
Low-E	low-emissivity
NFRC	National Fenestration Rating Council
SHGC	solar heat gain coefficient
VT	visible light transmittance
DOE	U.S. Department of Energy
LBNL	Lawrence Berkeley National Laboratory
PNNL	Pacific Northwest National Laboratory
ATI	Architectural Testing Inc.

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1.0 Introduction

As a major contributor to energy loss, older inefficient windows in existing buildings have long presented challenges in energy conservation Despite the fact that approximately 30 million windows are replaced each year with higher performing, insulated low-emissivity (low-E) windows, an estimated 47 million homes still have single glazing and an estimated 46 million homes have older double-pane windows with lower-performing clear glass (i.e., not modern high-performance low-E windows) (Cort 2013).

Low-E storm windows and panels have gained recent interest as a promising, cost-effective method to improve the energy efficiency of existing windows—particularly where window replacement is impractical, too expensive, or not allowed (e.g., in historic properties) (Cort 2013; Culp and Cort 2013; Knox and Widder 2014). Modern low-E storm windows insulate and air seal existing windows. The secondary panel reduces both conductive and convective heat loss. The addition of a low-E coating to the glass also reduces radiative heat loss, further lowering the overall heat transfer coefficient (U-factor).

Low-E coatings are multilayer nanoscale coatings of either metallic or metal oxide materials that reflect light in the mid-infrared spectrum but are transparent to visible light. As a result, low-E coated glass reduces radiative heat loss from warmer interior objects to the colder exterior, but is still transparent for use as a window. While the primary purpose of a low-E coatings is to reduce the U-factors, the optical properties of some low-E coatings can also be designed to reflect or absorb near-infrared and visible light in the solar spectrum, thereby also lowering solar heat gain through the glazing. These coatings are known as solar selective or solar control low-E coatings. Reducing the solar heat gain is beneficial in hot climates where cooling is the dominant building energy use, but can be a detriment in colder climates where the solar gain is beneficial in reducing heating demands during the winter. Thus, the appropriate low-E coating should be selected based on the climate and application. Because the primary application of low-E storm windows and panels is to reduce the energy use related to older windows with high heat loss in colder climates, high solar gain low-E coatings are most commonly used, although tinted solar selective options are also available for warmer locations. As such, the results presented in Chapter 2.0 are calculated with the high solar gain low-E coating.

Low-E coatings in new windows are sealed and protected in insulated glass units. However, for use in storm windows and panels (which are all single-pane products), the low-E coating must also be durable (i.e., not affected by cleaning or exposure to humidity). Therefore, the dominant type of low-E coating used in storm windows and panels is pyrolytic low-E coating, a ceramic tin oxide based coating deposited and baked onto glass as it is being formed. As a result, the coating is as durable as the glass itself. Modern low-E storm windows and panels are designed to be permanently installed, installed on the exterior or interior of the existing window, and are available in both fixed and operable versions.

Energy simulations can be used to evaluate the improvements in energy efficiency that result from installing low-E storm windows and panels in a variety of existing buildings with different building characteristics, climates, and/or occupancy. To accurately simulate the predicted energy improvement, it is necessary to estimate the key energy performance properties for the combined assembly of the panel installed over different types of primary windows as an input to the simulation. These performance properties include the U-factor (overall heat transfer coefficient including conductive, convective, and radiative heat transfer), solar heat gain coefficient (SHGC), and visible transmittance (VT). These are collectively known as the thermal and optical properties, and should be calculated for the overall window assembly including both glazing and framing. In addition, an estimate of the air leakage of the combined assembly is important to characterizing overall energy performance in the building.

This paper provides the representative U-factor, SHGC, and VT for various combinations of different types of storm windows and panels installed over different primary windows. Both exterior and interior panels with clear glass and low-E glass were analyzed. These were evaluated when installed over single-pane and double-pane primary windows with nonmetal and metal framing. Both operable and fixed versions of storm windows and panels were evaluated over operable and fixed primary windows, respectively.

2.0 Thermal and Optical Properties

An independent accredited laboratory (Architectural Testing Inc. [ATI]) conducted detailed simulations to determine the thermal and optical performance properties of both exterior and interior low-E storm windows installed in combination with different types of primary windows.[1] ATI used THERM 6.3/WINDOW 6.3 software from Lawrence Berkeley National Laboratory (LBNL) to perform detailed thermal and optical simulations in accordance with National Fenestration Rating Council (NFRC) 100-2010 and NFRC 200-2010 simulation procedures and the NFRC Simulation Manual, except for accounting for how low-E storm windows and panels are realistically attached over existing primary windows (e.g., onto brickmold, trim pieces, and window sills). Performance properties were calculated for the entire window assembly, including both glazing and framing.

The simulations used generic representative single and double pane primary window designs selected by ATI and actual storm window and panel designs provided by two manufacturers (i.e., Larson Manufacturing Company and QUANTAPANEL). Detailed geometry and dimensions are shown in Appendix A. Exact thermal and optical properties vary depending on the actual window over which the panel is installed. However, evaluating different storm windows over generic primary windows provides a standard comparison for estimating the improvement in energy performance achieved by installing a storm window as well as comparing the performance of different window and panel products. This is analogous to how NFRC ratings of new windows do not reflect actual performance of the exact window under all sizes and conditions, but instead provide an accurate performance comparison between products at a standard window size and standard environmental conditions. In both cases, when the U-factor and SHGC at standard conditions are then used in common building energy simulation software programs, many software programs can adjust the heat transfer for both the real product size and the simulated environmental conditions throughout the year (e.g., varying wind speed, outside temperature, and solar angle)

The U-factor, SHGC, and VT reported in this paper were calculated at the NFRC standard size (i.e., 1,200 x 1,500 mm for fixed and double-hung windows) and NFRC standard environmental conditions. For U-factor, NFRC standard conditions are 21°C (69.8°F) interior temperature, -18°C (-0.4°F) exterior temperature, 5.5 m/s (12.3 mph) wind speed, and zero solar irradiance (winter nighttime). For SHGC, NFRC standard conditions are 24°C (75.2°F) interior temperature, 32°C (89.6°F) exterior temperature, 2.75 m/s (6.15 mph) wind speed, and 783 W/m^2 (248 $Btu/hr\text{-}ft^2$) solar irradiance at normal incidence (summer daytime). The physical and optical properties of both the low-E and clear glazing products used in the WINDOW/THERM simulations were from the International Glazing Database managed by LBNL (LBNL 2013). The low-E glazing product used in the simulations had an emissivity of 0.15 and solar transmittance of 69%, which applies to the high solar gain pyrolytic low-E products from multiple

[1]This simulation work by ATI was originally performed under U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy award #DE-EE0004015, *Low-E Retrofit Demonstration and Educational Program*, TD Culp, SC Drumheller, J Wiehagen, conducted by Quanta Technologies Inc., August 2010-2013.

manufacturers that are most common in low-E storm windows and panels. For comparison, the clear glazing had an emissivity of 0.84 and solar transmittance of 86%.

The results are summarized below in Table 1 and Table 2. Low-E storm panels consistently provide significantly lower U-factor than clear storm panels. Over single-pane windows, the U-factor can be reduced by 47 to 53% with clear glass panels and by 59 to 64% with low-E panels. Over double-pane windows, the U-factor can be reduced by 32 to 45% with clear glass panels and by 43 to 57% with low-E panels. The SHGC is reduced by 8 to 17% with clear glass panels and by 17 to 28% with low-E panels. Interior panels consistently had a lower U-factor than exterior panels, although the difference was small—between 0 and 0.04 Btu/hr ft^2 F. These results are with the high solar gain low-E glazing most common in low-E storm windows and panels. For a solar control pyrolytic low-E glazing product in an exterior storm window, the U-factors would be the same (i.e., same emissivity), but the SHGC would be 20 to 30% lower, depending on the exact glazing product.

The benefit of the low-E glazing is also seen in the two-dimensional temperature profiles shown in Figure 1 taken from the heat transfer simulations in Appendix A. The interior surface temperature of the primary window significantly increases first with the addition of the exterior clear storm window, and then with the addition of low-E glass. This warmer interior surface temperature not only reflects the significantly reduced heat loss through the window, but also the improved thermal comfort and resistance to condensation formation. The human body interprets temperature disparities in its surroundings as thermal discomfort, so increasing the window surface temperature closer to its surroundings improves comfort for the occupant. Improved comfort also reduces the inclination for the occupant to increase the thermostat setting in response to feeling cold. Also, condensation of moisture on the window surface can form when the window surface temperature drops below the dew point of the room air. While the dew point and interior humidity depends strongly on the home and occupant lifestyle, increasing the window surface temperature will reduce the potential for condensation formation.

Table 1. U-Factor, SHGC, VT of Storm Windows and Panels over Nonmetal Framed Primary Windows

Base Window	Storm Type	U-Factor (Btu/hr ft^{2}F)	SHGC	VT
Wood Double Hung, Single Glazed	--	0.88	0.61	0.66
	Clear, Exterior	0.47	0.54	0.57
	Clear, Interior	0.46	0.54	0.59
	Low-E, Exterior	0.36	0.46	0.52
	Low-E, Interior	0.34	0.50	0.54
Wood Double Hung, Double Glazed	--	0.51	0.57	0.61
	Clear, Exterior	0.34	0.49	0.53
	Clear, Interior	0.32	0.51	0.55
	Low-E, Exterior	0.28	0.42	0.48
	Low-E, Interior	0.26	0.47	0.50
Wood Fixed, Single Glazed	--	0.87	0.64	0.69
	Clear, Exterior	0.46	0.58	0.62
	Clear, Interior	0.45	0.56	0.62
	Low-E, Exterior	0.34	0.50	0.56
	Low-E, Interior	0.34	0.52	0.57
Wood Fixed, Double Glazed	--	0.47	0.60	0.64
	Clear, Exterior	0.32	0.53	0.57
	Clear, Interior	0.32	0.54	0.58
	Low-E, Exterior	0.27	0.46	0.52
	Low-E, Interior	0.25	0.50	0.53

Table 2. U-Factor, SHGC, VT of Storm Windows and Panels over Metal-Framed Primary Windows

Base Window	Storm Type	U-Factor (Btu/hr ft^{2}F)	SHGC	VT
Aluminum Double Hung, Single Glazed	--	1.12	0.61	0.65
Worst-case mounting	Clear, Exterior	0.67	0.56	0.58
Thermally broken mounting (recommended)	Clear, Exterior	0.58	0.56	0.59
	Clear, Interior	0.53	0.53	0.59
Worst-case mounting	Low-E, Exterior	0.57	0.47	0.53
Thermally broken mounting (recommended)	Low-E, Exterior	0.44	0.48	0.54
	Low-E, Interior	0.41	0.50	0.54
Aluminum Double Hung, Double Glazed	--	0.75	0.58	0.60
Worst-case mounting	Clear, Exterior	0.55	0.51	0.54
Thermally broken mounting (recommended)	Clear, Exterior	0.45	0.52	0.55
	Clear, Interior	0.41	0.51	0.55
Worst-case mounting	Low-E, Exterior	0.49	0.44	0.49
Thermally broken mounting (recommended)	Low-E, Exterior	0.36	0.44	0.50
	Low-E, Interior	0.32	0.47	0.50
Aluminum Fixed, Single Glazed	--	1.06	0.72	0.77
Worst-case mounting	Clear, Exterior	0.62	0.59	0.62
Thermally broken mounting (recommended)	Clear, Exterior	0.55	0.61	0.65
	Clear, Interior	0.51	0.60	0.66
Worst-case mounting	Low-E, Exterior	0.51	0.50	0.57
Thermally broken mounting (recommended)	Low-E, Exterior	0.42	0.52	0.59
	Low-E, Interior	0.38	0.56	0.60
Aluminum Fixed, Double Glazed	--	0.62	0.67	0.71
Worst-case mounting	Clear, Exterior	0.47	0.54	0.58
Thermally broken mounting (recommended)	Clear, Exterior	0.40	0.56	0.60
	Clear, Interior	0.36	0.57	0.61
Worst-case mounting	Low-E, Exterior	0.42	0.47	0.52
Thermally broken mounting (recommended)	Low-E, Exterior	0.33	0.48	0.55
	Low-E, Interior	0.29	0.53	0.56

Fixed wood window, single glazed

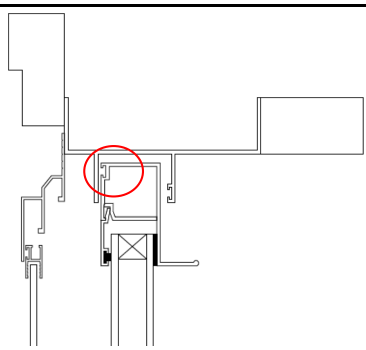
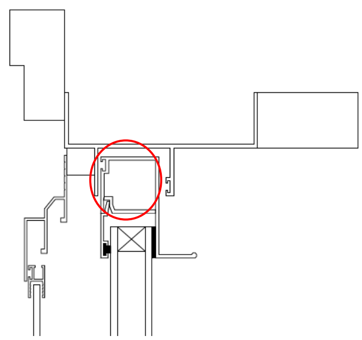
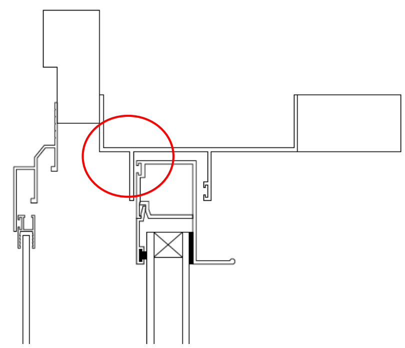
With exterior storm window, clear glass

With exterior storm window, low-E glass

Figure 1. Temperature Profiles of Single Glazed Wood Window with Exterior Clear and Low-E Storm Windows

The vast majority of storm windows and panels designed for permanent installation have durable aluminum frames. Therefore, one question is whether the aluminum frame affects the thermal performance. For storm windows installed over wood or other nonmetal framed primary windows, performance is not relatively sensitive to the mounting details due to the lack of a continuous metal thermal bridge from the outside to the inside. This is also true for interior panels installed inside metal-framed primary windows where the window sill and/or surrounding jambs provide a nonmetal thermal break with no direct metal-to-metal contact between the panel frame and primary window frame. However, for exterior storm windows installed over metal-framed primary windows, performance is more sensitive to how the storm panels are mounted. Three mounting cases were simulated, ranging from the worst-case scenario (i.e., the metal storm panel is directly mounted to the metal window frame [direct thermal bridge]) to the best scenario (i.e., the storm panel is mounted to the wood brickmold or other wood trim to create a thermal break with no direct metal-to-metal connection). The final U-factor can vary from 0.07 to 0.13 Btu/hr ft^2 F or 11 to 26% based on the mounting method. One example is shown in Table 3. The performance of the base window is still greatly improved by the addition of a low-E storm panel even with worst-case mounting, but for optimum thermal performance a thermal break is the recommended practice.

Table 3. Effect of Mounting Method Over Metal-Framed Base Windows

Exterior Low-E Storm Panel Over Single-Glazed Aluminum Double-Hung Window-Head Sections		
		
Direct metal-to-metal mount	Wood blind stop mount, but some metal of base window still exposed to exterior	Brickmold mount with no direct metal-to-metal contact
Base window: U = 1.12	Base window: U = 1.12	Base window: U = 1.12
With low-E storm: U = 0.57	With low-E storm: U = 0.52	With low-E storm: U = 0.44

Another common question is how the U-factor of the combined storm panel and base window is affected by the distance of the air space between the panel and the base window, as this distance will vary in the field based on the geometry of the existing window and surrounding area. Figure 2 shows how the center-of-glass U-factor varies with this gap distance, as calculated using WINDOW 7 software from LBNL. There are different regimes where U-factor varies with air gap due to the balance of different modes of convective and conductive heat transfer. The U-factor initially rapidly decreases at small gap distances to an optimum U-factor at around 0.5 inch, then slightly increases (by 7%) before leveling off. In the configurations modeled in Figure 2, the gap varies between 1 to 3.4 inches. This is consistent with feedback from one storm window manufacturer[1] who reported that the air gap of installed storm windows and panels ranges from 0.75 to 3 inches, with the most common distance being 1 to 2 inches. In this range, Figure 2 shows that variation in the air gap does not affect U-factor, and the U-factors calculated in this report are conservative.

[1]Communication with Quanta Technologies Inc.

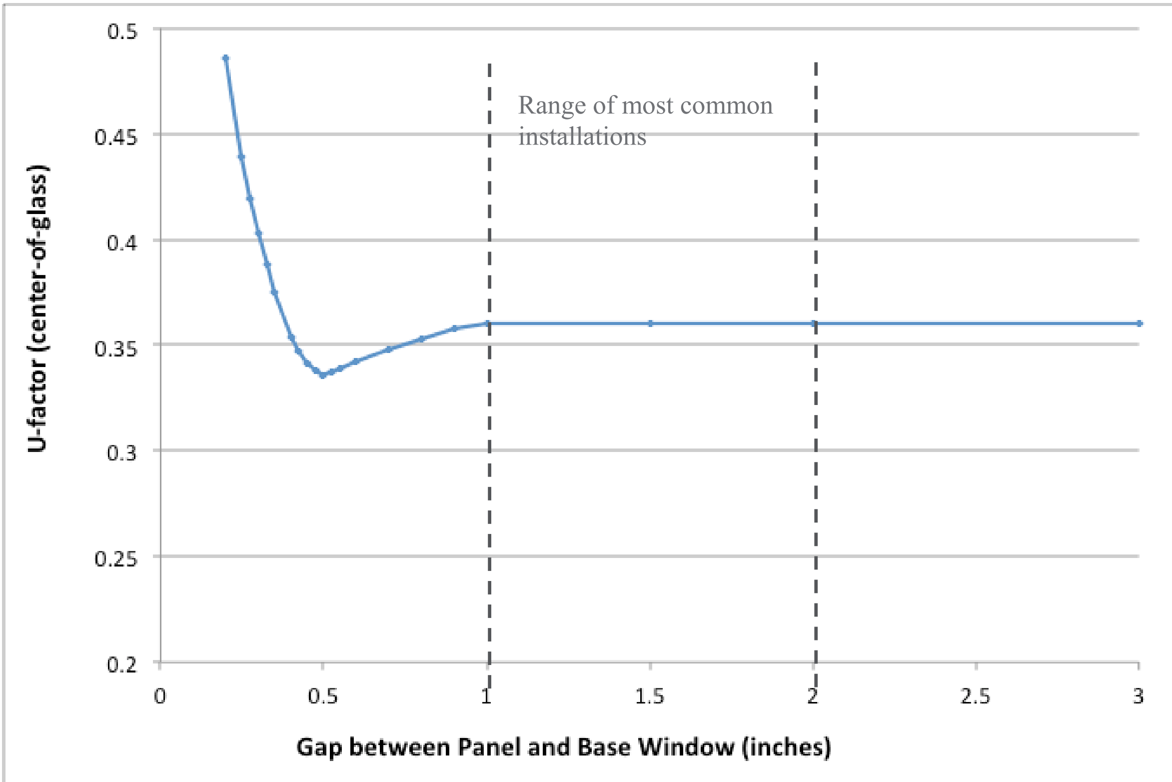


Figure 2. Effect of Glazing Gap on U-Factor of Combined Storm Panel and Base Window

3.0 Air Leakage

The U-factor accounts for heat transfer through the window assembly due to conduction, convection, and radiation. Although the U-factor calculation includes the convective effects of air movement adjacent to the window surfaces and within cavities of the assembly, it does not include the mass transfer of air leakage from the interior to the exterior of the building (or vice versa) around the frame and sash of the primary window and panel. In addition to the reduced heat loss measured by the U-factor, the overall air leakage of the window assembly has an important impact on overall building energy performance. Storm windows and panels can act as an air-sealing measure for existing windows in addition to the adding insulating value; thus, it is desirable to estimate the reduced air leakage following storm window and panel installation. Air leakage for storm windows and panels can easily be measured in the laboratory in accordance with ASTM-E283, and are typically less than 0.7 cfm/ft^2 at 75 Pa for exterior storm windows with weep holes and less than 0.1 cfm/ft^2 at 75 Pa for interior panels. However, what is important is not the air leakage of the storm window alone, but the limiting air leakage of the storm window combined with the primary window. This is difficult to predict because the air leakage of existing windows varies in the field based on type, age, and condition of the window. The air leakage of new windows has been required to be less than 0.3 cfm/ft^2 in the industry test standards since at least 1997 (AAMA/NWWDA 101/I.S.2-97 [WDMA 1997]) and in building energy codes going back to at least the 1998 International Energy Conservation Code (ICC 1998). However, the air leakage of new windows will increase over time due to various factors (e.g., degradation of weather seals and warpage of materials). Air leakage of 1.0 cfm/ft^2 is sometimes suggested as the baseline for older existing windows, which is actually conservative when looking at actual testing in the following recent field case studies of storm windows.

The first field case study of low-E storm windows in older homes was for six homes near Chicago ranging from 35 to 80 years old (Drumheller et al. 2007). Blower door tests of the overall home air leakage were conducted before and after installation of exterior storm windows over the single-pane windows. With no other changes or air sealing, the air leakage of the entire home was reduced by 5.7 to 8.6% simply from adding storm windows. The actual reduction in air leakage divided by the window area ranged from 2.3 to 5.4 cfm/ft^2, with an average of 3.9 cfm/ft^2. This is at a blower door test pressure of 50 Pa whereas window air leakage is commonly tested and reported in ASTM-E283 at a pressure of 75 Pa. Air leakage increases with pressure by a factor of

$$L_2/L_1 = \left[\frac{P_2}{P_1}\right]^n$$

where n ranges between 0.5 and 1. Therefore, the adjusted reduction in air leakage at 75 Pa is between 4.8 and 5.8 cfm/ft^2, meaning that the air leakage rate of the existing primary window was at least this high.

In a second field study, clear and low-E storm windows were tested in ten older homes with single-pane windows near Atlanta (Culp et al. 2013). The homes ranged from 35 to 86 years old. In this study, blower door testing showed that the air leakage of the overall home was reduced by 17% just by installing exterior storm windows, although the variability between homes and overall air leakage was higher than in the Chicago case study. After removing the high and low outliers, the average air-leakage reduction per square foot of window area was 4.6 cfm/ft^2 at 50 Pa, or between 5.7 and 6.9 cfm/ft^2 adjusted to 75 Pa.

Finally, in 2012, 101 apartments in two large three-story apartment buildings in Philadelphia were retrofitted with exterior low-E storm windows over the 50-year-old, single-pane, metal-framed windows (Culp et al. 2013). Blower door tests on individual apartments showed an average reduction in air leakage of 10% from installing exterior storm windows with no other air sealing. The average air-leakage reduction per square foot of window area was 3.3 cfm/ft^2 at 50 Pa, or between 4.1 and 5.0 cfm/ft^2 adjusted to 75 Pa. Again, this means that the air-leakage rate of the existing primary window was at least this high.

All three field studies suggest that older single-pane windows in existing buildings have an air leakage of at least 4 to 7 cfm/ft^2 at 75 Pa. Based on the field studies and lab tests, the following values in Table 4 are suggested as reasonable but conservative air-leakage values to estimate the reduction in air leakage due to the use of storm windows and panels.

While there is certainly variability in the field, the values in Table 4 will give conservative estimates as the field studies suggest the measured difference (e.g., from 3.0 to 0.3 = 2.7 cfm/ft^2 for installing exterior storm windows over single-pane windows) can actually be much higher. These values are most applicable to detached housing and multifamily buildings with a mixture of older operable and fixed windows. For buildings with newer windows or predominantly tighter fixed windows (e.g., commercial offices), initial air leakage will be lower.

Table 4. Approximate Air Leakage for Different Window Types

Window Type	Leakage (cfm/ft^2 at 75 Pa)
Older single-pane windows	3
Older double-pane windows	1
Combined assembly with older style and/or leakier storm windows installed	0.7
Combined assembly with new exterior storm windows installed	0.3
Combined assembly with new interior storm windows/panels installed	0.1

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Appendix A

WINDOW/THERM Simulation Report from Architectural Testing Inc.

Architectural Testing

STORM WINDOW ANALYSIS
COMPUTER SIMULATION REPORT

Rendered to:
BIRCH POINT CONSULTING

SERIES/MODEL:
Interior and Exterior Storm Windows

Report Number: C2692.02-116-45
Report Date: 07/24/13

130 Derry Court
York, PA 17406-8405
phone: 717-764-7700
fax: 717-764-4129
www.archtest.com

Architectural Testing

STORM WINDOW ANALYSIS
COMPUTER SIMULATION REPORT

Rendered to:
BIRCH POINT CONSULTING
W6025 Rim of the City Road
La Crosse, Wisconsin 54601

Report Number:	C2692.02-116-45
Simulation Date:	07/24/13
Report Date:	07/24/13

Project Summary:
Architectural Testing, Inc. was contracted to perform U-Factor and Solar Heat Gain Coefficient computer simulations in accordance with the National Fenestration Rating Council (NFRC). The products were evaluated in full compliance to the standards listed below, except that the storm windows were applied to generic base windows. The results represent the performance of the storm window when installed over the generic base window design.

Standards:
NFRC 100-2010: *Procedure for Determining Fenestration Product U-Factors*
NFRC 200-2010: *Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence*

Software:

Frame and Edge Modeling:	THERM 6.3.46
Center-of-Glass Modeling:	WINDOW 6.3.74
Total Product Calculations:	WINDOW 6.3.74
Spectral Data Library:	29.0

Simulations Specimen Description:

Series/Model:	Interior and Exterior Storm Windows
Type:	Fixed and Double Hung
Frame/Sash Material (Base Window):	Wood or Aluminum
Frame/Sash Material (Storm Window):	Aluminum
Standard Size:	1200mm x 1500mm

130 Derry Court
York, PA 17406-8405
phone: 717-764-7700
fax: 717-764-4129
www.archtest.com

Glass Description:

Base Windows

Single Glazed	1/4" Clear Glass
Double Glazed	1/8" Clear Glass, Both Layers
	1/2" Air Gap with Standard Aluminum Dual Sealed Spacer

Storm Windows

Clear	1/8" Clear Glass
Low-e	1/8"Hard Coat Low-e Glass, AFG Comfort E-PS (e = 0.148)

Frame Description:

Wood Windows - All wood was modeled as Coniferous woods (Softwoods)
Aluminum Windows - All aluminum was modeled as painted aluminum
All Windows - All windows used wood brockmould and trim pieces

Results:

Interior and Exterior Storm Windows
Wood Base Windows

Base Window Configuration	Storm Type	U-Factor	SHGC	VT
Wood Double Hung, Single Glazed	-	0.881	0.614	0.659
	Clear, Exterior	0.466	0.537	0.570
	Clear, Interior	0.458	0.535↑	0.593
	Low-e, Exterior	0.356	0.458	0.518
	Low-e, Interior	0.344	0.497	0.539
Wood Double Hung, Double Glazed	-	0.507	0.574	0.608
	Clear, Exterior	0.343	0.494	0.528
	Clear, Interior	0.324	0.509	0.549
	Low-e, Exterior	0.282	0.425	0.481
	Low-e, Interior	0.259	0.471	0.501
Wood Fixed, Single Glazed	-	0.869	0.644	0.693
	Clear, Exterior	0.455↑	0.582	0.620
	Clear, Interior	0.453	0.563	0.624
	Low-e, Exterior	0.344	0.496	0.564
	Low-e, Interior	0.341	0.523	0.567
Wood Fixed, Double Glazed	-	0.472	0.601	0.639
	Clear, Exterior	0.323	0.535↓	0.574
	Clear, Interior	0.315↑	0.535↑	0.578
	Low-e, Exterior	0.266	0.460	0.524
	Low-e, Interior	0.251	0.495↑	0.527

↑-Rounds Up ↓ Rounds Down

Results (continued):

Interior and Exterior Storm Windows
Aluminum Base Windows

Base Window Configuration	Storm Type	U-Factor	SHGC	VT
Aluminum Double Hung, Single Glazed	-	1.121	0.613	0.651
Mounting Case 1	Clear, Exterior	0.642	0.541	0.566
Mounting Case 2	Clear, Exterior	0.579	0.560	0.589
Mounting Case 3	Clear, Exterior	0.674	0.556	0.582
	Clear, Interior	0.531	0.534	0.589
Mounting Case 1	Low-e, Exterior	0.525↑	0.462	0.514
Mounting Case 2	Low-e, Exterior	0.441	0.478	0.536
Mounting Case 3	Low-e, Exterior	0.566	0.475↓	0.529
	Low-e, Interior	0.406	0.495↑	0.536
Aluminum Double Hung, Double Glazed	-	0.750	0.576	0.602
Mounting Case 1	Clear, Exterior	0.510	0.498	0.525↑
Mounting Case 2	Clear, Exterior	0.446	0.517	0.548
Mounting Case 3	Clear, Exterior	0.549	0.513	0.541
	Clear, Interior	0.410	0.510	0.548
Mounting Case 1	Low-e, Exterior	0.442	0.428	0.479
Mounting Case 2	Low-e, Exterior	0.355↑	0.444	0.500
Mounting Case 3	Low-e, Exterior	0.489	0.442	0.494
	Low-e, Interior	0.325↓	0.471	0.500
Aluminum Fixed, Single Glazed	-	1.064	0.715↑	0.770
Mounting Case 1	Clear, Exterior	0.613	0.564	0.595↓
Mounting Case 2	Clear, Exterior	0.552	0.611	0.649
Mounting Case 3	Clear, Exterior	0.621	0.588	0.621
	Clear, Interior	0.505↑	0.598	0.663
Mounting Case 1	Low-e, Exterior	0.499	0.481	0.541
Mounting Case 2	Low-e, Exterior	0.419	0.521	0.590
Mounting Case 3	Low-e, Exterior	0.512	0.503	0.565↑
	Low-e, Interior	0.379	0.555↑	0.603
Aluminum Fixed, Double Glazed	-	0.622	0.668	0.709
Mounting Case 1	Clear, Exterior	0.455↓	0.518	0.551
Mounting Case 2	Clear, Exterior	0.404	0.561	0.601
Mounting Case 3	Clear, Exterior	0.475↓	0.540	0.576
	Clear, Interior	0.362	0.569	0.615↓
Mounting Case 1	Low-e, Exterior	0.399	0.446	0.502
Mounting Case 2	Low-e, Exterior	0.328	0.483	0.548
Mounting Case 3	Low-e, Exterior	0.424	0.466	0.525↓
	Low-e, Interior	0.286	0.527	0.560

↑-Rounds Up ↓ Rounds Down

Ratings values included in this report are for submittals to an NFRC-licensed IA and are not meant to be used directly for labeling purposes. Only those values identified on a valid Certification Authorization Report (CAR) by an NFRC accredited Inspection Agency (IA) are to be used for labeling purposes. The ratings values were rounded in accordance to the NFRC unit conversion and rounding policy.

Architectural Testing is an NFRC accredited simulation laboratory and all simulations were conducted in full compliance with NFRC approved procedures and specifications. The NFRC procedure requires that the computational results be verified through actual test results.

Architectural Testing will service this report for the entire test record retention period. Test records that are retained such as detailed drawings, datasheets, representative samples of test specimens, or other pertinent project documentation will be retained by Architectural Testing, Inc. for the entire test record retention period. The test record retention end date for this report is July 24, 2017.

Results obtained are simulated values and were secured by using the designated test methods. This report does not constitute certification of this product nor an opinion or endorsement by this laboratory. It is the exclusive property of the client so named herein and relates only to the product simulated. This report may not be reproduced, except in full, without the written approval of Architectural Testing, Inc.

For ARCHITECTURAL TESTING, INC.:

SIMULATED BY:	REVIEWED BY:
Michael J. Thoman (Digitally Signed by: Michael J. Thoman)	Kristen L. Livelsberger (Digitally Signed by: Kristen L. Livelsberger)
Michael J. Thoman	Kristen L. Livelsberger
Director - Thermal Testing and Simulations	Senior Simulation Technician
	Simulator-In-Responsible-Charge

MJT:mjt
C2692.02-116-45

Attachments (pages): This report is complete only when all attachments listed are included.

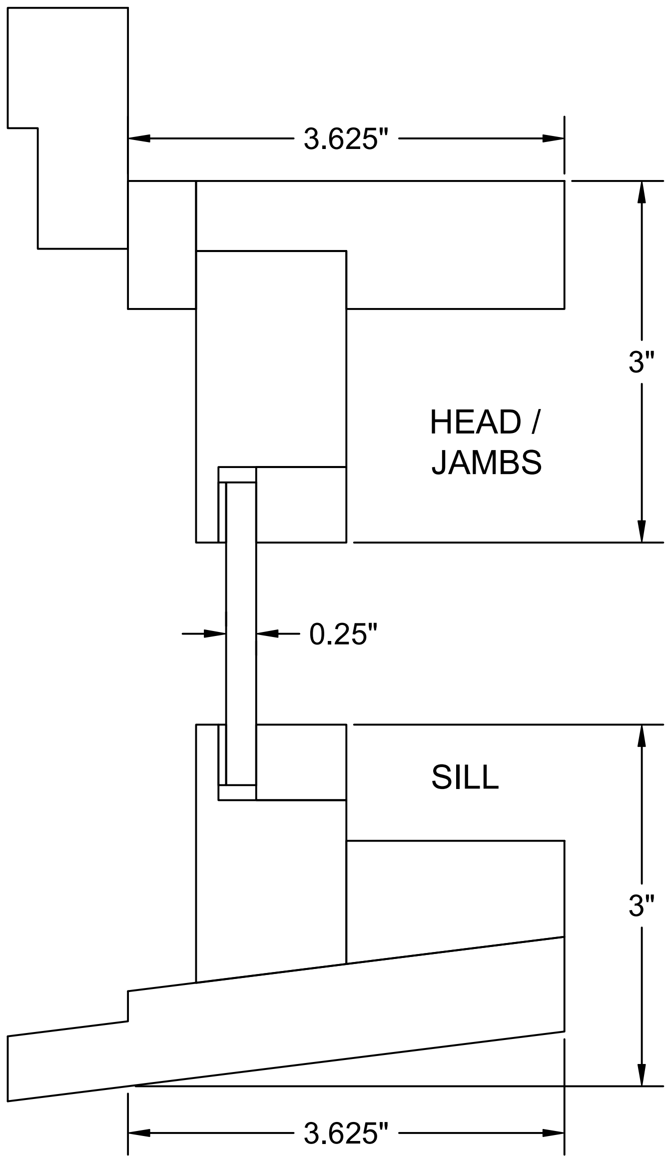
- Appendix A: Generic Base Window Drawings (10)
- Appendix B: Exterior Storm Windows on Base Window Drawings (20)
- Appendix C: Interior Storm Windows on Base Window Drawings (10)
- Appendix D: Exterior Fixed Storm Window Drawings (7)
- Appendix E: Exterior Double Hung Storm Window Drawings (1)
- Appendix F: Interior Fixed Storm Window Drawings (1)
- Appendix G: Interior Double Hung Storm Window Drawings (5)
- Appendix H: Color Temperature Plots (5)

Revision Log

Rev. #	Date	Page(s)	Revision(s)
.01R0	6/16/2013	All	- Original Report Issue to Birch Point Consulting.
.02R0	7/24/2013	All	- Revised Base Window and Mounting Details.

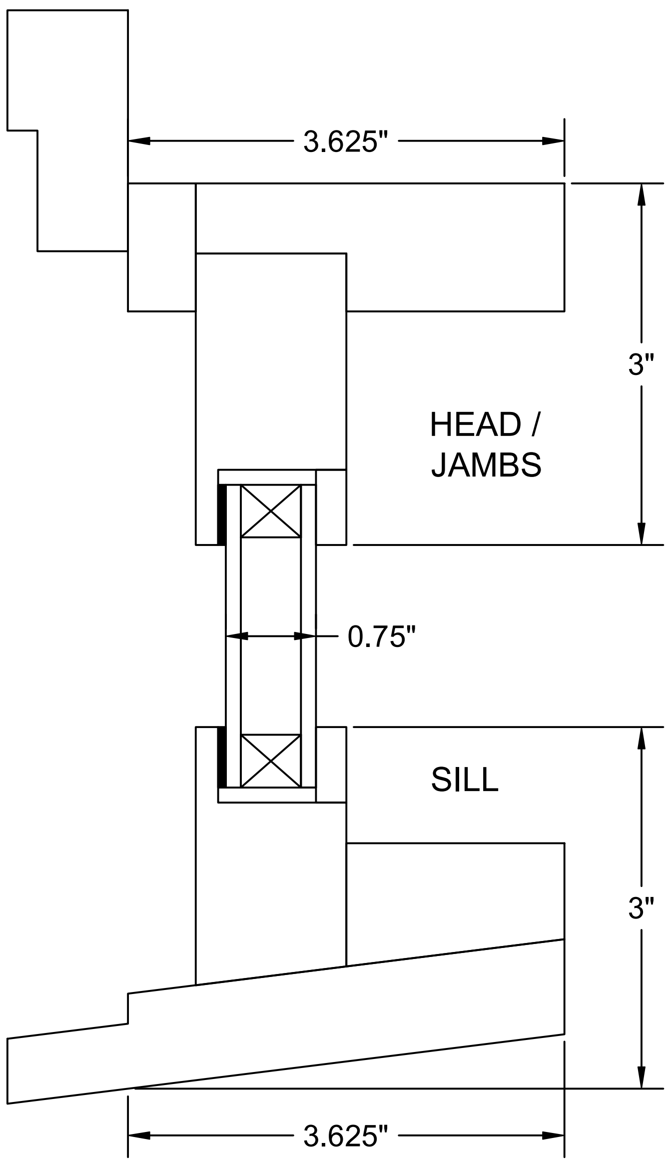
Generic Base Window Drawings

Appendix A
C2692.02-116-45



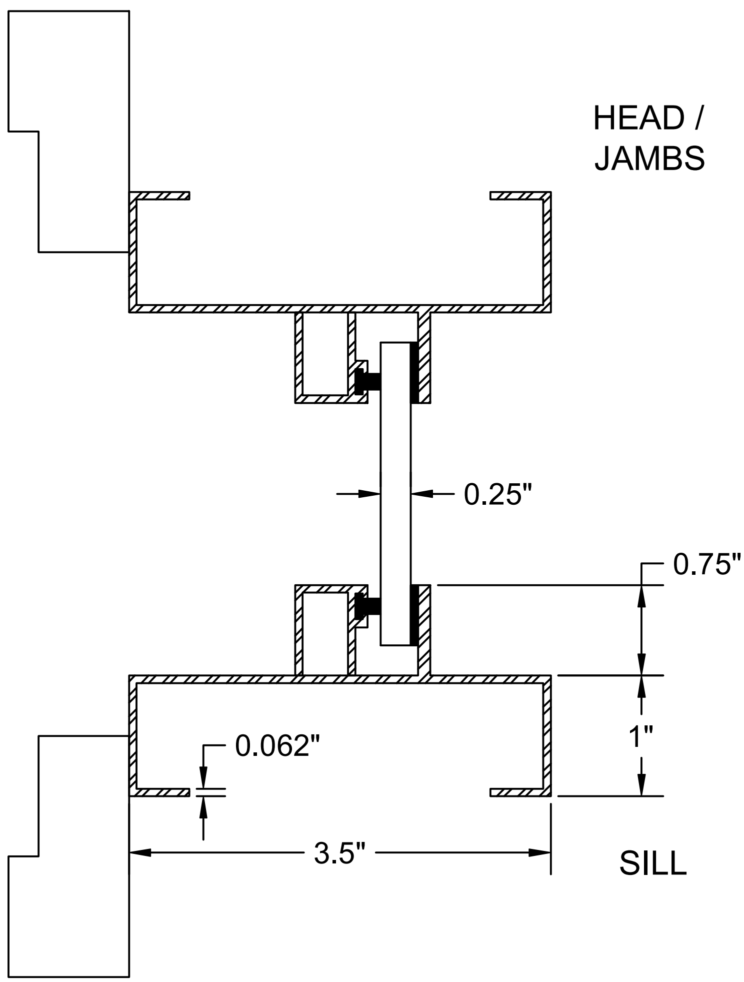
GENERIC WOOD FIXED WINDOW

Single Glazed



GENERIC WOOD FIXED WINDOW

Dual Glazed



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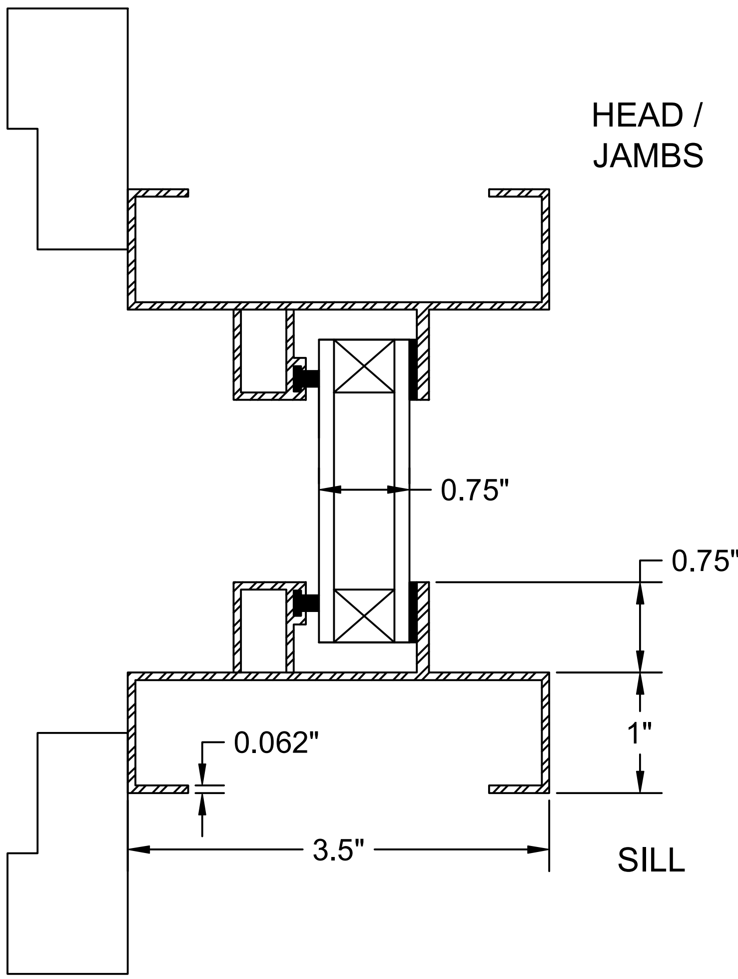

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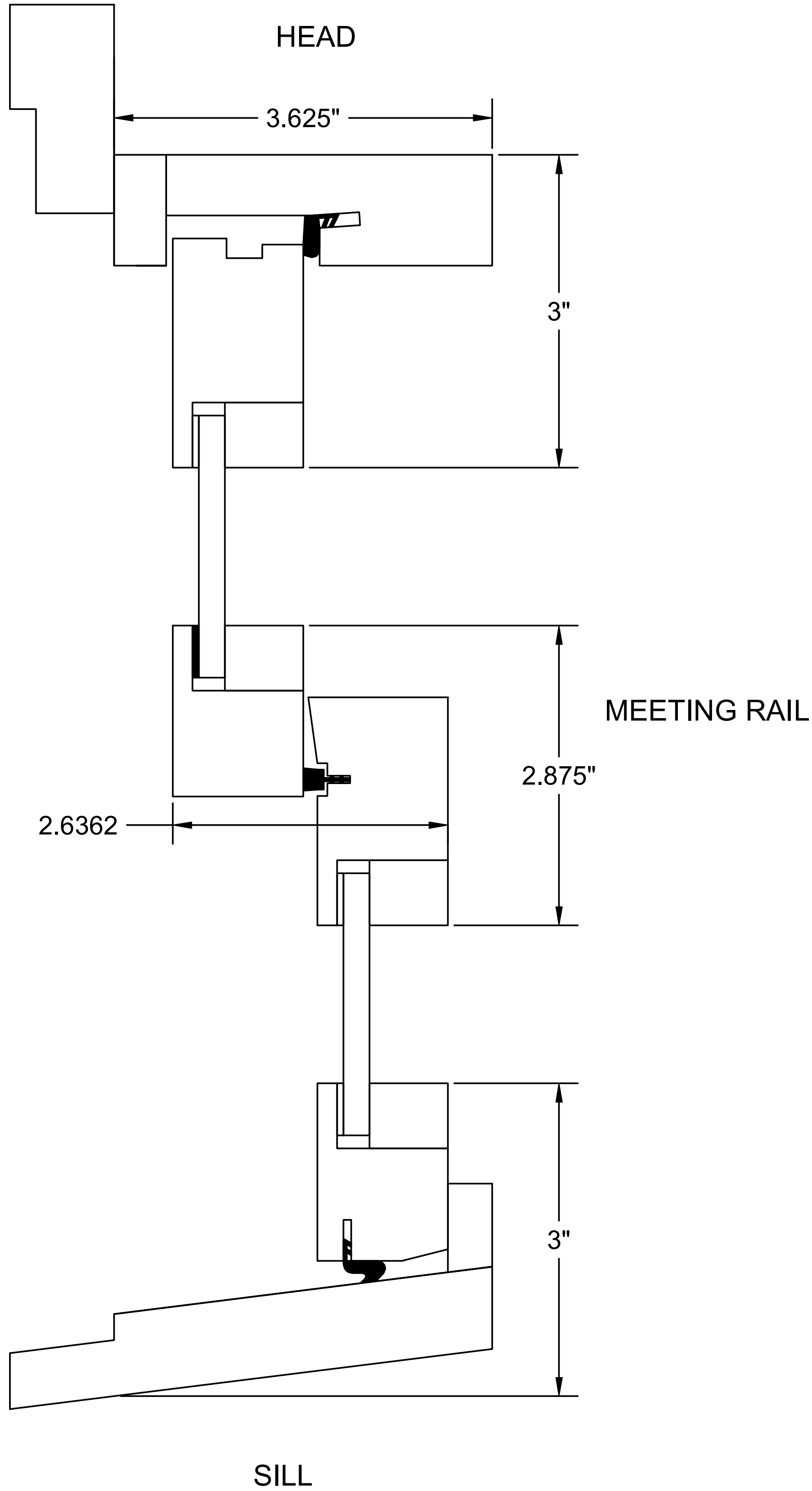
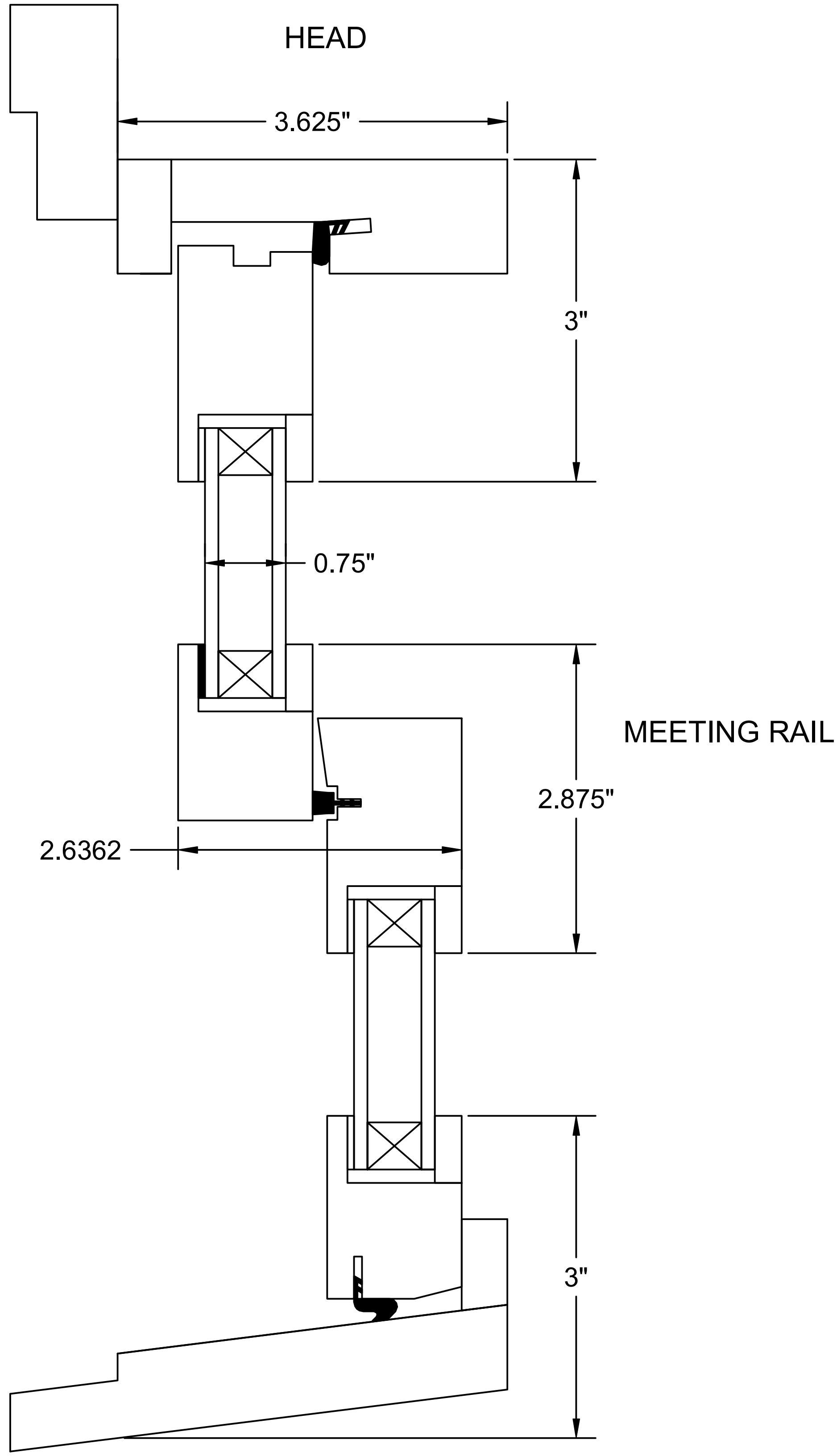
Dual Glazed



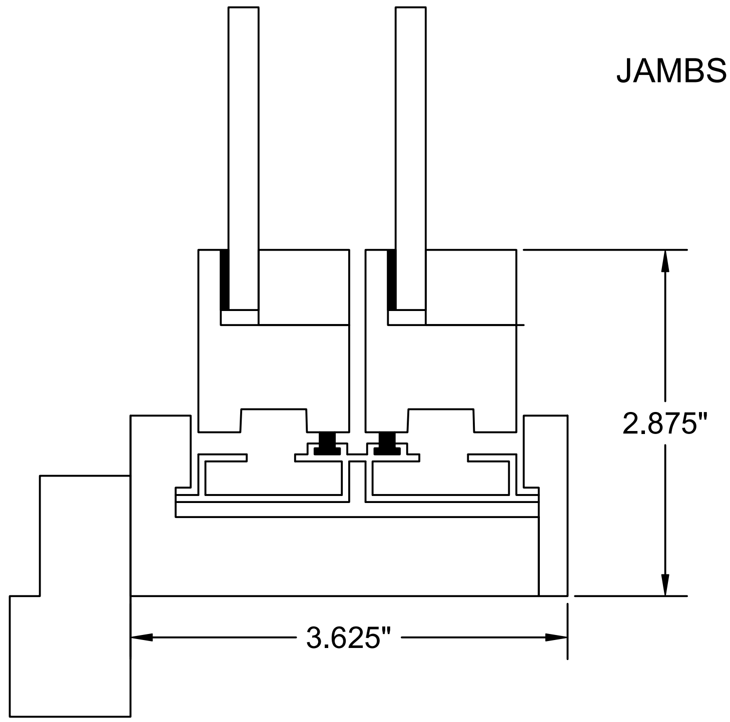
GENERIC WOOD DOUBLE HUNG WINDOW

Single Glazed



GENERIC WOOD DOUBLE HUNG WINDOW

Dual Glazed



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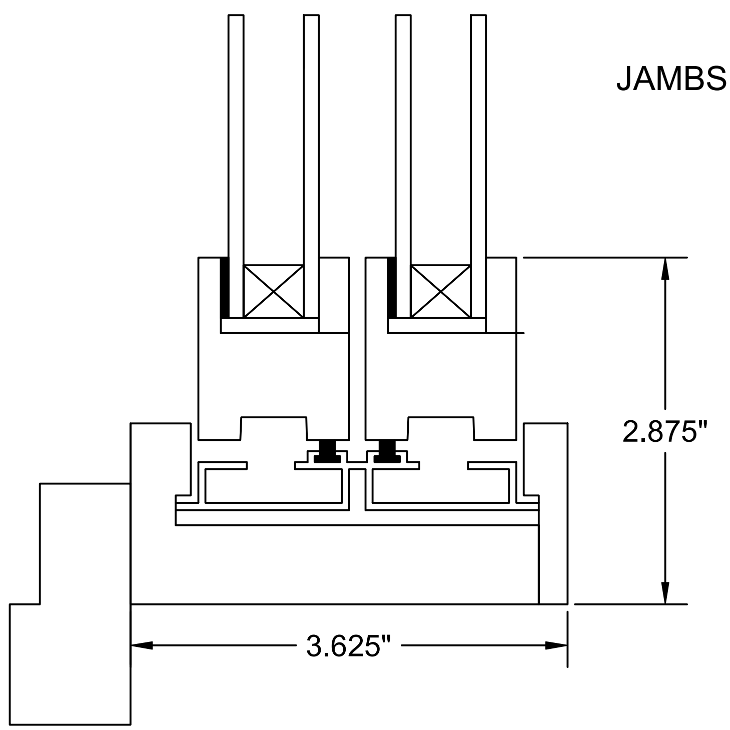
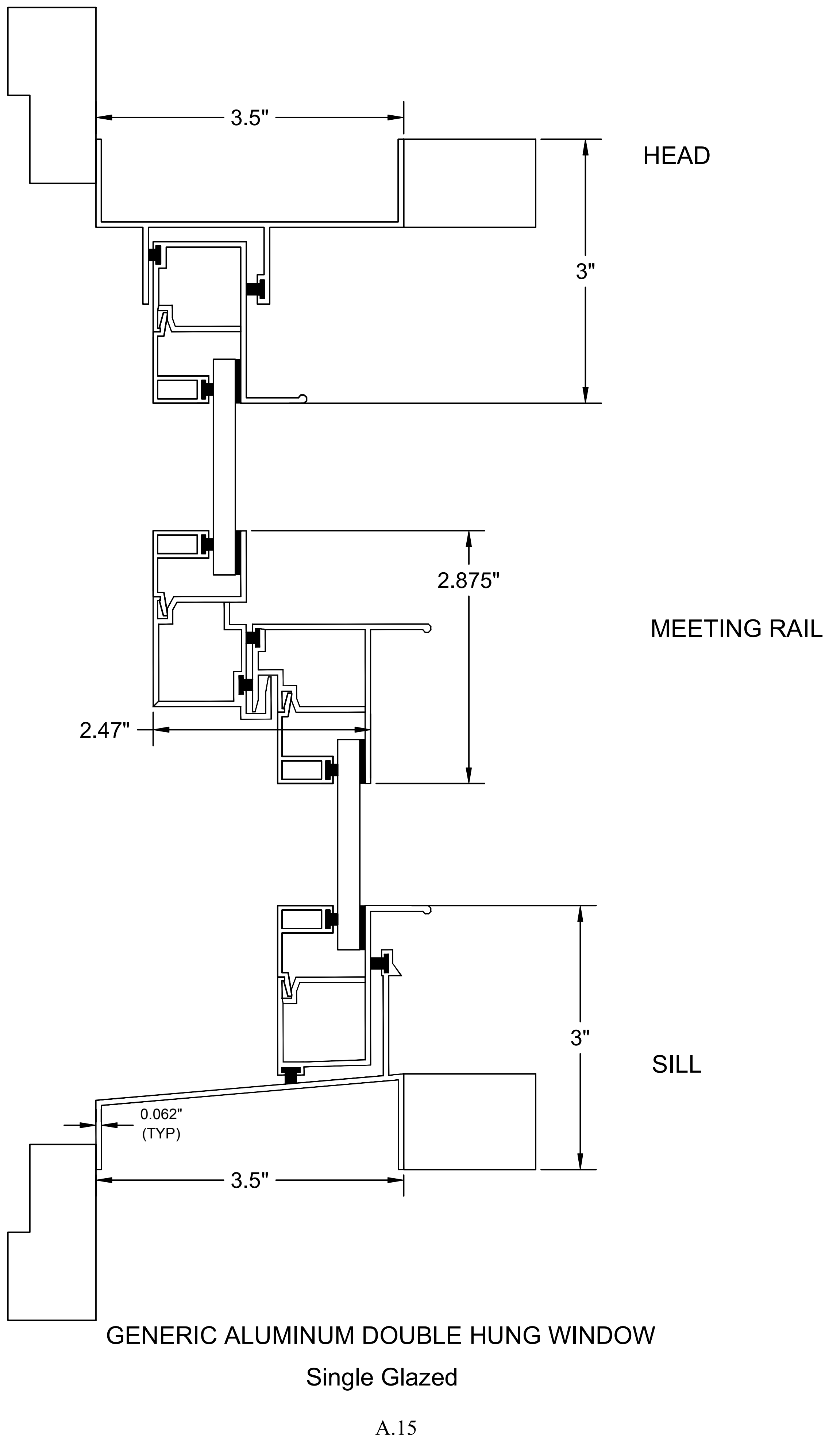
Single Glazed



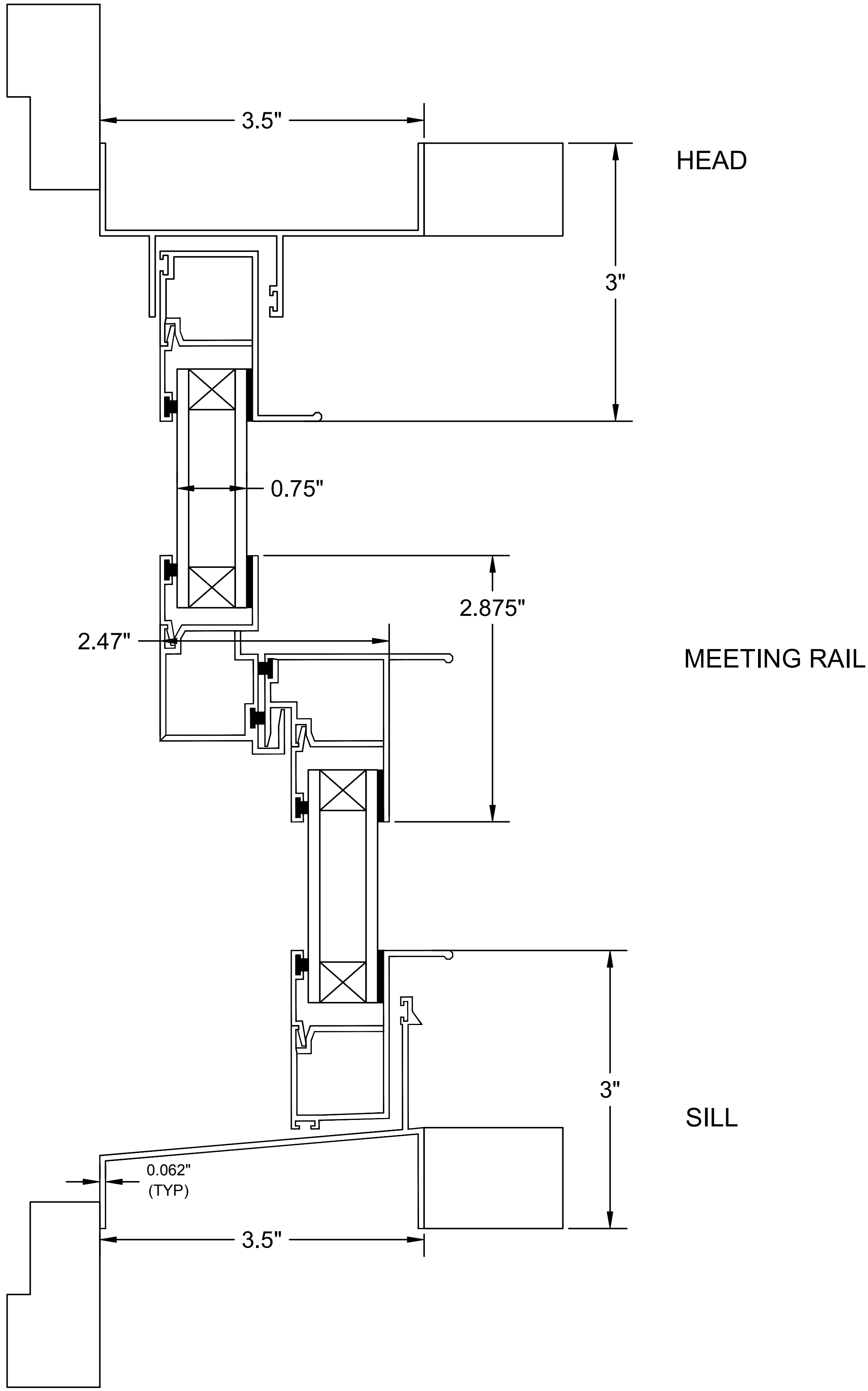
GENERIC WOOD DOUBLE HUNG WINDOW

Dual Glazed



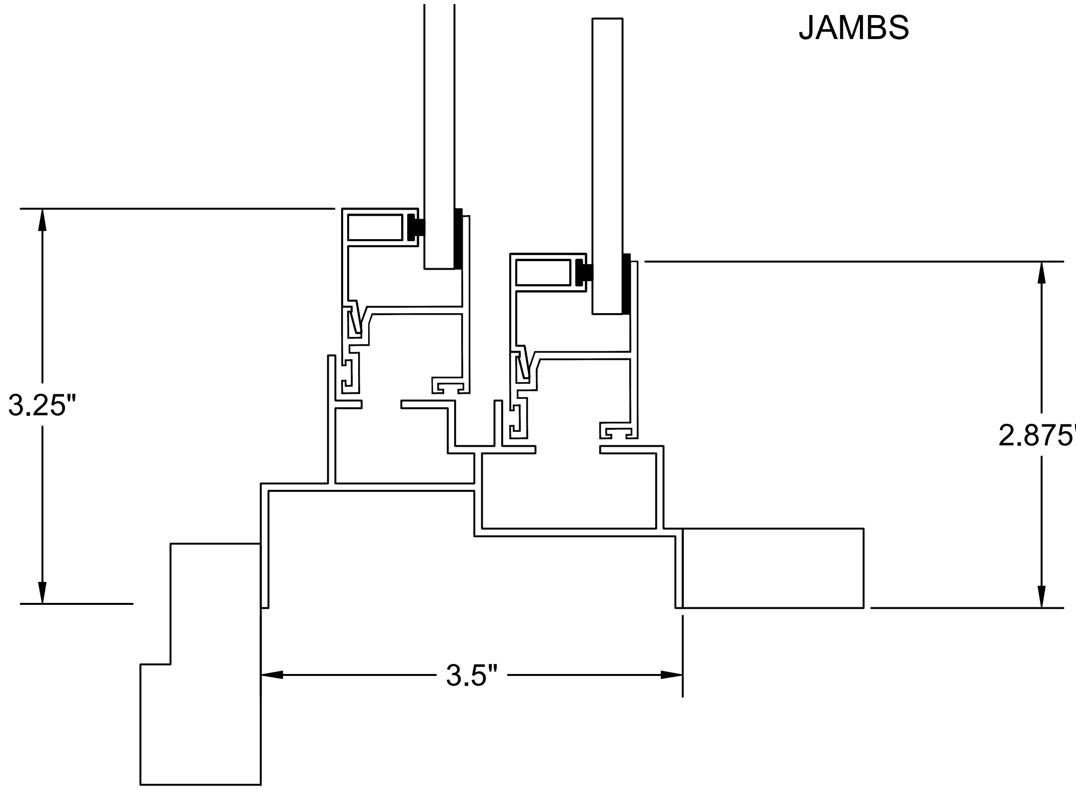
GENERIC ALUMINUM DOUBLE HUNG WINDOW

Single Glazed



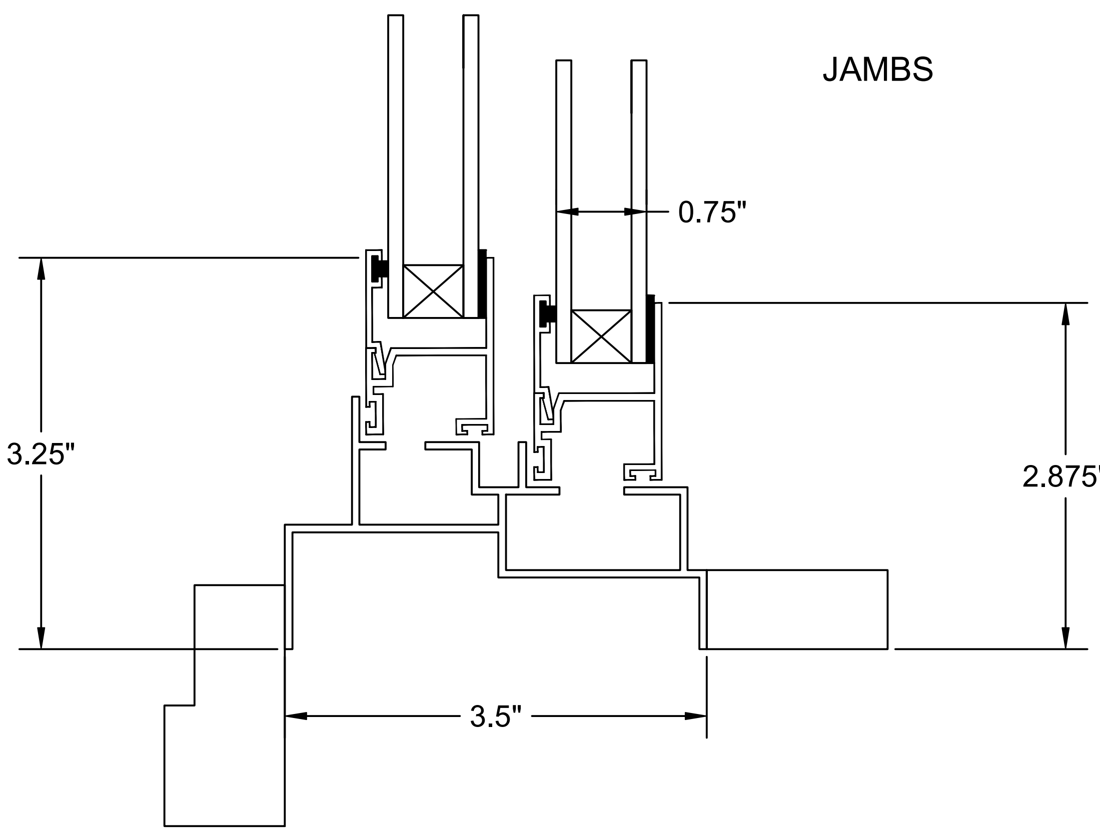
GENERIC ALUMINUM DOUBLE HUNG WINDOW

Dual Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW

Single Glazed



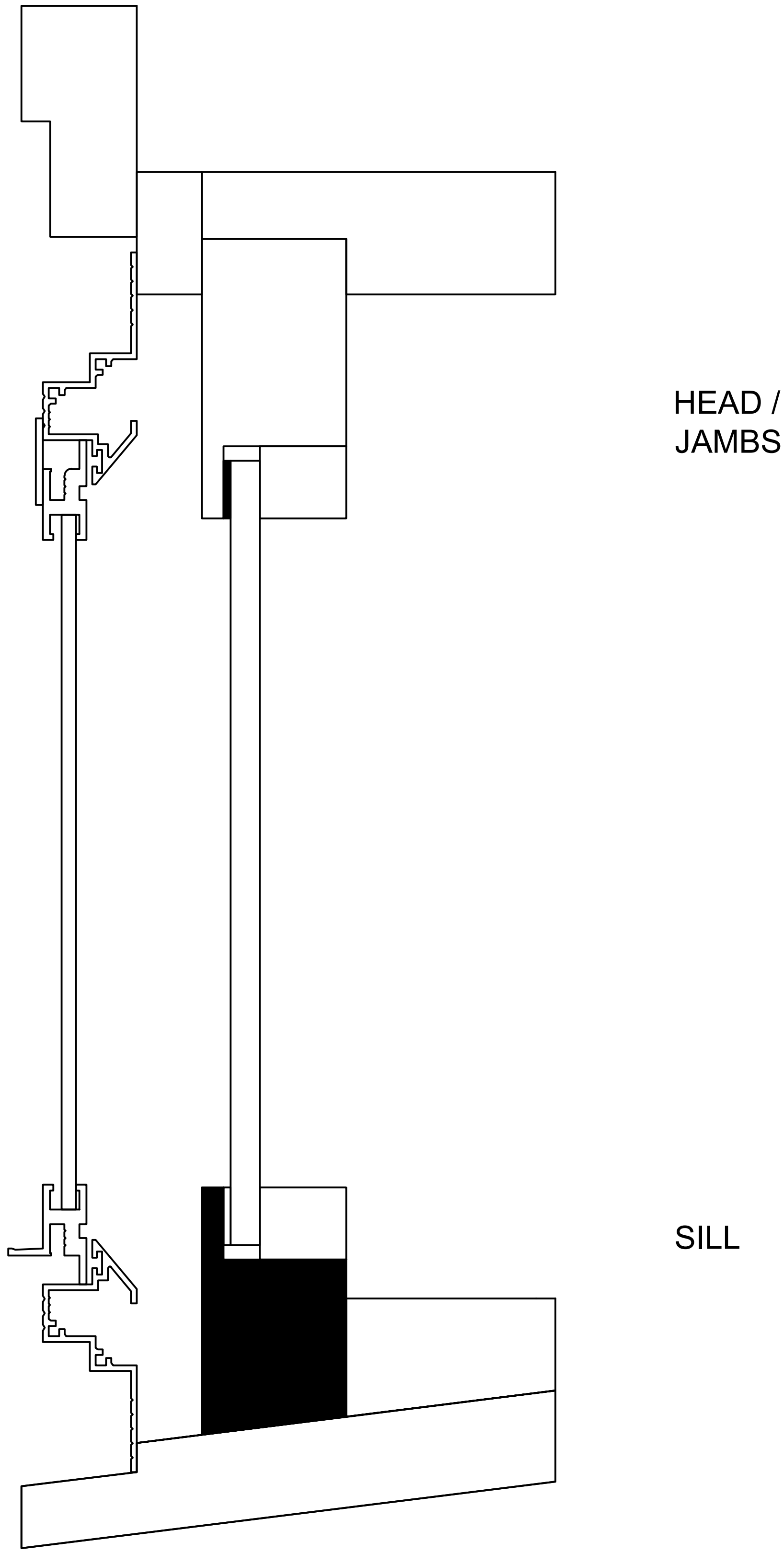
GENERIC ALUMINUM DOUBLE HUNG WINDOW

Dual Glazed

Exterior Storm Windows on Base Window Drawings

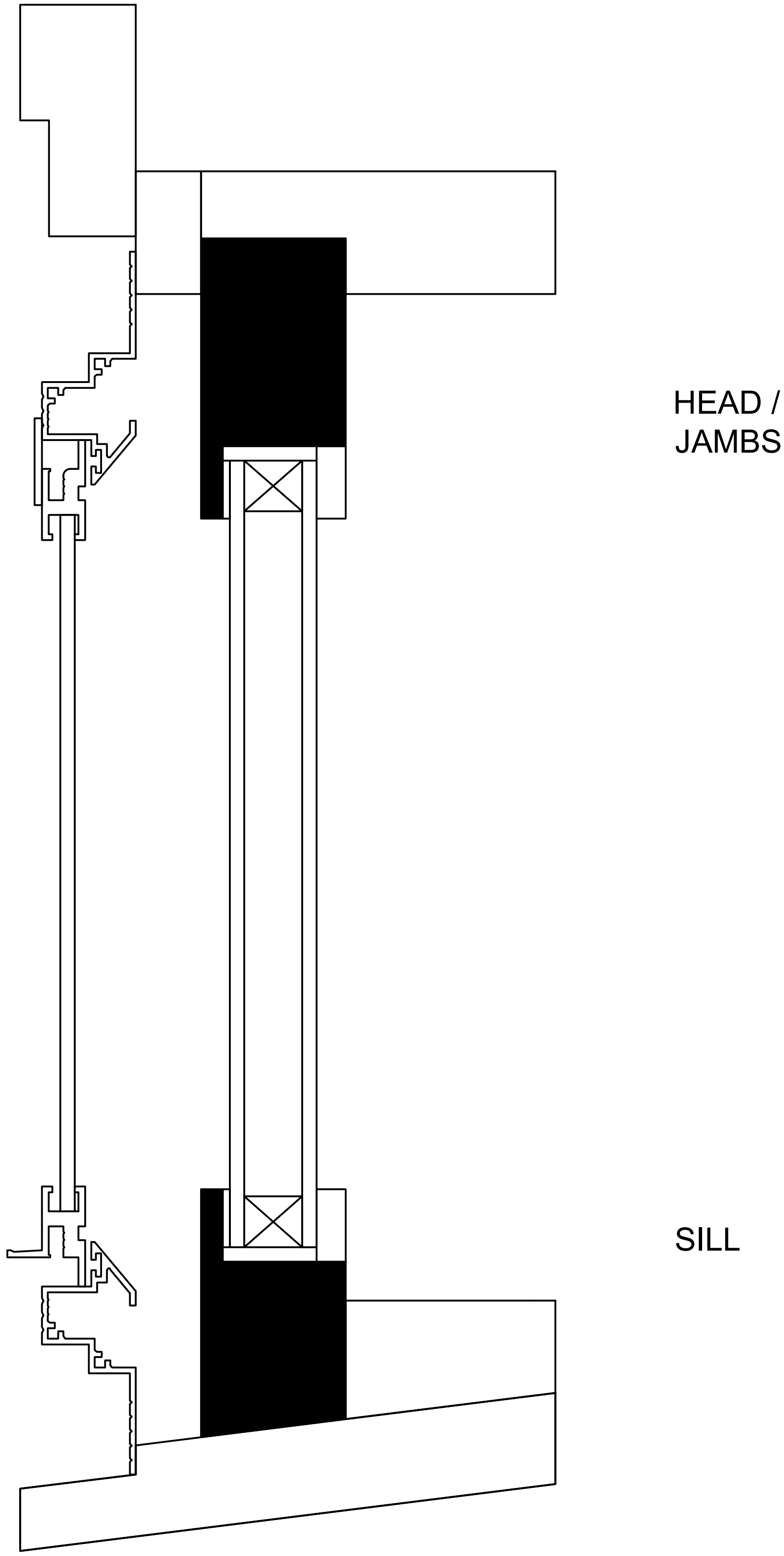
Appendix B

C2692.02-116-45



GENERIC WOOD FIXED WINDOW

Single Glazed



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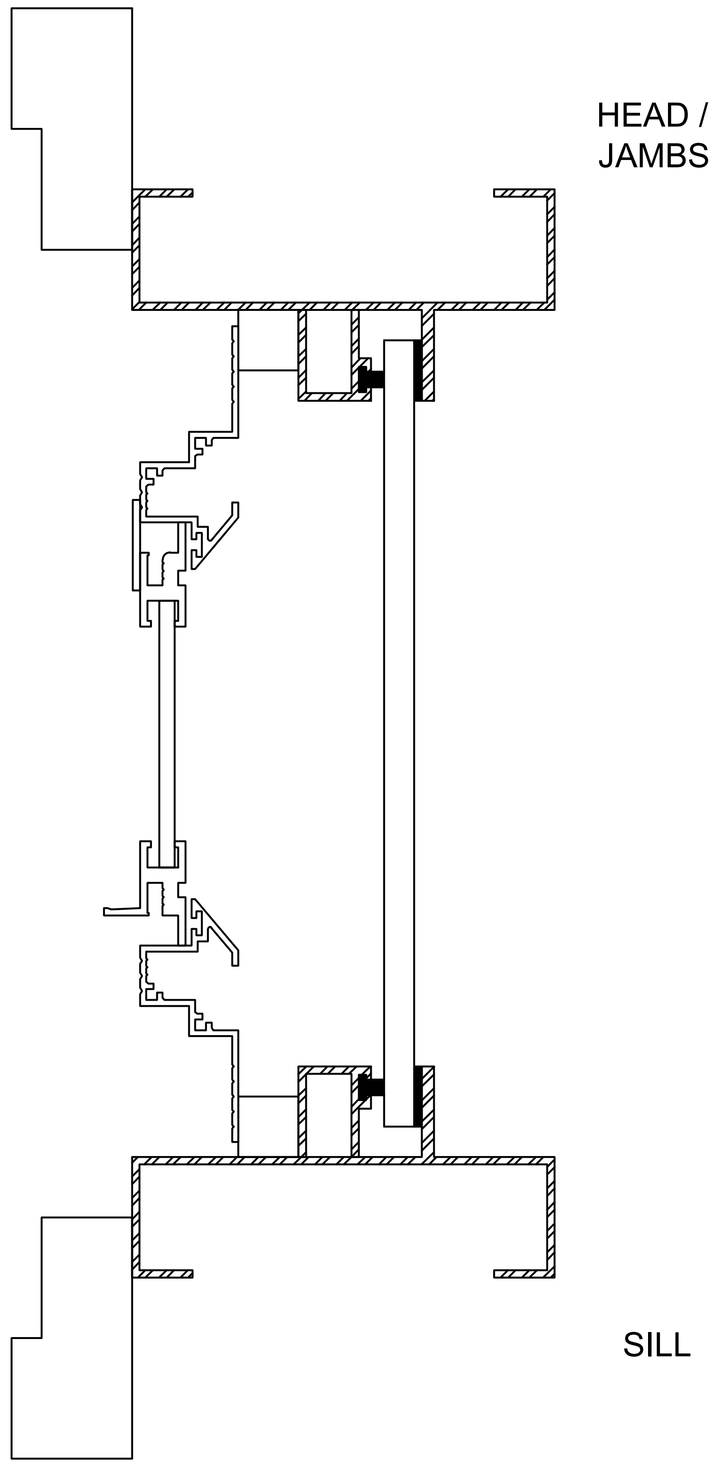

GENERIC ALUMINUM FIXED WINDOW - CASE 1

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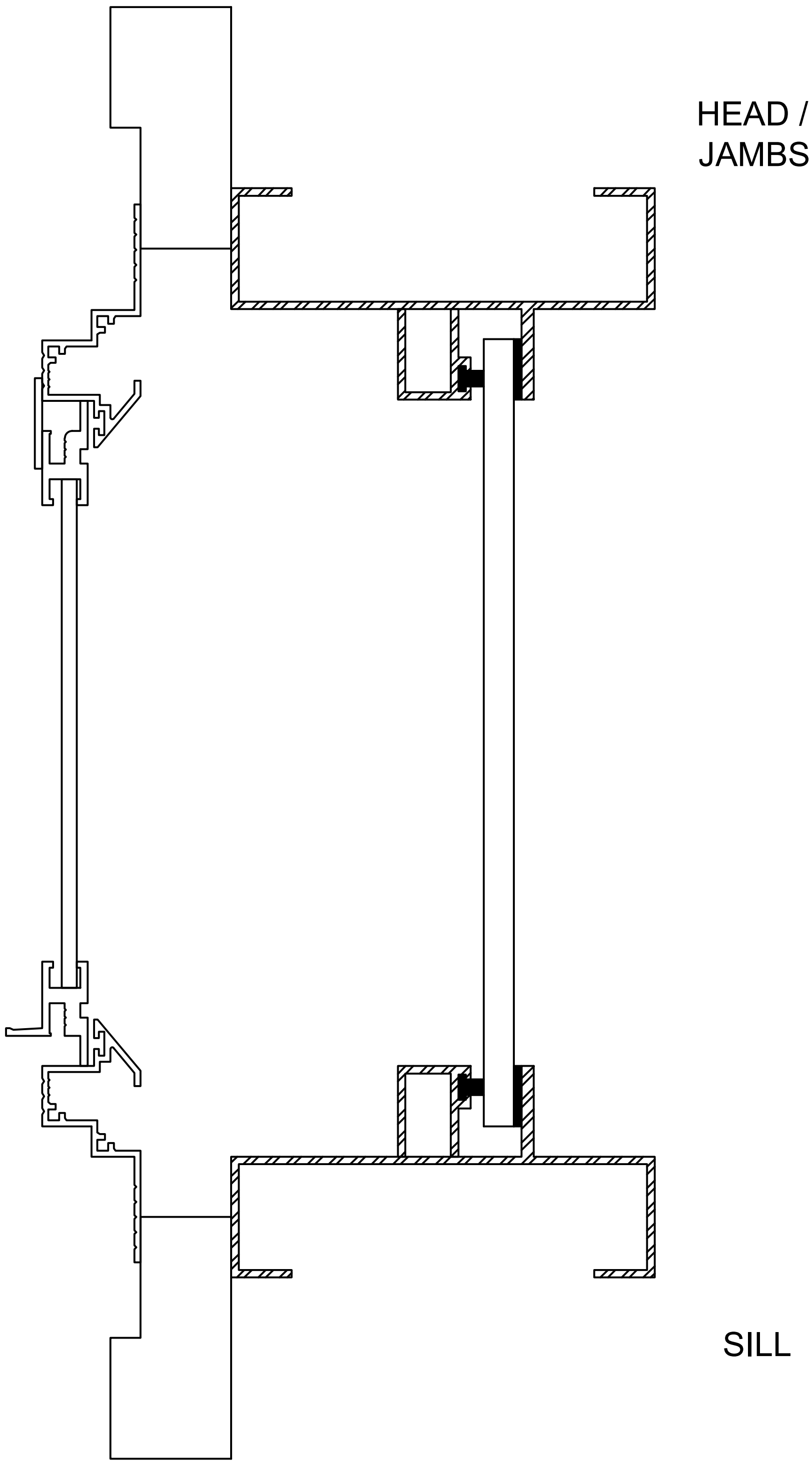

GENERIC ALUMINUM FIXED WINDOW - CASE 2

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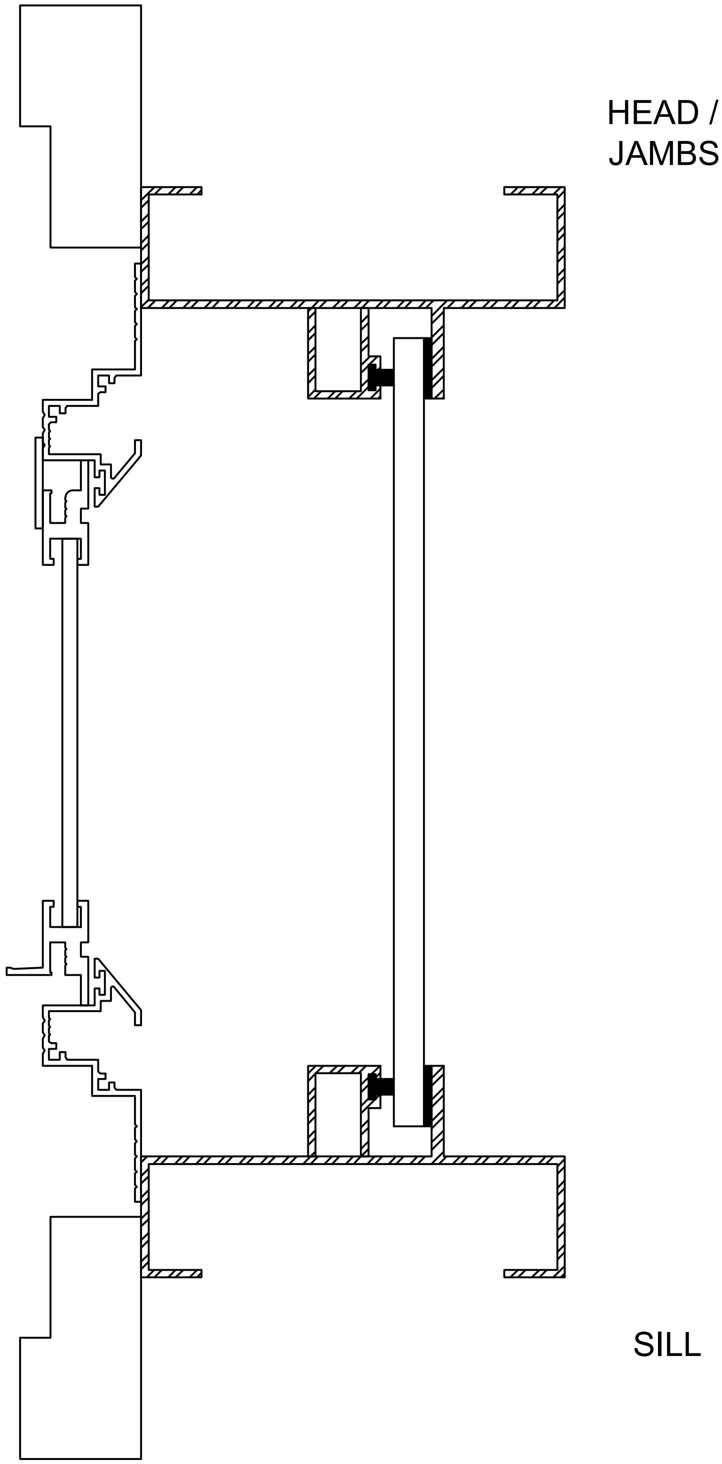
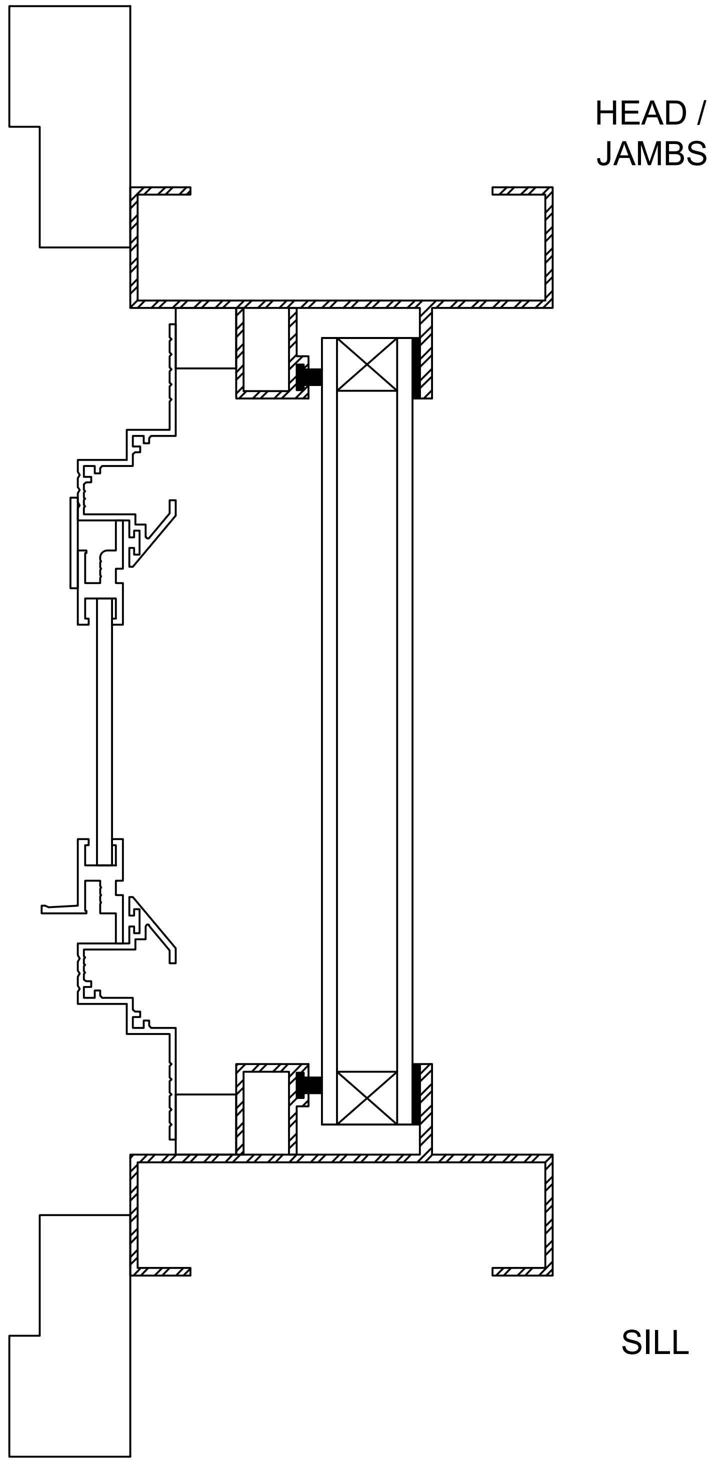


GENERIC ALUMINUM FIXED WINDOW - CASE 3

Single Glazed



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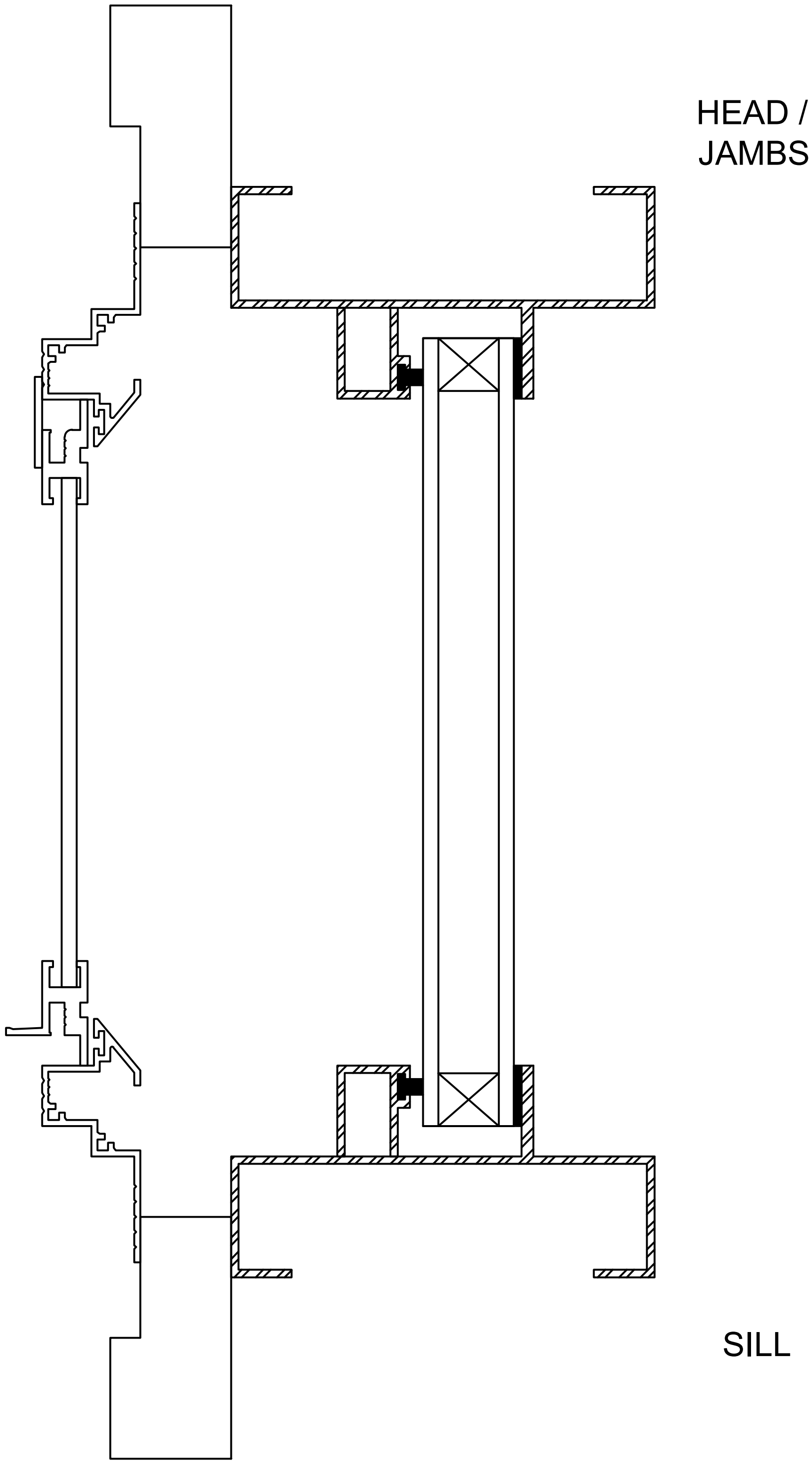
Dual Glazed



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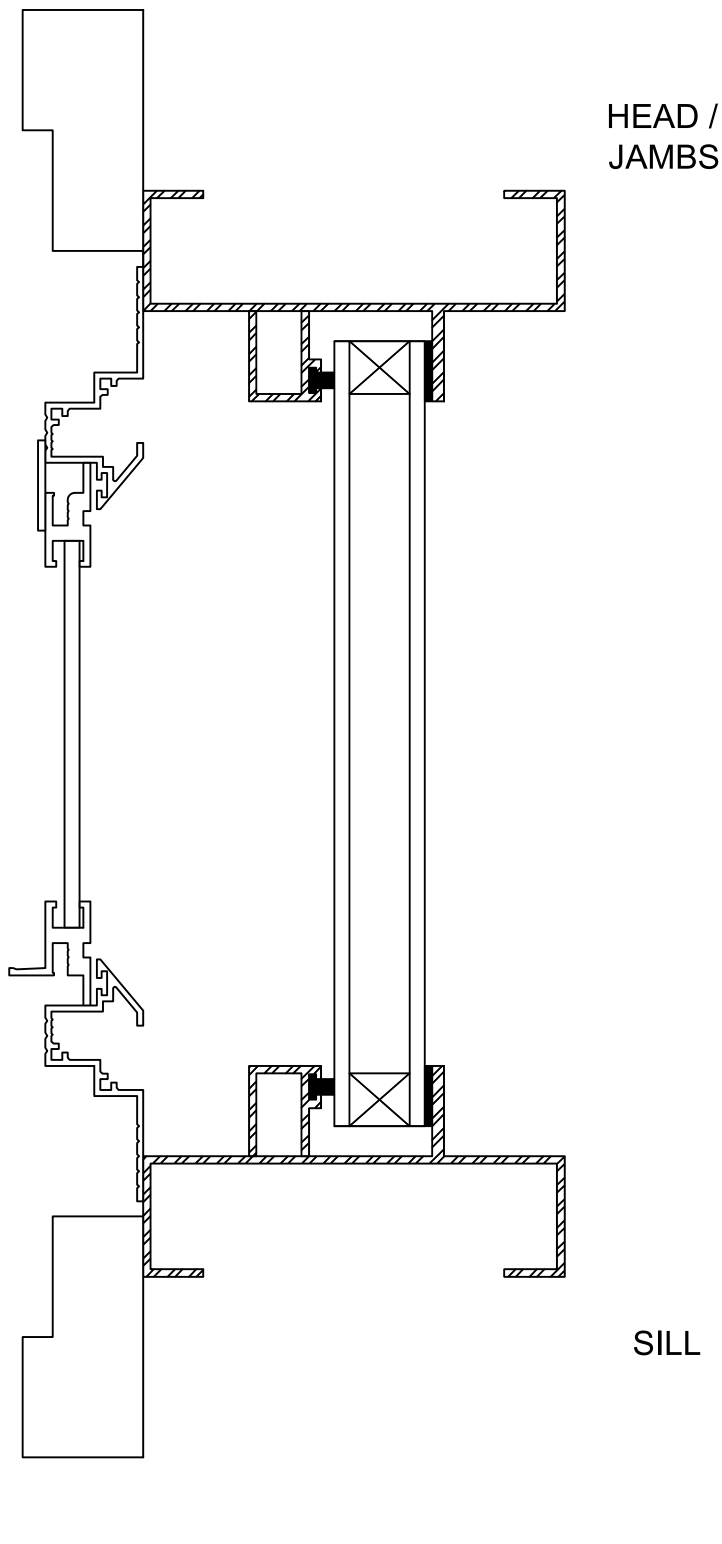

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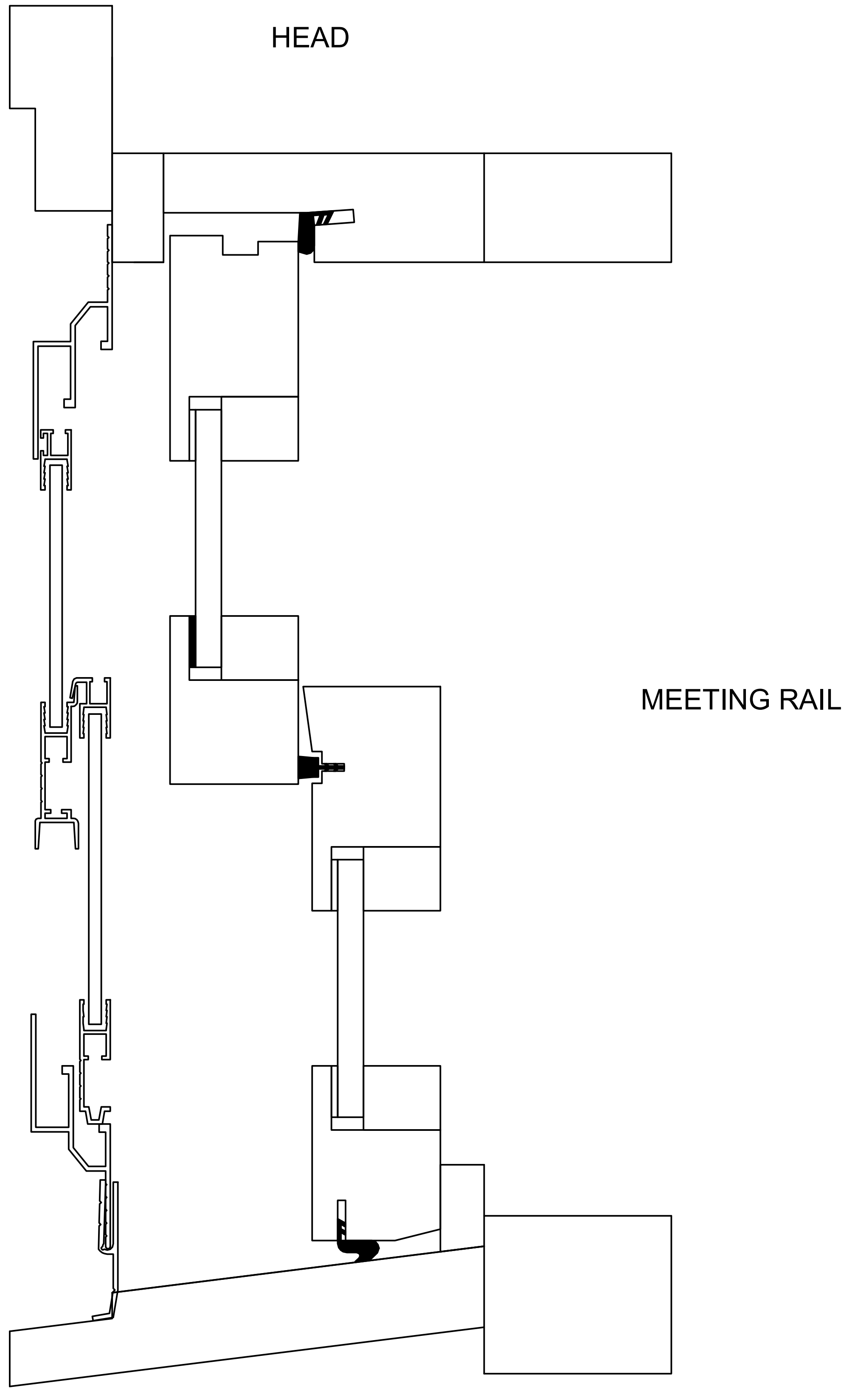

GENERIC WOOD DOUBLE HUNG WINDOW

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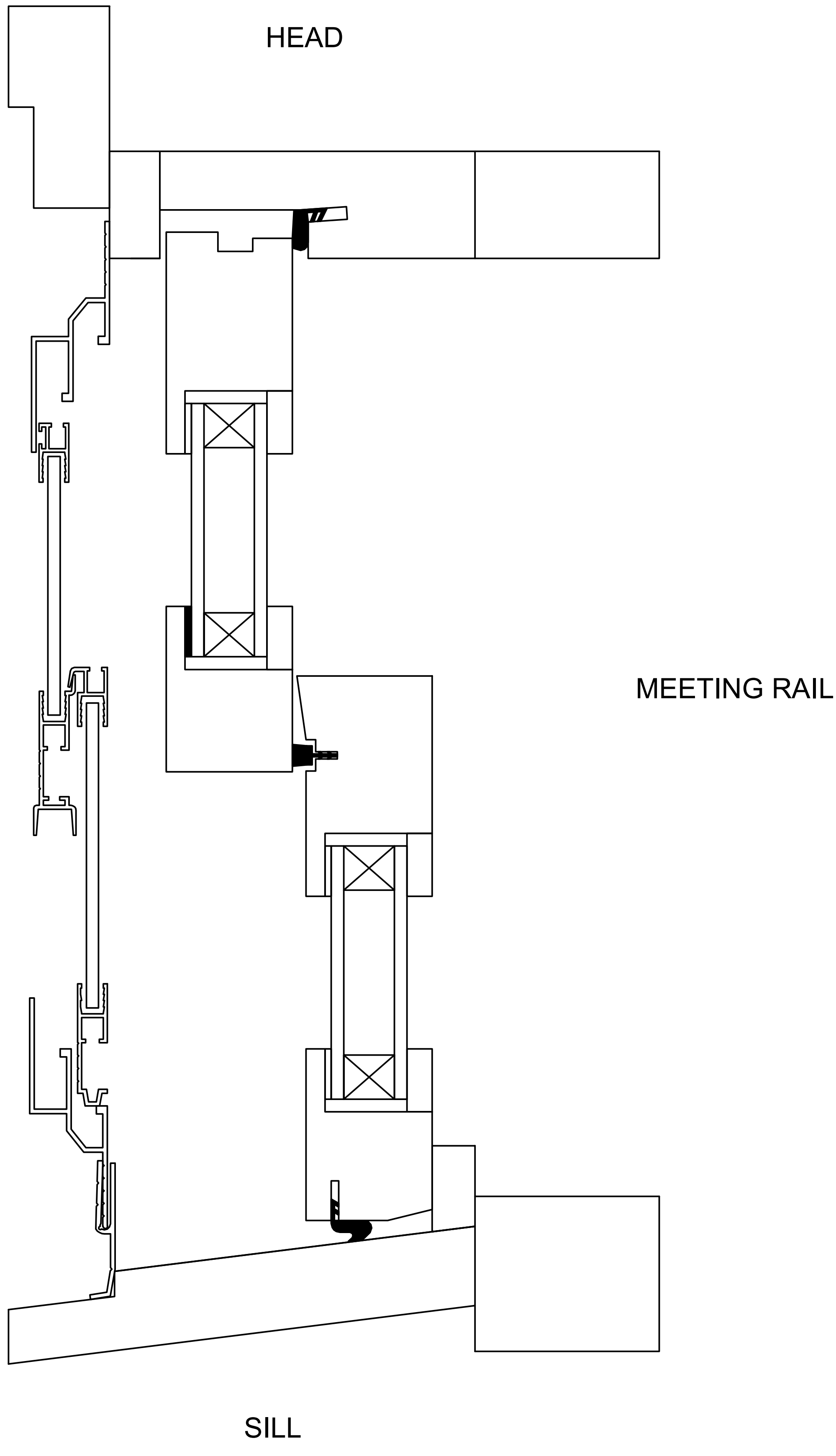
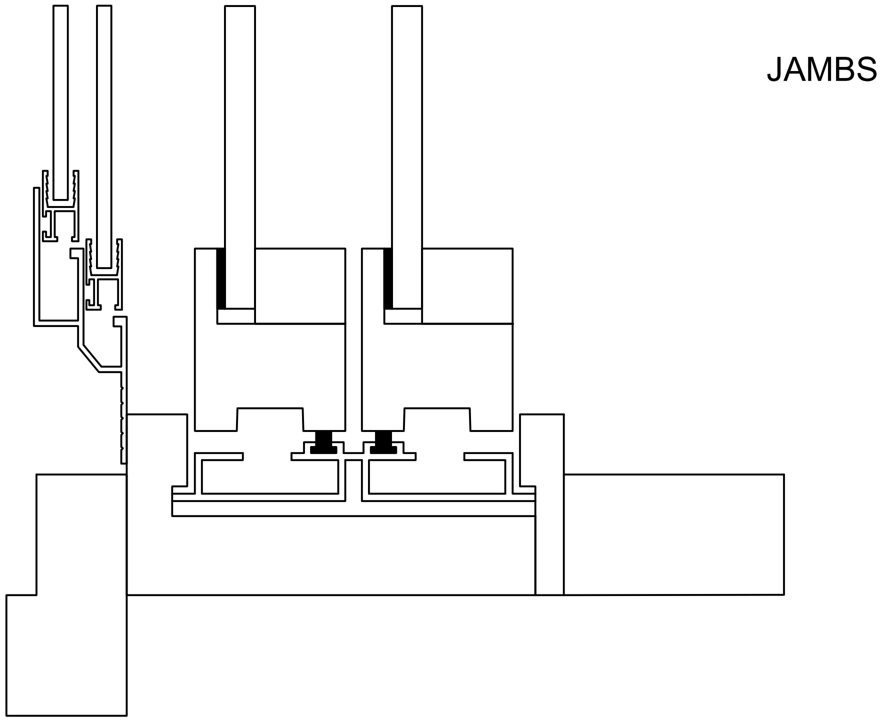


GENERIC WOOD DOUBLE HUNG WINDOW

Dual Glazed



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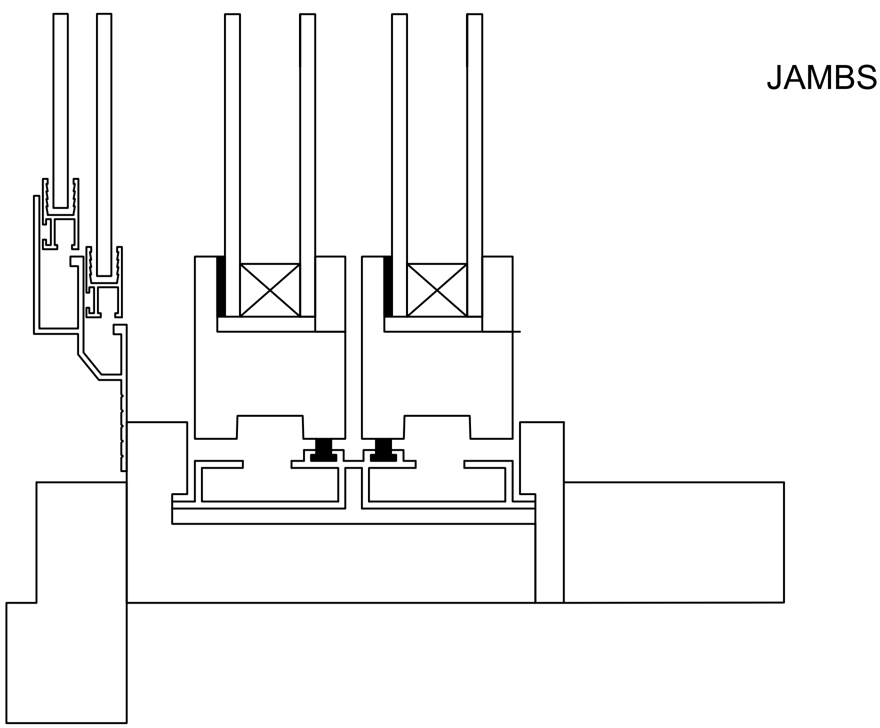
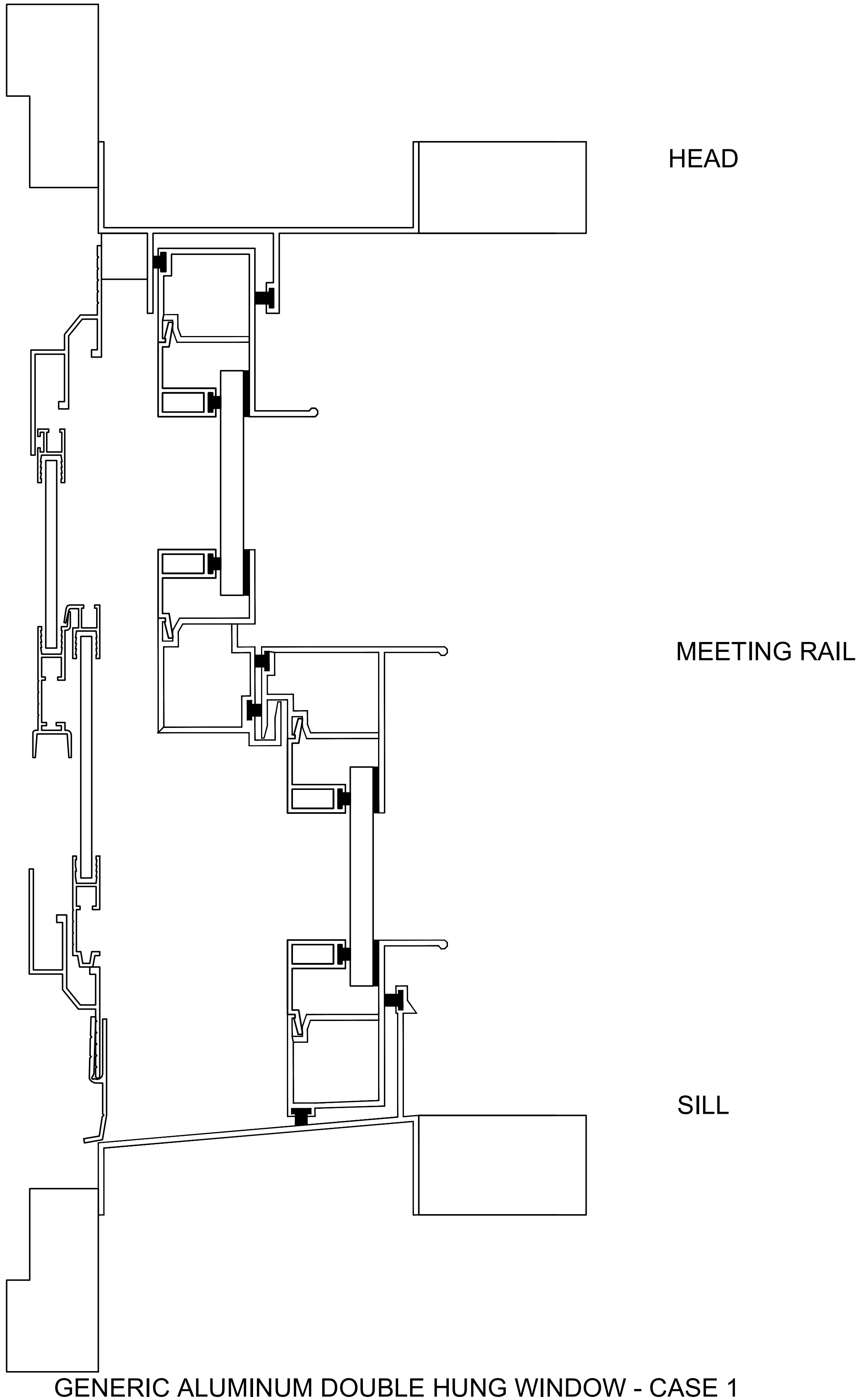
Single Glazed



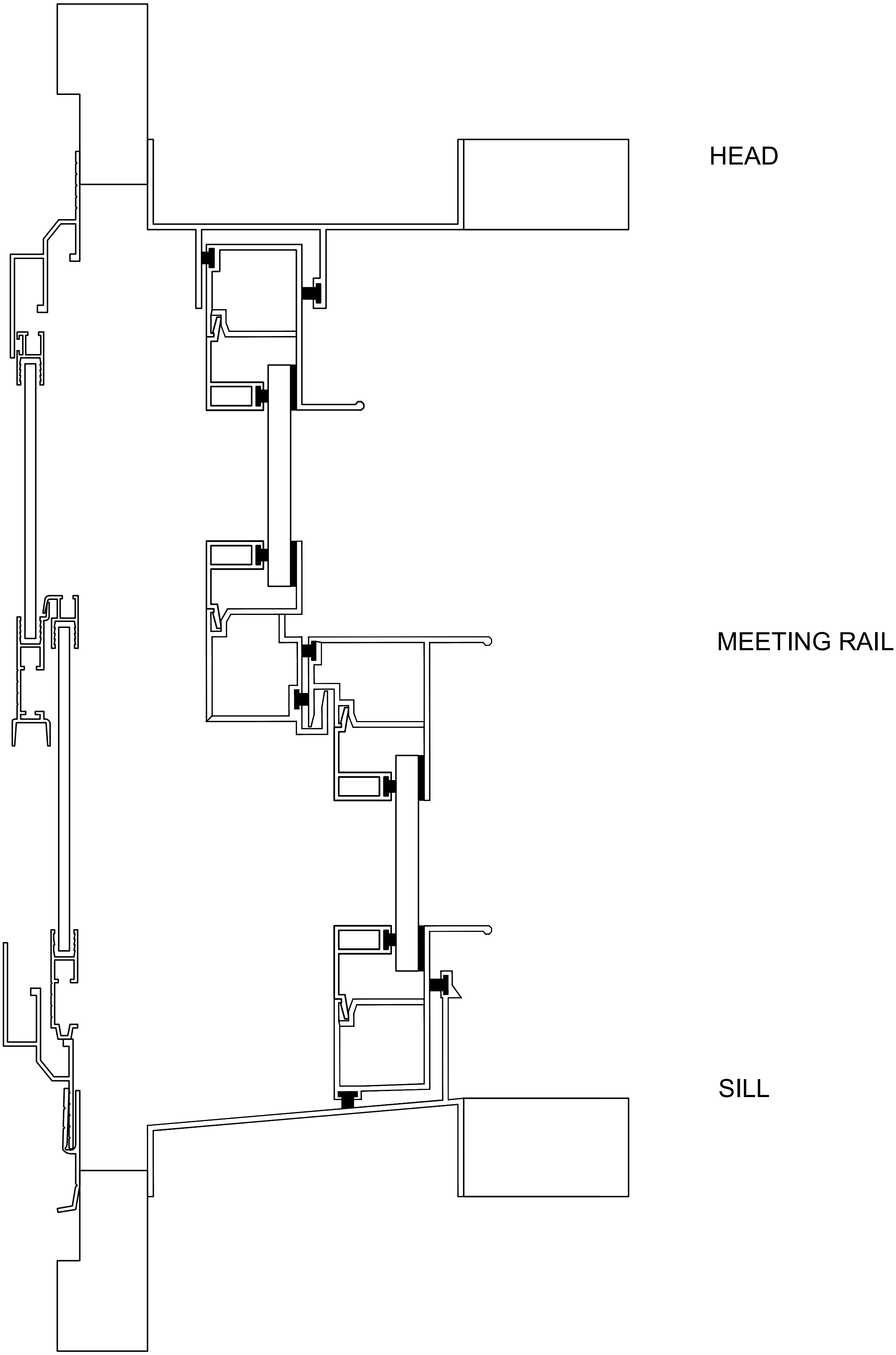
GENERIC WOOD DOUBLE HUNG WINDOW

Dual Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 1

Single Glazed



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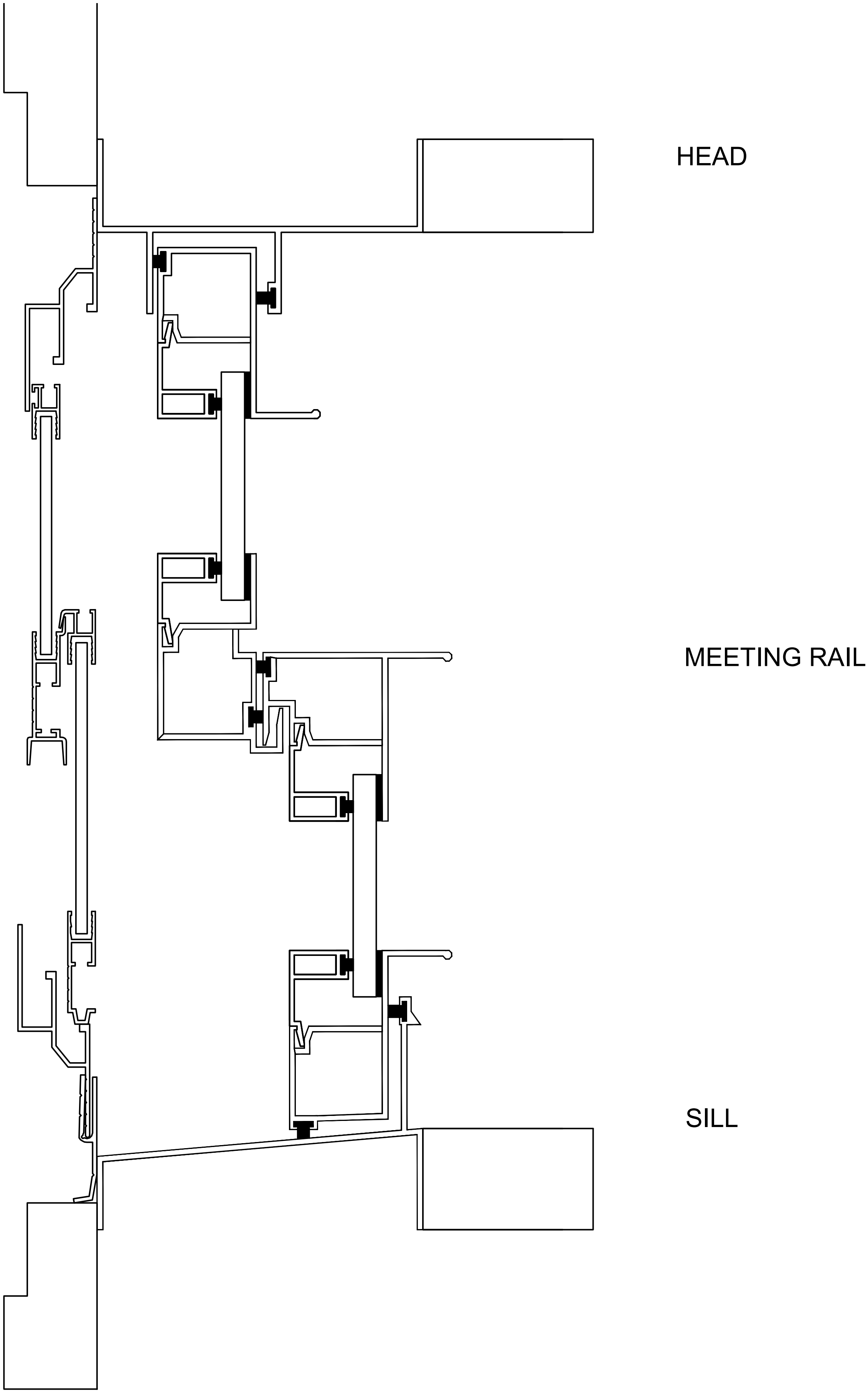

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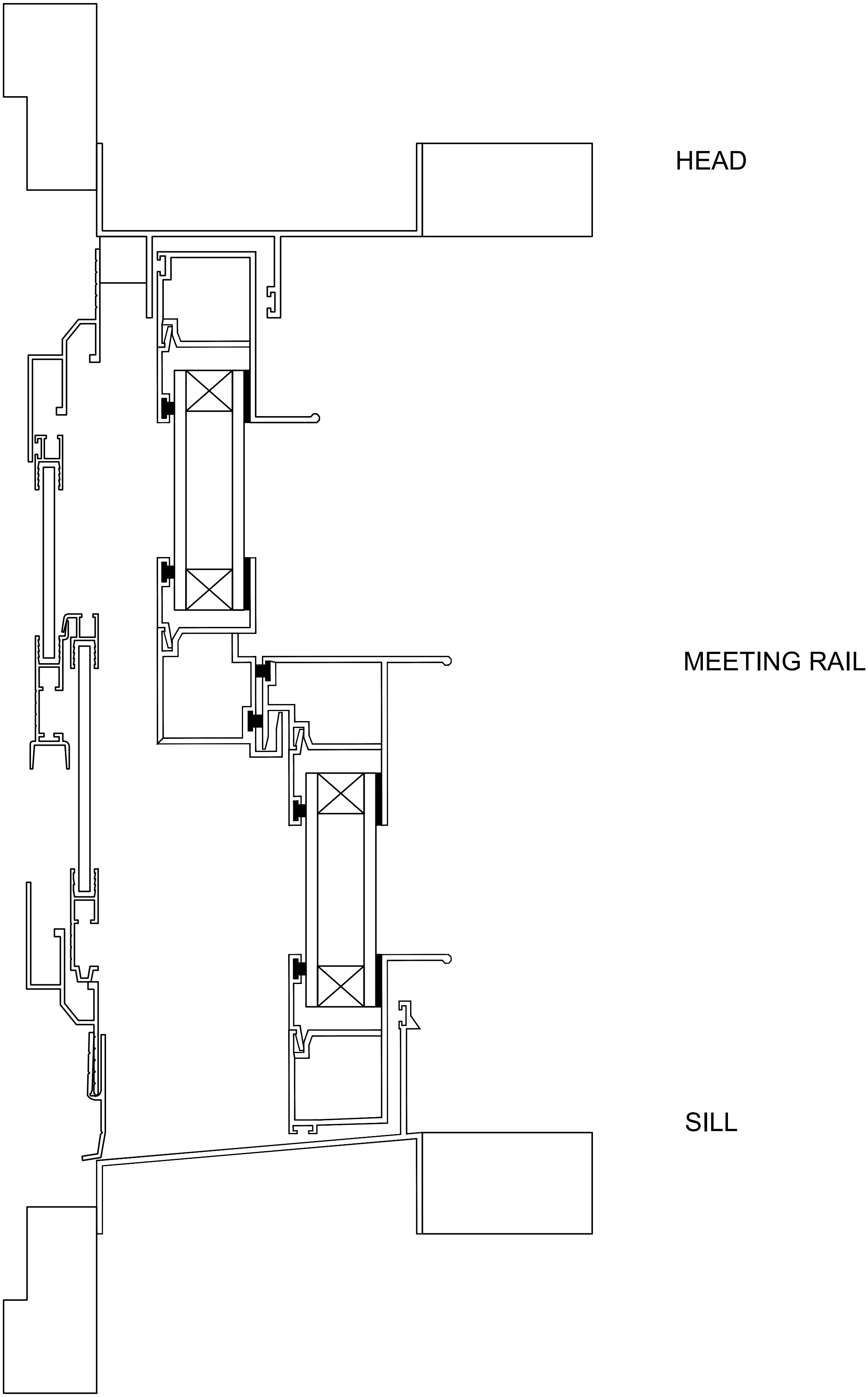
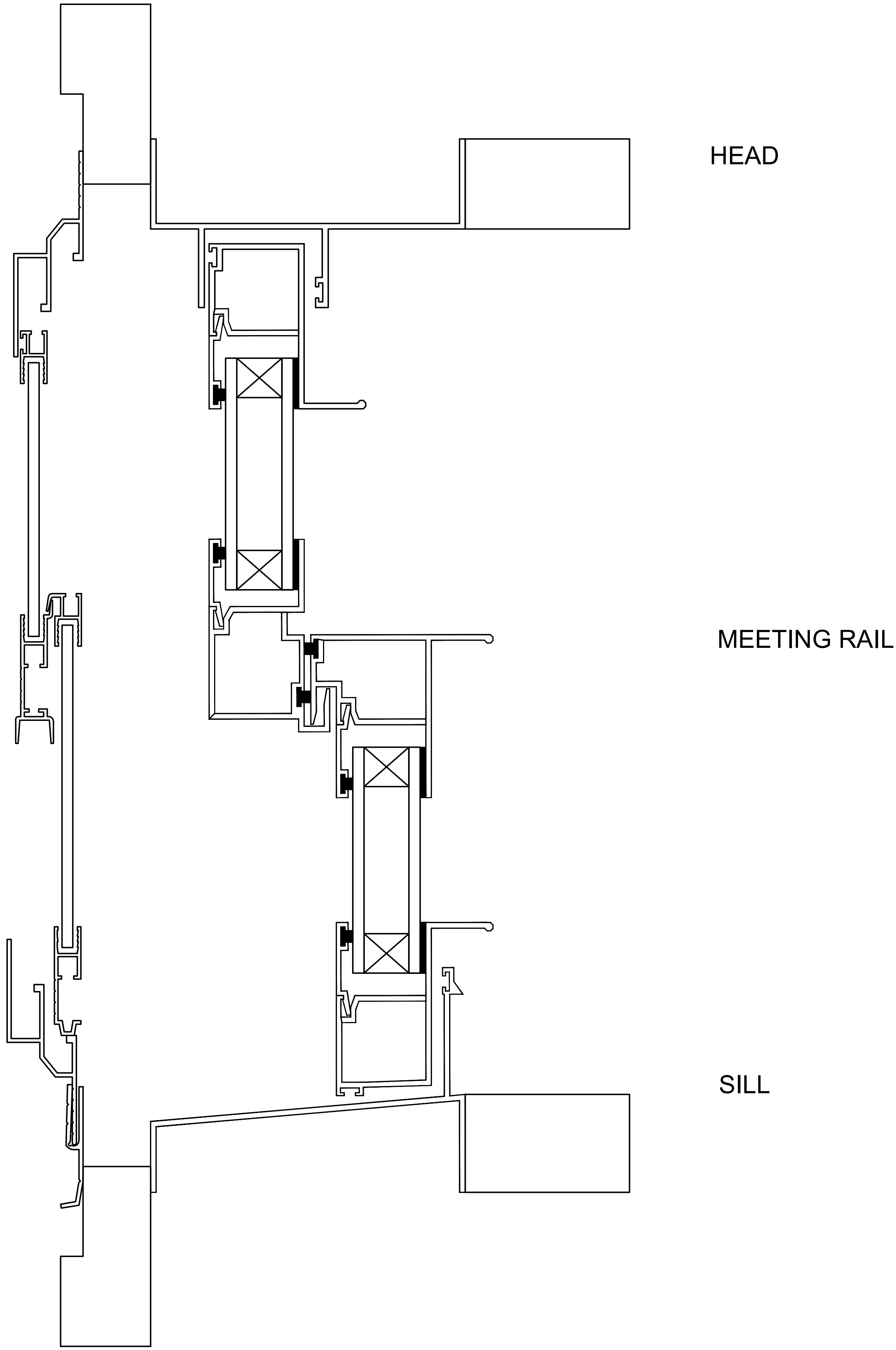


GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 1

Dual Glazed



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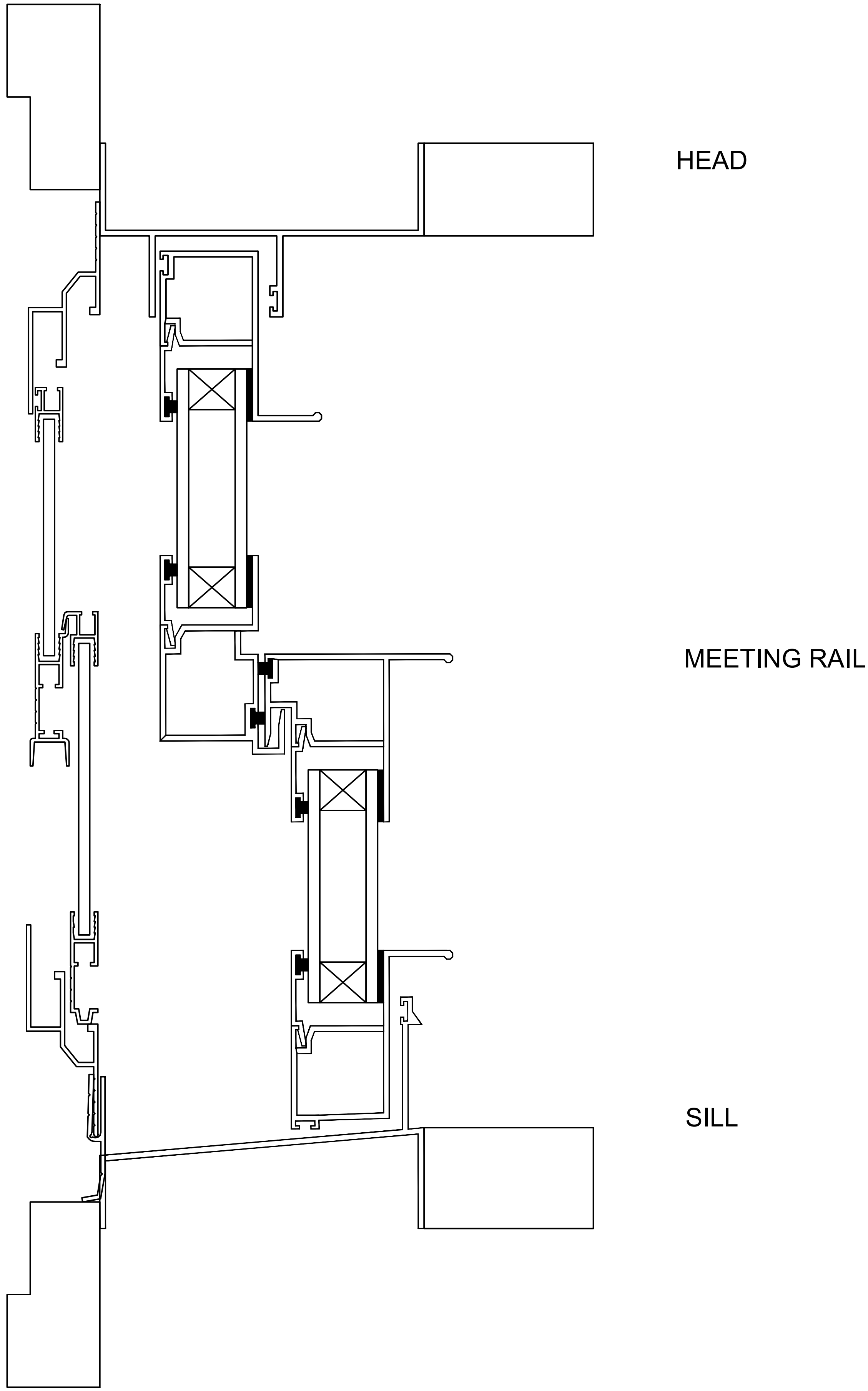
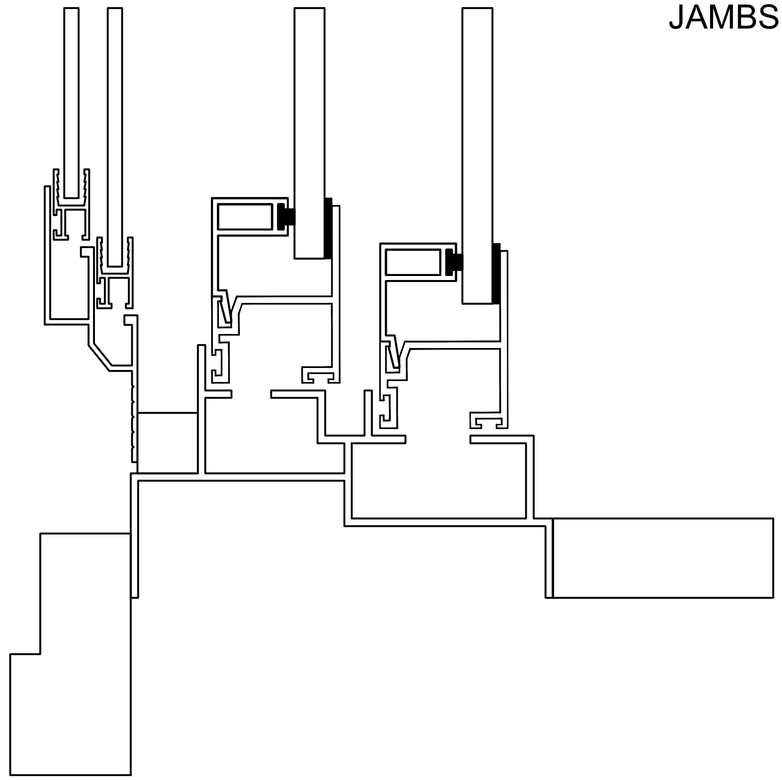


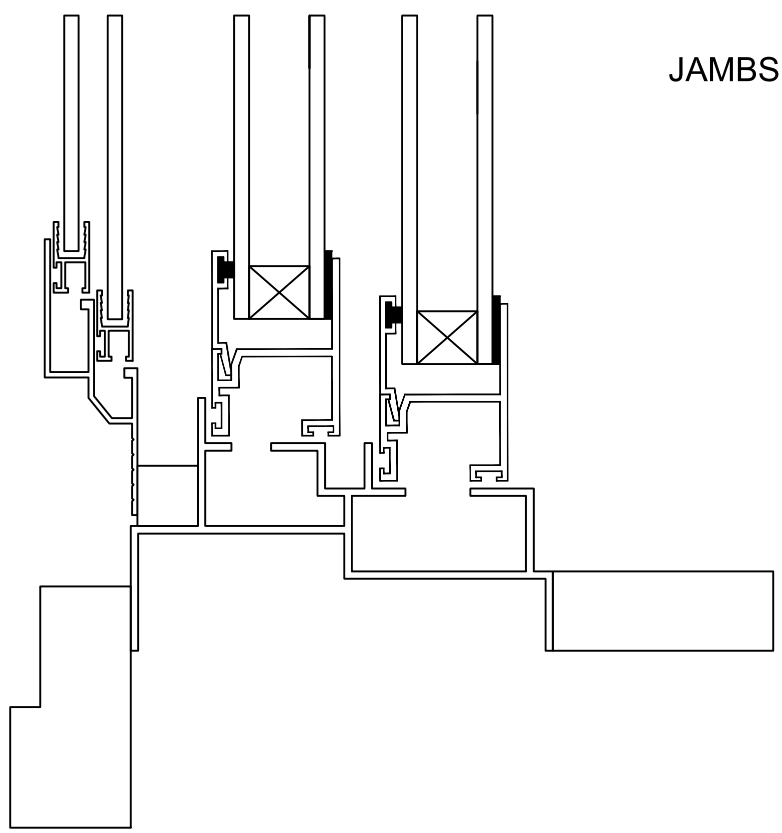
GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 3

Dual Glazed



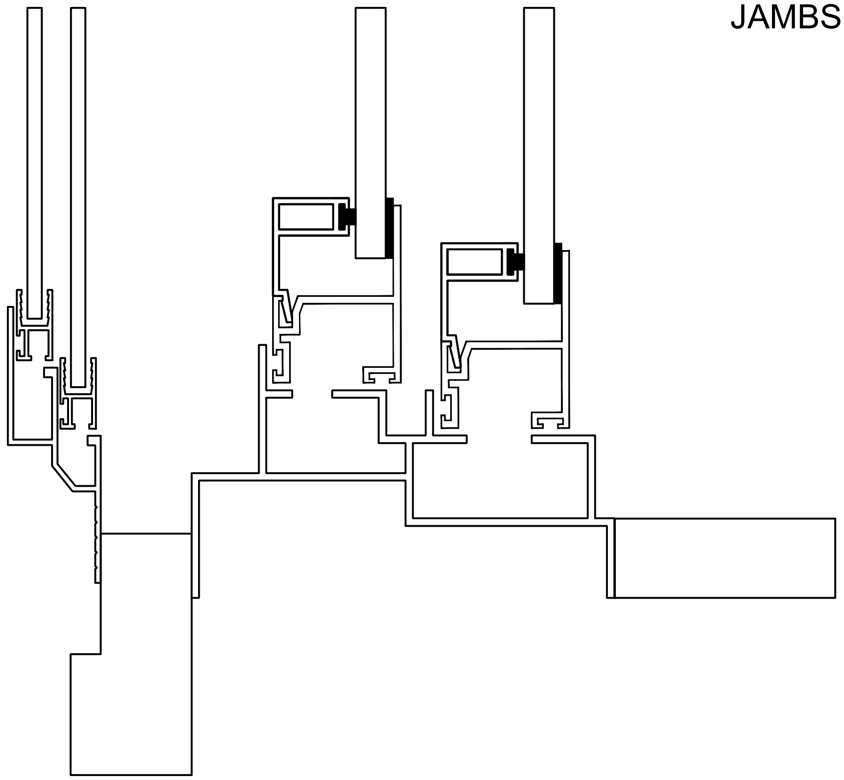
GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 1

Single Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 1

Dual Glazed



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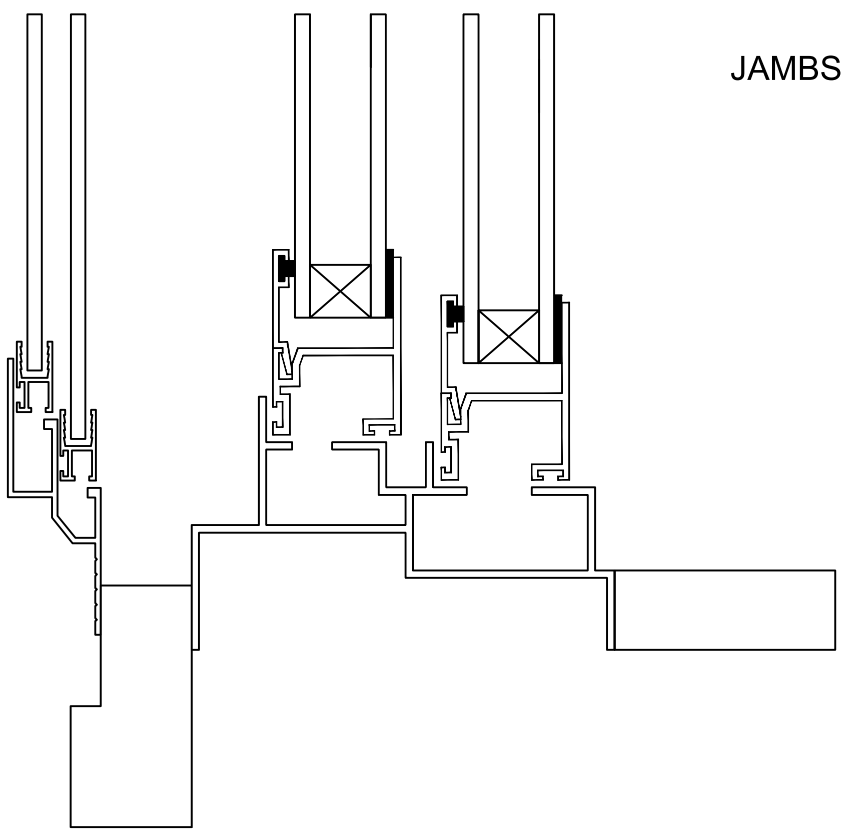

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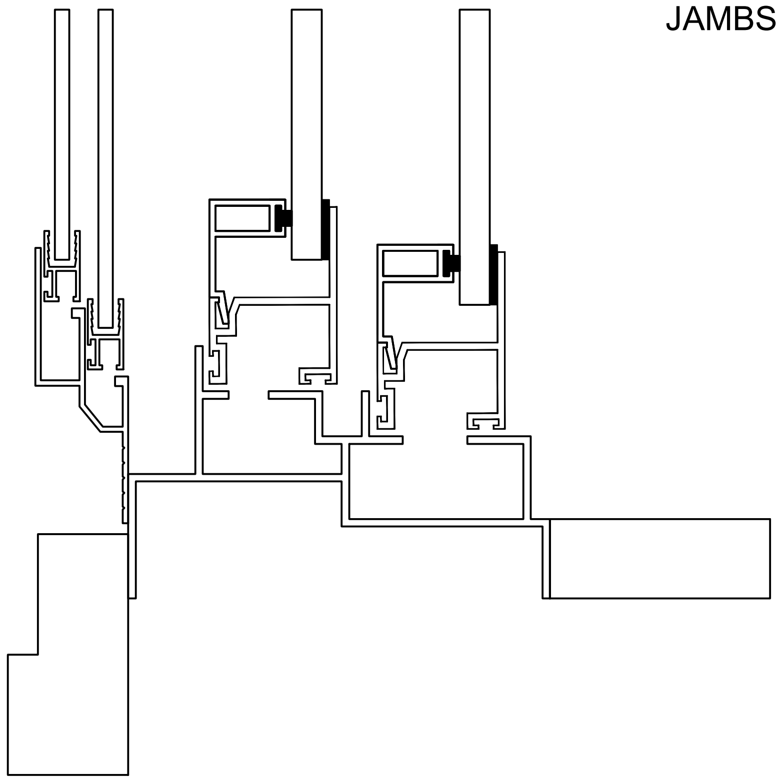
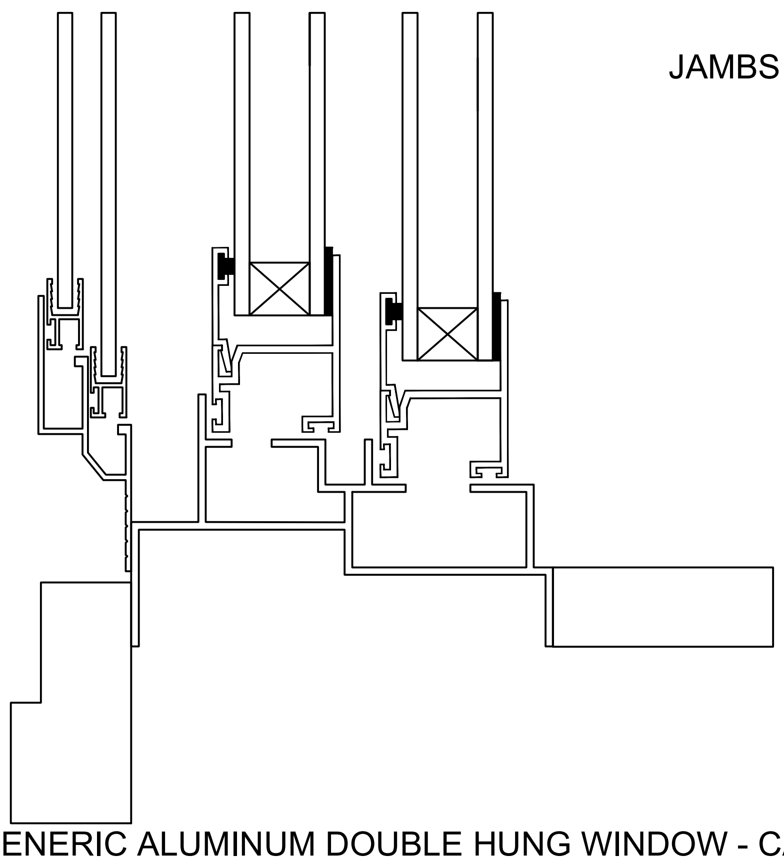
Dual Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 3

Single Glazed



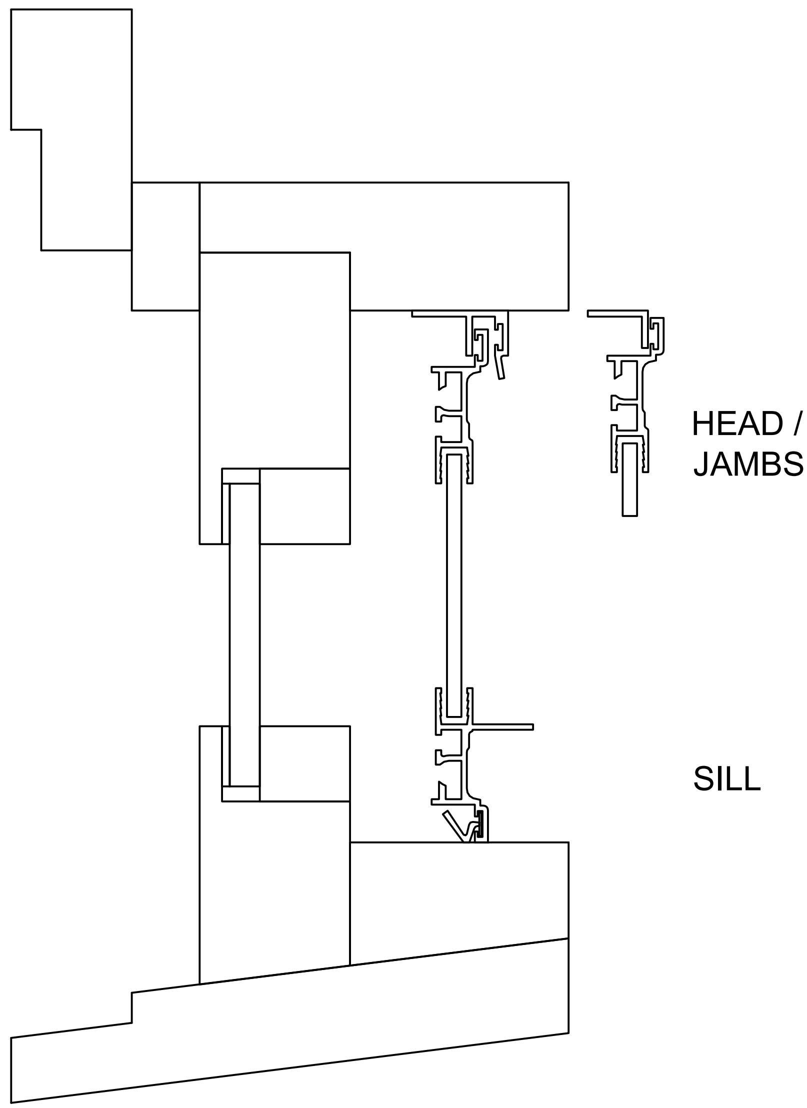
GENERIC ALUMINUM DOUBLE HUNG WINDOW - CASE 3

Dual Glazed

Interior Storm Windows on Base Window Drawings

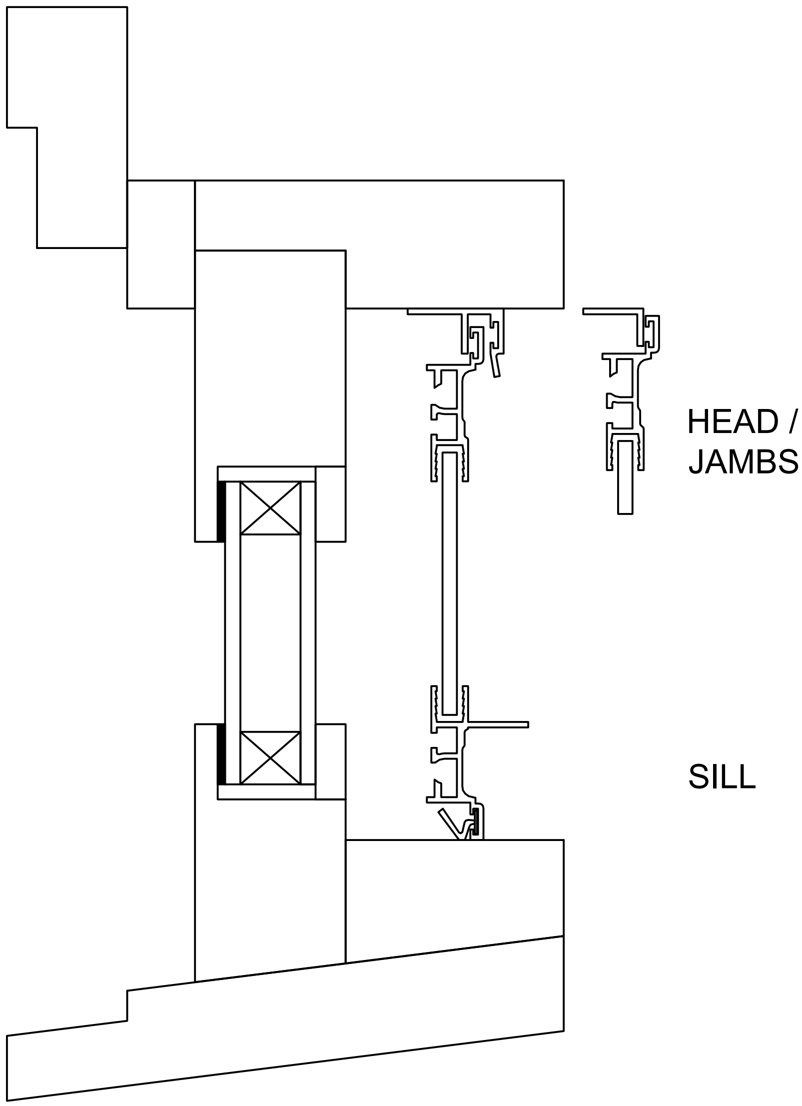
Appendix C

C2692.02-116-45



GENERIC WOOD FIXED WINDOW

Single Glazed



GENERIC WOOD FIXED WINDOW

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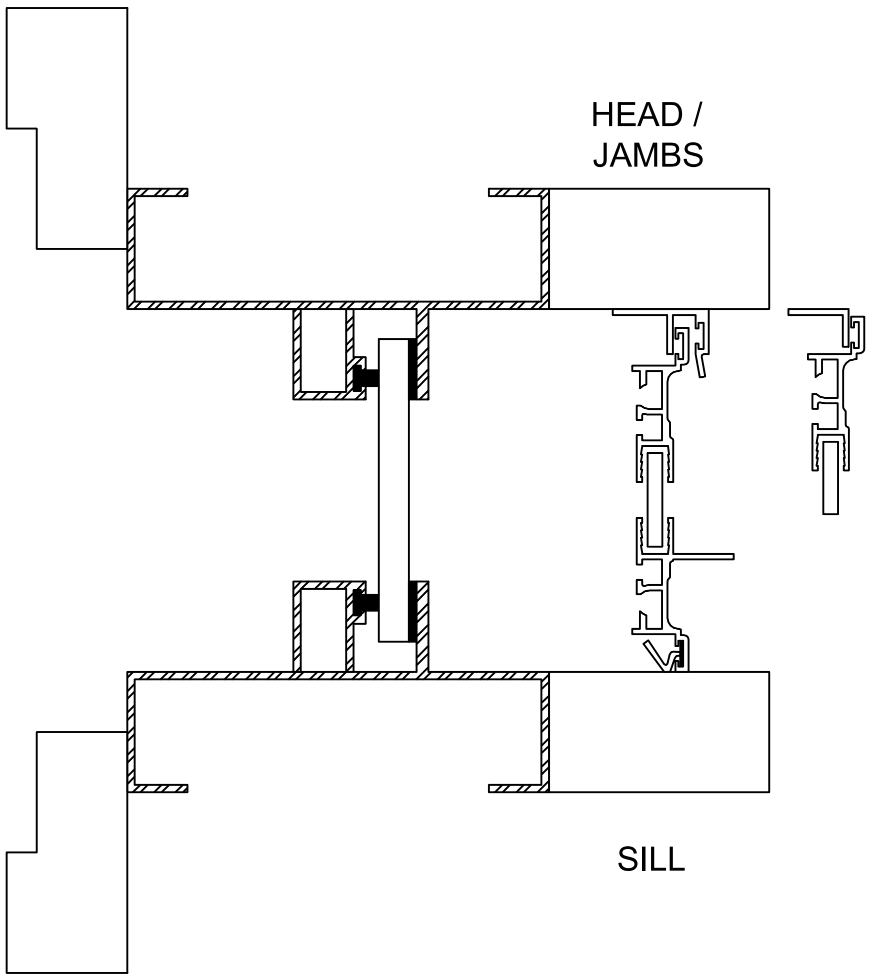
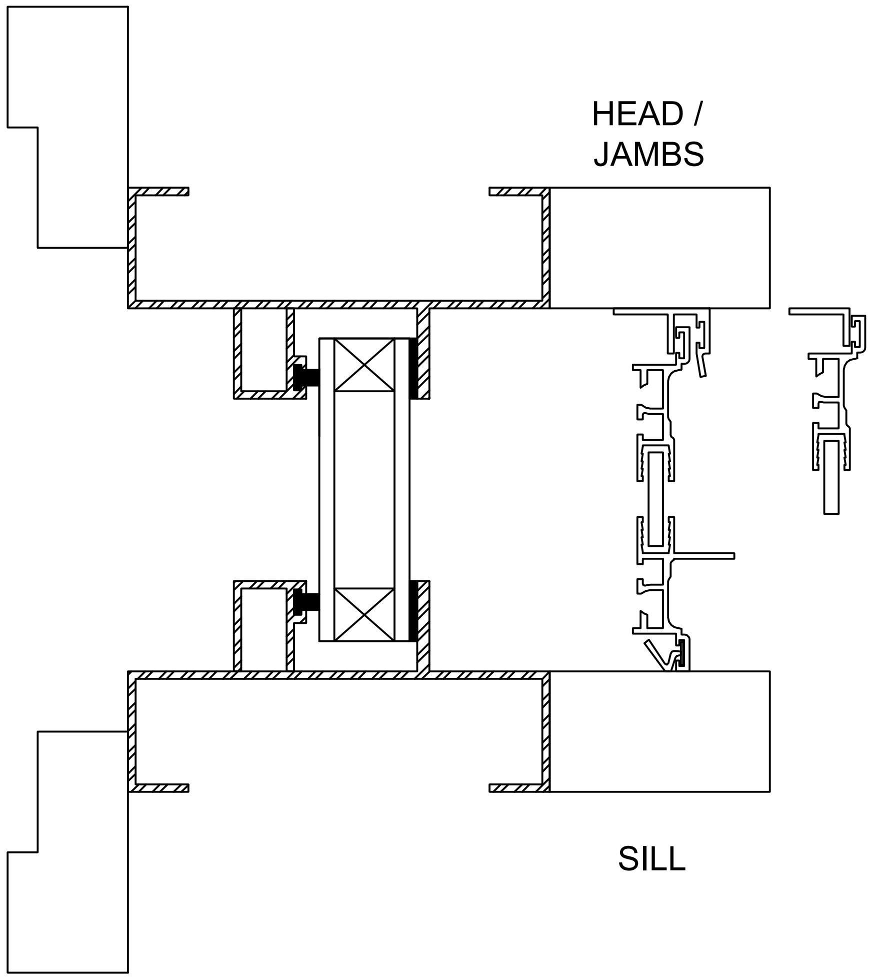


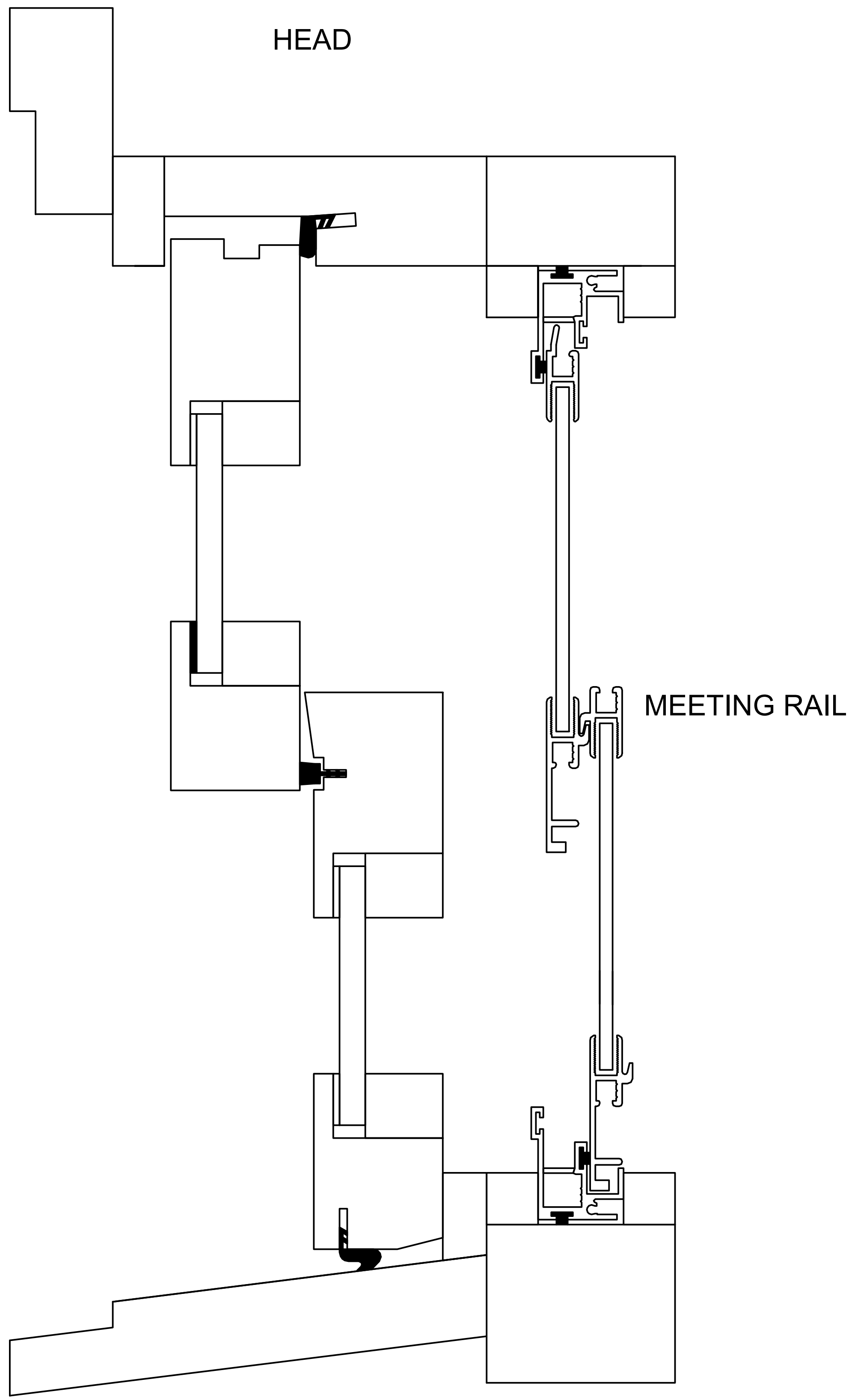
GENERIC ALUMINUM FIXED WINDOW

Single Glazed



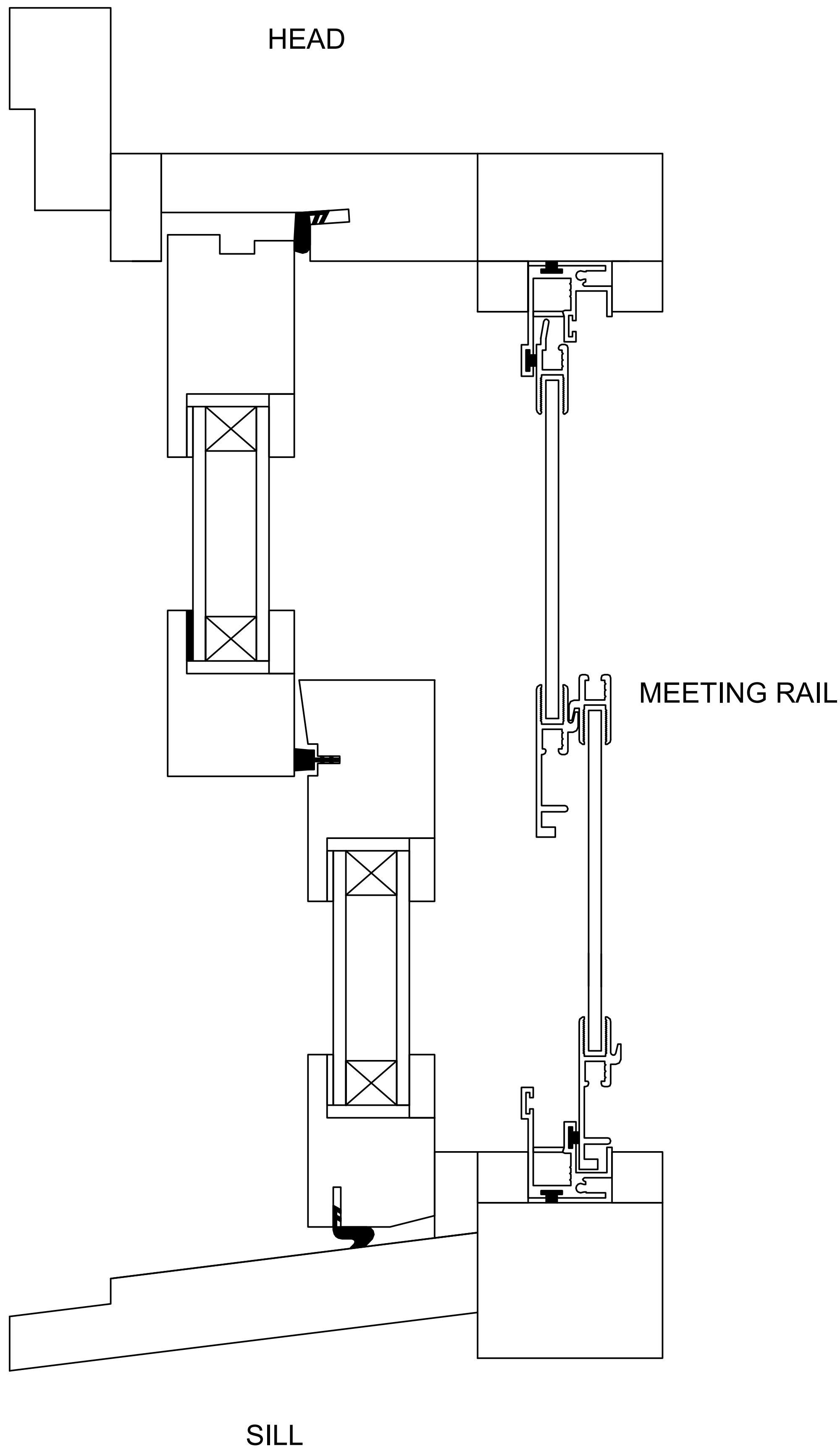
GENERIC ALUMINUM FIXED WINDOW

Dual Glazed



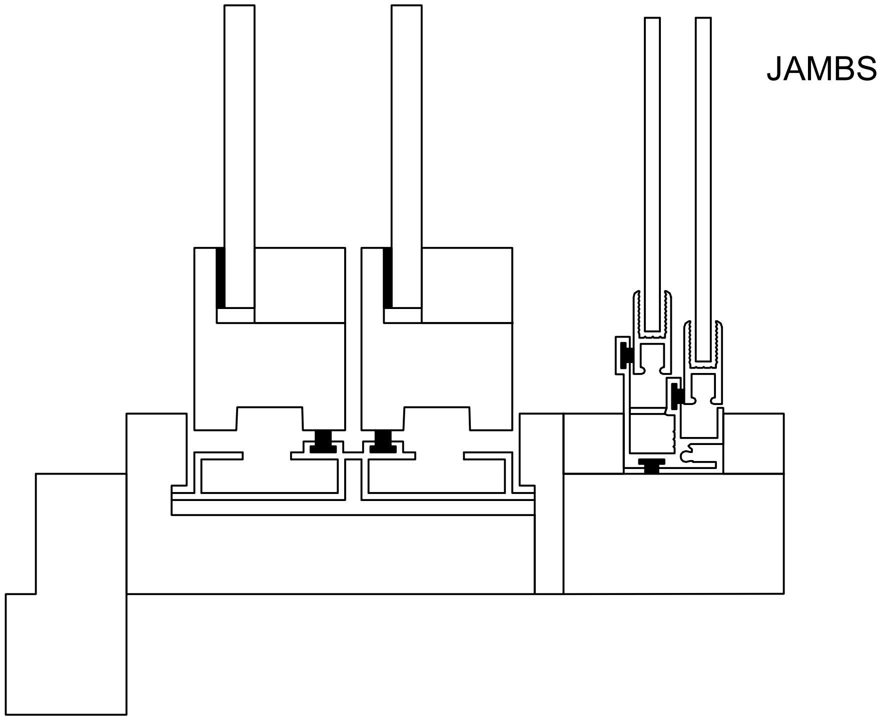
GENERIC WOOD DOUBLE HUNG WINDOW

Single Glazed



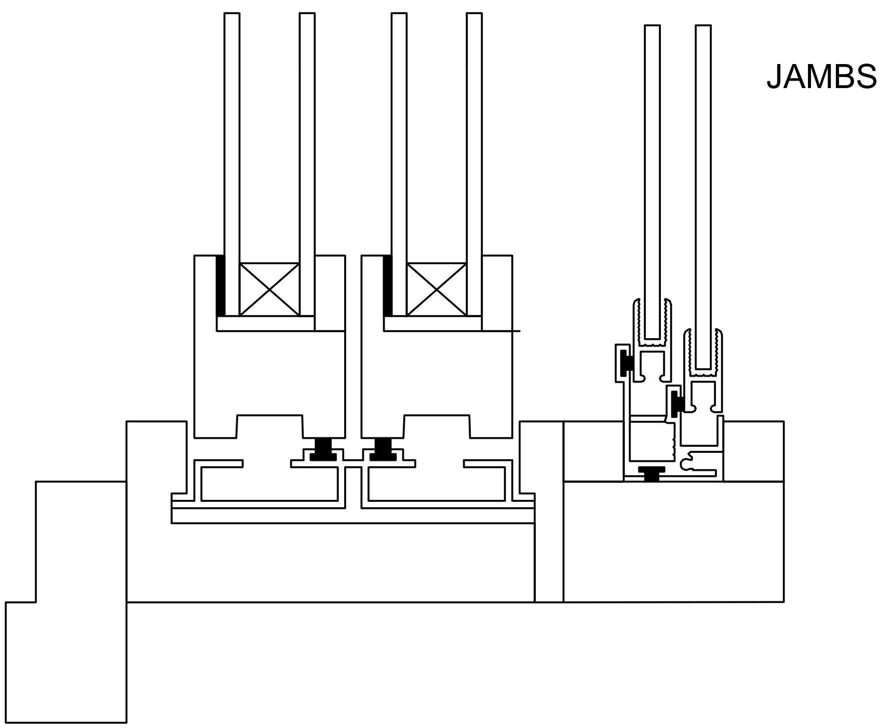
GENERIC WOOD DOUBLE HUNG WINDOW

Dual Glazed



GENERIC WOOD DOUBLE HUNG WINDOW

Single Glazed



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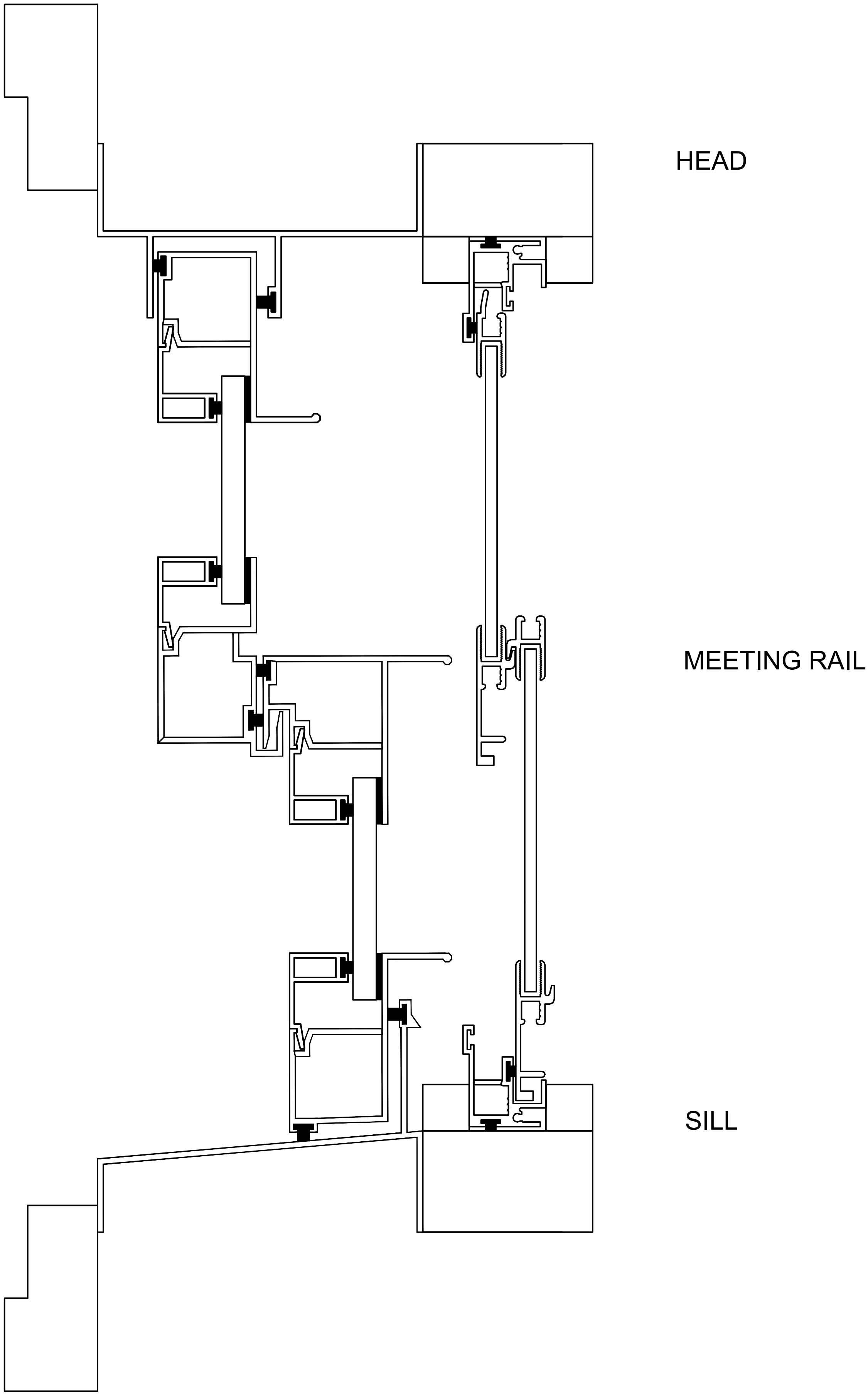

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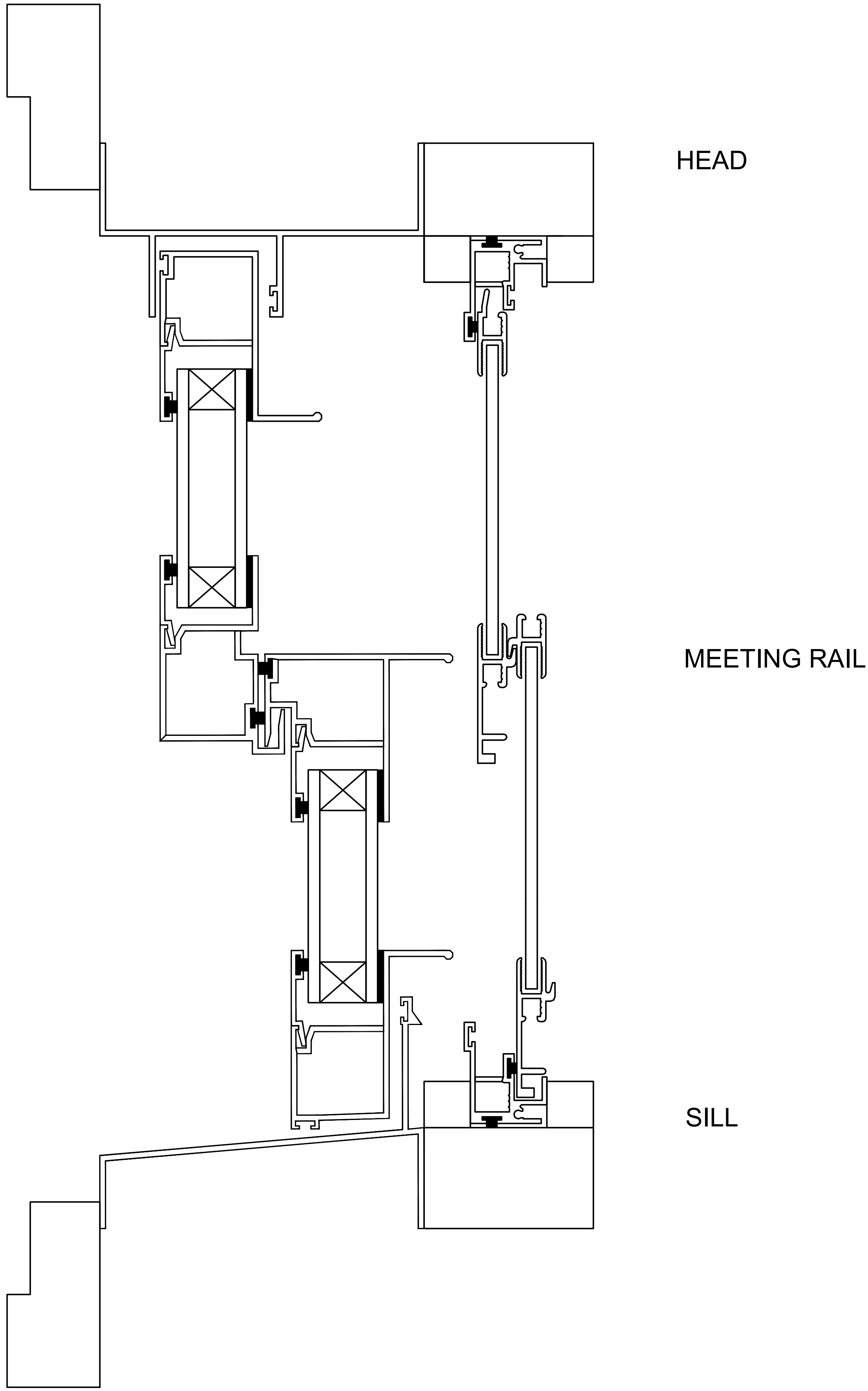
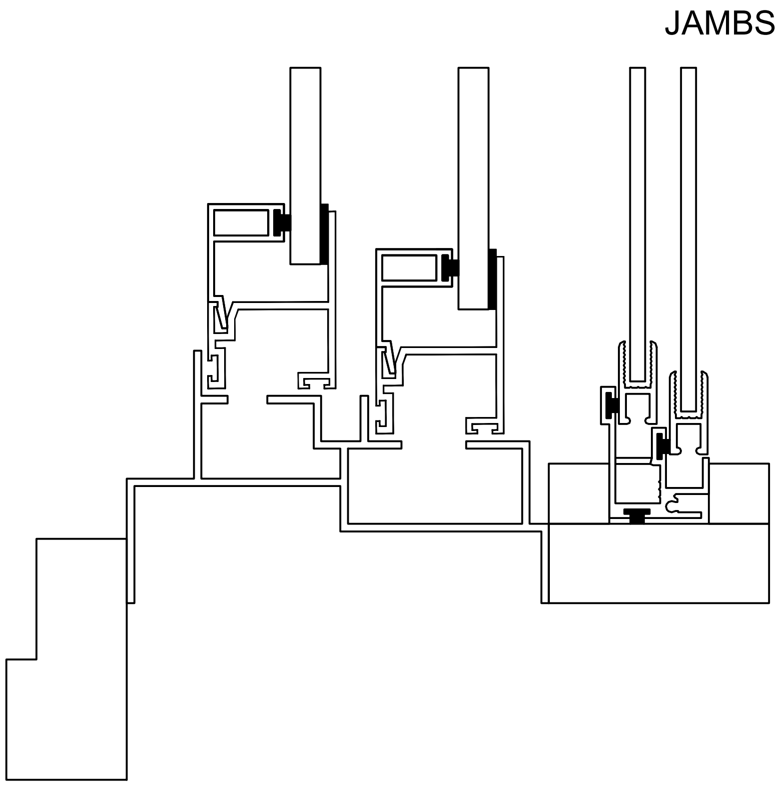
Single Glazed



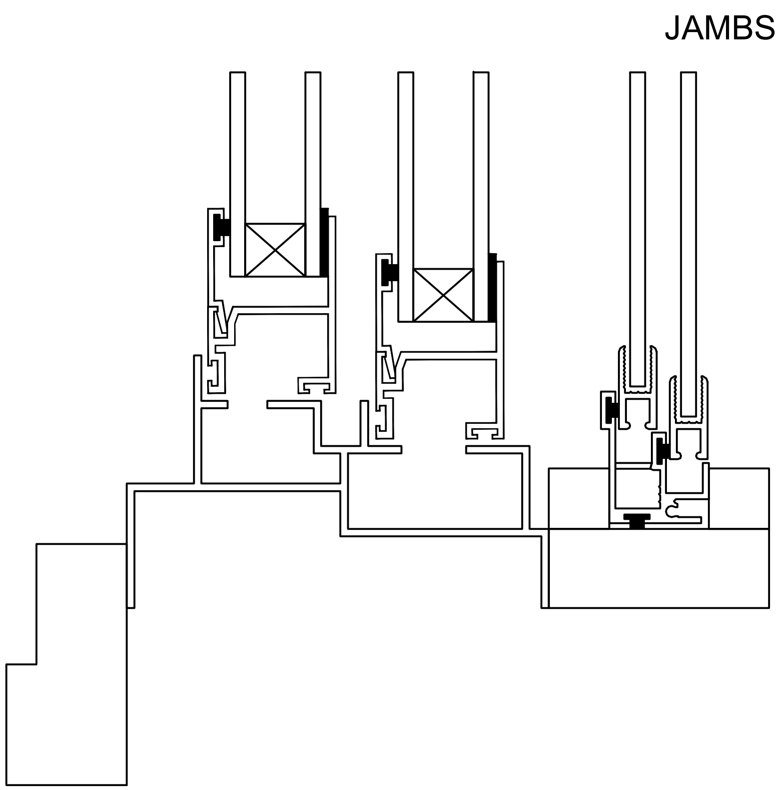
GENERIC ALUMINUM DOUBLE HUNG WINDOW

Dual Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW

Single Glazed



GENERIC ALUMINUM DOUBLE HUNG WINDOW

Dual Glazed

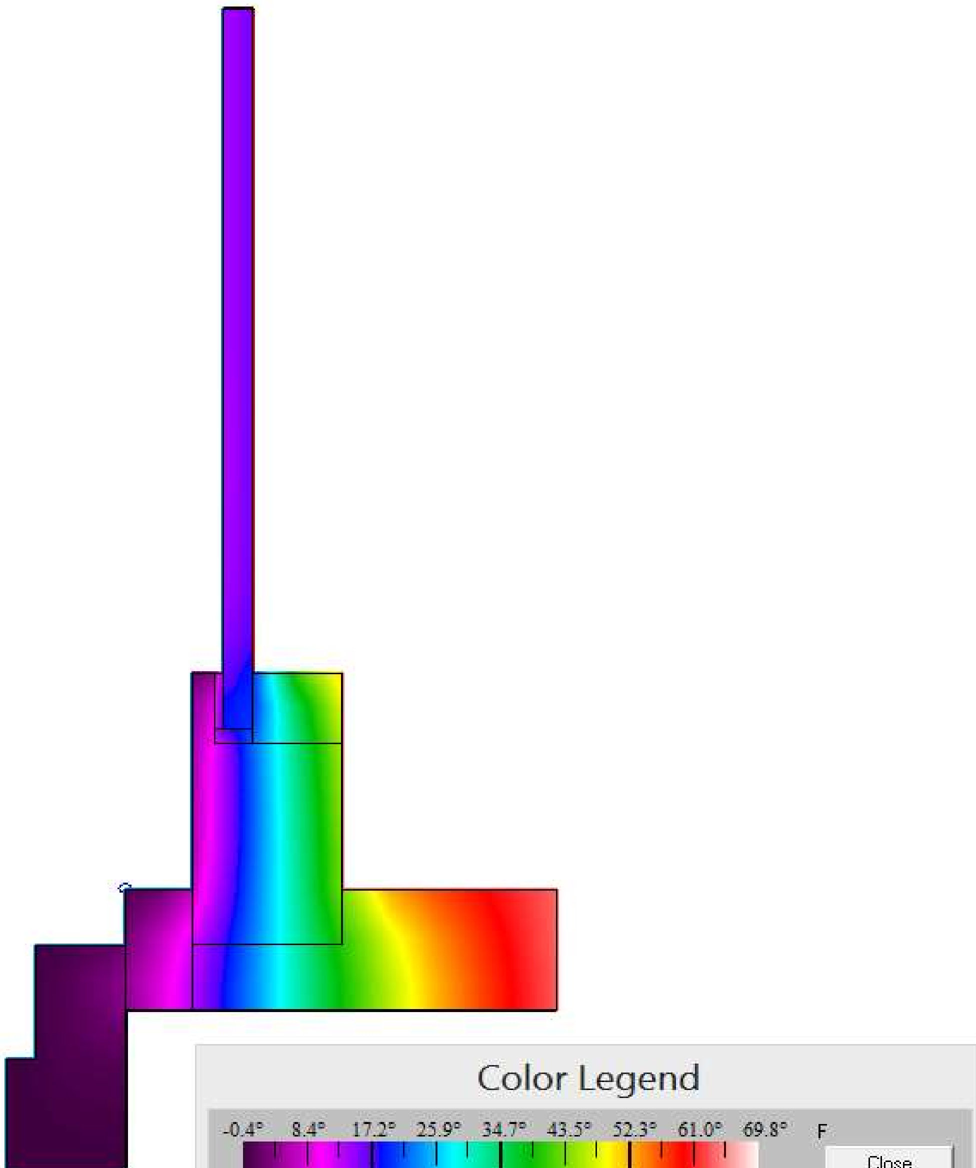
Color Temperature Plots

Appendix H

C2692.02-116-45

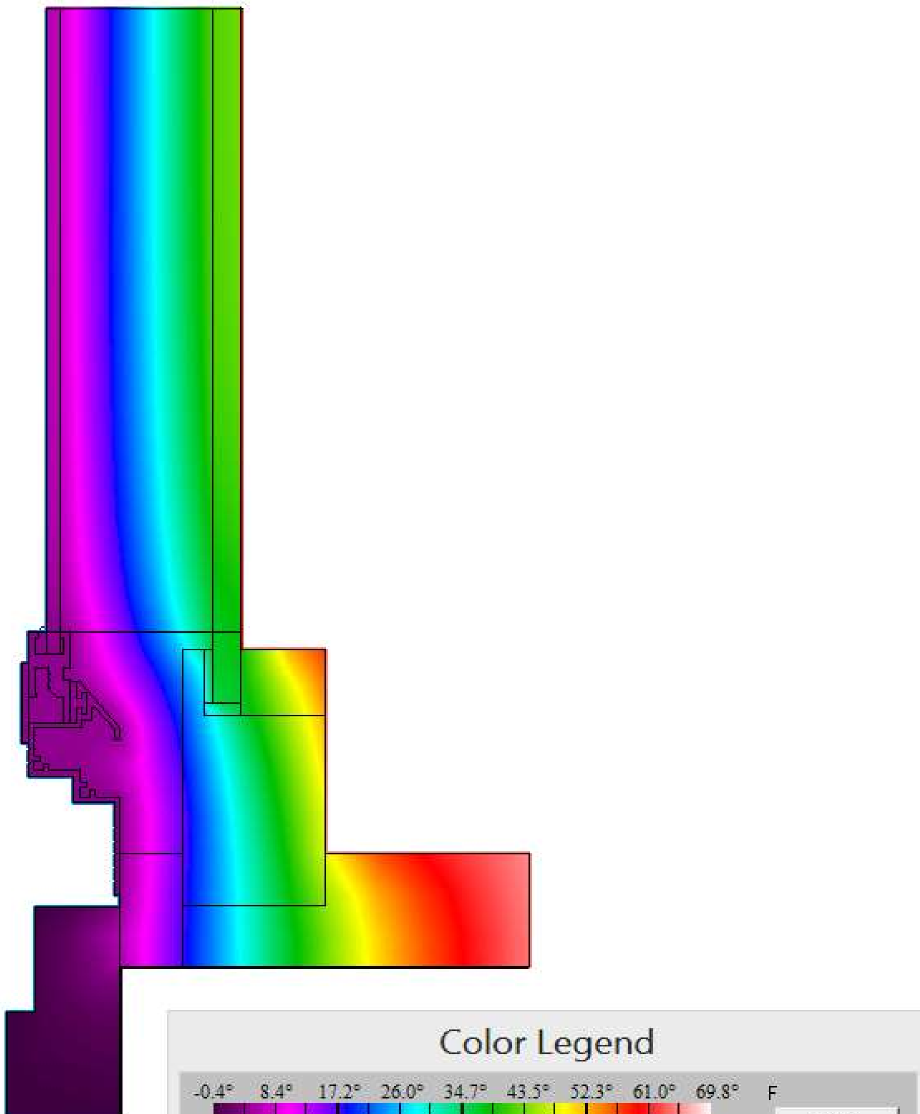
Wood Fixed - Single Glazed

Base Window



Wood Fixed - Single Glazed

Exterior Storm - Clear Glass

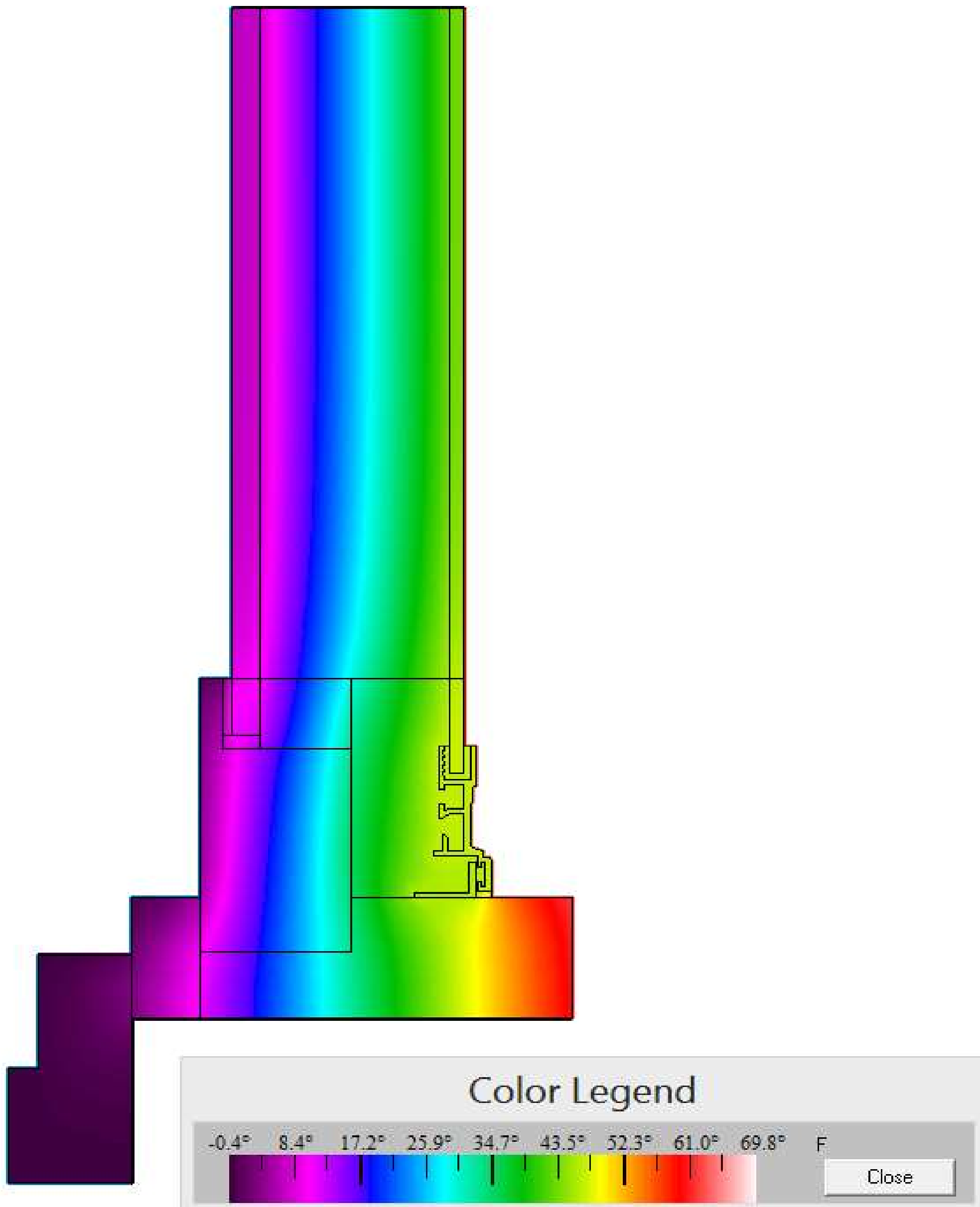


Wood Fixed - Single Glazed

Exterior Storm - Low-e Glass

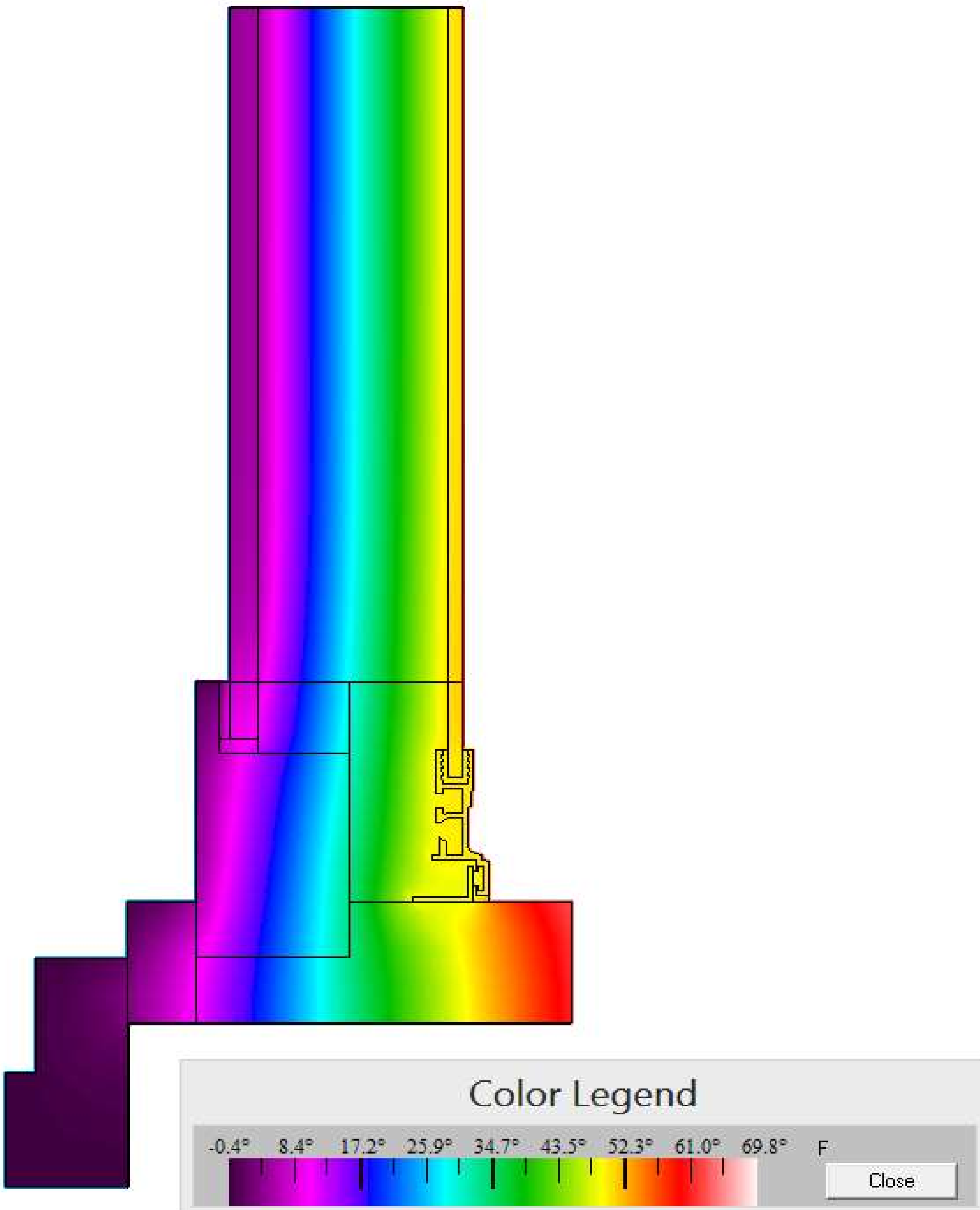
Wood Fixed - Single Glazed

Interior Storm - Clear Glass



Wood Fixed - Single Glazed

Interior Storm - Low-e Glass



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