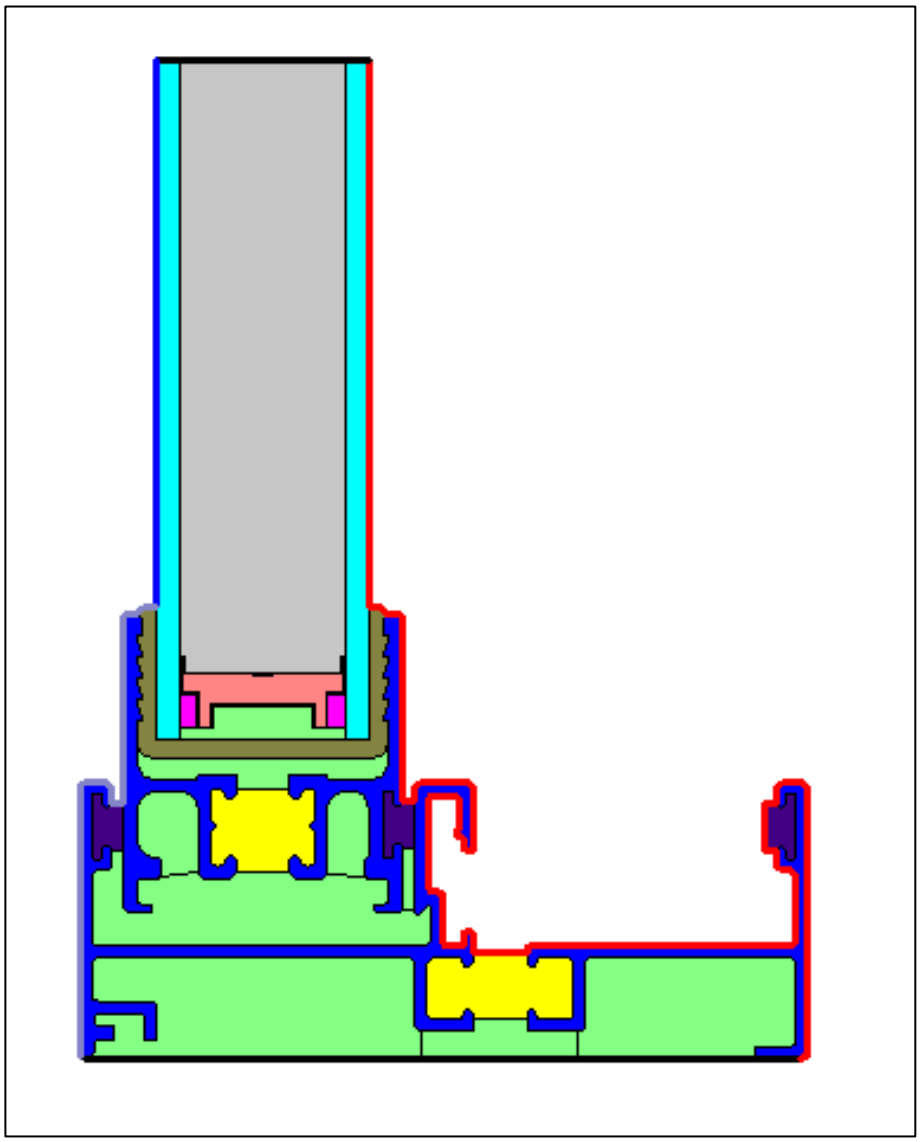
THERM 6.3 / WINDOW 6.3
NFRC Simulation Manual



Lawrence Berkeley National Laboratory

January 2011

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory
is an equal opportunity employer.

LBNL-48255

THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual

Robin Mitchell, Christian Kohler, Ling Zhu and Dariush Arasteh
Windows and Daylighting Group
Building Technologies Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, California 94720
http://windows.lbl.gov/software/software.html

John Carmody
College of Architecture and Landscape Architecture
University of Minnesota
Minneapolis, Minnesota

Charlie Huizenga
Center for Environmental Design Research
University of California
Berkeley, California

Dragan Curcija
Carli, Inc
Amherst, Massachusetts

January 2011

© Regents of the University of California

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, Building Technologies Program of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Contents

1. INTRODUCTION 1-1

1.1. Overview 1-1

2. FENESTRATION PRODUCTS 2-1

2.1. Overview 2-1
2.2 Fenestration Product Sash Operation 2-1
2.2.1. Projected or Hinged Windows 2-2
2.2.2. Sliding Windows 2-2
2.2.3. Sliding Glass Doors 2-2
2.2.4. French Doors and Folding Patio Doors 2-2
2.2.5. Skylights and Roof Windows 2-2
2.3 Performance Implications of Basic Fenestration Types 2-3
2.3.1. Hinged Windows 2-3
2.3.2. Sliding Windows 2-3
2.3.3. Sliding Glass and French Doors 2-4
2.4 Frame Materials 2-4
2.4.1. Wood Frames 2-4
2.4.2. Aluminum Frames 2-4
2.4.3. Vinyl Frames 2-5
2.4.4. Fiberglass and Engineered Thermoplastics 2-5
2.4.5. Wood Composites 2-5
2.4.6. Hybrid and Composite Frames 2-5
2.5 Basic Glazing Materials 2-5
2.5.1. Glass 2-6
2.5.2. Plastics 2-6
2.6 Improved Glazing Products 2-7
2.6.1. Tinted Glazing 2-7
2.6.2. Reflective Coatings and Films 2-8
2.6.3. Double Glazing 2-8
2.6.4. Glass Coatings and Tints in Double Glazing 2-8
2.6.5. Gap Width in Multiple Glazed Units 2-9
2.6.6. Divided Lights 2-9
2.6.7. Special Products 2-10
2.6.8. Multiple Panes or Films 2-10
2.6.9. Low-Emittance Coatings 2-11
2.6.9.1. Coating Placement 2-12
2.6.9.2. Coating Types 2-12
2.6.10. Gas Fills 2-13
2.7 Thermally Improved Edge Spacers 2-14

3. FENESTRATION HEAT TRANSFER BASICS.....3-1

3.1. Overview 3-1
3.2 Energy Flow Mechanisms 3-1
3.3 Temperature Driven Heat Transfer 3-2
3.3.1. Conduction 3-3
3.3.2. Convection 3-3
3.3.3. Radiation 3-3
3.3.4. U-factor 3-3
3.3.4.1. Total Product U-factor 3-4
3.3.4.2. Center-of-Glazing U-factor 3-4
3.3.4.3. Edge Effects 3-4
3.3.4.4. Frames and Sashes 3-4
3.3.4.5. Overall U-factor 3-4
3.4 Solar Heat Gain and Visible Transmittance 3-5
3.4.1. Determining Solar Heat Gain 3-5
3.4.2. Solar Heat Gain Coefficient (SHGC) 3-6
3.4.3. Visible Transmittance 3-6
3.5 Condensation Resistance 3-7
3.5.1. Impact of Glazing Type and Spacers on Condensation 3-8
3.5.2. Condensation Resistance 3-8
3.5.3. Outdoor Condensation 3-9
3.5.4. Condensation Between Glazings 3-9
3.6 Infiltration 3-9
3.7 Solar Properties of Glazing Materials 3-10
3.7.1. Transmittance 3-10
3.7.2. Reflectance 3-11
3.7.3. Absorptance 3-12
3.8 Infrared Properties of Glazing Materials (Emittance) 3-12

4. SUMMARY OF ALGORITHMS.....4-1

4.1. THERM and WINDOW Algorithms 4-1
4.1.1. WINDOW 4-1
4.1.2. THERM: 4-1
4.2 WINDOW Computational Method 4-1
4.3 THERM Computational Methods 4-3
4.4 Total Product Calculations 4-5
4.4.1. U-factor 4-5
4.4.2. Solar Heat Gain Coefficient (SHGC) 4-6
4.4.3. Visible Transmittance 4-6
4.4.4. Condensation Resistance 4-7

5. MODELING CENTER-OF-GLAZING WITH WINDOW.....5-1

5.1. Overview 5-1
5.2. Glass Library 5-2
5.2.1. Updating Glass Library from the IGDB 5-3
5.3 Glazing System Library -- Center-of-Glazing U-factor 5-4
5.3.1. Environmental Conditions 5-7

5.3.2. Coatings 5-9
5.3.3. Gas Fill 5-10
5.3.4. Laminated Glass / Applied Films 5-11
5.4 Solar Heat Gain Coefficient and Visible Transmittance 5-11

7. TOTAL PRODUCT CALCULATIONS USING WINDOW 7-1

7.1. Overview 7-1
7.2 Frame and Edge U-factors from THERM 7-1
7.3 Center-of-Glazing U-factors from WINDOW 7-3
7.4 Overall Product U-factor, SHGC, VT, and CR Calculations 7-5
7.4.1. Individual Product SHGC and VT (SHGC 0 & 1, VT 0 & 1) 7-7
7.4.2. Whole Product U-factor With Dividers 7-11
7.5 Project Databases 7-12

8. SPECIAL CASES 8-1

8.1. Overview 8-1
8.2 Meeting Rails 8-2
8.2.1. Modeling Meeting Rails 8-2
8.2.2. Steps for Meeting Rail U-factor Calculation 8-3
8.2.3. Steps for Meeting Rail Condensation Resistance Calculation 8-8
8.3 Dividers 8-10
8.3.1. Internal Dividers (Suspended Grilles) 8-10
8.3.1.3. Gas Filled Glazing Systems 8-18
8.3.2. Simulated Divided Lites 8-22
8.3.3. True Divided Lites 8-31
8.3.4. Door Caming 8-39
8.4 Storm Windows 8-45
8.4.1. Modeling Steps 8-45
8.4.2. Storm Window Example 8-47
8.4.3. Steps for Storm Window Condensation Resistance Calculation 8-51
8.5 Skylights 8-54
8.5.1. Skylight Modeling Steps 8-54
8.5.2. Skylight Mounting Details 8-56
8.5.3. Example Flush Mounted Skylight Problem 8-57
8.5.4. Domed Skylights / Glass Block 8-67
8.5.5. Sloped Glazing Systems with Large Gaps: 8-69
8.6 Tubular Daylighting Devices 8-70
8.6.6. Example Tubular Devices Problem 8-74
8.6.7. Example: Tubular Device Problem With the Double-Glazed Diffuser Plate 8-83
8.7 Doors 8-89
Boundary Conditions for Steel Skin Doors 8-89
8.8 Spacers 8-90
8.8.1. Overview 8-90
8.8.2. Linking Glazing Cavity properties (imported from WINDOW) for Open Spacers 8-91
8.9 Non Continuous Thermal Bridge Elements 8-93
8.9.3. Modeling Steps 8-93
8.9.4. Equations 8-94

8.9.5. Example 1: Bolts in Curtain Wall 8-95
8.9.6. Example 2: Thermally slotted cross-section 8-99
8.9.7. Example 3: Skip-and-debridge: 8-102
8.10 Site Built fenestration products
(Curtain Walls, Window Walls and Sloped Glazing) 8-105
8.10.1. Curtain Walls, Window Walls, and Sloped Glazing 8-105
8.10.2. Curtain Wall Modeling Procedure 8-107
8.11. Retractable Venetian Blinds in Fully Open Position 8-119
8.11.3. Venetian Blind Fully Retracted
Inside a Double-Glazed System 8-120
8.11.4. Venetian Blind Fully Retracted Between a
Double-Glazed System and a Third Glazing Layer 8-125
8.12 Garage / Rolling Doors 8-130
8.12.1. Sectional Garage Door (Insulated and Non-Insulated) 8-130
8.12.2. Rolling Door 8-137
8.13. Creating a Laminate in Optics for NFRC 8-143
8.13.1. Overview 8-143
8.13.2. Laminate Interlayer Data 8-144
8.13.3. Constructing a Laminate in Optics5 8-145
8.14. Creating an Applied Film Layer in Optics for NFRC Certification 8-157
8.14.1. Overview 8-157
8.14.2. Film Data 8-158
8.14.3. Using this Procedure for NFRC 200: 8-159
8.14.4. Creating a Layer with an Applied Film in Optics5 8-159
8.15. Framed Intermediate Pane 8-167
8.15.1. Overview 8-167
8.15.2. THERM Modeling Details 8-168

9. SAMPLE PROBLEMS 1

9.1. Overview 1
9.2 Problem 1: Vinyl Fixed Window 2
9.2.1. Description 2
9.2.2. Glazing Matrix 2
9.2.3. Center-of-glazing Modeling (WINDOW) 3
9.2.4. Edge-of-glazing and Frame Modeling for U-Factor (THERM) 4
9.2.5. Total Product U-Factor 9
9.2.6. Individual Product SHGC and VT using
SHGC 0 & 1 and VT 0 & 1 11
9.2.7. Drawings Vinyl Fixed Window 14
9.3 Problem 2: Aluminum Horizontal Slider Window 16
9.3.1. Description 16
9.3.2. Glazing Matrix 17
9.3.3. Center-of-glazing Modeling (WINDOW) 17
9.3.4. Edge-of-glazing and Frame Modeling (THERM) 18
9.3.5. Total Product U-Factor 27
9.3.6. Individual Product SHGC and VT using
SHGC 0 & 1 and VT 0 & 1 28
9.3.7. Drawings for Aluminum Horizontal Slider 30
9.4 Problem 3: Skylight 35
9.4.1. Description 35

9.4.2. Glazing Matrix 35
9.4.3. Center-of-glazing Modeling (WINDOW).....36
9.4.4. Edge-of-glazing and Frame Modeling (THERM).....37
9.4.5. Total Product U-Factor.....41
9.4.6. Individual Product SHGC and VT using SHGC 0 & 1 and VT 0 & 1.....42
9.4.7. Skylight Drawings. 45
9.5 Problem 4: Door 46
9.5.1. Description.....46
9.5.2. Glazing Matrix 46
9.5.3. Center-of-Glazing Modeling (WINDOW).....47
9.5.4. Edge-of-glazing and Frame Modeling for U-Factor (THERM) 48
9.5.5. Total Product U-Factor, SHGC and VT 59
9.5.6. Wood Stile and Rail Door Drawings. 59

10. ACKNOWLEDGEMENTS.....10-1

APPENDIX A. The Application of ISO 15099 to NFRC 100 and 200 ..... A-1

APPENDIX B. References B-1

1. INTRODUCTION

1.1. Overview

This document, the *THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual*, discusses how to use the THERM and WINDOW programs to model products for NFRC certified simulations and assumes that the user is already familiar with those programs. In order to learn how to use these programs, it is necessary to become familiar with the material in both the *THERM User's Manual* and the *WINDOW User's Manual*.

This manual covers the modeling procedures for products that are allowed to be certified using the simulation method as covered in the appropriate NFRC standards documents. There are modeling capabilities in WINDOW 6.3 and THERM 6.3 that are not covered in the NFRC documents, and these cannot be used for NFRC product certification.

In general, this manual references the User's Manuals rather than repeating the information.

If there is a conflict between either of the *User Manual* and this *THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual*, the *THERM 6.3 / WINDOW 6.3 NFRC Simulation Manual* takes precedence.

If this manual is in conflict with any NFRC standards, the standards take precedence. For example, if samples in this manual do not follow the current taping and testing NFRC standards, the standards not the samples in this manual, take precedence. NFRC periodically publishes technical interpretations to clarify or provide modeling techniques, rules, and procedures for simulating products in THERM and WINDOW. Refer to the NFRC website to review all technical interpretations.

2. FENESTRATION PRODUCTS

2.1. Overview

Much of the information in this chapter is taken from *Residential Windows: A Guide to New Technologies and Energy Performance* by John Carmody, Stephen Selkowitz, and Lisa Heschong.

Although glazing materials are the focus of much of the innovation and improvement in fenestration products, the overall performance of any unit is determined by the complete fenestration product assembly. The assembly includes the operating and fixed parts of the product frame as well as associated hardware and accessories. These are defined and illustrated at the beginning of this section. The next two sections address the different options available for sash operation and new advances in frame materials designed to improve product energy efficiency. Proper installation is an important aspect of their performance as well. The final section of this chapter discusses other installation issues.

2.2 Fenestration Product Sash Operation

There are numerous operating types available for fenestration products. Traditional operable types include the projected or hinged types such as casement, awning, and hopper, and the sliding types such as double- and single-hung and horizontal sliding. In addition, the current market includes storm windows, sliding and swinging patio doors, skylights and roof-mounted (i.e., sloping) windows, and systems that can be added to a house to create bay or bow windows, miniature greenhouses, or full sun rooms.

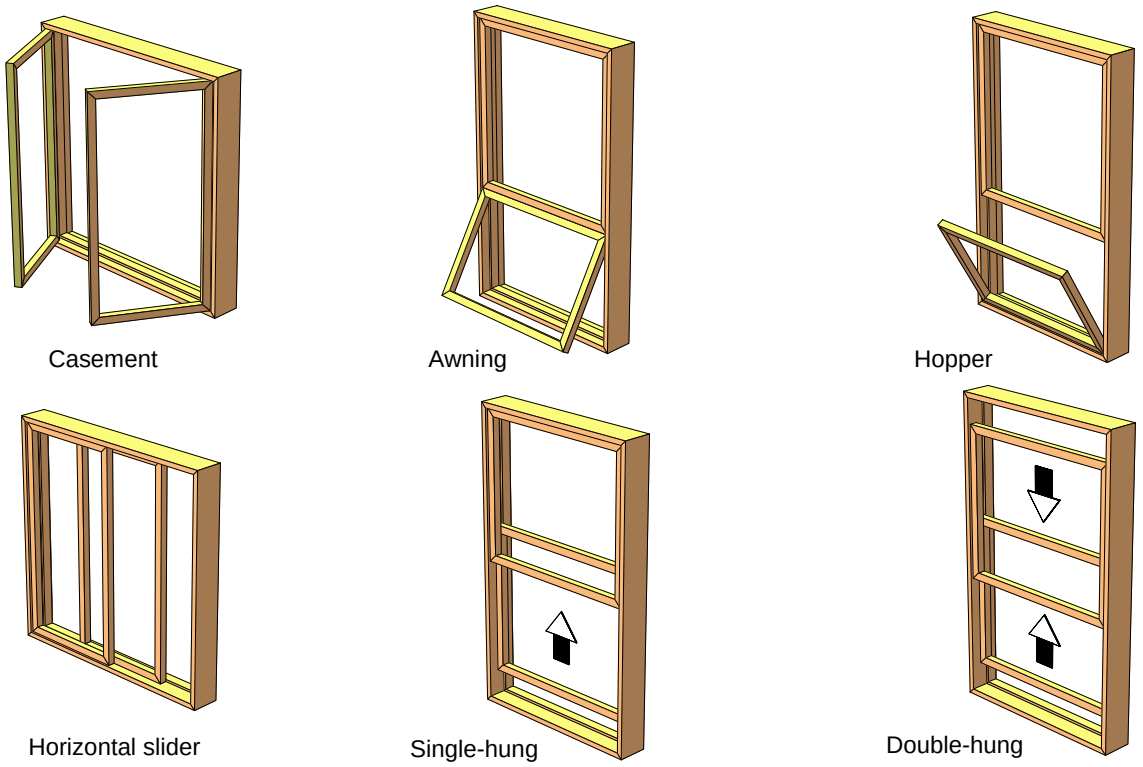


Figure 2-1. Fenestration Operator Types

2.2.1. Projected or Hinged Windows

Hinged windows include casements, awnings, and hoppers—hinged at the side, top, and bottom, respectively. Some manufacturers also make pivoting and combination windows that allow for easier cleaning of the exterior surfaces. Hinged windows, especially casements, project outward, providing significantly better ventilation than sliders of equal size. Because the sash protrudes from the plane of the wall, it can be controlled to catch passing breezes, but screens must be placed on the interior side. Virtually the entire casement window area can be opened, while sliders are limited to less than half of the window area.

2.2.2. Sliding Windows

Sliders are the most common type of windows and include horizontal sliders and single-hung and double-hung windows. Ventilation area can vary from a small crack to an opening of one-half the total glass area. Screens can be placed on the exterior or interior of the window unit.

In double-hung or double-sliding units, both sashes can slide. In double-sliding units, the same net amount of glass area can be opened for ventilation as in single sliders, but it can be split between the top and bottom or two ends of the window for better control of the air flow.

2.2.3. Sliding Glass Doors

Sliding glass doors (patio doors) are essentially big sliding windows. As extremely large expanses of glass, patio doors exaggerate all of the issues related to comfort and energy performance. Since the proportion of glass to frame is very high for a glass sliding door, the selection of high-performance glass can have significant benefits.

2.2.4. French Doors and Folding Patio Doors

French doors and folding glazed doors are growing in popularity. A basic double French door consists of two hinged doors with no center mullion, resulting in a 1.5 to 1.8 m (5- to 6-foot) wide opening. Folding doors are typically made of pairs of hinged doors, so that a double folding door with two pairs of doors can create an opening of 3.7 m (12 feet) or more.

2.2.5. Skylights and Roof Windows

The vast majority of skylights are permanently fixed in place, mounted on a curb above a flat or sloped roof. However, hatch-style skylights that can be opened with an extended crank, push latch, or remote control motor are becoming more common. Some skylights have a domed profile made of one or two layers of tinted or diffusing plastic.

A roof window is a hybrid between a skylight and a standard window. They have become increasingly popular as homeowners and designers seek to better utilize space in smaller houses by creating habitable rooms under sloping roofs. They are glazed with glass rather than plastic and are available with most of the glazing and solar control options of standard windows. Both fixed and operable versions are available, and the operable roof windows can be opened manually or by a motorized system. In addition, some manufacturers offer special venting mechanisms that allow some ventilation air flow without actually opening the window. Operable skylights or vents allow hot air that rises to the ceiling level to be effectively exhausted from the space.

Skylights and roof windows present a special case for insulating around windows because they are typically set into the thickest, most heavily insulated framing in the house, and they must also meet much more stringent conditions for shedding water. In order to create a positive water flow around them, skylights are commonly mounted on “curbs” set above the roof plane. These curbs, rising 15 to 30 centimeters (6 to 12

inches) above the roof, create additional heat loss surfaces, right where the warmest air of the house tends to collect. Ideally, they should be insulated to the same level as the roof. In practice, it is often difficult to achieve insulation levels much above R-11. Some manufacturers provide curbs prefabricated out of a rigid insulating foam, which can be further insulated at the site.

Roof windows, mounted in a sloping roof, often include a metal flashing system. If this metal flashing is in contact with a metal window frame, it can create additional surfaces for conducting heat. Thus, as with thermally broken aluminum windows, care should be taken to ensure a thermal separation between the cold outer metal surfaces and metal parts of the window frame that are exposed to the warm interior air.

2.3 Performance Implications of Basic Fenestration Types

There are subtle performance differences between a fixed and operable fenestration product that fills an identical rough opening. The fixed unit will typically have a smaller fraction of frame and proportionately more glass than the similar operable unit. Thus, fixed products with high-performance glass will have a better, lower U-factor, but a higher SHGC due to a smaller frame area and larger glass area. Fixed products have very low infiltration rates, but then they also do not provide natural ventilation and do not satisfy building code requirements for fire egress.

For operating fenestration products, the type of operation has little direct effect on the U-factor or SHGC of the unit, but it can have a significant effect on the air infiltration and ventilation characteristics. Operation can be broken into two basic types: sliding products and hinged products. The comments below are a general characterization of American fenestration products; however, they may not apply to a specific product made by a given manufacturer.

2.3.1. Hinged Windows

Hinged windows such as casements, awnings, and hoppers generally have lower air leakage rates than sliding windows from the same manufacturer because the sash closes by pressing against the frame, permitting the use of more effective compression-type weatherstripping. In most types, the sash swings closed from the outside, so that additional external wind pressure tends to push the sash more tightly shut. Hinged windows require a strong frame to encase and support the projecting sash. Also, because projecting-type sashes must be strong enough to swing out and still resist wind forces, the stiffer window units do not flex as readily in the wind. In addition, hinged windows have locking mechanisms that force the sash against the weatherstripping to maximize compression. These design details tend to reduce air infiltration of hinged windows in comparison to sliders.

2.3.2. Sliding Windows

Sliding windows, whether single-hung, double-hung, or horizontal sliders, generally have higher air leakage rates than projecting or hinged windows. Sliding windows typically use a brush-type weatherstripping that allows the sash to slide past. This type is generally less effective than the compression gaskets found in projecting windows. The weatherstrip effectiveness also tends to be reduced over time due to wear and tear from repeated movement of the sliding sash. The frames and sashes of sliding units can be made with lighter, less rigid frame sections since they only need to support their own weight. This lightness may permit the sliding frames to flex and can allow more air leakage under windy conditions. Manufacturers can choose to engineer greater stiffness in their products by design and material selection.

Slider window performance can also be improved with latching mechanisms that compress the sash to the fixed frame and by the addition of compression weatherstripping at the head and sill of double-hung windows or the end jamb of horizontal sliders.

2.3.3. Sliding Glass and French Doors

As previously noted, sliding doors are essentially big sliding windows. However, they are more complicated because of their size and weight and because the sill is also a door threshold, which must keep water out while allowing easy passage of people and objects. The threshold is typically the most difficult part of the frame to weatherstrip effectively.

French doors benefit from being much more like traditional doors than sliding doors. French doors can use weatherstripping and operating hardware designed for similar non-glazed doors. However, when there are large openings with multiple hinged doors, it is more difficult to positively seal the joints between door leaves and to create the stiffness that will resist infiltration.

2.4 Frame Materials

The material used to manufacture the frame governs the physical characteristics of the fenestration product, such as frame thickness, weight, and durability, but it also has a major impact on the thermal characteristics of the product. Increasingly, manufacturers are producing hybrid or composite sash and frames, in which multiple materials are selected and combined to best meet the overall required performance parameters. Thus, a simple inspection of the inner or outer surface of the frame is no longer an accurate indicator of the total material or its performance. Since the sash and frame represent from 10 to 30 percent of the total area of the fenestration unit, the frame properties will significantly influence the total product performance.

2.4.1. Wood Frames

Wood fenestration products are manufactured in all configurations, from sliders to swinging windows. Wood is favored in many residential applications because of its appearance and traditional place in house design.

A variation of the wooden product is to clad the exterior face of the frame with either vinyl or aluminum, creating a permanent weather-resistant surface. Clad frames thus have lower maintenance requirements, while retaining the attractive wood finish on the interior.

From a thermal point of view, wood-framed products perform well. The thicker the wood frame, the more insulation it provides. Wood-framed fenestration products typically exhibit low heat loss rates.

However, metal cladding, metal hardware, or the metal reinforcing often used at corner joints can degrade the thermal performance of wood frames. If the metal extends through the fenestration product from the cold side to the warm side of the frame, it creates a thermal short circuit, conducting heat more quickly through that section of the frame.

2.4.2. Aluminum Frames

The biggest disadvantage of aluminum as a fenestration product frame material is its high thermal conductance. It readily conducts heat, greatly raising the overall U-factor of a fenestration unit. Because of its high thermal conductance, the thermal resistance of an aluminum frame is determined more by the amount of surface area of the frame than by the thickness or the projected area, as with other frame materials. Thus, an aluminum frame profile with a simple compact shape will perform much better than a profile with many fins and undulations.

In cold climates, a simple aluminum frame can easily become cold enough to condense moisture or frost on the inside surfaces of fenestration product frames. Even more than the problem of heat loss, the condensation problem spurred development of a more insulating aluminum frame.

The most common solution to the heat conduction problem of aluminum frames is to provide a “thermal break” by splitting the frame components into interior and exterior pieces and use a less conductive material

to join them. There are many designs available for thermally broken aluminum frames. The most prevalent technique used in residential fenestration products is called "pouring and debridging." The frame is first extruded as a single piece with a hollow trough in the middle. This is filled with a plastic that hardens into a strong intermediate piece. The connecting piece of aluminum is then milled out, leaving only the plastic to join the two halves of aluminum. Functionally, the resulting piece is cut, mitered, and assembled like a simple aluminum extrusion. Thermally, the plastic slows the heat flow between the inside and outside. There are other manufacturing techniques for producing a thermal break (such as crimped-in-place polymer strips), but the thermal results are similar.

2.4.3. Vinyl Frames

Plastics are relative newcomers as fenestration product frame materials in North America. Vinyl, also known as polyvinyl chloride (PVC), is a versatile material with good insulating value.

The thermal performance of vinyl frames is roughly comparable to wood. Large hollow chambers within the frame can allow unwanted heat transfer through convection currents. Creating smaller cells within the frame reduces this convection exchange, as does adding an insulating material. Most manufacturers are conducting research and development to improve the insulating value of their vinyl fenestration product assemblies.

2.4.4. Fiberglass and Engineered Thermoplastics

In addition to vinyl fenestration products two other polymer-based technologies have become available, fiberglass and thermoplastics. Frames can be made of glass-fiber-reinforced polyester, or fiberglass, which is pultruded into lineal forms and then assembled into fenestration products. These frames are dimensionally stable and have good insulating value by incorporating air cavities (similar to vinyl).

2.4.5. Wood Composites

Most people are familiar with composite wood products, such as particle board and laminated strand lumber, in which wood particles and resins are compressed to form a strong composite material. The wood fenestration product industry has now taken this a step further by creating a new generation of wood/polymer composites that are extruded into a series of lineal shapes for frame and sash members. These composites are stable, and have the same or better structural and thermal properties as conventional wood, with better moisture resistance and more decay resistance. They can be textured and stained or painted much like wood. They were initially used in critical elements, such as sills and thresholds in sliding patio doors, but are now being used for entire units. This approach has the added environmental advantage of reusing a volume of sawdust and wood scrap that would otherwise be discarded.

2.4.6. Hybrid and Composite Frames

Manufacturers are increasingly turning to hybrid frame designs that use two or more of the frame materials described above to produce a complete fenestration product system. The wood industry has long built vinyl- and aluminum-clad products to reduce exterior maintenance needs. Vinyl manufacturers and others offer interior wood veneers to produce the finish and appearance that many homeowners desire. Split-sash designs may have an interior wood element bonded to an exterior fiberglass element.

2.5 Basic Glazing Materials

Two basic materials are used for fenestration product glazing: glass, which is by far the most common, and plastics, which have many specialized applications.

2.5.1. Glass

Traditionally, fenestration products have been made of clear glass. Most residential-grade clear glass today is produced with the float technique in which the glass is "floated" over a bed of molten tin. This provides extremely flat surfaces, uniform thicknesses, and few if any visual distortions. The glass has a slight greenish cast, due to iron impurities, but this is generally not noticeable except from the edge. An even higher-quality glass with reduced iron content eliminates the greenness and also provides a higher solar energy transmittance. This is commonly called "water-white glass."

Obscure glasses still transmit most of the light but break up the view in order to provide privacy. This effect is generally achieved either with decorative embossed patterns or with a frosted surface that scatters the light rays.

By adding various chemicals to glass as it is made, glass can be produced in a wide variety of colors. Glass colors are typically given trade names, but the most frequently used colors can be generally described as clear, bronze, gray, and blue-green. After clear glass, the gray glasses are most commonly used in residential construction, as they have the least effect on the perceived color of the light. Tinted glass is discussed later in this chapter.

The mechanical properties of glass can be altered, as well as its basic composition and surface properties. Heat-strengthening and tempering make glass more resistant to breakage. Heat-strengthened glass is about twice as strong as standard glass. Tempered glass is produced by reheating and then quickly chilling the glass. It breaks into small fragments, rather than into long, possibly dangerous shards. Laminated glass is a sandwich of two outer layers of glass with a plastic inner layer that holds the glass pieces together in the event of breakage. Fully tempered and laminated glass is required by building codes in many door and fenestration product applications.

2.5.2. Plastics

Several plastic materials have been adapted for use as glazing materials. Their primary uses are fenestration products with special requirements and skylights.

The following list of plastic glazing materials covers the major types of plastic glazing materials and compares their general properties:

- Clear acrylic is widely available and relatively inexpensive. It is available in various tints and colors. It has excellent visible light transmittance and longevity. However, it is softer than glass, which makes it vulnerable to scratching.
- Frosted acrylic is like clear acrylic, except that it diffuses light and obscures the view. It comes in varying degrees of light transmittance. Most bubble skylights are made of frosted acrylic.
- Clear polycarbonate is like acrylic sheet, but it is harder and tougher, offering greater resistance to scratching and breakage. It is more expensive than acrylic.
- Fiber-reinforced plastic is a tough, translucent, flexible sheet material with good light-diffusing properties. Short lengths of fiberglass are embedded in a polymer matrix to form flat or ribbed sheets. Stiff, insulating, translucent panels are created by bonding double layers to a metal frame and adding fiberglass insulation. It is also formed into corrugated sheets as a translucent roofing material. Surface erosion may shorten its useful life.
- Extruded multicell sheet, usually made with acrylic or polycarbonate plastic, is a transparent or tinted plastic extruded into a double- or triple-wall sheet with divider webs for stiffness, insulating value, and light diffusion.
- Polyester is a thin film used to carry specialized coatings and/or to divide the air space between two layers of glass into multiple air spaces. Highly transparent, it is protected from abuse and weathering by

the two exterior glass layers. It can also be used in tinted or coated forms as film that is glued to the inner surface of existing fenestration products for retrofitting applications.

2.6 Improved Glazing Products

There are three fundamental approaches to improving the energy performance of glazing products:

1. Alter the glazing material itself by changing its chemical composition or physical characteristics. An example of this is tinted glazing. The glazing material can also be altered by creating a laminated glazing.
2. Apply a coating to the glazing material surface. Reflective coatings and films were developed to reduce heat gain and glare, and more recently, low-emittance and spectrally selective coatings have been developed to improve both heating and cooling season performance.
3. Assemble various layers of glazing and control the properties of the spaces between the layers. These strategies include the use of two or more panes or films, low-conductance gas fills between the layers, and thermally improved edge spacers.

Two or more of these approaches may be combined. Each of these improvements to the glazing is discussed below

2.6.1. Tinted Glazing

Both plastic and glass materials are available in a large number of tints. The tints absorb a portion of the light and solar heat. Tinting changes the color of the fenestration product.

Tinted glazings retain their transparency from the inside, so that the outward view is unobstructed. The most common colors are neutral gray, bronze, and blue-green, which do not greatly alter the perceived color of the view and tend to blend well with other architectural colors. Many other specialty colors are available for particular aesthetic purposes.

Tinted glass is made by altering the chemical formulation of the glass with special additives. Its color changes with the thickness of the glass and the addition of coatings applied after manufacture. Every change in color or combination of different glass types affects transmittance, solar heat gain coefficient, reflectivity, and other properties. Glass manufacturers list these properties for every color, thickness, and assembly of glass type they produce.

Tinted glazings are specially formulated to maximize their absorption across some or all of the solar spectrum and are often referred to as “heat-absorbing.” All of the absorbed solar energy is initially transformed into heat within the glass, thus raising the glass temperature. Depending upon climatic conditions, up to 50 percent of the heat absorbed in a single layer of tinted glass may then be transferred via radiation and convection to the inside. Thus, there may be only a modest reduction in overall solar heat gain compared to other glazings.

There are two categories of tinted glazing: the traditional tints that diminish light as well as heat gain, and spectrally selective tints that reduce heat gain but allow more light to be transmitted to the interior. The traditional tinted glazing often forces a trade-off between visible light and solar gain. For these bronze and gray tints, there is a greater reduction in visible light transmittance than there is in solar heat gain coefficient. This can reduce glare by reducing the apparent brightness of the glass surface, but it also reduces the amount of daylight entering the room.

To address the problem of reducing daylight with traditional tinted glazing, glass manufacturers have developed new types of tinted glass that are “spectrally selective.” They preferentially transmit the daylight portion of the solar spectrum but absorb the near-infrared part of sunlight. This is accomplished by adding special chemicals to the float glass process. Like other tinted glass, they are durable and can be used in both monolithic and multiple-glazed fenestration product applications. These glazings have a light blue or green

tint and have visible transmittance values higher than conventional bronze- or gray-tinted glass, but have lower solar heat gain coefficients. Because they are absorptive, they are best used as the outside glazing in a double-glazed unit. They can also be combined with Low-E coatings to enhance their performance further.

2.6.2. Reflective Coatings and Films

As the solar heat gain is lowered in single-pane tinted glazings, the visible light transmission drops even faster, and there are practical limits on how low the solar heat gain can be made using tints. If larger reductions are desired, a reflective coating can be used to lower the solar heat gain coefficient by increasing the surface reflectivity of the material. These coatings usually consist of thin metallic layers. The reflective coatings come in various metallic colors (silver, gold, bronze), and they can be applied to clear or tinted glazing (the substrate). The solar heat gain of the substrate can be reduced a little or a lot, depending on the thickness and reflectivity of the coating, and its location on the glass.

As with tinted glazing, the visible light transmittances of reflective glazings are usually reduced substantially more than the solar heat gain.

2.6.3. Double Glazing

Storm windows added onto the outside of window frames during the stormy winter season were the first double-glazed fenestration products. They reduce infiltration from winter winds by providing a seal around all the operating sash and they improve the insulating value of the glazing as well.

When manufacturers began to experiment with factory-sealed, double-pane glass to be installed for year-round use, they encountered a number of technical concerns, such as how to allow for different thermal movement between the two panes, how to prevent moisture from forming between the panes and condensing on an inaccessible surface, and how to allow for changes in atmospheric pressure as the assembly was moved from factory to installation site. These issues have been successfully addressed over the years with a variety of manufacturing techniques and material selections.

When double-glass units first came on the market, the two glass layers were often fused around the perimeter to make a permanently sealed air space. In recent years, however, spacers and polymer sealants have largely replaced glass-to-glass seals, and have proven sufficiently durable for residential applications. The layers of glass are separated by and adhere to a spacer, and the sealant, which forms a gas and moisture barrier, is applied around the entire perimeter. Normally, the spacer contains a desiccant material to absorb any residual moisture that may remain in the air space after manufacture. Sealed insulating glass units are now a mature, well proven technology. Designs utilizing high-quality sealants and manufactured with good quality control should last for decades without seal failure.

2.6.4. Glass Coatings and Tints in Double Glazing

Both solar reflective coatings and tints on double-glazed fenestration products are effective in reducing summer heat gain; however, only certain coatings contribute to reducing winter heat loss, and tints do not affect the heat loss rates at all. It is possible to provide reflective coatings on any one of the four surfaces, although they are usually located on the outermost surface or on the surfaces facing the air space. Coating location can also depend on the type of coating. Some vacuum-deposited reflective coatings must be placed in a sealed air space because they would not survive exposure to outdoor elements, finger prints, or cleaning agents. Pyrolytic coatings that are created with a high-temperature process as the glass is formed are extremely hard and durable and can be placed anywhere. Each location produces a different visual and heat transfer effect. Other advanced coatings such as low-emittance and spectrally selective coatings are normally applied to double-glazed or triple-glazed fenestration products. These applications are discussed later in this chapter.

Double-pane units can be assembled using different glass types for the inner and outer layers. Typically, the inner layer is standard clear glass, while the outer layer can be tinted, reflective, or both. The solar heat gain coefficient is reduced because the tinted glass and clear glass both reduce transmitted radiation. In addition, this design further reduces solar heat gain because the inner clear glass, the gas fill, and any Low-E coating keep much of the heat absorbed by the outer glass from entering the building interior.

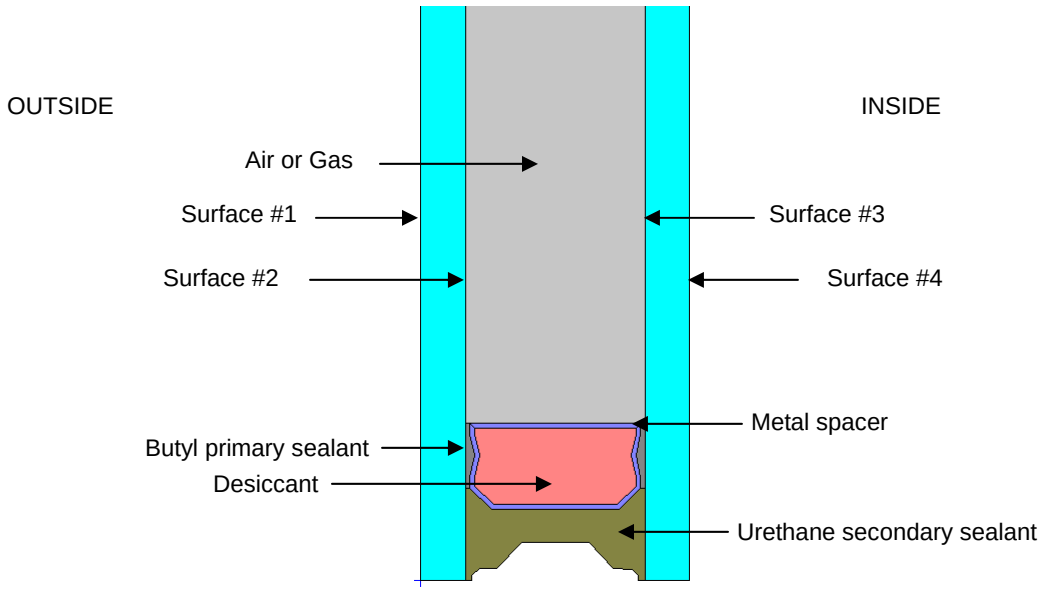


Figure 2-2. Insulating Glass Unit (IGU).

2.6.5. Gap Width in Multiple Glazed Units

Fenestration product manufacturers have some flexibility to reduce heat transfer by selecting the best gap width between two or more glazings. The air space between two pieces of glass reaches its optimum insulating value at about 1/2-inch (12 mm) thickness when filled with air or argon. As the gap gets larger, convection in the gap increases and slowly increases heat transfer. Below 3/8 inch (9 mm), conduction through the air gap increases and the U-factor rises more rapidly. Krypton gas has its optimum thickness at about 1/4 inch (6 mm), so that if smaller air gaps are required, for example in a three-layer fenestration product whose overall exterior dimensions are limited, krypton may be the best selection, although it is also more costly.

2.6.6. Divided Lights

Manufacturers have been struggling with the problem of many homeowners' preference for traditional, divided light fenestration products, which have many small panes separated by thin bars called muntins. With single-pane glass, true divided lights actually improved the thermal performance of the fenestration product because the wood muntins had a higher insulating value than the glass. Some manufacturers have introduced "true divided light" insulated units, in which traditional-looking muntins hold small, individual, insulated panes. However, these are expensive and difficult to fabricate with insulated glass and have greater thermal losses due to the number of edges, which now have metal in them.

A second option is to produce a single, large sealed glass unit with "muntins" glued to the inside and outside surfaces, while a grid is placed in the middle of one large insulated unit, giving the visual effect of divided lights. This reduces fabrication costs but does not reduce resistance to heat flow if the muntins in the middle are metal and if they touch both lights of glass.

A third option, which is more energy efficient, is to build a large-pane insulated unit that has snap-on or glued-on grilles to simulate the traditional lights.

The energy performance of the simple snap-on grid will be similar to a unit without any mullions; however, the true divided lights will result in greater heat transfer because of the additional edges.

2.6.7. Special Products

Glass blocks present a very special case of double glazing. They provide light with some degree of visual privacy. Plastic blocks, which have a lower U-factor than glass, are also available. However, when installed, the necessary grouting reduces the energy efficiency. Also, metal mesh and steel reinforcing bars, used between blocks to provide structural stability, provide thermal bridges which also reduce energy efficiency.

Plastic glazings are available in a number of configurations with double layers. Double-glazed acrylic bubble skylights are formed with two layers separated by an air space of varying thickness, ranging from no separation at the edges to as much as 3 inches (7.6 cm) at the top of the bubble. The average separation is used to calculate the effective U-factor.

Multicell polycarbonate sheets, which can be mounted with the divider webs running vertically or horizontally, are available. The divider webs increase the effective insulating value of the glazing by reducing convection exchange within the cells, especially when they are mounted horizontally.

2.6.8. Multiple Panes or Films

By adding a second pane, the insulating value of the fenestration product glass alone is doubled (the U-factor is reduced by half). As expected, adding a third or fourth pane of glass further increases the insulating value of the fenestration product, but with diminishing effect.

Triple- and quadruple-glazed fenestration products became commercially available in the 1980s as a response to the desire for more energy-efficient products. There is a trade-off with this approach, however. As each additional layer of glass adds to the insulating value of the assembly, it also reduces the visible light transmission and the solar heat gain coefficient, thereby reducing the fenestration product's value for providing solar gains or daylighting. In addition, other complications are encountered. Additional panes of glass increase the weight of the unit, which makes mounting and handling more difficult and transportation more expensive.

Because of the difficulties discussed above, it is apparent there are physical and economic limits to the number of layers of glass that can be added to a fenestration product assembly. However, multiple-pane units are not limited to assemblies of glass. One popular innovation is based on substituting an inner plastic film for the middle layer of glass. The plastic film is very lightweight, and because it is very thin, it does not increase the thickness of the unit. The glass layers protect the inner layer of plastic from scratching, mechanical abuse, corrosion, weathering, and visual distortions caused by wind pressure. Thus, the strength and durability of plastic as a glazing material are no longer issues when the plastic is protected from physical abuse and weathering by inner and outer layers of glass. The plastic films are specially treated to resist UV degradation and they are heat shrunk so they remain flat under all conditions.

The plastic inner layer serves a number of important functions. It decreases the U-factor of the fenestration product assembly by dividing the inner air space into multiple chambers. Units are offered with one or two inner layers of plastic. Secondly, a Low-E coating can be placed on the plastic film itself to further lower the U-factor of the assembly. Also, the plastic film can be provided with spectrally selective coatings to reduce solar gain in hot climates without significant loss of visible transmittance. The performance of multiple-pane fenestration product assemblies with low-emittance coatings and gas fills is described in the following sections.

2.6.9. Low-Emittance Coatings

The principal mechanism of heat transfer in multilayer glazing is thermal radiation from a warm pane of glass to a cooler pane. Coating a glass surface with a low-emittance material and facing that coating into the gap between the glass layers blocks a significant amount of this radiant heat transfer, thus lowering the total heat flow through the fenestration product. The improvement in insulating value due to the Low-E coating is roughly equivalent to adding another pane of glass to a multipane unit.

The solar spectral reflectances of Low-E coatings can be manipulated to include specific parts of the visible and infrared spectrum. A glazing material can then be designed to optimize energy flows for solar heating, daylighting, and cooling.

With conventional clear glazing, a significant amount of solar radiation passes through the fenestration product, and then heat from objects within the house is reradiated back through the fenestration product. For example, a glazing design for maximizing solar gains in the winter would ideally allow all of the solar spectrum to pass through, but would block the reradiation of heat from the inside of the house. The first Low-E coatings were designed to have a high solar heat gain coefficient and a high visible transmittance to transmit the maximum amount of sunlight into the interior while reducing the U-factor significantly.

A glazing designed to minimize summer heat gains but allow for some daylighting would allow visible light through, but would block all other portions of the solar spectrum, including ultraviolet light and near-infrared, as well as long-wave heat radiated from outside objects, such as paving and adjacent buildings, as shown in Figure 2-3. These second-generation Low-E coatings were designed to reflect the solar near-infrared, thus reducing the total solar heat gain coefficient while maintaining high levels of light transmission. Variations on this design (modified coatings and/or glazings) can further reduce summer solar heat gain and control glare.

There are three basic types of Low-E coatings available on the market today:

1. **High-transmission Low-E:**
   These Low-E glass products are often referred to as pyrolitic or hard coat Low-E glass, due to the glass coating process. The properties presented here are typical of a Low-E glass product designed to reduce heat loss but admit solar gain.
2. **Moderate-transmission Low-E:**
   These Low-E glass products are often referred to as sputtered (or soft-coat products) due to the glass coating process. (Note: Low solar gain Low-E products are also sputtered coatings.) Such coatings reduce heat loss and let in a reasonable amount of solar gain.
3. **Low-transmission Low-E:**
   These Low-E products are often referred to as sputtered (or soft-coat) due to the glass coating process. (Note: Moderate solar gain Low-E products are also sputtered coatings.) This type of Low-E product, sometimes called spectrally selective Low-E glass, reduces heat loss in winter but also reduces heat gain in summer. Compared to most tinted and reflective glazings, this Low-E glass provides a higher level of visible light transmission for a given amount of solar heat reduction.

The type and quality of Low-E coating will affect not only the U-factor, but also the transmittance and solar heat gain coefficient of a glass. All these properties (U-factor, VT, and SHGC) need to be taken into consideration in characterizing a particular glazing product.

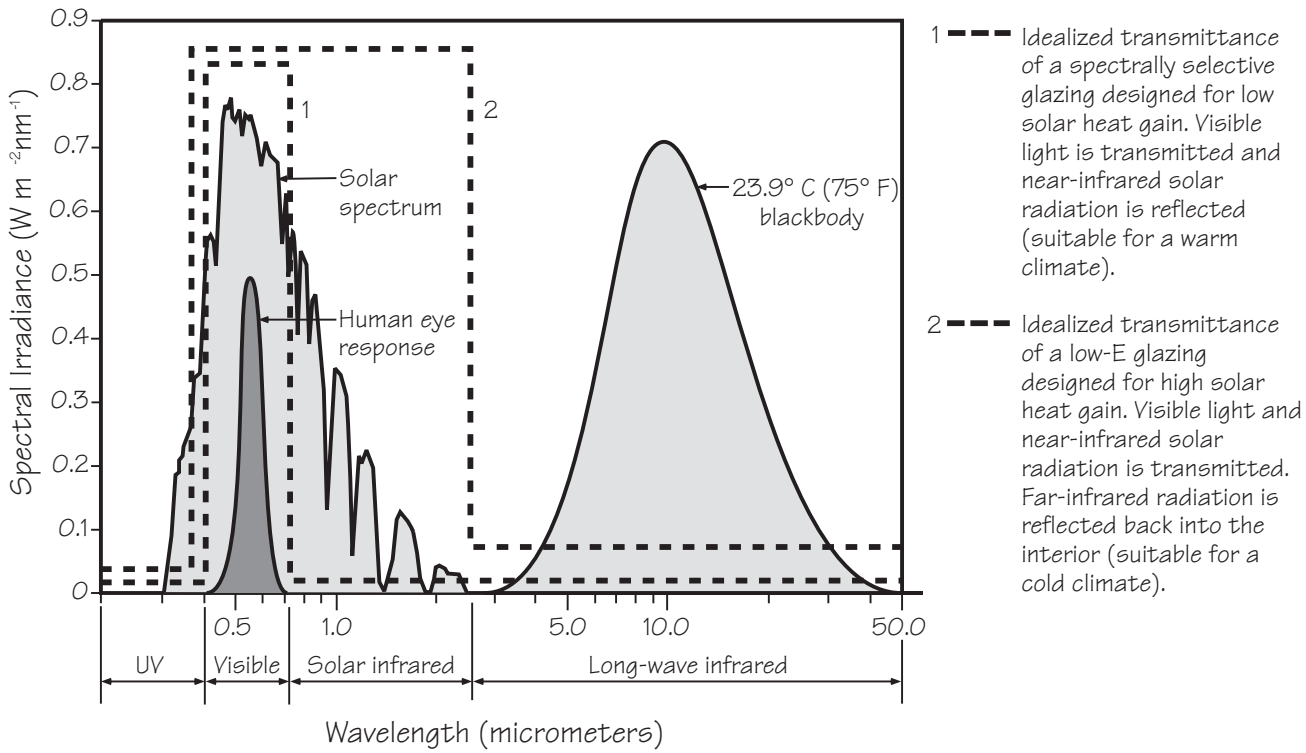


Figure 2-3. Ideal spectral transmittance for glazings in different climates. (Source: "Sensitivity of Fenestration Solar Gain to Source Spectrum and Angle of Incidence." ASHRAE Transactions 10, R. McCluney, June 1996).

2.6.9.1. Coating Placement

The placement of a Low-E coating within the air gap of a double-glazed fenestration product does not significantly affect the U-factor but it does influence the solar heat gain coefficient (SHGC). That is why, in heating-dominated climates, placing a Low-E coating on the #3 surface (outside surface of the inner pane) is recommended to maximize winter passive solar gain at the expense of a slight reduction in the ability to control summer heat gain. In cooling climates, a coating on the #2 surface (inside surface of the outer pane) is generally best to reduce solar heat gain and maximize energy efficiency. Manufacturers sometimes place the coatings on other surfaces (e.g., #2 surface in a heating climate) for other reasons, such as minimizing the potential for thermal stress. Multiple Low-E coatings are also placed on surfaces within a triple-glazed fenestration product assembly, or on the inner plastic glazing layers of multipane assemblies referred to as superwindows (discussed later in this chapter), with a cumulative effect of further improving the overall U-factor.

2.6.9.2. Coating Types

There are two basic types of Low-E coatings – sputtered and pyrolytic, referring to the process by which they are made. The best of each type of coating is colorless and optically clear. Some coatings may have a slight hue or subtle reflective quality, particularly when viewed in certain lighting conditions or at oblique angles.

A sputtered coating is multilayered (typically, three primary layers, with at least one layer of metal) and is deposited on glass or plastic film in a vacuum chamber. The total thickness of a sputtered coating is only 1/10,000 of the thickness of a human hair. Sputtered coatings often use a silver layer and must be protected from humidity and contact. For this reason they are sometimes referred to as “soft coats.” Since sputtering is a low-temperature process, these coatings can be deposited on flat sheets of glass or thin plastic films. While sputtered coatings are not durable in themselves, when placed into a sealed double- or triple-glazed assembly

they should last as long as the sealed glass unit. Sputtered coatings typically have lower emittances than pyrolytic coatings. They are available commercially with emittance ratings of e = 0.10 to as low as e = 0.02 (e = 0.20 means that 80 percent of the long-wavelength radiant energy received by the surface is reflected, while e = 0.02 means 98 percent is reflected). For uncoated glass, e = 0.84, which means only 16 percent of the radiant energy received by the surface is reflected.

A typical pyrolytic coating is a metallic oxide, most commonly tin oxide with some additives, which is deposited directly onto a glass surface while it is still hot. The result is a baked-on surface layer that is quite hard and thus very durable, which is why this is sometimes referred to as a "hard coat." A pyrolytic coating can be ten to twenty times thicker than a sputtered coating but is still extremely thin. Pyrolytic coatings can be exposed to air, cleaned with normal cleaning products, and subjected to general wear and tear without losing their Low-E properties.

Because of their greater durability, pyrolytic coatings are available on single-pane glass and separate storm windows, but not on plastics, since they require a high-temperature process. In general, though, pyrolytic coatings are used in sealed, double-glazed units with the Low-E surface inside the sealed air space. While there is considerable variation in the specific properties of these coatings, they typically have emittance ratings in the range of e = 0.20 to e = 0.10.

A laminated glass with a spectrally selective Low-E sputtered coating on plastic film sandwiched between two layers of glass offers the energy performance of single-pane, spectrally selective glass and the safety protection of laminated glass. However, in this configuration, since the Low-E surface is not exposed to an air space, there is no effect on the glazing U-factor.

2.6.10. Gas Fills

Another improvement that can be made to the thermal performance of insulating glazing units is to reduce the conductance of the air space between the layers. Originally, the space was filled with air or flushed with dry nitrogen just prior to sealing. In a sealed glass insulating unit air currents between the two panes of glazing carry heat to the top of the unit and settle into cold pools at the bottom. Filling the space with a less conductive gas minimizes overall transfer of heat between two glass layers.

Manufacturers have introduced the use of argon and krypton gas fills, with measurable improvement in thermal performance. Argon is inexpensive, nontoxic, nonreactive, clear, and odorless. The optimal spacing for an argon-filled unit is the same as for air, about 1/2 inch (12 mm). Krypton has better thermal performance, but is more expensive to produce. Krypton is particularly useful when the space between glazings must be thinner than normally desired, for example, 1/4 inch (6 mm). A mixture of krypton and argon gases is also used as a compromise between thermal performance and cost.

Filling the sealed unit completely with argon or krypton presents challenges that manufacturers continue to work on. A typical gas fill system adds the gas into the cavity with a pipe inserted through a hole at the edge of the unit. As the gas is pumped in, it mixes with the air, making it difficult to achieve 100 percent purity. Recent research indicates that 90 percent is the typical concentration achieved by manufacturers today. Some manufacturers are able to consistently achieve better than 95 percent gas fill by using a vacuum chamber. An uncoated double-pane unit filled with 90 percent argon gas and 10 percent air yields a slightly more than 5 percent improvement in the insulating value at the center of the glass, compared to the same unit filled with air. However, when argon and krypton fills are combined with Low-E coatings and multipane glazings, more significant reductions of 15 to 20 percent can be achieved. Since the Low-E coating has substantially reduced the radiation component of heat loss, the gas fill now has a greater proportional effect on the remaining heat transfer by convection and conduction.

2.7 Thermally Improved Edge Spacers

The layers of glazing in an insulating glass (IG) unit must be held apart at the appropriate distance by spacers. The spacer system must provide a number of additional functions in addition to keeping the glass units at the proper dimension:

- accommodate stress induced by thermal expansion and pressure differences;
- provide a moisture barrier that prevents passage of water or water vapor that would fog the unit;
- provide a gas-tight seal that prevents the loss of any special low-conductance gas in the air space;
- create an insulating barrier that reduces the formation of interior condensation at the edge.

Older double-pane wood fenestration products used a wood spacer that could not be hermetically sealed and thus was vented to the outside to reduce fogging in the air gap. Modern versions of this system function well but, because they are not hermetically sealed, cannot be used with special gas fills or some types of Low-E coatings. Early glass units were often fabricated with an integral welded glass-to-glass seal. These units did not leak but were difficult and costly to fabricate, and typically had a less-than-optimal narrow spacing. The standard solution for insulating glass units (IGUs) that accompanied the tremendous increase in market share of insulating glass in the 1980s was the use of metal spacers, and sealants. These spacers, typically aluminum, also contain a desiccant that absorbs residual moisture. The spacer is sealed to the two glass layers with organic sealants that both provide structural support and act as a moisture barrier. There are two generic systems for such IGUs: a single-seal spacer and a double-seal system.

In the single-seal system , an organic sealant, typically a butyl material, is applied behind the spacer and serves both to hold the unit together and to prevent moisture intrusion. These seals are normally not adequate to contain special low-conductance gases.

In a double-seal system , a primary sealant, typically butyl, seals the spacer to the glass to prevent moisture migration and gas loss, and a secondary backing sealant, often silicone, provides structural strength. When sputtered Low-E coatings are used with double-seal systems, the coating must be removed from the edge first ("edge deletion") to provide a better edge seal.

Since aluminum is an excellent conductor of heat, the aluminum spacer used in most standard edge systems represented a significant thermal "short circuit" at the edge of the IGU, which reduces the benefits of improved glazings. As the industry has switched from standard double-glazed IGUs to units with Low-E coatings and gas fills, the effect of this edge loss becomes even more pronounced. Under winter conditions, the typical aluminum spacer would increase the U-factor of a Low-E, gas fill unit slightly more than it would increase the U-factor of a standard double-glazed IGU. The smaller the glass area, the larger the effect of the edge on the overall product properties. In addition to the increased heat loss, the colder edge is more prone to condensation.

Fenestration product manufacturers have developed a series of innovative edge systems to address these problems, including solutions that depend on material substitutions as well as radically new designs. One approach to reducing heat loss has been to replace the aluminum spacer with a metal that is less conductive, e.g., stainless steel, and change the cross-sectional shape of the spacer. Another approach is to replace the metal with a design that uses materials that are better insulating. The most commonly used design incorporates spacer, sealer, and desiccant in a single tape element. The tape includes a solid, extruded thermoplastic compound that contains a blend of desiccant materials and incorporates a thin, fluted metal shim of aluminum or stainless steel. Another approach uses an insulating silicone foam spacer that incorporates a desiccant and has a high-strength adhesive at its edges to bond to glass. The foam is backed with a secondary sealant. Both extruded vinyl and pultruded fiberglass spacers have also been used in place of metal designs.

There are several hybrid designs that incorporate thermal breaks in metal spacers or use one or more of the elements described above. Some of these are specifically designed to accommodate three- and four-layer glazings or IGUs incorporating stretched plastic films. All are designed to interrupt the heat transfer pathway at the glazing edge between two or more glazing layers.

Warm edge spacers have become increasingly important as manufacturers switch from conventional double glazing to higher-performance glazing. For purposes of determining the overall fenestration product U-factor, the edge spacer has an effect that extends beyond the physical size of the spacer to a band about 63.5 mm (2.5 inches) wide. The contribution of this 63.5 mm (2.5-inch) wide "glass edge" to the total fenestration product U-factor depends on the size of the product. Glass edge effects are more important for smaller fenestration products, which have a proportionately larger glass edge area. For a typical residential-size window (0.8 by 1.2 meters , 3 by 4 feet), changing from a standard aluminum edge to a good-quality warm edge will reduce the overall fenestration product U-factor by 0.01 to 0.02 Btu/hr- ft^2-°F.

3. FENESTRATION HEAT TRANSFER BASICS

3.1. Overview

Much of the information in this chapter is taken from the book *Residential Windows: A Guide to New Technologies and Energy Performance* by John Carmody, Stephen Selkowitz, and Lisa Heschong. Additional information can also be found in the ASHRAE *2001 Handbook of Fundamentals*.

3.2 Energy Flow Mechanisms

Overall energy flow through a fenestration product is a function of:

- **Temperature Driven Heat Transfer:** When there is a temperature difference between inside and outside, heat is lost or gained through the fenestration product frame and glazing by the combined effects of conduction, convection, and radiation. This is indicated in terms of the U-factor of a fenestration assembly.
- **Solar Gain:** Regardless of outside temperature, heat can be gained through fenestration products by direct or indirect solar radiation. The amount of heat gain through products is measured in terms of the solar heat gain coefficient (SHGC) of the glazing.
- **Infiltration:** Heat loss and gain also occur by infiltration through cracks in the fenestration assembly. This effect is measured in terms of the amount of air (cubic feet or meters per minute) that passes through a unit area of fenestration product (square foot or meter) under given pressure conditions. In reality, infiltration varies with wind-driven and temperature-driven pressure changes. Infiltration also contributes to summer cooling loads in some climates by raising the interior humidity level.

The *2001 ASHRAE Handbook of Fundamentals* contains the following equation for calculating the energy flow through a fenestration product (assuming no humidity difference and excluding air infiltration):

$$q = U_t * A_{pf}(t_{out} - t_{in}) + \left(SHGC_t * A_{pf} * E_t\right) \qquad [3\text{-}1]$$

Where:

q = instantaneous energy flow, W (Btu/h)

U_o = overall coefficient of heat transfer (U-factor), W/m^2-^{o}K (Btu/h-ft^2-^{o}F)

t_{in} = interior air temperature, ^{o}C (^{o}F)

t_{out} = exterior air temperature, ^{o}C (^{o}F)

A_{pf} = Total projected area of fenestration, m^2 (ft^2)

$SHGC_t$ = overall solar heat gain coefficient, non-dimensional

E_t = incident total irradiance, W/m^2-^{o}K (Btu/h-ft^2-^{o}F)

This equation shows that the properties of U-factor, SHGC, and infiltration are major factors which determine the energy flow through a fenestration product. For this reason, the NFRC rating system rates the U-factor,

SHGC, and air infiltration of products, and the *NFRC 100, NFRC 200,* and *NFRC 400* documents define the procedures for calculating these values for the total product.

3.3 Temperature Driven Heat Transfer

Fenestration product heat loss/gain due to temperature is a combination of three modes of heat transfer:

1. Conduction (heat traveling through a solid material, the way a frying pan warms up) through glazing, spacer, and frame elements
2. Convection (the transfer of heat by the movement of gases or liquids, like warm air rising from a candle flame) through air layers on the exterior and interior fenestration product surfaces and between glazing layers
3. Radiative heat transfer (the movement of heat energy through space without relying on conduction through the air or by movement of the air, the way you feel the heat of a fire) between glazing layers, or between IG units and interior or exterior spaces.

Solar radiation absorbed by glazing layers will contribute to the temperature driven heat transfer, while solar radiation transmitted by the glazing system will be independent of the temperature driven heat transfer. Absorbed solar radiation will partially be transmitted into the conditioned space and will be included in SHGC. These three modes of heat transfer are shown schematically in Figure 3-1. Heat flows from warmer to cooler bodies, thus from inside to outside in winter, and reverses direction in summer during periods when the outside temperature is greater than indoors.

The amount of heat transfer due to these three processes is quantified by its U-factor (W/m^2-^oC or Btu/h-ft^2-^oF). The inverse of heat flow, or resistance to heat transfer, is expressed as an R-value. NFRC's rating system quantifies and predicts U-factors.

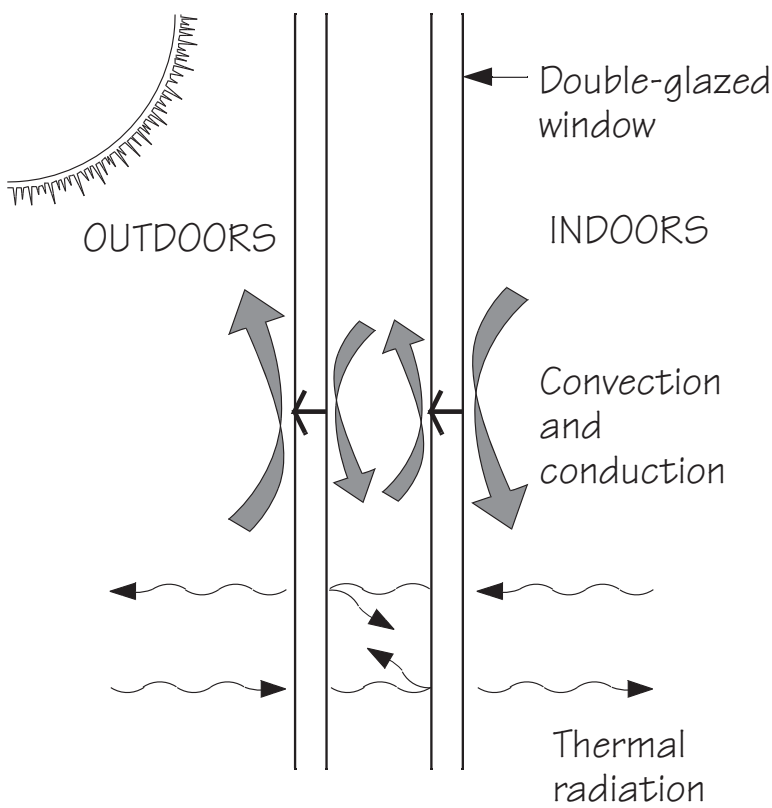


Figure 3-1. Mechanisms of heat transfer in a fenestration product.

3.3.1. Conduction

Compared to a well-insulated wall, heat transfer through a typical older fenestration product is generally much higher. A single-glazed fenestration product has roughly the same insulating qualities as a sheet of metal—most of the insulating value comes from the air layer on each surface of the glass. Such a product can be considered a thermal hole in a wall and typically has a heat loss rate ten to twenty times that of the wall. A product with such a poor insulating value allows heat to flow out of a space almost unimpeded. If the temperature inside is 21°C (70°F) and outside is -18°C (0°F), the glass surface of a single-glazed product would be about -8°C (17°F) — cold enough to form frost on the inside of the glass.

3.3.2. Convection

Convection affects the heat transfer in many places in the assembly: the inside glazing surface, the outside glazing surface, inside frame cavities, and inside any air spaces between glazings. A cold interior glazing surface cools the air adjacent to it. This denser cold air then falls to the floor, starting a convection current which is typically perceived as a "draft" caused by leaky fenestration products. One remedy for this situation is to install a product with lower heat loss rates that provides a warmer glass surface.

On the exterior, a component of the heat transfer rate of a fenestration product is the air film against the glazing surface. As wind blows across the product (causing convection), and the insulating value of this air film diminishes which contributes to a higher rate of heat loss. Finally, when there is an air space between layers of glazing, convection currents can facilitate heat transfer through this air layer. By adjusting the space between the panes of glass, as well as choosing a gas fill that insulates better than air, double-glazed fenestration products can be designed to minimize this effect.

3.3.3. Radiation

All objects emit invisible thermal radiation, with warmer objects emitting more than colder ones. Hold your hand in front of an oven window and you will feel the radiant energy emitted by that warm surface. Your hand also radiates heat to the oven window, but since the window is warmer than your hand, the net balance of radiant flow is toward your hand and it is warmed. Now imagine holding your hand close to a single-glazed window in winter. The window surface is much colder than your hand. Each surface emits radiant energy, but since your hand is warmer, it emits more toward the window than it gains and you feel a cooling effect. Thus, a cold glazing surface in a room chills everything else around it.

3.3.4. U-factor

The U-factor is the standard way to quantify insulating value. It indicates the rate of heat flow through the fenestration product. The U-factor is the total heat transfer coefficient of the fenestration system, in W/m^2-°C (Btu/hr-ft^2-°F), which includes conductive, convective, and radiative heat transfer for a given set of environmental conditions. It therefore represents the heat flow per hour, in Watts (Btu per hour) through each square meter (square foot) of fenestration product for a 1°C (1°F) temperature difference between the indoor and outdoor air temperature. The smaller the U-factor of a material, the lower the rate of heat flow. The total R-value, which measures thermal resistance, is the reciprocal of the total U-factor (R=1/U).

The U-factor depends on the thermal properties of the materials in the fenestration product assembly, as well as the weather conditions, such as the temperature differential between indoors and outside, and wind speed. NFRC has standardized the exterior conditions (called environmental conditions) for U-factor calculations for product ratings using the following temperatures and wind speeds:

- Wind Speed: 12.3 km (5.5 mph/hr)
- Indoor air temperature: 21°C (70°F)

- Outdoor air temperature: -18°C (0°F).

Skylights and roof fenestration products are simulated at a 20 degree slope from horizontal.

3.3.4.1. Total Product U-factor

The U-factor of a total fenestration assembly is a combination of the insulating values of the glazing assembly itself, the edge effects that occur in the insulated glazing unit, and the insulating value of the frame and sash.

3.3.4.2. Center-of-Glazing U-factor

The U-factor of the glazing portion of the fenestration unit is affected primarily by the total number of glazing layers, the dimension separating the various layers of glazing, the type of gas that fills the separation, and the characteristics of coatings on the various surfaces. The U-factor for the glazing alone is referred to as the center-of-glass U-factor.

3.3.4.3. Edge Effects

A U-factor calculation assumes that heat flows perpendicular to the plane of the fenestration product. However, fenestration products are complex three-dimensional assemblies, in which materials and cross sections change in a relatively short space.

For example, metal spacers at the edge of an insulating glass unit have much higher heat flow than the center of the insulating glazing, which causes increased heat loss along the outer edge of the glazing. The relative impact of these "edge effects" becomes more important as the insulating value of the rest of the assembly increases.

3.3.4.4. Frames and Sashes

The heat loss through a fenestration product frame can be quite significant: in a typical 1.2 by 0.9 m (4′ by 3′) double-hung wood frame product, the frame and sash can occupy approximately 30 percent of the product area.

In a frame with a cross section made of one uniform, solid material, the U-factor is based on the conduction of heat through the material. However, hollow frames and composite frames with various reinforcing or cladding materials are more complex. Here, conduction through materials must be combined with convection of the air next to the glazing and radiant exchange between the various surfaces.

Furthermore, frames rarely follow the same cross section around a fenestration product. For example, a horizontal slider has seven different frame cross sections, each with its own rate of heat flow.

3.3.4.5. Overall U-factor

Since the U-factors are different for the glazing, edge-of-glazing zone, and frame, it can be misleading to compare U-factors if they are not carefully described. In order to address this problem, the concept of a total fenestration product U-factor is utilized by the National Fenestration Rating Council (NFRC). A specific set of engineering assumptions and procedures must be followed to calculate the overall U-factor of a fenestration unit using the NFRC method. In most cases, the overall U-factor is higher than the U-factor for the glazing alone, since the glazing remains superior to the frame in insulating value.

The U-factor of a product is calculated with the product in a vertical position. A change in mounting angle can affect its U-factor.

3.4 Solar Heat Gain and Visible Transmittance

The second major energy performance characteristic of fenestration products is the ability to control solar heat gain through the glazing. Solar heat gain through fenestration products tends to be the single most significant factor in determining the air-conditioning load of a residential building. The intensity of heat gain from solar radiation can greatly surpass heat gain from other sources, such as outdoor air temperature or humidity.

Visible transmittance (VT) is an optical property that indicates the amount of visible light transmitted through the glazing. Although VT does not directly affect heating and cooling energy use, it is used in the evaluation of energy-efficient fenestration products and therefore is discussed following the solar heat gain section.

The origin of solar heat gain is the direct and diffuse radiation coming directly from the sun and the sky or reflected from the ground and other surfaces. Some radiation is directly transmitted through the glazing to the space, and some may be absorbed in the glazing and then indirectly admitted to the space. Sunlight is composed of electromagnetic radiation of many wavelengths, ranging from short-wave invisible ultraviolet, to the visible spectrum, to the longer, invisible near-infrared waves. About half of the sun's energy is visible light; the remainder is largely infrared with a small amount of ultraviolet. This characteristic of sunlight makes it possible to selectively admit or reject different portions of the solar spectrum. While reducing solar radiation through fenestration products is a benefit in some climates and during some seasons, maximizing solar heat gain can be a significant energy benefit under winter conditions. These often conflicting directives can make selection of the "best" product a challenging task. See Section 2.6.9 for a more detailed discussion of these properties of fenestration products.

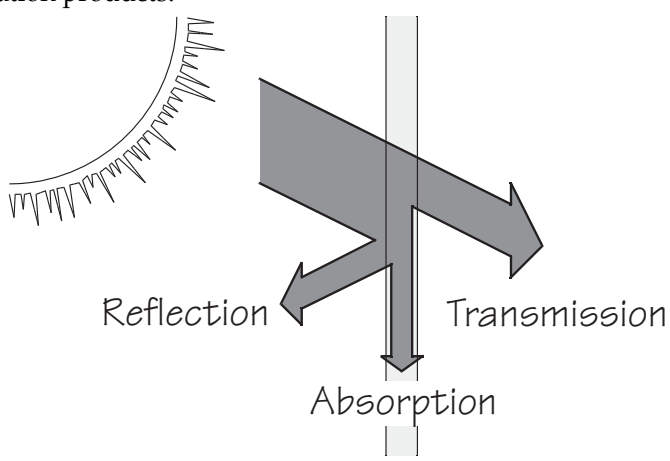


Figure 3-2. A glazing system's properties of reflection, transmission and absorption determine what happens to solar gain.

3.4.1. Determining Solar Heat Gain

There are two means of indicating the amount of solar radiation that passes through a fenestration product. These are solar heat gain coefficient (SHGC) and shading coefficient (SC). In both cases, the solar heat gain is the combination of directly transmitted radiation and the inward-flowing portion of absorbed radiation (Figure 3-3). However, SHGC and SC have a different basis for comparison or reference. The SHGC value is calculated for NFRC rating and certification. SHGC replaces SC because it more correctly accounts for angle-dependent effects. SC represents the ratio of solar heat gain through the system relative to that through 3 mm (1/8-inch) clear glass at normal incidence.

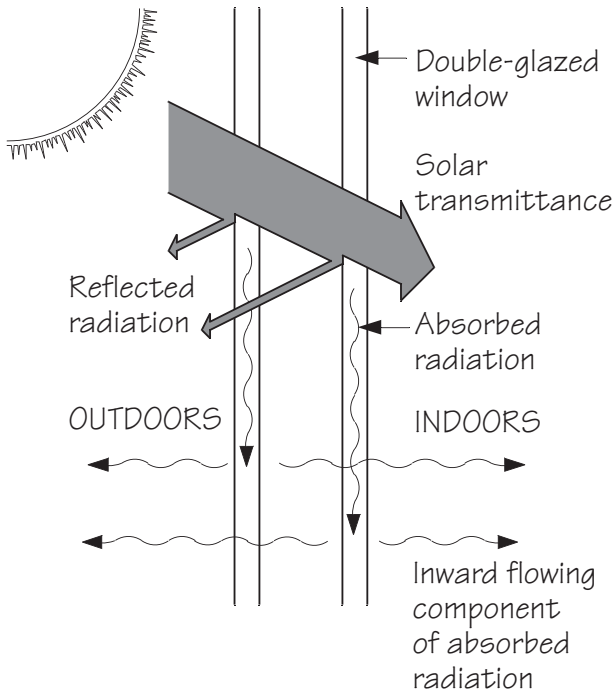


Figure 3-3. A glazing system's properties of reflection, transmission and absorption determine what happens to solar gain.

3.4.2. Solar Heat Gain Coefficient (SHGC)

The solar heat gain coefficient (SHGC) represents the solar heat gain through the fenestration system relative to the incident solar radiation. Although SHGC can be determined for any angle of incidence, the default and most commonly used reference is normal incidence solar radiation. NFRC rated SHGC's are at 0° incidence. The SHGC refers to total fenestration product system performance and is an accurate indication of solar gain under a wide range of conditions. SHGC is expressed as a dimensionless number from 0 to 1.0. A high SHGC value signifies high heat gain, while a low value means low heat gain.

3.4.3. Visible Transmittance

Visible transmittance is the amount of light in the visible portion of the spectrum that passes through a glazing material. This property does not directly affect heating and cooling loads in a building, but it is an important factor in evaluating energy-efficient fenestration products. Transmittance is influenced by the glazing type, the number of layers, and any coatings that might be applied to the glazings. These effects are discussed in more detail later in this chapter in conjunction with a review of various glazing and coating technologies. Visible transmittance of glazings ranges from above 90 percent for water-white clear glass to less than 10 percent for highly reflective coatings on tinted glass.

Visible transmittance is an important factor in providing daylight, views, and privacy, as well as in controlling glare and fading of interior furnishings. These are often contradictory effects: a high light transmittance is desired for view out at night, but this may create glare at times. These opposing needs are often met by providing glazing that has high visible transmittance and then adding attachments such as shades or blinds to modulate the transmittance to meet changing needs.

NFRC reports visible transmittance as a rating on the label. Note that NFRC's rating is a whole product rating that combines the effect of both glazing and frame. There are many cases where the transmittance of glazing alone will be required, so it is important to make sure that the appropriate properties are being compared.

In the past, products that reduced solar gain (with tints and coatings) also reduced visible transmittance. However, new spectrally selective tinted glasses and selective coatings have made it possible to reduce solar heat gain with little reduction in visible transmittance.

3.5 Condensation Resistance

Condensation has been a persistent and often misunderstood problem associated with windows. In cold climates, single-glazed windows characteristically suffer from water condensation and the formation of frost on the inside surface of the glass in winter. The surface temperature of the glass drops below either the dew point or frost point of the inside room air.

Excessive condensation can contribute to the growth of mold or mildew, damage painted surfaces, and eventually rot wood trim. Since the interior humidity level is a contributing factor, reducing interior humidity is an important component of controlling condensation.

Condensation can also be a problem on the interior surfaces of window frames. Metal frames, in particular, conduct heat very quickly, and will "sweat" or frost up in cool weather. Solving this condensation problem was a major motivation for the development of thermal breaks for aluminum windows.

Infiltration effects can also combine with condensation to create problems. If a path exists for warm, moisture-laden air to move through or around the window frames, the moisture will condense wherever it hits its dew point temperature, often inside the building wall. This condensation can contribute to the growth of mold in frames or wall cavities, causing health problems for some people, and it encourages the rotting or rusting of window frames. Frames must be properly sealed within the wall opening to prevent this potential problem. In some instances, the infiltration air will be dry, such as on cold winter days, and it will thus help eliminate condensation on the window surfaces.

Condensation can cause problems in skylights and roof windows as well as typical windows. "Leaky" skylights are frequently misdiagnosed. What are perceived to be drops of water from a leak are more often drops of water condensing on the cold skylight surfaces. A skylight is usually the first place condensation will occur indicating too much moisture in the interior air. Insulating the skylight well and providing adequate air movement assists in reducing condensation. Also, the use of more highly insulating glazing with a well-designed frame can help solve this problem. In many systems, a small "gutter" is formed into the interior frame of the skylight where condensate can collect harmlessly until it evaporates back into the room air.

The *NFRC Publication NFRC 501: User Guide to NFRC 500* contains more information about condensation resistance.

3.5.1. Impact of Glazing Type and Spacers on Condensation

Figure 3-4 indicates condensation potential for four glazing types at various outdoor temperature and indoor relative humidity conditions. Condensation can occur at any points that fall on or above the curves. As the U-factor of windows improves, there is a much smaller range of conditions where condensation will occur. Figure 3-4 must be used with caution, since it shows condensation potential for the center of glazing area only (the area at least 63.5 mm (2.5 inches) from the frame/glazing edge). Usually condensation will first occur at the lower edge of the product where glazing temperatures are lower than in the center.

As Figure 3-4 shows, double-glazed products create a warmer interior glazing surface than single-glazing, reducing frost and condensation. The addition of low-E coatings and argon gas fill further reduce condensation potential. The triple-glazed product with low-E coatings has such a warm interior surface that condensation on any interior surfaces may be eliminated if humidity levels are maintained at reasonable levels.

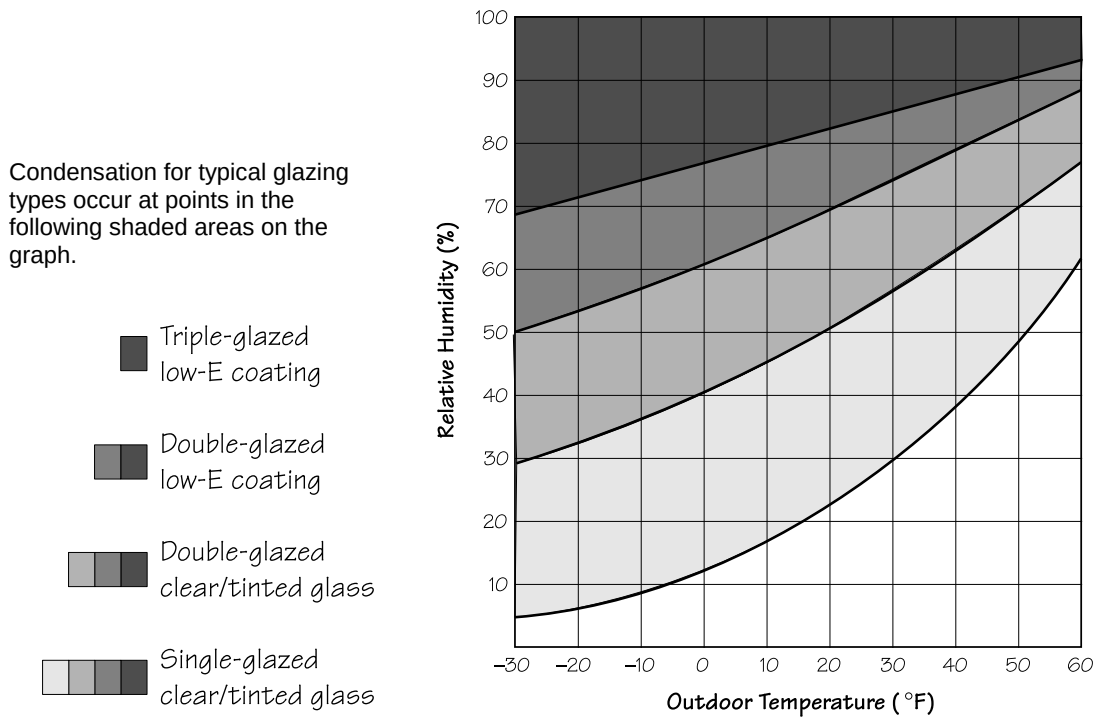


Figure 3-4. Condensation potential on glazing (center of glazing) at various outdoor temperature and indoor relative humidity conditions.

Condensation forms at the coldest locations, such as the lower corners or edges of an insulated product even when the center of glazing is above the limit for condensation. Generally, as the insulating value of the glazing is improved, the area where condensation can occur is diminished. Condensation potential increases as the outdoor temperature is lowered and the indoor relative humidity increases.

3.5.2. Condensation Resistance

NFRC has developed a Condensation Resistance (CR) value for rating for how well a fenestration product can resist the formation of condensation on the interior surface of the product at a specific set of environmental conditions. The CR calculation method is defined in the *NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values*.

3.5.3. Outdoor Condensation

Under some climate conditions, condensation may occur on the exterior glazing surface of a window. This is more likely to occur on higher-performance windows with low-E coatings or films, and low-conductance gas fills that create very low U-factors. By preventing heat from escaping from the interior, the exterior surfaces of the window approach outside air temperature. These exterior temperatures may be below the exterior dew point causing condensation on the exterior glazing surfaces. This is most likely to happen when there is a clear night sky, still air, and high relative humidity, in addition to the right temperature conditions. Like other dew formed at night, exterior window condensation will disappear as surfaces are warmed by the sun. It is the excellent thermal performance of well-insulated glazing that creates the condition where the outer glazing surface can be cold enough to cause condensation to form.

3.5.4. Condensation Between Glazings

A more annoying problem can arise with double-pane windows, which is condensation between the panes. Moisture can migrate into the space between the panes of glass and condense on the colder surface of the exterior pane. This condensation is annoying not only because it clouds the view and stains the interior surfaces, but because it may mean that the glazing unit must be replaced if it is a sealed insulating glazing unit. In a non-sealed unit, simpler remedies may correct the situation.

Factory-sealed insulated glazing utilizes a permanent seal to prevent the introduction of moisture. The void may be filled with air or dry gases, such as argon. A desiccant material in the edge spacer between the panes is used to absorb any residual moisture in the unit when it is fabricated or any small amount that might migrate into the unit over many years. These windows will fog up when moisture leaking into the air space through the seals overwhelms the ability of the desiccant to absorb it. This could happen early in the window's life (the first few years) if there is a manufacturing defect, or many decades later because of diffusion through the sealant. Quality control in manufacture, sealant selection, window design, and even installation can influence the rate of failure. Once a sealed window unit fails, it is not generally possible to fix it, and the sealed unit must be replaced. Moisture in the unit is also likely to reduce the effectiveness of low-E coatings and suggests that gas fills may be leaking out. Most manufacturers offer a warranty against sealed-glazing failure which varies from a limited period to the lifetime of the window.

When condensation occurs between glazings in a non-sealed unit, there are several possible remedies. Most manufacturers who offer non-sealed double glazing include a small tube connecting the air space to the outside air, which tends to be dry during winter months. Check to be sure that the inner glazing seals tightly to the sash, and clear the air tube if it has become obstructed. In some cases, reducing interior room humidity levels may help alleviate the problem.

3.6 Infiltration

Infiltration is the leakage of air through cracks in the building envelope. Infiltration leads to increased heating or cooling loads when the outdoor air entering the building needs to be heated or cooled. Fenestration products and doors are typically responsible for a significant amount of the infiltration in homes. In extreme conditions, depending on the type and quality, infiltration can be responsible for as much heat loss or gain as the rest of the product. The level of infiltration depends upon local climate conditions, particularly wind conditions and microclimates surrounding the house. Typically, U-factor and SHCG effects far outweigh infiltration effects. Tight sealing and weatherstripping of the fenestration product, including sash, and frames is of paramount importance in controlling infiltration.

High quality fixed fenestration products help to reduce infiltration because they are easier to seal and keep tight. Operable fenestration products are necessary for ventilation, but they are also more susceptible to air leakage. Operable units with low air leakage rates are characterized by good design and high-quality construction and weatherstripping. They also feature mechanical closures that positively clamp the product shut against the wind. For this reason, compression-seal products such as awning, hopper, and casement

designs are generally more effectively weatherstripped than are sliding-seal products. Sliding products rely on wiper-type weatherstripping, which is more subject to wear over time and can be bypassed when it flexes under wind pressure.

3.7 Solar Properties of Glazing Materials

Three things happen to solar radiation as it passes through a glazing material. Some is transmitted, some is reflected, and the rest is absorbed. These are the three components of solar that determine many of the other energy performance properties of a glazing material, such as the solar heat gain coefficient and shading. Manipulating the proportion of transmittance, reflectance, and absorptance for different wavelengths of solar radiation has been the source of much recent innovation in fenestration energy performance.

Visible light is a small portion of the electromagnetic spectrum (see Figure 2-3). Beyond the blues and purples lie ultraviolet radiation and other higher-energy short wavelengths, from X rays to gamma rays. Beyond red light are the near-infrared, given off by very hot objects, the far-infrared, given off by warm room-temperature objects, and the longer microwaves and radio waves.

Glazing types vary in their transparency to different parts of the spectrum. On the simplest level, a glass that appears to be tinted green as you look through it toward the outside will transmit more sunlight from the green portion of the visible spectrum, and reflect/absorb more of the other colors. Similarly, a bronze-tinted glass will absorb the blues and greens and transmit the warmer colors. Neutral gray tints absorb most colors equally.

This same principle applies outside the visible spectrum. Most glass is partially transparent to at least some ultraviolet radiation, while plastics are commonly more opaque to ultraviolet. Glass is opaque to far-infrared radiation but generally transparent to near-infrared. Strategic utilization of these variations has made for some very useful glazing products.

The basic properties of glazing that affect solar energy transfer are:

- Visible transmittance
- Reflectance
- Absorptance

Each is described below.

3.7.1. Transmittance

Transmittance refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., “visible light transmittance,” “UV transmittance,” or “total solar energy transmittance.” Each describes a different characteristic of the glazing. Visible transmittance is the total fenestration product system's transmittance across the visible portion of the solar spectrum. Although VT can be determined for any angle of incidence, the default and most commonly used reference is normal incidence solar radiation. Transmission of visible light determines the effectiveness of a type of glass in providing daylight and a clear view through the fenestration product. For example, tinted glass has a lower visible light transmittance than clear glass.

With the recent advances in glazing technology, manufacturers can control how glazing materials behave in these different areas of the spectrum. The basic properties of the substrate material (glass or plastic) can be altered, and coatings can be added to the surfaces of the substrates. For example, a product optimized for daylighting and for reducing heat gains should transmit an adequate amount of light in the visible portion of the spectrum, while excluding unnecessary heat gain from the near-infrared part of the electromagnetic spectrum.

On the other hand, a product optimized for collecting solar heat gain in winter should transmit the maximum amount of visible light as well as the heat from the near-infrared wavelengths in the solar spectrum, while blocking the lower-energy radiant heat in the far-infrared range that is an important heat loss component. These are the strategies of spectrally selective and low-emittance coatings, described later in the chapter.

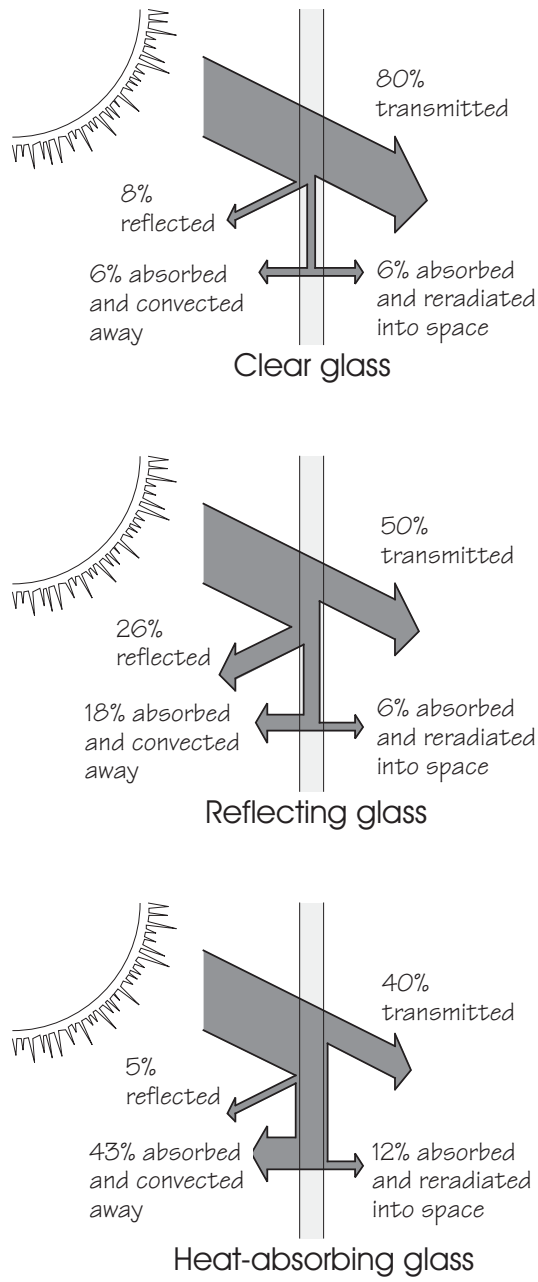


Figure 3-5. Different glass types have different characteristics for the amount of solar radiation reflected, transmitted, absorbed, and re-radiated.

3.7.2. Reflectance

Just as some light reflects off of the surface of water, some light will always be reflected at every glass surface. A specular reflection from a smooth glass surface is a mirror-like reflection similar to when you see an image of yourself in a store window. The natural reflectivity of glass is dependent on the quality of the glass surface, the presence of coatings, and the angle of incidence of the light. Today, virtually all glass manufactured in the

United States is float glass and has a very similar quality with respect to reflectance. The sharper the angle at which the light strikes, however, the more the light is reflected rather than transmitted or absorbed . Even clear glass reflects 50 percent or more of the light striking it at incident angles greater than about 70 degrees. (The incident angle is formed with respect to a line perpendicular to the glass surface.)

Coatings can often be detected by careful examination of a reflected bright image, even if the coating is a transparent low-E coating. Hold a match several inches from a fenestration product at night and observe the reflections of the match in the glass. You will see two closely spaced images for each layer of glass, since the match reflects off the front and back surface of each layer of glass. A wider spacing between the two sets of pairs of images occurs with a wider air space between the glass panes. A subtle color shift in one of the reflected images normally indicates the presence of a low-E coating.

The reflectivity of various glass types becomes especially apparent during low light conditions. The surface on the brighter side acts like a mirror because the amount of light passing through the fenestration product from the darker side is less than the amount of light being reflected from the lighter side. This effect can be noticed from the outside during the day and from the inside during the night. For special applications when these surface reflections are undesirable (i.e., viewing merchandise through a store window on a bright day), special coatings can virtually eliminate this reflective effect.

The reflectivity of glass can be increased by applying various metallic coatings to the surface. Early processes used a liquid alloy of mercury and tin to create mirrors. A silvering process developed in 1865 improved the performance of mirrors. Today, mirror-like surfaces can be created by using vacuum-deposited aluminum or silver, or with a durable pyrolytic coating applied directly to the glass as it is manufactured. Thick coatings can be fully reflective and virtually opaque; a thinner coating is partially reflective and partially transmitting.

Most common coatings reflect all portions of the spectrum. However, in the past twenty years, researchers have learned a great deal about the design of coatings that can be applied to glass and plastic to reflect only selected wavelengths of radiant energy. Varying the reflectance of far-infrared and near- infrared energy has formed the basis for low-emittance coatings for cold climates, and for spectrally selective low-emittance coatings for hot climates.

3.7.3. Absorptance

Energy that is not transmitted through the glass or reflected off of its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the temperature of the glass.

Typical 1/8-inch (3 mm) clear glass absorbs only about 4 percent of incident sunlight. The absorptance of glass is increased by adding to the glass chemicals that absorb solar energy. If they absorb visible light, the glass appears dark. If they absorb ultraviolet radiation or near-infrared, there will be little or no change in visual appearance. Clear glass absorbs very little visible light, while dark tinted glass absorbs a considerable amount. The absorbed energy is converted into heat, warming the glass. Thus, when these “heat-absorbing” glasses are in the sun, they feel much hotter to the touch than clear glass. They are generally gray, bronze, or blue-green and are used primarily to lower the solar heat gain coefficient and to control glare. Since they block some of the sun’s energy, they reduce the cooling load placed on the building and its air-conditioning equipment. Absorption is not the most efficient way to reduce cooling loads, as discussed later.

3.8 Infrared Properties of Glazing Materials (Emittance)

When heat or light energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. This ability of a material to radiate energy is called its emissivity. Fenestration products, along with all other household objects, typically emit, or radiate, heat in the form of long-wave far-infrared energy. This emission of radiant heat is one of the important heat transfer pathways for a fenestration product. Thus, reducing the product’s emission of heat can greatly improve its insulating properties.

Standard glass has an emittance of 0.84 over the long wavelength portion of the spectrum, meaning that it emits 84 percent of the energy possible for an object at its temperature. It also means that for long-wave radiation (where there is no transmittance) striking the surface of the glass, 84 percent is absorbed and only 16 percent is reflected. By comparison, low-E glass coatings have an emittance as low as 0.04. This glazing would emit only 4 percent of the energy possible at its temperature, and thus reflect 96 percent of the incident long-wave infrared radiation.

4. SUMMARY OF ALGORITHMS

4.1. THERM and WINDOW Algorithms

This section is a brief overview of the calculational algorithms found in THERM and WINDOW. Much more detailed documentation is available and is referenced in the appropriate parts of this discussion. The algorithms in both programs are based on ISO 15099, with the exceptions documented in Appendix A of this manual.

4.1.1. WINDOW

The WINDOW program calculates:

- Center-of-glazing properties of a glazing system
- Total product area-weighted properties (based on previously calculated center-of-glazing properties, frame, edge-of-glazing, divider, and divider-edge properties calculated in THERM)

WINDOW algorithms are documented in two publications, both of which can be found on the LBNL WINDOW 6 Documentation website (http://windows.lbl.gov/software/window/6/w6_docs.htm):

- "WINDOW 5: Program Description, A PC Program for Analyzing the Thermal Performance of Fenestration Products", R. Mitchell, C. Kohler, D. Arasteh, John Carmody, C. Huizenga, Dragan Curcija, LBNL-44789 DRAFT, June 2001;
- TARCOG: Mathematical Models and Computer Algorithms for Calculation of Thermal Performance of Glazing Systems with or without Shading Devices.

4.1.2. THERM:

The THERM program calculates:

- Frame and edge-of-glazing properties, the results of which are imported into WINDOW where the total product properties are calculated.

4.2 WINDOW Computational Method

Heat transfer across a fenestration product is a function of both the temperature difference between the inside and outside and the incident solar radiation on the product. In order to evaluate heat transfer through a specific product, its configuration and physical dimensions must be specified. This includes the glazing properties (visible, total solar and infrared optical properties, and thermal conductivity), the gap gas (air or low-conductivity gas) thermophysical properties, spacer and frame characteristics, and environmental conditions.

Fenestration product heat transfer through the center-of-glazing area is primarily a one-dimensional process. It is analyzed by breaking down the glazing system cross section into an assembly of nodes and calculating the heat transfer between each node. Under steady-state conditions, the temperatures of the nodes are such that the net energy flux entering each node is equal to that leaving each node. To perform the energy balance, WINDOW models the user-defined glazing system as a one-dimensional, steady-state resistance network, shown in Figure 4-1. An iterative solution method is then used to converge upon the correct temperature distribution. From this temperature distribution, any desired performance index can be calculated.

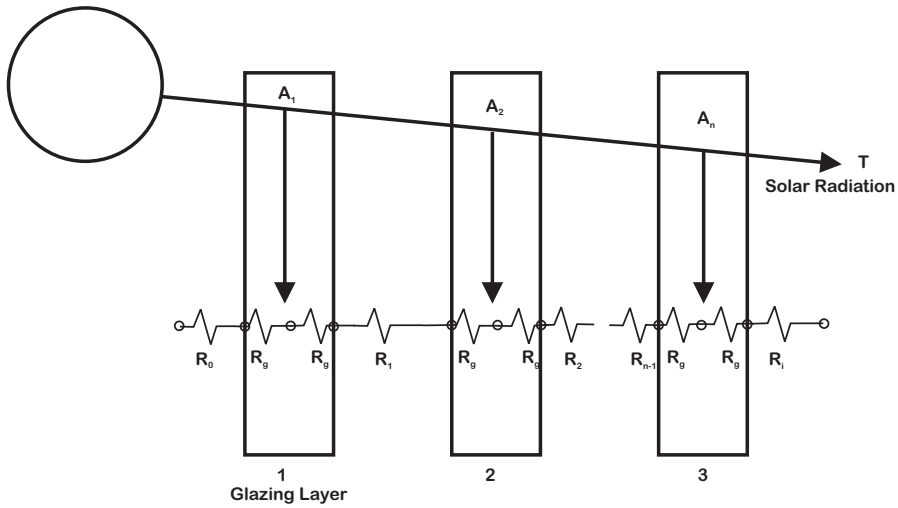


Figure 4-1. Resistance network used to model center-of-glazing heat transfer in WINDOW.

Two temperature nodes are assigned to each glazing layer (front and back surface), along with outdoor and indoor air temperature nodes. The resistance between each node equals the inverse of the sum of the radiative and conductive/convective heat transfer coefficients. The temperature-dependent conduction/convection and effective-radiation heat transfer coefficients for the outward-facing and inward-facing surfaces and for the gas-filled gaps are calculated from the temperature distribution. The heat transfer coefficients between the nodes within the solid materials simply depend on the conductivity of the materials, where the materials are considered to be homogenous.

Conductive/convective heat transfer coefficients are calculated based on empirical relationships. The outdoor film coefficient depends on the wind speed and the direction from which the wind is blowing. The indoor film coefficient is a function of the difference between the inward-facing surface temperature, the indoor temperature, and the height of the fenestration product. Gap heat transfer coefficients are computed from empirical equations for the Nusselt number. The Nusselt number is a non-dimensional quantity that relates the temperature difference between the surfaces bounding the gap, and width, height and thermophysical properties of the gap gas. Fenestration product tilt is also accounted for in all conductive/convective correlations.

The radiative energy flux leaving each surface is calculated from the Stephan-Boltzmann law using the surface infrared hemispherical emissivity and temperature. The net radiative flux between radiating nodes divided by the associated temperature difference gives an effective radiation heat transfer coefficient.

The measure of the heat transmission through the fenestration product is its overall U-factor, which is the inverse of the total thermal resistance in the absence of solar radiation. The measure of energy transfer due to solar radiation is the Solar Heat Gain Coefficient or SHGC, which is calculated from the solar-optical properties of the glazing and framing system, and the portion of absorbed solar energy that is transmitted to the indoor side.

To accurately model glazing systems with multiple spectrally selective glazings (i.e., glazings with solar-optical properties which vary by wavelength, such as many low-emissivity coatings), a multi-band model is used in WINDOW. In this model, WINDOW calculates the transmittance and reflectance for the glazing layer or the glazing system wavelength by wavelength, and then weights the properties by the appropriate weighting functions to obtain the total solar, visible, thermal infrared properties, as well as the damage-weighted transmittance and the transmittance between 0.30 and 0.38 microns. To use the multi-band model, WINDOW needs a spectral data file for each glazing layer. These data files are updated and maintained by LBNL and available from NFRC. If some of the glazing layers in a glazing system do not have a spectral data file, WINDOW assumes a flat spectral behavior of the glazings without the spectral data files, based on their stated visible and solar properties. For NFRC certification simulation, the NFRC-approved spectral data files must be used (indicated by a # symbol in the WINDOW Glass Library).

4.3 THERM Computational Methods

THERM incorporates a two-dimensional heat transfer model, utilizing a finite element method to numerically solve the governing two-dimensional energy equation. The geometry of the fenestration system consists of the frame and glazing sections, where glazing materials are transferred from the WINDOW program. Frame materials are directly assigned in the THERM program and the appropriate boundary conditions are applied on the frame surfaces exposed to indoor room air and outdoor air, while the bottom frame surfaces and the top of glazing surfaces are assigned adiabatic boundary conditions. The numerical model needs to have boundary conditions assigned to each boundary surface of the model in order to be completely defined.

Boundary conditions on indoor and outdoor surfaces consist of both a convection and radiation component. The convection component on the indoor side is specified through the use of a temperature dependent surface heat transfer coefficient, based on natural convection correlations. For each frame material type there is a constant value of the convective surface heat transfer coefficient. The radiation component is modeled explicitly through the use of a detailed, view-factor-based radiation model. This model assumes that the indoor environment has a uniform temperature and the emissivity of a black body (ε=1.0), while the appropriate emissivity is assigned to each frame and glass surface. While the majority of surfaces have an emissivity of 0.9, metals like Aluminum have an emissivity of 0.2. On the outdoor side, the convective portion of the boundary condition is specified as a constant, dependent on the wind velocity. The radiation component is modeled explicitly, but under the simplified black body assumption (i.e., each surface on the outdoor fenestration boundary has a perfect view of the outdoor environment with the view factor of 1.0).

The convection and radiation in glazing and frame cavities is approximated through the use of an effective conductivity, k_{eff}, which assumes the gas to be an equivalent solid with the conductivity being equal to the base conductivity of the gas, plus the convection and the radiation component added to the conductivity value. The effective conductivity of the glazing is transferred from the WINDOW program, while for frame cavities, their value is calculated by the THERM program based on the geometry, heat flow direction, surface emissivities and temperatures. The frame cavities may be completely enclosed or partially ventilated (only on the outdoor side), depending on the configuration and size of the section, connecting the frame cavity with the outdoor environment.

Upon the completion of the numerical simulation, the error estimator portion of the program makes local error estimates, and based on the error levels, refines troublesome regions of the model and recalculates the entire model. This procedure is repeated until no local regions show error levels higher than what is prescribed. This error estimator is based on the error energy norm methodology by Zinkiewitz (see the THERM 2.0 User's Manual, Section 9, References)

The details of the models are in the "THERM 2.0 Users Manual (THERM 2.0 for Analyzing Two-Dimensional Heat Transfer Through Building Products)" and "Conrad 5 and Viewer 5 Technical and Programming Documentation" [Curcija 2006]. The following diagram shows the program flow.

Figure 4-2 shows the steps involved in a THERM analysis.

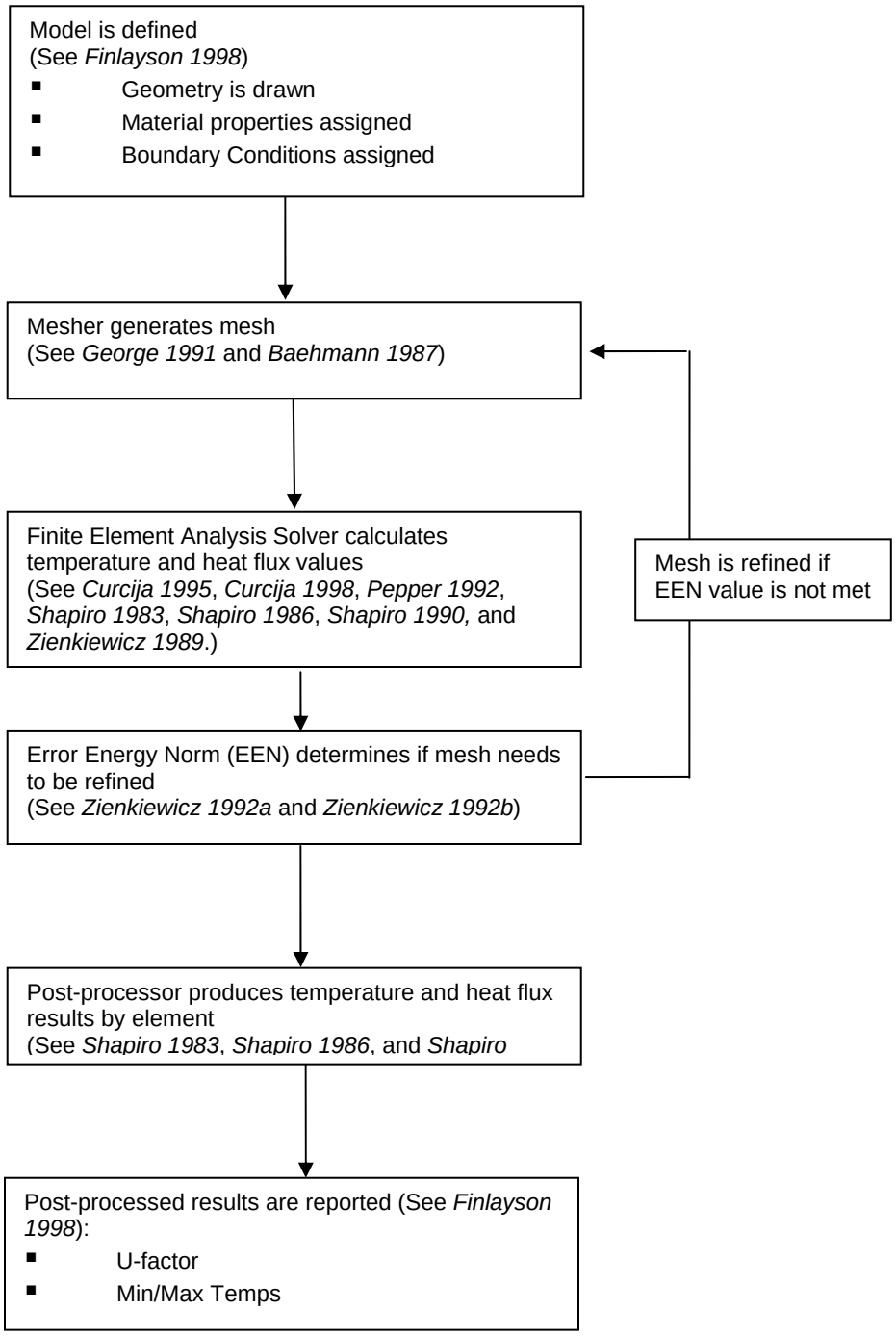


Figure 4-2. THERM program calculation procedures flow chart.

4.4 Total Product Calculations

The total fenestration product properties for U-factor, SHGC and VT are based on an area-weighted average of the product's component properties which are:

- the center-of-glazing properties of the glazing system
- the frame
- edge-of-glazing
- divider
- Edge-of-divider

The frame edge and divider edge properties depend on the center-of-glazing properties of the associated glazing system.

This area-weighted total product value can be calculated using the WINDOW program, or other calculation tool such as a spreadsheet. This procedure for this area-weighted calculation is:

1. Multiply the component property by the component area
2. Sum these area-weighted component properties
3. Divide the area-weighted sum by the total projected area of the product

The operator types (fixed, vertical slider, horizontal slider, casement) determine which components (head, jamb, sill and meeting rail) are required to calculate the whole product area-weighted values.

4.4.1. U-factor

The whole-product area weighted U-factor calculation, shown below, is documented in Equation 4 in "NFRC 100: Procedures for Determining Fenestration Product U-factors".

$$U_t = \frac{\left[\sum(U_f * A_f) + \sum(U_d * A_d) + \sum(U_e * A_e) + \sum(U_{de} * A_{de}) + \sum(U_c * A_c)\right]}{A_{pf}} \quad [4\text{-}1]$$

Where:

U_t = Total product U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_{pf} = Projected fenestration product area, m² (ft²).

U_f = Frame U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_f = Frame area, m² (ft²).

U_d = Divider U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_d = Divider area, m² (ft²).

U_e = Edge-of-glazing U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_e = Edge-of-glazing area, m² (ft²).

U_{de} = Edge-of-divider U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_{de} = Edge-of-divider Area, m² (ft²).

U_c = Center-of-glazing U-factor, W/m²-°K , (Btu/hr-ft²-°F).

A_c = Center-of-glazing area in ft² (m²).

4.4.2. Solar Heat Gain Coefficient (SHGC)

The total solar heat gain coefficient is determined by an area-weighted average of contributions from the transparent and the opaque elements in the fenestration product. The SHGC is a function of the solar transmittance, the solar absorptances of each layer and the inward flowing fraction of thermal energy. The SHGC is calculated for each component of the product separately. See ISO 15099 for detailed algorithm documentation

All the transparent regions (center-of-glazing, edge-of-glazing, and edge-of-divider) have the same SHGC. Once the SHGC of the opaque elements is determined the total SHGC is calculated as the area-weighted average of the SGHC through the transparent and the opaque portions of the fenestration product as shown below.

$$SHGC_t = \frac{\left[(SHGC_f * A_f) + (SHGC_d * A_d) + (SHGC_e * A_e) + (SHGC_{de} * A_{de}) + (SHGC_c * A_c)\right]}{A_{pf}} \quad [4\text{-}2]$$

Where:

$SHGC_t$ = Total product SHGC (dimensionless).

A_{pf} = Projected fenestration product area, m² (ft²).

$SHGC_f$ = Frame SHGC (dimensionless).

A_f = Frame area in, m² (ft²).

$SHGC_d$ = Divider SHGC (dimensionless).

A_d = Divider area in, m² (ft²).

$SHGC_e$ = Edge-of-glazing SHGC (dimensionless).

$SHGC_e$ = Edge-of-glazing area in, m² (ft²).

$SHGC_{de}$ = Edge-of-divider SHGC (dimensionless).

$SHGC_{de}$ = Edge-of-divider Area in, m² (ft²).

$SHGC_c$ = Center-of-glazing SHGC (dimensionless).

A_c = Center-of-glazing area, m² (ft²).

For NFRC rating purposes, Section 6 of *NFRC 200* shall be followed to obtain SHGC values.

4.4.3. Visible Transmittance

The whole-product area weighted visible transmittance calculation is shown below.

$$VT_t = \frac{\left[(VT_f * A_f) + (VT_d * A_d) + (VT_e * A_e) + (VT_{de} * A_{de}) + (VT_c * A_c)\right]}{A_{pf}} \quad [4\text{-}3]$$

Where:

VT_t = Total product VT (dimensionless)

A_{pf} = Projected fenestration product area, m² (ft²).

VT_f = Frame VT (dimensionless).

A_f = Frame area, m² (ft²).

VT_d = Divider VT (dimensionless).

A_d = Divider area, m² (ft²).

VT_e = Edge-of-glazing VT (dimensionless).

VT_e = Edge-of-glazing area, m² (ft²).

VT_{de} = Edge-of-divider VT (dimensionless).

VT_{de} = Edge-of-divider, m² (ft²).

VT_c = Center-of-glazing VT (dimensionless).

A_c = Center-of-glazing area, m² (ft²).

For opaque components (all known frames and dividers) the component visible transmittance (VT_f , VT_d) are zero. Also note that, as defined by NFRC 200, visible transmittance $VT_c = VT_e = VT_{de}$

For NFRC rating purposes, Section 6 of NFRC 200 shall be followed to obtain VT values.

4.4.4. Condensation Resistance

The whole-product Condensation Resistance calculation is implemented in WINDOW according to *NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values*. The procedure is based on the calculated surface temperature on the indoor side of the glazing and frame boundaries. The glazing cavity model for condensation resistance is based on the variable convective surface heat transfer coefficient, rather then effective conductivity. This is because the spatial distribution of surface temperatures are important, and therefore the effective conductivity model for the glazing cavity, which produces sufficiently accurate average results, does not produce sufficiently accurate local results. The details of the methodology are given in "Conrad 5 and Viewer 5 Technical and Programming Documentation" [Curcija 2006].

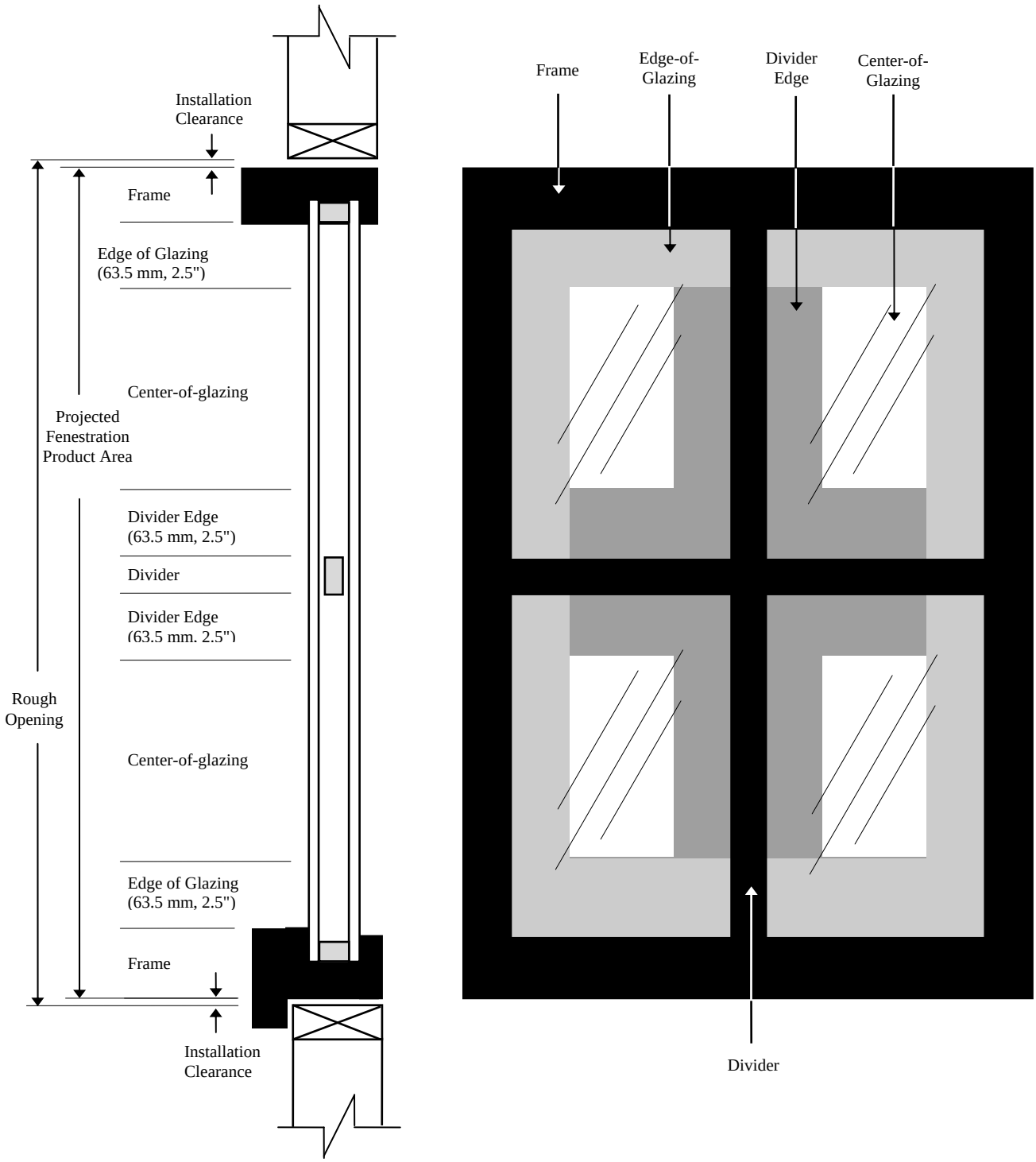
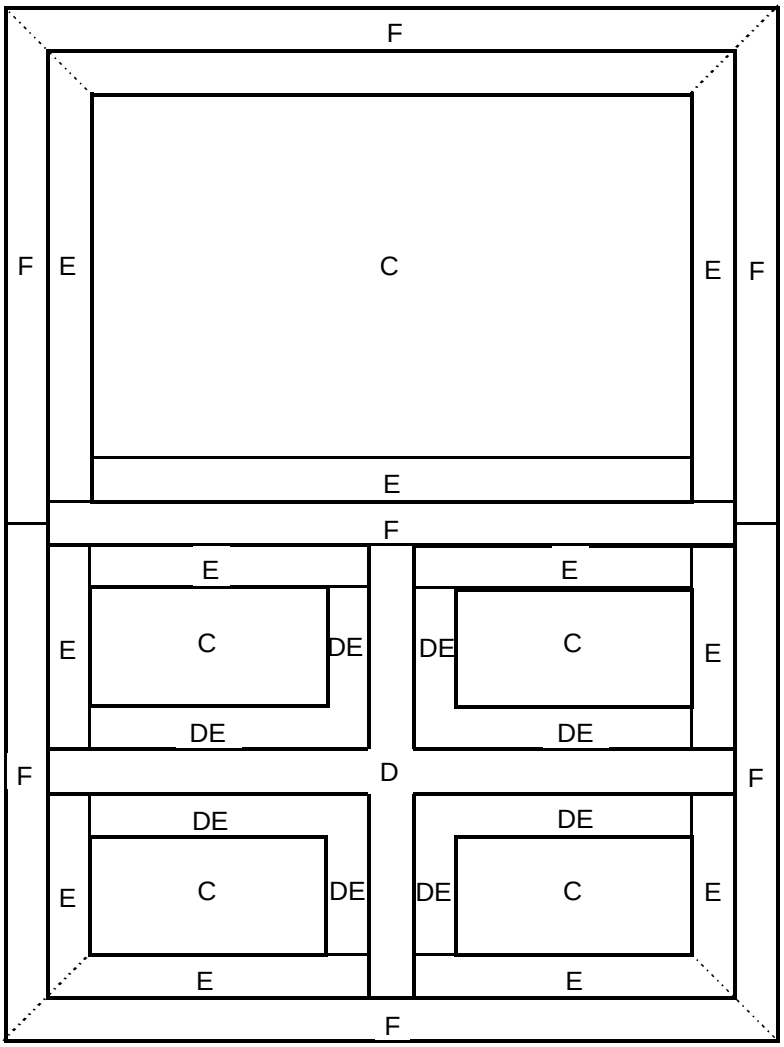


Figure 4-3. Components for the whole product area-weighted calculation. The view on the left is a section, and the view on the right is an elevation.

The following figure is from *NFRC 100* and shows in detail how each section of the product is area-weighted. The WINDOW program implements this scheme for area-weighting.

Figure 1: Fenestration Product Schematic—Vertical Elevation



LEGEND

C	Center-of-glazing
E	Edge-of-glazing
F	Frame
D	Divider
DE	Edge-of-divider

Center-of-glazing, edge-of-glazing, divider, edge-of-divider and frame areas for a typical fenestration product. Edge-of-glazing and edge-of-divider areas are 63.5 mm (2.5 in.) wide. The sum of these component areas equals the total projected fenestration product area.

Figure 4-4. Schematic for whole product area-weighting from the NFRC 100 document.

5. MODELING CENTER-OF-GLAZING WITH WINDOW

5.1. Overview

The WINDOW program calculates the center-of-glazing U-factor (U_c), Solar Heat Gain Coefficient ($SHGC_c$), Visible Transmittance (VT_c) and Fading Resistance (FR) according to the following procedures:

- *NFRC 100: Procedure for Determining Fenestration Product Thermal Properties*
- *NFRC 200: Procedure for Determining Fenestration Product Solar Heat Gain Coefficients at Normal incidence*
- *NFRC 300: Procedure for Determining Solar Optical Properties of Simple Fenestration Product*
- *NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values*
- *ISO 15099: Thermal Performance of Windows, Doors and Shading Devices – Detailed Calculations*

The WINDOW User's Manual, *WINDOW 5: Program Description, A PC Program for Analyzing the Thermal Performance of Fenestration Products* (http://windows.lbl.gov/software) contains detailed information about how to use the program, and can be used to become familiar with the program before reading this manual.

For NFRC simulations, the procedure for calculating the center-of-glazing U-factor in WINDOW is:

- Verify that the **Glass Library** entries are from the currently approved International Glazing Data Library associated with the Optics program (the following website contains current updates: http://windows.lbl.gov/software and click on the International Glazing Database link)
- Create a glazing system for the product to be modeled which is composed of entries from the **Glass** and **Gas Libraries**
- This Glazing System can then be imported into THERM to calculate the frame and edge-of-glazing values
- The Glazing System is also used in WINDOW when constructing the whole product in the Window Library.

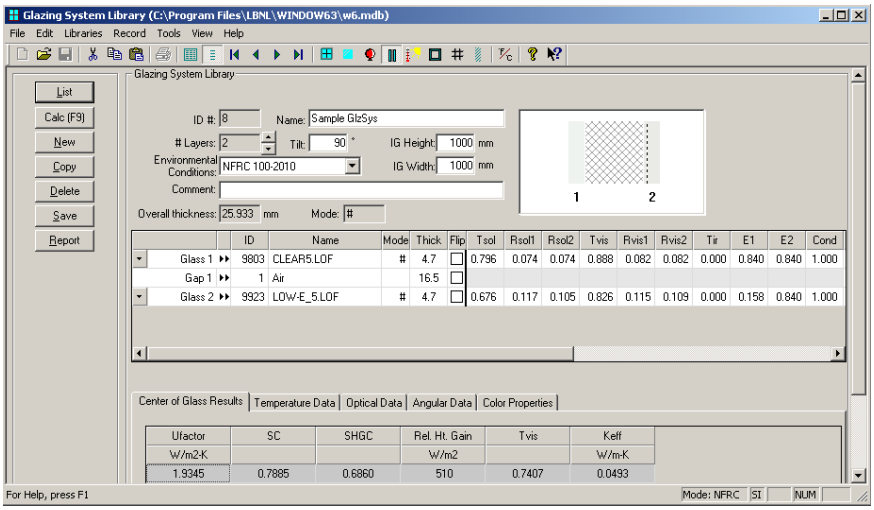


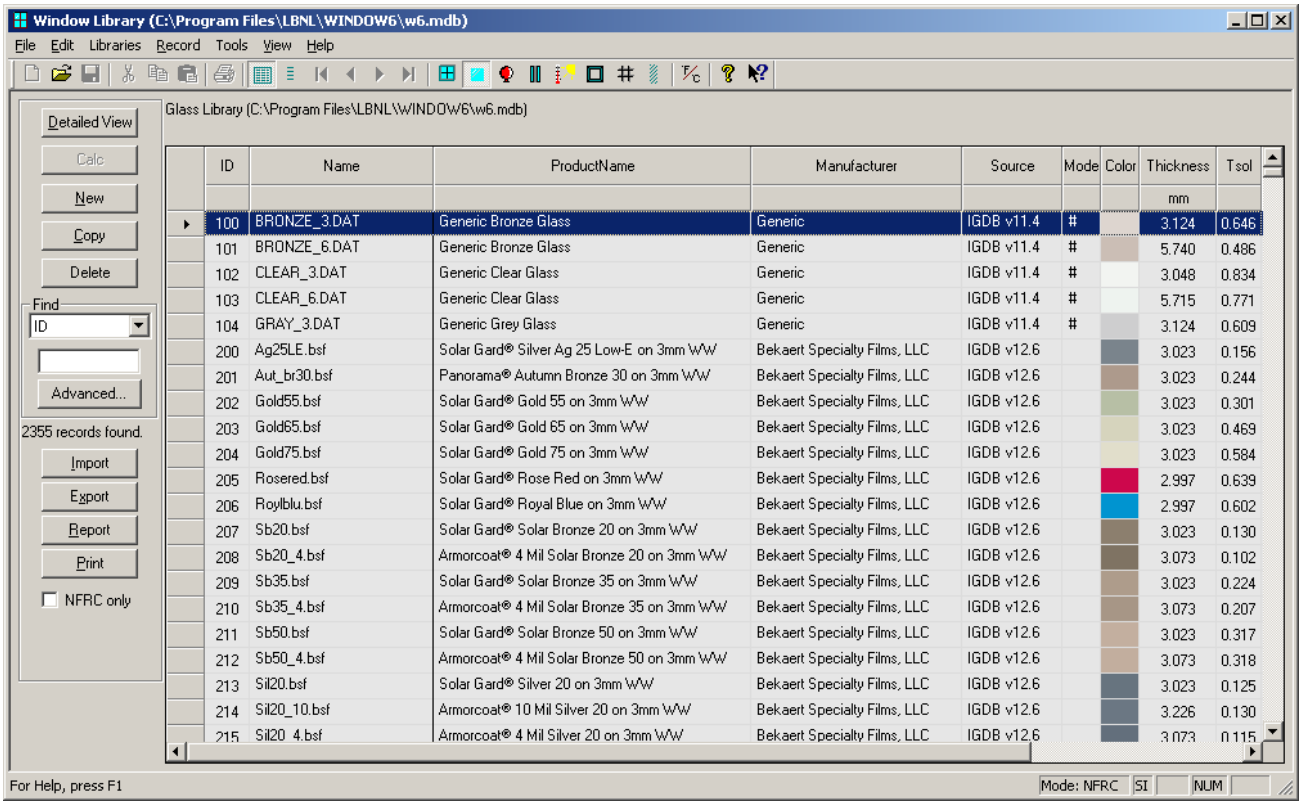
Figure 5-1. WINDOW Glazing System Library Detailed View.

5.2. Glass Library

The **Glass Library** contains individual glass layers that can be used to construct glazing systems. For NFRC simulations, the NFRC approved glass layers from the International Glazing Database shall be used. WINDOW will install a current International Glazing Database, but the library is updated frequently so check the website mentioned in Section 5.1 for updates. The data in the International Glazing Database is determined according to the *NFRC 300* procedure. When the NFRC approved glass data is used, a **#** symbol appears in the **Mode** fields of both the **Glass Library** (shown in Figure 5-2) and the **Glazing System Library** (shown in Figure 5-1). All certification simulations must use the most current NFRC-approved International Glazing Database (IGDB).

The Glass Library imported from the International Glazing Database contains glass products of specific manufacturers, as well as several entries for generic uncoated products, indicated by the Manufacturer field being set to "Generic". The values for these generic entries are not measured properties from any specific glass products, but are averaged spectral data from at least two samples.

See Section 8 for instructions about how to create laminates and applied films in the Optics program and import them into the WINDOW Glass Library.



ID	Name	ProductName	Manufacturer	Source	Mode	Color	Thickness	Tsol
							mm	
100	BRONZE_3.DAT	Generic Bronze Glass	Generic	IGDB v11.4	#		3.124	0.646
101	BRONZE_6.DAT	Generic Bronze Glass	Generic	IGDB v11.4	#		5.740	0.486
102	CLEAR_3.DAT	Generic Clear Glass	Generic	IGDB v11.4	#		3.048	0.834
103	CLEAR_6.DAT	Generic Clear Glass	Generic	IGDB v11.4	#		5.715	0.771
104	GRAY_3.DAT	Generic Grey Glass	Generic	IGDB v11.4	#		3.124	0.609
200	Ag25LE.bsf	Solar Gard® Silver Ag 25 Low-E on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.156
201	Aut_br30.bsf	Panorama® Autumn Bronze 30 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.244
202	Gold55.bsf	Solar Gard® Gold 55 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.301
203	Gold65.bsf	Solar Gard® Gold 65 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.469
204	Gold75.bsf	Solar Gard® Gold 75 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.584
205	Rosered.bsf	Solar Gard® Rose Red on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			2.997	0.639
206	Roylblu.bsf	Solar Gard® Royal Blue on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			2.997	0.602
207	Sb20.bsf	Solar Gard® Solar Bronze 20 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.130
208	Sb20_4.bsf	Armorcoat® 4 Mil Solar Bronze 20 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.073	0.102
209	Sb35.bsf	Solar Gard® Solar Bronze 35 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.224
210	Sb35_4.bsf	Armorcoat® 4 Mil Solar Bronze 35 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.073	0.207
211	Sb50.bsf	Solar Gard® Solar Bronze 50 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.317
212	Sb50_4.bsf	Armorcoat® 4 Mil Solar Bronze 50 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.073	0.318
213	Sil20.bsf	Solar Gard® Silver 20 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.023	0.125
214	Sil20_10.bsf	Armorcoat® 10 Mil Silver 20 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.226	0.130
215	Sil20_4.bsf	Armorcoat® 4 Mil Silver 20 on 3mm WW	Bekaert Specialty Films, LLC	IGDB v12.6			3.073	0.115

Figure 5-2. WINDOW Glass Library.

On the left hand side of the screen, of particular interest is the **NFRC only** checkbox; if checked, only the records with a "#" in the **Mode** column will be displayed, which are the records certified for NFRC simulations.

Detailed View Click on this button to see all the information about the currently highlighted record.

The optical properties defined for each glass entry are listed below:

ID The unique ID associated with this record. For records whose **Source** is "Optics", this ID is the "NFRC ID" from the International Glazing Database. For records whose **Source** is

	"User", this ID is assigned automatically by WINDOW but can be overwritten by the user as long as it is unique.
Name	The name of the glass layer. If the record was imported from the International Glazing Database, this name will automatically come from that database.
Product Name	The **Product Nam**e field from the International Glazing Database.
Manufacturer	The name of the glass manufacturer. If the record was imported from the International Glazing Database, this name will automatically come from that database.
Source	Source of the glass record. Current options are: ▪ **IGDB v<nn.n>:** Indicates that the data was imported from the International Glazing Database (IGDB), with the database version number, such as, 11.4. These records will have the spectral data information from the International Glazing Database. ▪ **User:** Indicates that the data was created when the user copied an existing record into a new record. User defined records will not have associated spectral data values.
Mode	An identifier to determine if the glass layer is approved by NFRC. Only records with "#" in this field can be used for NFRC simulations, except for laminates and applied films that are imported from the Optics5 User Database. See Section 8 for more details.
Color	A graphic representation of the color of the glass.
Thickness	Glass thickness. Units: mm (SI); inches (IP).
Tsol	Solar transmittance of the glazing layer.
Rsol1	Solar reflectance of the glazing layer, exterior-facing side.
Rsol2	Solar reflectance of the glazing layer, interior-facing side.
Tvis	Visible transmittance of the glazing layer.
Rvis1	Visible reflectance of the glazing layer, exterior-facing side.
Rvis2	Visible reflectance of the glazing layer, interior-facing side.
Tir	Thermal infrared (longwave) transmittance of the glazing layer.
emis1	Infrared (longwave) emittance of the glazing layer, exterior-facing side
emis2	Infrared (longwave) emittance of the glazing layer, interior-facing side

5.2.1. Updating Glass Library from the IGDB

The International Glazing Database (IGDB) is updated by LBNL approximately every three months. These updates are available on the LBNL IGDB website (http://windowoptics.lbl.gov/data/igdb). The WINDOW Glass Library should be updated when these IGDB releases occur. There are detailed instructions on the website listed above about how to do this update.

5.3 Glazing System Library -- Center-of-Glazing U-factor

The center-of-glazing U-factor is determined in the WINDOW **Glazing System Library**. A glazing system is created by specifying layers of glass from the **Glass Library**, as well as the gas fill material between the layers, such as air or argon. Detailed instructions about creating a glazing system can be found in the *WINDOW 5 User's Manual*. A sample glazing system library entry is shown in Figure 5-3.

When defining a glazing system, the number of glass layers (**# Lay**), the **Tilt**, and the **Environmental Conditions** (**Env Cond**) must be specified. For NFRC certification calculations the **Environmental Conditions** have restricted values, as discussed in the next section. Also, the glass layers must be from the Glass Library using approved records from the International Glazing Database, indicated by a **#** value in the **Mode** field of the glass layer record, as shown in Figure 5-3.

*Note: to see the U-factor value to four decimal places, click on **File/Preferences** menu choice and in the **Options** tab, set the **Display Precision** field to"4"*

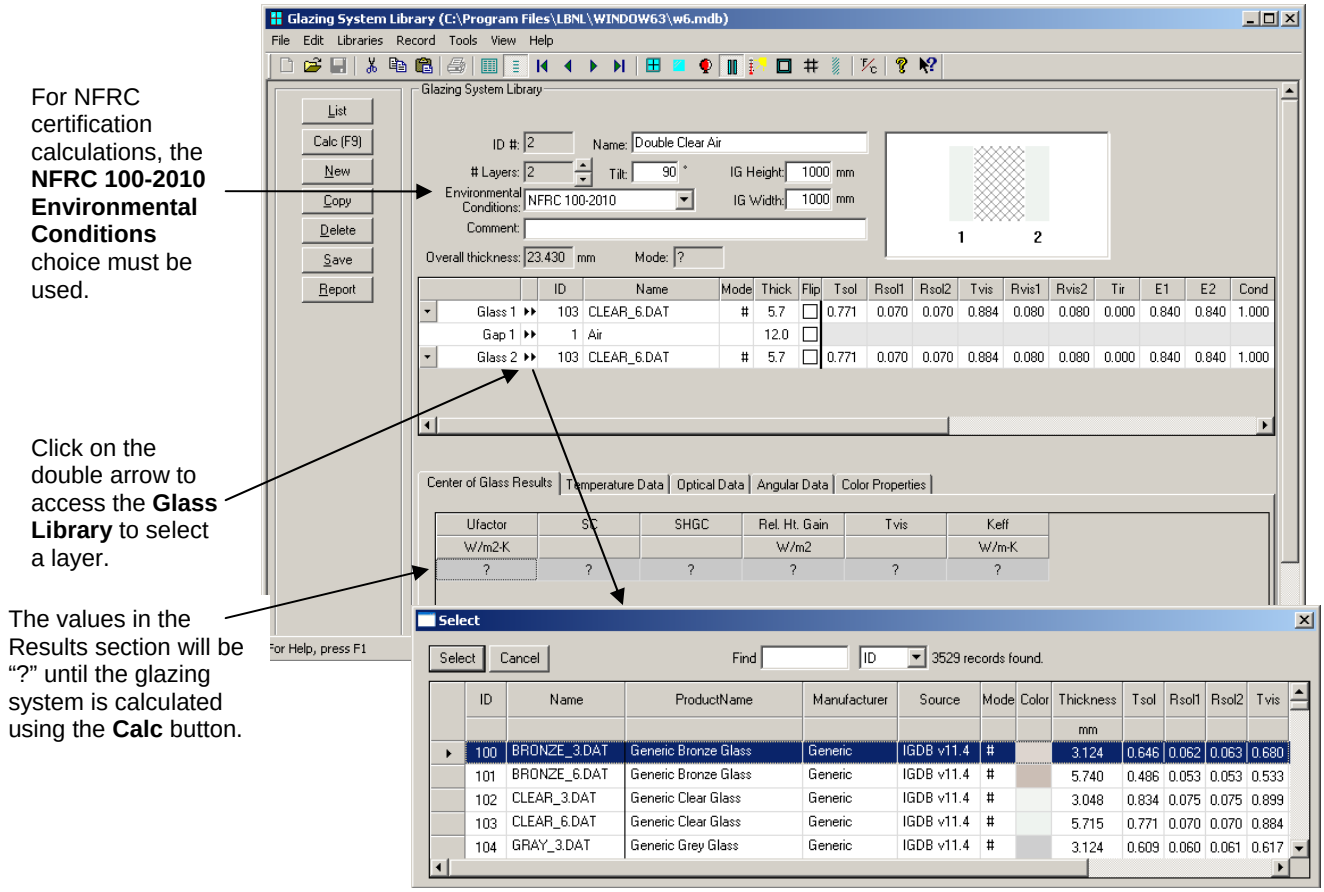
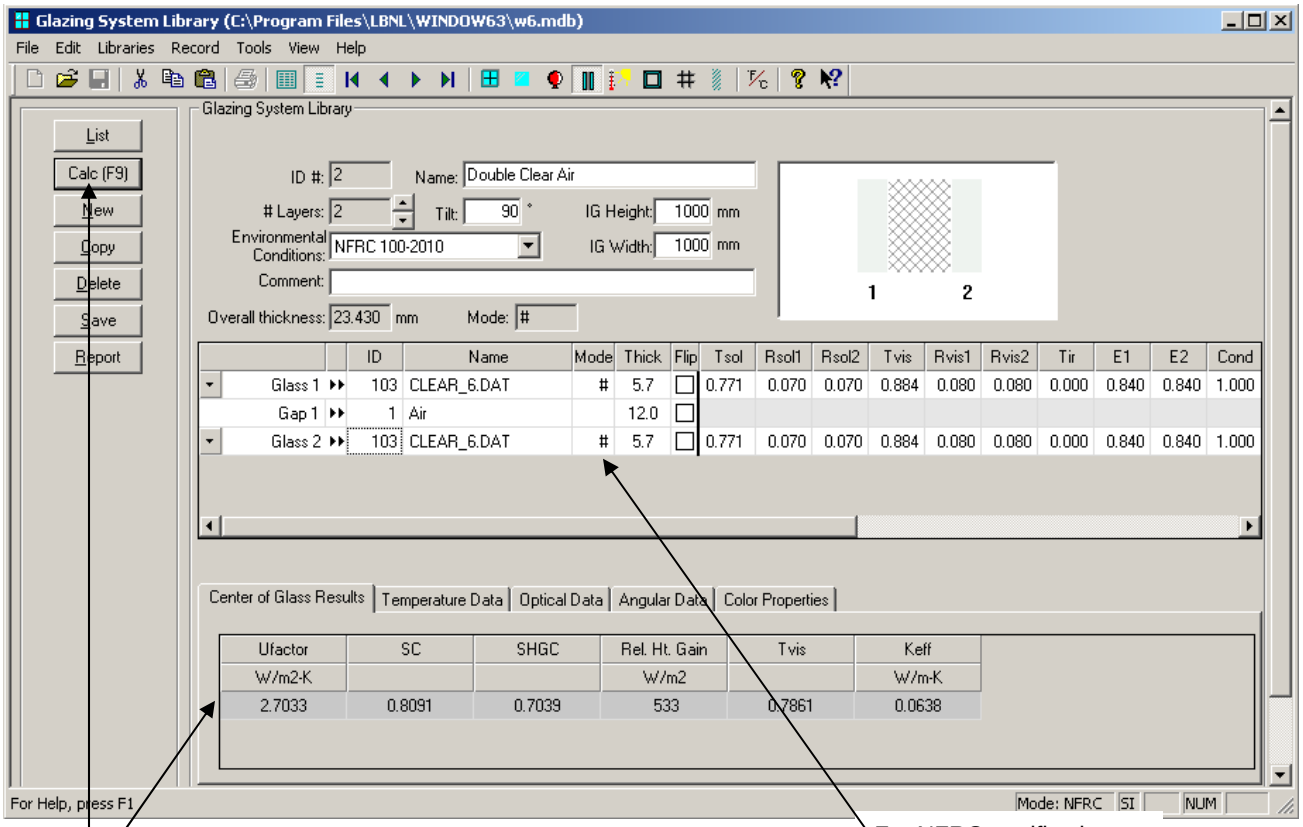


Figure 5-3. Selecting glass layers in the Glazing Systems Library.



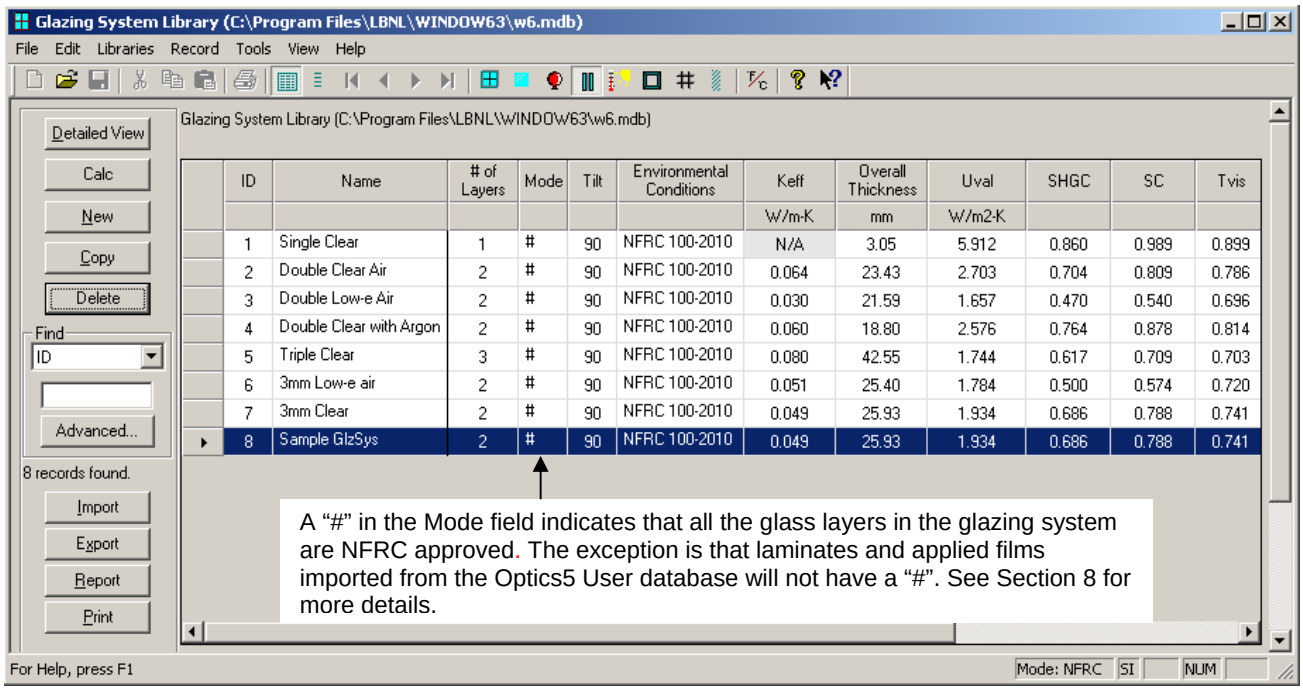
When the glass and gap layers have been defined, click on the **Calc** button and the center-of-glazing U-factor as well as other results will be displayed in the **Results** section at the bottom of the screen. This value is used when the glazing system is imported into THERM.

For NFRC certification calculations of SHGC and VT, glass layers from the **Glass Library** with a # in the Mode field shall be used. The # indicates that the record is approved for NFRC simulations.

Figure 5-4. Calculating results in the Glazing Systems Library.

The Center of Glass Results tab at the bottom of the screen shows the results for the glazing system. The U-factor results are based on a default glazing system height of one meter. This center-of-glazing U-factor value will be recalculated in the Window Library to reflect the true height of the product being modeled. (See *Section 7*, "Total Product Calculations", for more information).

All the **Glazing System Library** records can be seen in the **List View**, access by clicking the **List** button from the **Glazing System Library Detailed View**.



ID	Name	# of Layers	Mode	Tilt	Environmental Conditions	Keff	Overall Thickness	Uval	SHGC	SC	Tvis
						W/m-K	mm	W/m2-K			
1	Single Clear	1	#	90	NFRC 100-2010	N/A	3.05	5.912	0.860	0.989	0.899
2	Double Clear Air	2	#	90	NFRC 100-2010	0.064	23.43	2.703	0.704	0.809	0.786
3	Double Low-e Air	2	#	90	NFRC 100-2010	0.030	21.59	1.657	0.470	0.540	0.696
4	Double Clear with Argon	2	#	90	NFRC 100-2010	0.060	18.80	2.576	0.764	0.878	0.814
5	Triple Clear	3	#	90	NFRC 100-2010	0.080	42.55	1.744	0.617	0.709	0.703
6	3mm Low-e air	2	#	90	NFRC 100-2010	0.051	25.40	1.784	0.500	0.574	0.720
7	3mm Clear	2	#	90	NFRC 100-2010	0.049	25.93	1.934	0.686	0.788	0.741
8	Sample GlzSys	2	#	90	NFRC 100-2010	0.049	25.93	1.934	0.686	0.788	0.741

Figure 5-5. The List View of the Glazing System Library shows all the glazing systems.

5.3.1. Environmental Conditions

When defining the glazing system for use in an NFRC certified simulation, the **NFRC 100-2010** choice must be used for the **Environmental Conditions** (Env Cnd) parameter, which contains the parameters defined by *NFRC 100*. Figure 5-4 shows the NFRC 100-2001 choice in the WINDOW **Environmental Conditions Library**. Table 5-1 lists the values for the U-factor calculation and Table 5-2 lists the values for the Solar Heat Gain Coefficient calculation.

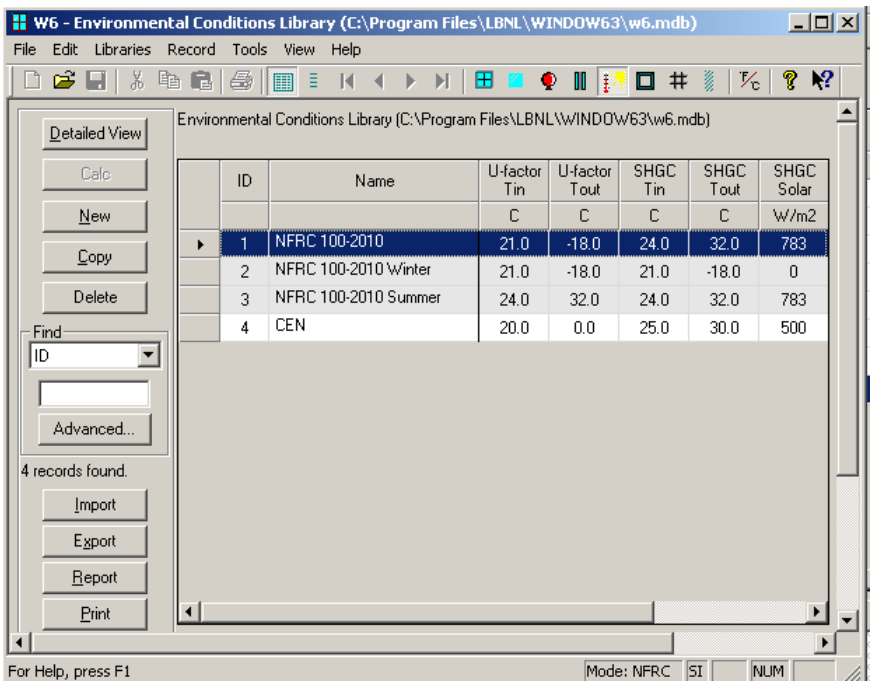


Figure 5-6. WINDOW Environmental Conditions Library List View.

Use the NFRC 100-2004 Environmental Conditions Library in WINDOW for NFRC center-of-glazing simulations

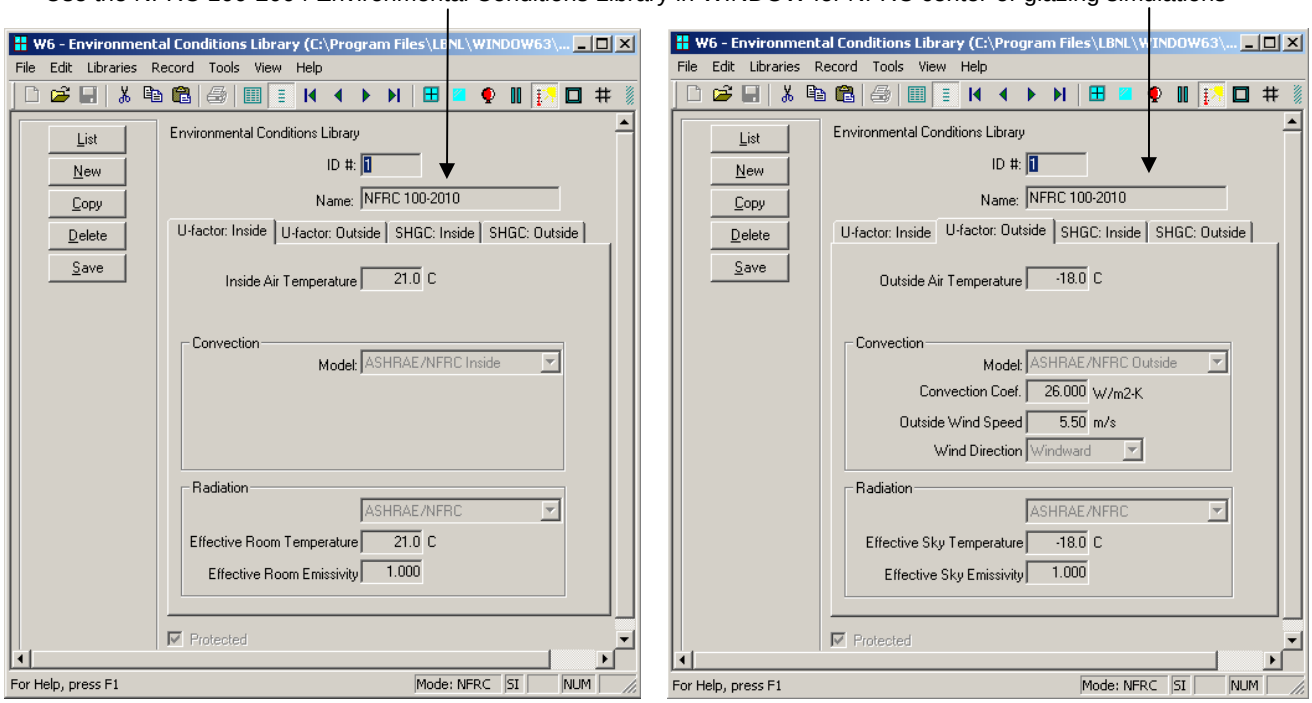


Figure 5-7. WINDOW Environmental Conditions Library Detailed View of U-factor settings.

Table 5-1. Environmental Conditions for NFRC Simulations for U-factor calculations.

Variable	SI Units	IP Units (reference only)
Outside Temperature	-18°C	0°F
Inside Temperature	21°C	70°F
Wind Speed	5.5 m/s	12.3 mph
Wind Direction	Windward	Windward
Direct Solar	0 W/m²	0 Btu/hr-ft²
Sky Temperature (Tsky)	-18°C	0°F
Sky Emissivity (Esky)	1.00	1.00

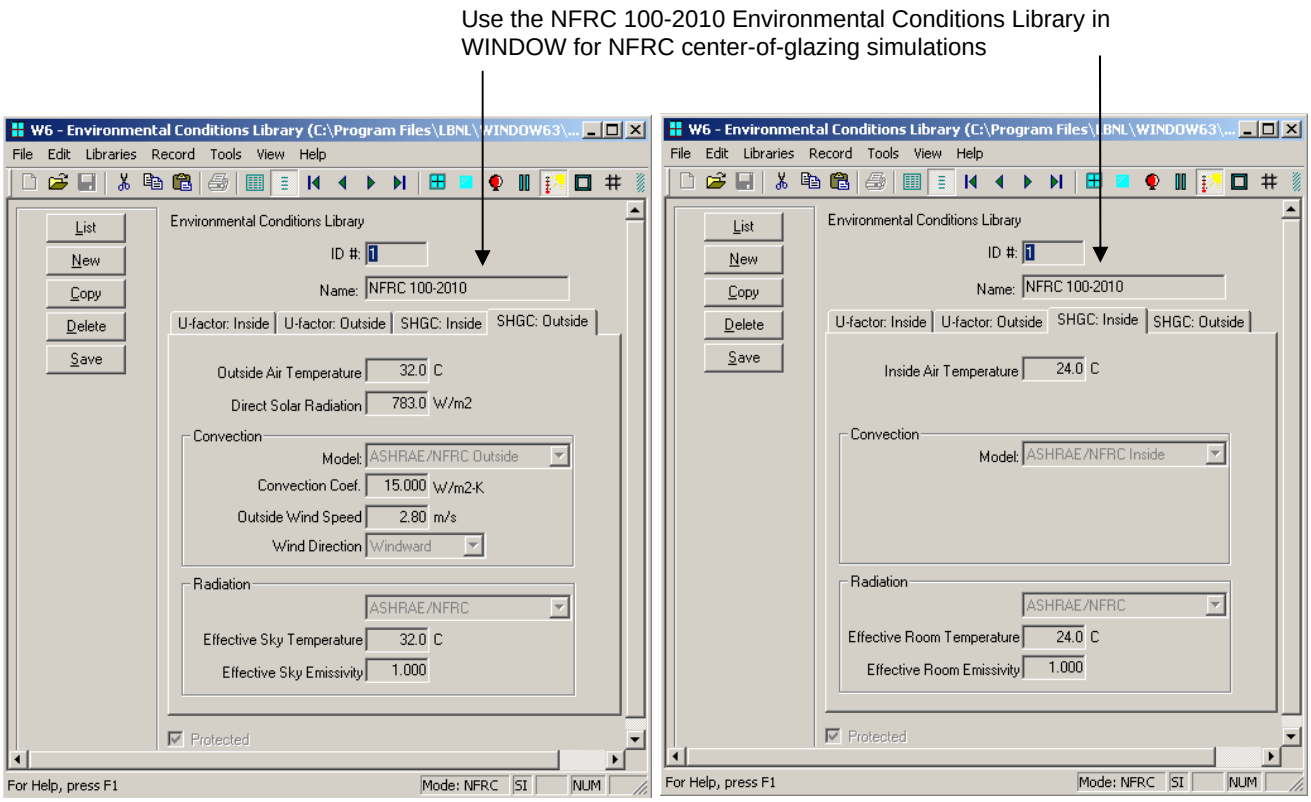


Figure 5-8. WINDOW Environmental Conditions Library – Settings for SHGC.

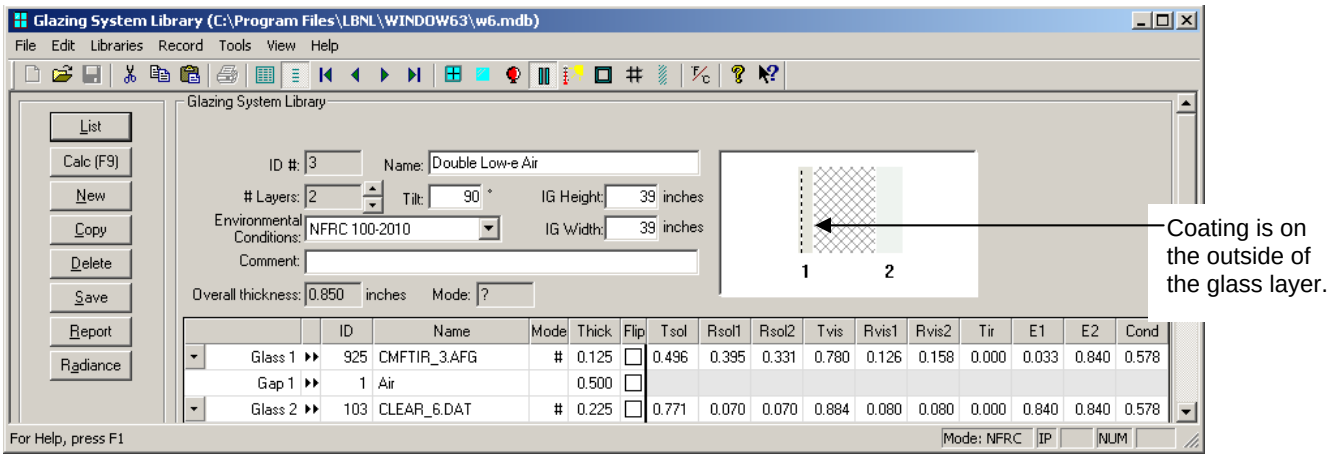
Table 5-2. Environmental Conditions for NFRC Simulations for SHGC and VT calculations.

Variable	SI Units	IP Units
Outside Temperature	32°C	89°F
Inside Temperature	24°C	75°F
Wind Speed	2.75 m/s	6.15 mph
Wind Direction	Windward	Windward
Direct Solar	783 W/m²	248.2Btu/hr-ft²
Sky Temperature (Tsky)	32°C	89°F
Sky Emissivity (Esky)	1.00	1.00

It is possible to make new environmental conditions with specific conditions specified, in order to evaluate the design of a product. However, only the pre-defined **NFRC 100-2010** shall be used for NFRC rating purposes.

5.3.2. Coatings

The location of coatings on a glass layer can affect the **center-of-glazing** U-factor and therefore the whole product calculation, so it is important to specify the location correctly. When using a glass entry from the WINDOW **Glass Library**, if the coating is not on the correct surface, the glass layer shall be flipped. To flip a glass layer, while on a glass layer in **Edit** mode, click on the **Flip** checkbox, and the glass surfaces will be flipped, as indicated by the dashed line in the graphic display of the glazing system.



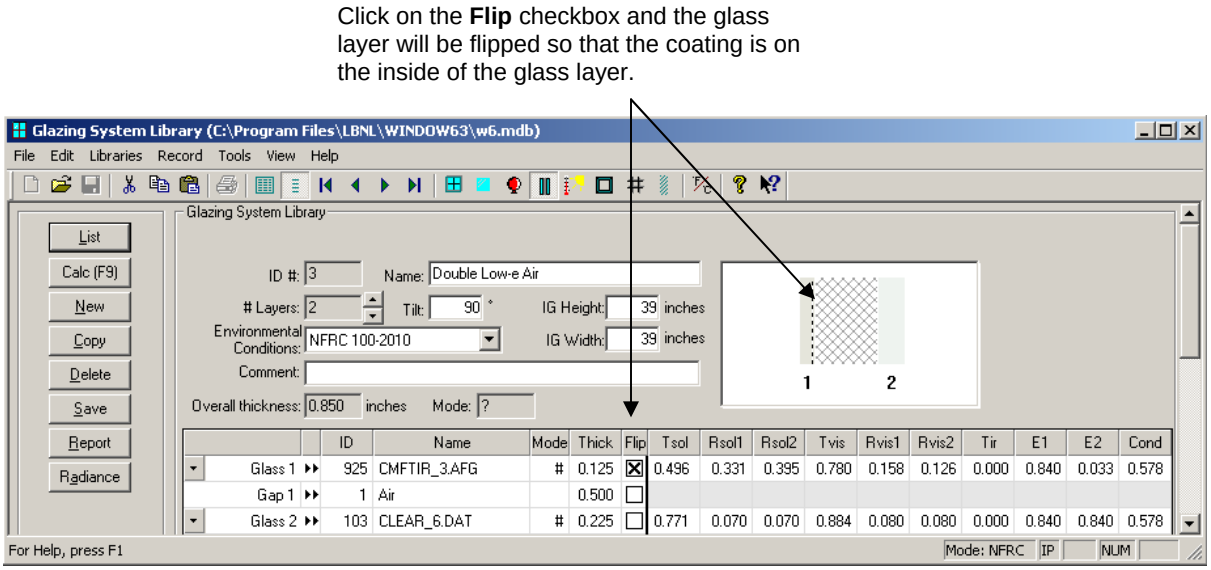


Figure 5-9. Use the Flip checkbox to flip the coatings on a glass layer.

5.3.3. Gas Fill

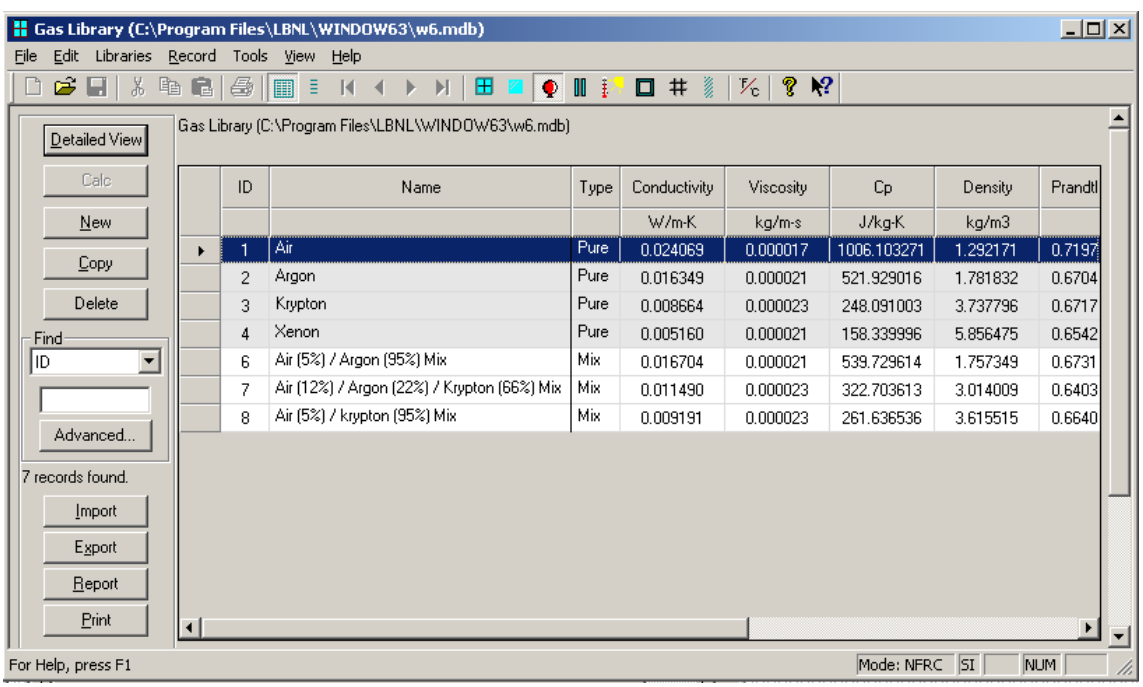
The gas used to fill the gap between the glass layers makes a significant contribution to the **center-of-glazing** U-factor, although it does not have much affect on the Solar Heat Gain Coefficient. For NFRC certified simulations, the gas to be shipped in the fenestration product shall be modeled. When creating a glazing system in WINDOW, choose the appropriate gas fill from the **Gas Library**, which contains the maximum gas fills that can be used, as shown in the figure below. Custom gas mixtures can be defined in the **Gas Library**. See the *WINDOW User's Manual* for more details about making a new gas mixture in the **Gas Library**.

When a gas is used to fill the gap between glass layers, there is always a mixture of the gas and air. The amount of air mixed in is dependent on many factors including the method used to fill the gap, either evacuated chamber filling, two-probe filling with a concentration sensor, or single-probe timed filling. Table 5-3 shows the maximum gas concentrations that can be achieved with each method. For NFRC certification simulations, the simulator shall request the gas-filling technique and the gas concentration for their product from the manufacturer.

Table 5-3. Gas Concentrations based on Filling Technique.

Filling Technique	Maximum Gas Concentrations Achieved
Evacuated Chamber Filling	97%
Two-Probe Filling with a Concentration Sensor	95% for Argon filled 90% for any other gas (Krypton, Xenon, etc)
Single-Probe Timed Filling	60-90%

For IG units with multiple gases, the simulation shall be performed using the gas concentrations stipulated by the manufacturer, but in no case can the simulation exceed the "Maximum Gas Concentration" shown in table 5.3 for the fill technique used. In the case where the fill technique is "Two-Probe with concentration sensor" and the gas mix is Krypton & Argon, the Maximum Gas Concentration of the mixed gas shall not exceed 90%.



ID	Name	Type	Conductivity	Viscosity	Cp	Density	Prandtl
			W/m-K	kg/m-s	J/kg-K	kg/m3	
1	Air	Pure	0.024069	0.000017	1006.103271	1.292171	0.7197
2	Argon	Pure	0.016349	0.000021	521.929016	1.781832	0.6704
3	Krypton	Pure	0.008664	0.000023	248.091003	3.737796	0.6717
4	Xenon	Pure	0.005160	0.000021	158.339996	5.856475	0.6542
6	Air (5%) / Argon (95%) Mix	Mix	0.016704	0.000021	539.729614	1.757349	0.6731
7	Air (12%) / Argon (22%) / Krypton (66%) Mix	Mix	0.011490	0.000023	322.703613	3.014009	0.6403
8	Air (5%) / krypton (95%) Mix	Mix	0.009191	0.000023	261.636536	3.615515	0.6640

Figure 5-10. WINDOW Gas Library.

5.3.4. Laminated Glass / Applied Films

Section 8 describes the procedures for creating laminated glass layers and applied films using Optics and importing the results into the WINDOW Glass Library.

5.4 Solar Heat Gain Coefficient and Visible Transmittance

The document *NFRC 200: Procedure for Determining Fenestration Product Solar heat Gain Coefficients at Normal Incidence* contains the rules and definitions for calculating the Solar Heat Gain Coefficient and Visible Transmittance for products. Consult NFRC 200 to determine how to group products for these calculations, as well as algorithm documentation.

In WINDOW, the center-of-glazing Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) are automatically calculated in the **Glazing System Library** in the **Center of Glass Results** tab, as shown in the figure below.

In addition, these values are calculated for the whole product and for the NFRC SHGC 0 and 1 and VT 0 and 1 cases in the Window Library, as explained in Chapter 7 of this manual.

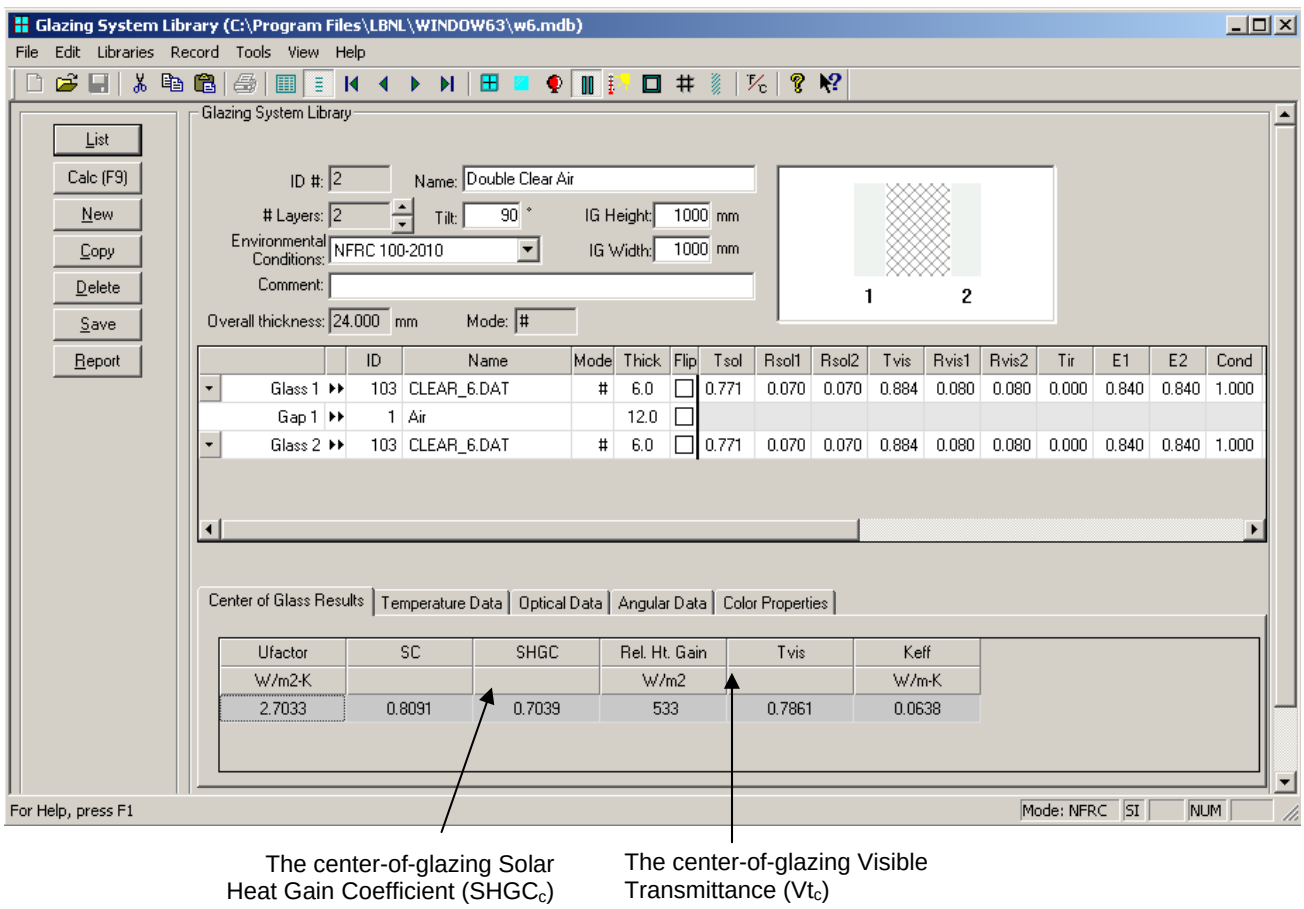


Figure 5-11. The center-of-glazing SHGC and VT are calculated in the WINDOW ***Glazing System Library****.*

6. MODELING FRAME AND EDGE HEAT TRANSFER WITH THERM

6.1. Overview

In order to calculate the total product U-factor, the U-factor must be determined for the following components, and then these values must be area-weighted for the whole product:

- Center-of-glazing values from WINDOW
- Frame and edge-of-glazing values from THERM

The *NFRC 100: Procedures for Determining Fenestration Product U-factors* is the definitive source for the methodology for calculating U-factors, and should be used for situations not covered in this manual. In addition, NFRC Technical Interpretations supplement the NFRC 100 document, and these should also be consulted when questions arise.

6.2 Cross-Sections to be Modeled

The fenestration product b eing modeled must be divided into the cross-sections which completely define the heat transfer through the product. THERM is used to calculate the U-factor values for the edge-of-glazing as well as the frame components (sill, head, jamb, meeting rail, and divider).

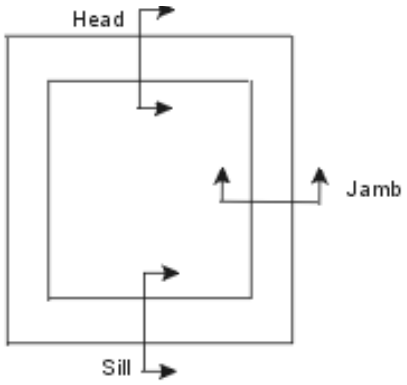
The operator type of the fenestration product, as well as the configuration of each component of the frame, will determine the number of cross sections that must be modeled. Table 6-1 lists the minimum and maximum cross sections that must be modeled for each operator type, and Figure 6-1 illustrates where the cross sections must be taken. The maximum assumes that each frame cross section is unique and therefore must be modeled. If there are some cross sections of the frame which are identical, such as a fixed window with the same cross section for the jambs, then only one cross section needs to be modeled for the jamb. However, the new modeling assumptions for cavities when modeling Condensation Resistance, based on ISO 15099, require that different cross sections be modeled for head, sill, and jambs if those cross sections contain frame cavities. If only U-factor is being modeled, the head and the sill can be combined into one calculation if the geometries for each are the same.

Although all the Product types listed in Table 1 of NFRC 100 are not listed here in Table 6-1 or Figure 6-1, these four basic categories cover all the geometries in NFRC 100.

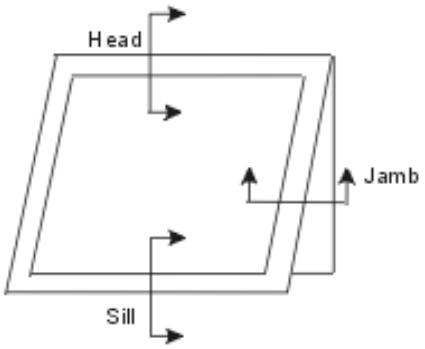
Table 6-1. Cross sections to be modeled

Operator Type	Number of Cross Sections to Model			Cross Sections
	Minimum		Maximum	
Single Lite (Fixed, Picture, Transom, Casement, Awning, etc)	**CR & U Calc**	**U only Calc**	4	▪ Head ▪ Jamb (1 or 2) ▪ Sill
	3 If Jambs are the same	2 If Head and Sill are the same		
Two Lite Vertical (Vertical Slider)	5 If Left and Right Upper Jambs are the same, and Left and Right Lower Jambs are the same	4 If Head and Sill are the same	7	▪ Head Fixed or Vent ▪ Jamb Fixed & Vent ▪ Sill Fixed & Vent ▪ Meeting Rail
Two Lite Horizontal (Horizontal Slider, Sliding Patio Door)	7	5 If Head and Sill are the same	7	▪ Head Fixed & Vent ▪ Jamb Fixed & Vent ▪ Sill Fixed & Vent ▪ Meeting Rail
Two-lite casement, (Window Wall, Curtain Wall)	4 If Left and Right Head are the same, Left and Right Sills are the same, and Left and Right Jambs are the same.	4	7	▪ Head Fixed & Vent ▪ Jamb Fixed & Vent ▪ Sill Fixed & Vent ▪ Meeting Rail

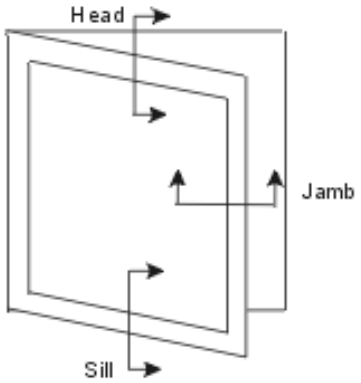
.



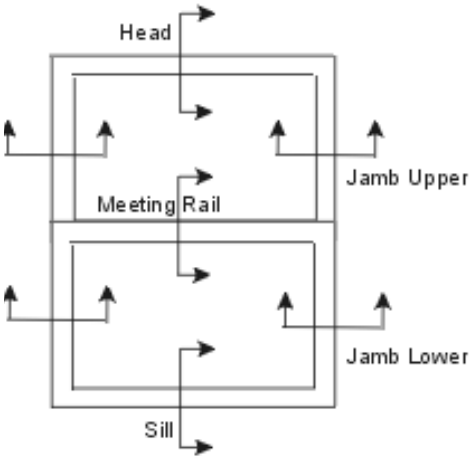
Fixed
(Max. 4, Min 3 cross sections)



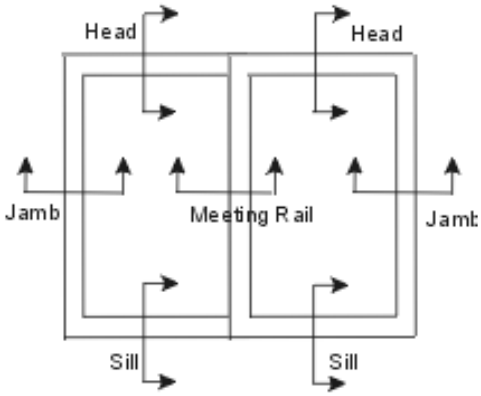
Projecting/Awning
(Max. 4, Min 3 cross sections)



Casement
(Max. 4, Min 3 cross sections)



Vertical Slider
(Max. 7, Min 5 cross sections)



Horizontal Slider
(Max. 7, Min 4 cross sections)

Figure 6-1. Minimum and maximum cross sections to be modeled based on operator type.

6.3 Draw the Cross Sections

After the number of cross sections to be modeled has been determined, draw them in THERM. The Section 5, "Drawing Cross-Section Geometry" in the *THERM User's Manual* contains detailed instructions about how to draw cross sections. This section of the THERM NFRC Simulation Manual contains information pertaining specifically to the NFRC procedures.

6.3.1. Getting Started – Drawings and DXF Files

In order to reproduce accurate cross sections in THERM, it is necessary to use dimensioned drawings and/or DXF files. Section 5.2, "Importing a DXF or Bitmap File as an Underlay" in the *THERM User's Manual*.

If only dimensioned drawings are available (assembly drawings and die drawings), and there are no DXF files, it is still possible to create a cross-section in THERM. Section 5.5, "Drawing Using the Keyboard (Numeric Cursor Positioning)" of the *THERM User's Manual*.

6.3.2. File Properties -- Cross-Section Type

It is extremely important to specify the **Cross Section Type** in the **THERM File Properties** dialog box (accessed from the **File/Properties** menu). The **Cross Section Type**, in combination with the glazing system orientation, will determine how many of the parameters in the the ISO 15099 simulation models are implemented, such as the frame cavity gravity vector. This setting will appear in the WINDOW **Frame Library** in the **Type** field, and it also appears in the lower right-hand corner of the main THERM screen.

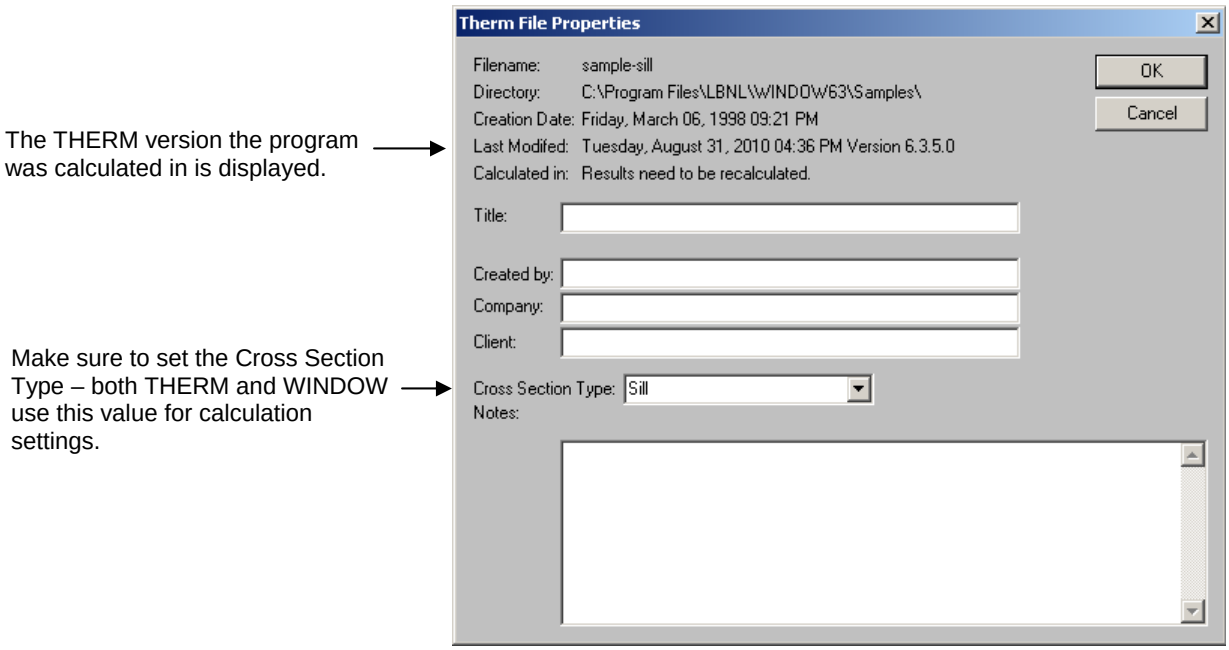


Figure 6-2 The Cross Section Type value from the THERM File Properties is used by the ISO 15099 models to determine the gravity vector and also in WINDOW to determine the method for calculating the Condensation Resistance values.

6.3.3. Cross-Section Orientation

For NFRC simulations using THERM, all cross sections shall be oriented in a vertical direction, i.e., all the glazing systems must be pointing either up or down, not horizontally. (The exception is for skylights, which are modeled at a 20 degree tilt; see Section 8.5 for a discussion of modeling skylights). When creating the cross section, the frame components may be drawn horizontally if that is easiest (i.e., if the DXF file is drawn that way), but *before importing the glazing system*, rotate the cross section so that the glazing will come in either up or down.

So, for example, jamb cross sections can be drawn horizontally, but they must be rotated into a vertical position for modeling. Figure 6-3 shows how a DXF file might be drawn. The horizontal jamb and meeting rail sections can be drawn horizontally as in the DXF file until the point of importing the glazing system, at which time they must be rotated 90 degrees. For heads, the glass should face down, for sills and jambs the glass should face up, with the inside surfaces of the model facing to the right and the exterior surfaces facing to the left.

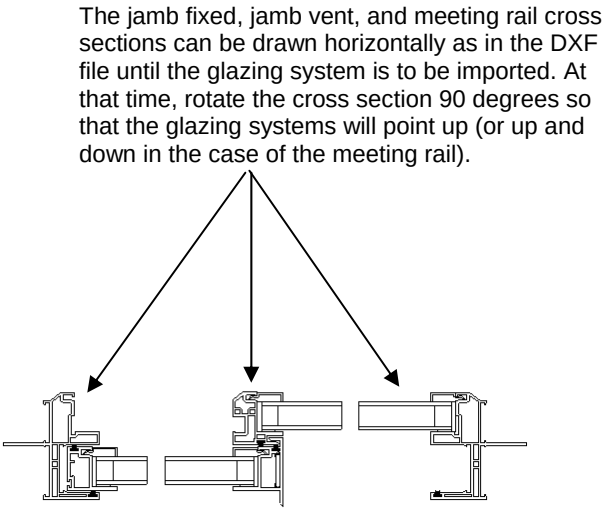
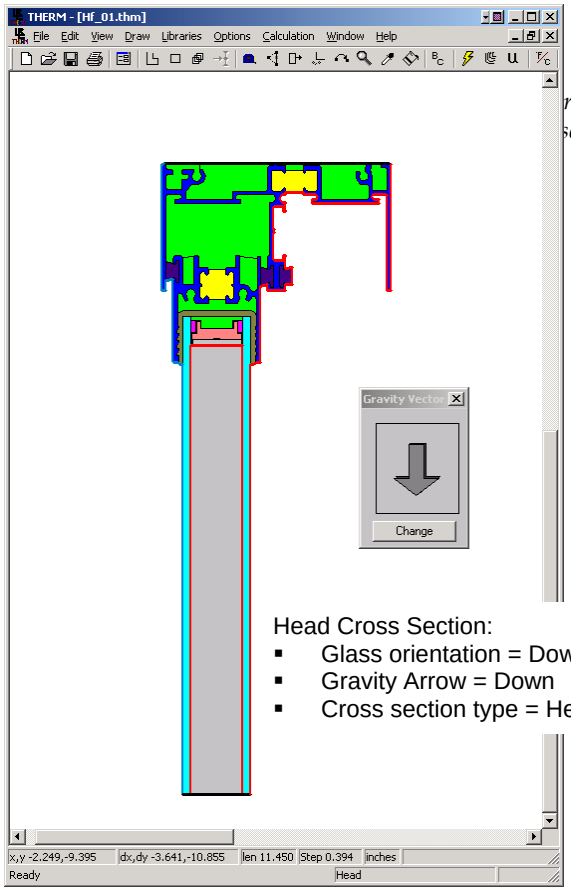
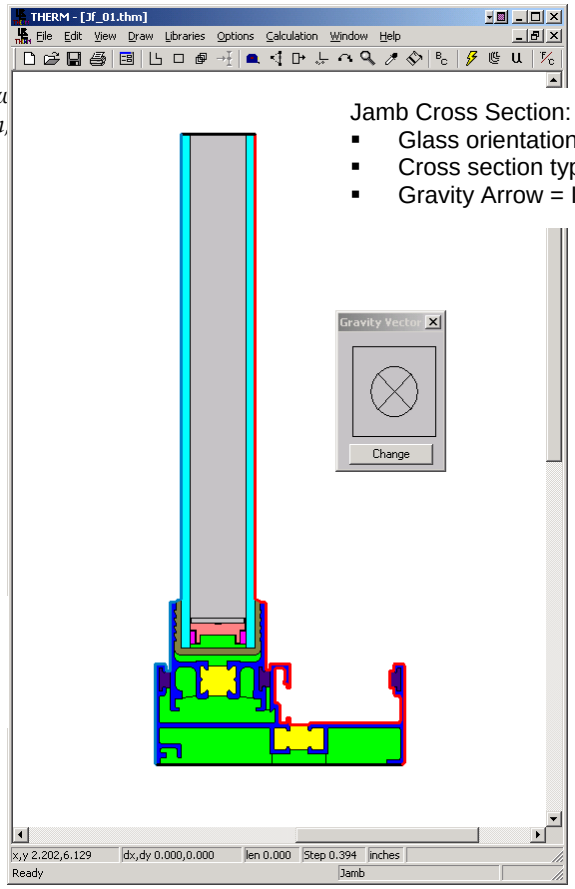


Figure 6-3. DXF file with horizontal cross sections that must be rotated 90 degrees before importing glazing systems and simulating.



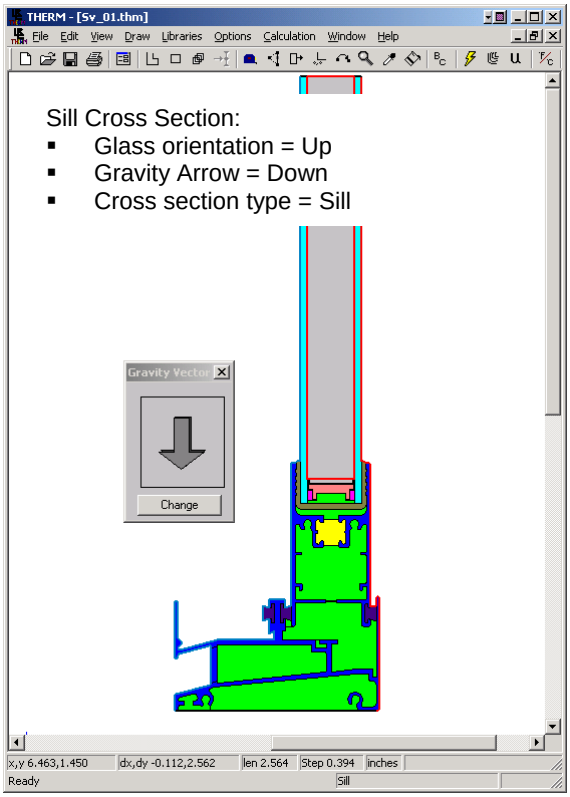
Head Cross Section:

- Glass orientation = Down
- Gravity Arrow = Down
- Cross section type = Head



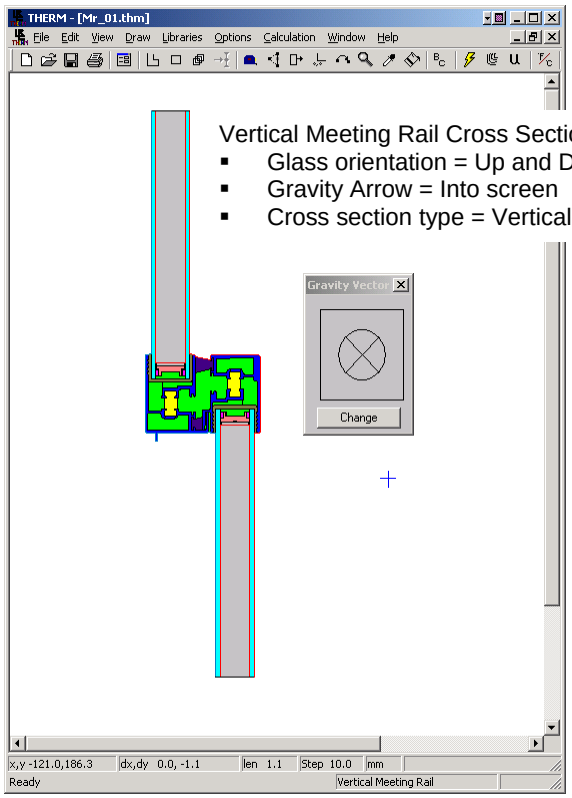
Jamb Cross Section:

- Glass orientation = Up
- Cross section type = Jamb
- Gravity Arrow = Into screen



Sill Cross Section:

- Glass orientation = Up
- Gravity Arrow = Down
- Cross section type = Sill



Vertical Meeting Rail Cross Section:

- Glass orientation = Up and Down
- Gravity Arrow = Into screen
- Cross section type = Vertical Meeting Rail

6.3.4. What is Not Modeled

NFRC 100 specifically excludes certain options on fenestration products which are not modeled in THERM. These options include:

- Screen Systems: Screen systems include trim/stops that hold/cover the screen. Minor frame changes are allowed to accommodate the screen system and may be represented by a product offered without a screen.
- Optional Interior trim
- Removable grilles applied to the interior or exterior surface of the glass (i.e., snap-on grilles). Grilles or dividers between glass layers must be modeled under some circumstances, as discussed in Section 8.3, "Modeling Internal Dividers."
- Optional jamb, head, and sill extensions
- Interior or exterior shading devices
- Nailing flanges which can be removed from a fenestration product, and which are removed for testing. These may be vinyl flanges on wood windows, or flanges on vinyl or aluminum windows designed to be removed for some installations. Permanent nailing flanges that would be in place during a test shall be modeled.

In addition, as stated in *NFRC 100*, "including but not limited to screws and bolts in curtainwalls and pour-and-debridge thermal breaks which are not full debridged, shall be simulated". For the time being, components that *do not* have to be modeled include:

- Hinges
- Locks
- Balances
- Non-continuous Operator Hardware
- Weep Holes
- Setting Blocks
- Shear Blocks
- Corner Keys

6.3.5. Deformable Parts

Because deformable parts, such as glazing clips, weatherstripping and other snap-in parts, are often drawn in the undeformed states in DXF files and assembly drawings (many times in the DXF files they overlap other parts), simulator judgement is still required to ensure that these parts are modeled in a way that results in accurate heat transfer results. For example, there are several instances when small air gaps can be replaced with solid materials, such as in sweeps and seals.

6.3.6. Frame Cavities

For NFRC Simulations, frame cavities are modeled using the ISO 15099 Cavity Model. There are default items in the Material Library that can be used to model frame cavities:

- **Frame Cavity NFRC 100:** to be used for all interior frame cavities
- **Frame Cavity Slightly Ventilated NFRC 100:** to be used for frame cavities open to the exterior. See Section 6.3.7, Vented Exterior Cavities, for a complete description of when to apply these cavities.

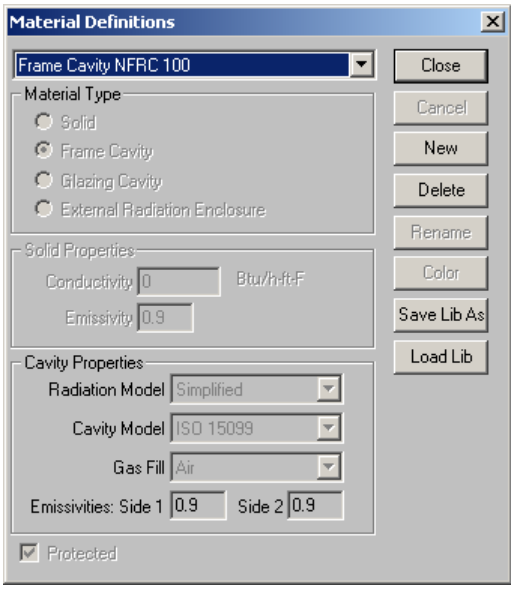


Figure 6-5. Default frame cavity material for NFRC Simulations.

As shown in the figure above, the Frame Cavity **NFRC 100** material has the following characteristics:

- **Radiation Model:** Simplified
- **Cavity Model:** ISO 15099
  This cavity model is an implementation of the ISO 15099 standard, and will cause THERM to automatically calculate the cavity wall temperatures, emissivities and heat flow direction.
- **Gas Fill:** Air
- **Emissivities:**
  The default emissivities that are included in this frame cavity material are essentially irrelevant because THERM will recalculate and override them during the simulation of the cross section. However, when either the "Frame Cavity NFRC 100" or the "Frame Cavity Slightly Ventilated NFRC 100", the frame cavity surfaces will be outlined in red. Double-clicking on one of these red surface segments will display a dialog box that can be edited. This allows the emissivity values assigned by the program to be overridden. The edited values will then be what the program uses for the simulation.

THERM also makes the following assumptions about the frame cavity:

- **Default frame cavity height:** 1 meter
- **Gravity vector:** based on Cross Section Type (see *Section 6.3.2*, "Cross Section Type", and *Section 6.3.3*, "Cross Section Orientation")

If the frame cavity model is set to "ISO 15099", which it is for **Frame Cavity NFRC 100***the emissivities, temperatures and heat flow direction will be automatically calculated by the program during simulation*. Therefore, the default values that appear for individual frame cavities before the simulation do not need to be edited. These automatic calculations are computed as follows:

- **Heat Flow Direction:** The calculated heat flow direction will depend on the Cross Section Type setting, accessed from the File/Properties menu. It also depends on the orientation of the glazing system, ie, whether it is imported up, down, left or right. The "gravity vector" can be displayed using the View/Gravity Arrow menu. (See the *THERM User's Manual* for a discussion of the gravity vector). The assumptions for each type of cross section are the following:
  - **Head:** Cross Section Type = Head, glass imported facing down, gravity vector is pointing down
  - **Sill:** Cross Section Type = Sill, glass imported facing up, gravity vector is pointing down
  - **Jamb:** Cross Section Type = Jamb, glass imported facing up, gravity vector is pointing into the screen
  - **Meeting Rail:** Cross Section Type = Meeting Rail, glass imported facing up and down, gravity vector is pointing into the screen for a horizontal slider and gravity vector is pointing down for a vertical slider.
- **Temperature:** The program calculates the temperatures of the cavity walls based on the surrounding material temperatures, and determines the heat flow direction based on the temperature differences. It is not necessary to change the initial default cavity temperatures before the simulation. After the simulation, the calculated temperatures can be viewed by double clicking on a frame cavity.
- **Emissivity:** The program determines the emissivities of the frame cavity walls based on the emissivity values of adjacent materials. If there are materials with different emissivities in the walls perpendicular to the heat flow direction, the program will area-weight the emissivity values. After the simulation, the calculated emissivities can be viewed by double clicking on a frame cavity.

  It is important to remember that the emissivity of a metal surface, such as aluminum and steel, will depend on the surface finish, i.e., painted or unpainted. Many metal cross sections, particularly extrusions, will be painted on the outside, but unpainted on the inside. For unpainted metal surfaces, remember to change the emissivity to 0.20.

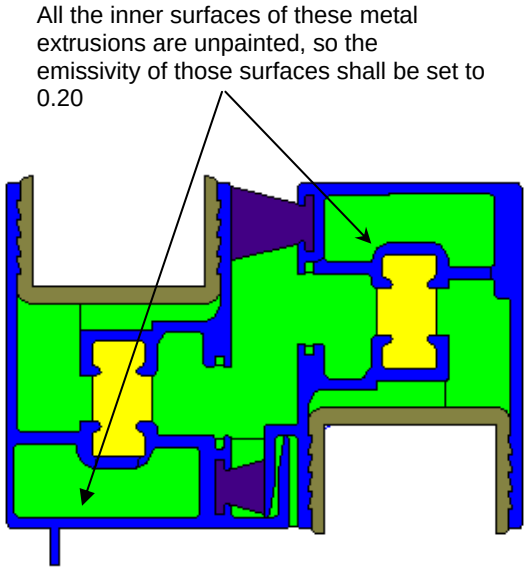


Figure 6-6. Set the emissivity of unpainted metal surfaces, such as the inside surfaces of extrusions, to 0.20.

When the cross section has been simulated, double click on a frame cavity to view the resulting heat flow direction, temperatures, and emissivities automatically calculated by the program, as shown in the figure below.

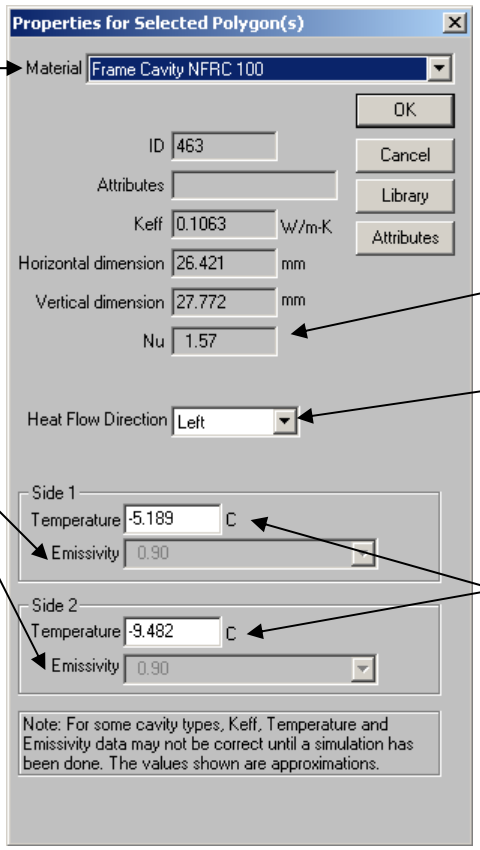
The information in this dialog box is from a frame cavity in a THERM file that has been simulated, so the values for Nusselt (Nu), Heat Flow Direction, Temperature and Emissivity (for Side 1 and Side 2) are not the default values, but have been automatically calculated by the program.

*NOTE: The **Attributes** button is used only for the NFRC CMAST program.*

Select the "Frame Cavity **NFRC 100**" choice from the **Material Library** pulldown list. Because the **Cavity Model** for that material is set to "ISO 15099", the heat flow direction, emissivities, and temperatureswill be automatically calculated.

The emissivity values are associated with the materials adjacent to the cavities, and they are automatically calculated by the program during the simulation. If there are materials adjacent to the cavity which have different emissivities, the program will area-weight the final values, as in this example.

Therefore, it is not necessary to check the emissivity of every frame cavity before the simulation because what is displayed are default values that are not particularly relevant.



The Nusselt number (Nu) is calculated *before* the simulation based on default temperatures, but will be *recalculated* based on the actual cavity temperatures during the simulation.

The **Heat Flow Direction** is automatically calculated by the program; therefore it is not necessary to check it for every cavity before the simulation.

The **Temperatures** are automatically calculated by the program.

Figure 6-7. Select the Frame Cavity choice from the Material Library that matches the emissivity for both sides of each frame.

THERM bases the convection in the frame cavity on rectangularizton of the cavity according to ISO 15099 specifications. The current NFRC procedure is to break up cavities that are separated by a connection, or "throat", less than or equal to 5 mm (0.20 inches). However, if a frame cavity has a Nusselt number less than or equal to 1.20 before simulating, it is not necessary to break it up into smaller cavities. The Nusselt number can be displayed by double clicking on the frame cavity, which displays the **Properties** dialog box. The horizontal and vertical dimensions of the bounding rectangle, which determine the Nusselt number, are also shown in this dialog box. When there is a constriction in a cavity, there will, in effect, be two separate air flows, separated by the constriction. This is the logic behind breaking up a cavity at the 5 mm throat constrictions. Certain cavities, even when there is a constriction in the cavity, will already have a small amount of convective heat transfer, which results in a Nusselt number close to 1.0. These cavities do not need to be separated into multiple cavities because the constriction is not altering the air flow.

Note: Before a file is calculated, the Nusselt number is based on the default temperatures and emissivities for the frame cavity. There is a slight chance that the Nusselt number of a cavity before a calculation is less than or equal to 1.20, and after the calculation is greater than 1.20. In this case, the cavity does not need to be broken up.

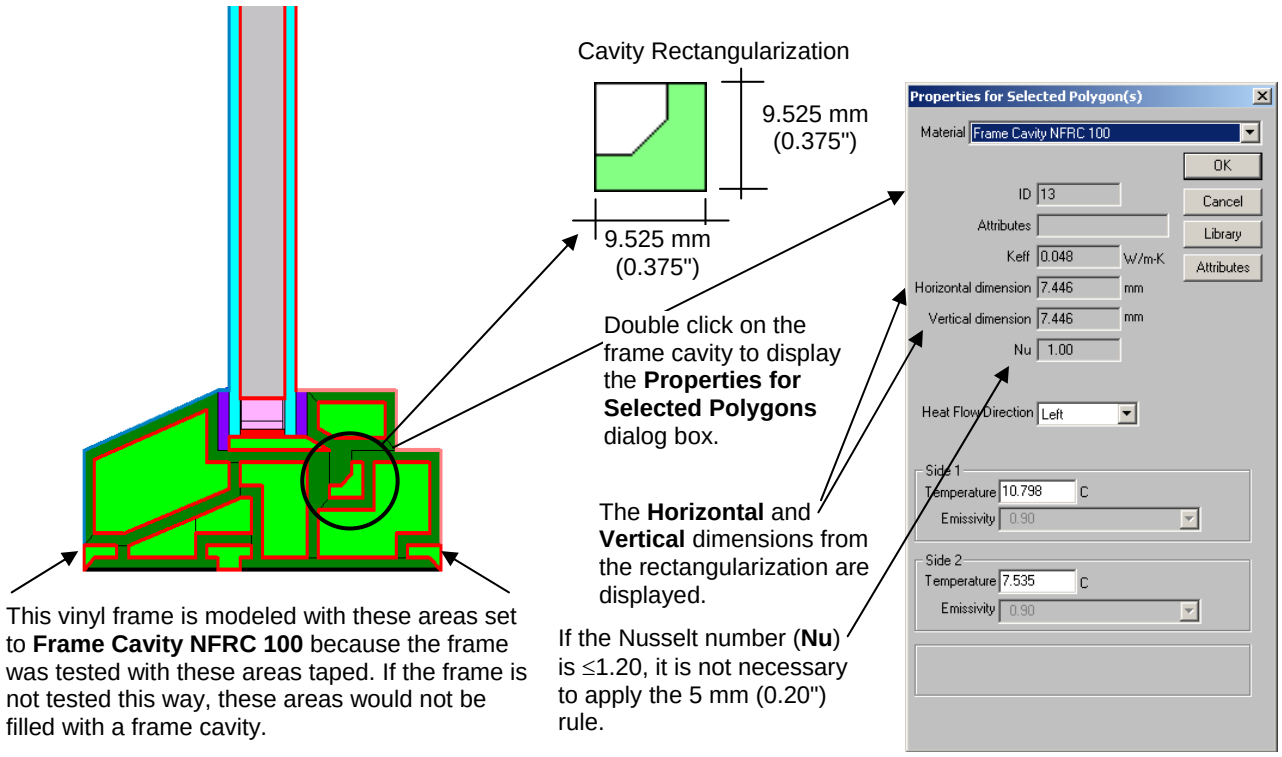


Figure 6-8. THERM uses the ISO 15099 rectangularization specification to model the thermal characteristics of cavities.

The best method for determining whether a frame cavity with a 5 mm (0.20”) throat will have to be divided up, and how to divide it if necessary, is the following:

1. Verify that there are throats (constrictions) in the frame cavity less than or equal to 5 mm (0.20 inches). If there are no throats, do not break up the cavity. A throat is defined as any place in a frame cavity where two walls, two points, or a wall and a point in the cavity are at or within 5 mm (0.20 inches) of each other.
2. Check the Nusselt Number of the undivided cavity. If the Nusselt Number is less than or equal to 1.20, the simulator shall not break the cavity into smaller polygons.
3. If the Nusselt Number is greater than 1.20, the simulator shall identify all cavities that are less than or equal to 5 mm (0.20 inches) in both opening and depth and define them as separate cavities.

4. Re-check the Nusselt number of the remaining large cavity. If it is less than or equal to 1.20, no further action is necessary. If the number is greater than 1.20, the simulator shall:

   a. Identify throats (constriction) in the cavity that are less than 5 mm (0.20 inches) and working from the largest part of the cavity to the smallest, break-up the larger cavity into smaller cavities, splitting first horizontally, then vertically, and finally (as a last resort) diagonally.

   b. Each time the cavity is broken, the simulator shall re-check the Nusselt number of the new cavities. If the Nusselt number in the remaining cavity/cavities is less than or equal to 1.20, no further action is necessary. If the Nusselt number for the remaining cavity/cavities is greater than 1.20, proceed, again, with step 4 until no further constrictions can be defined.

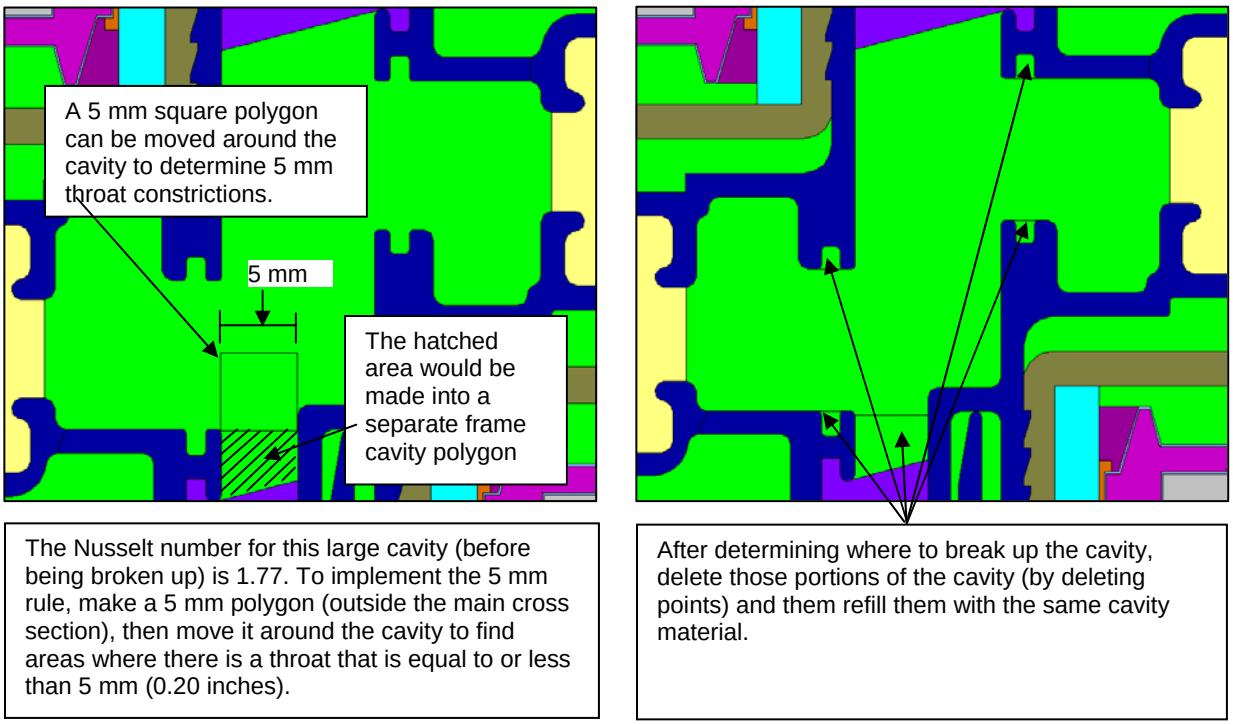


Figure 6-9. Breaking up frame cavities.

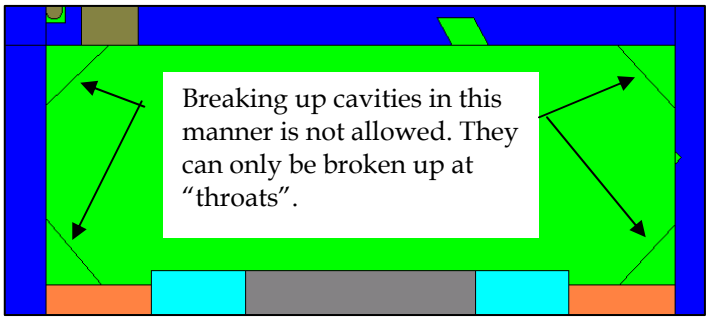


Figure 6-10. Breaking up frame cavities in this manner is not allowed.

6.3.7. Slightly Ventilated Exterior Cavities

For NFRC simulations, air cavities that are open to the exterior within a frame section, such as the air cavity under the sash of a casement window that is vented to the exterior, shall be modeled according to *ISO 15099, Section 6.7.1* which states that cavities greater than 2mm but equal to or less than 10 mm shall be modeled as slightly ventilated air cavities. The THERM Material Library has a default material for this case, called "Frame Cavity Slightly Ventilated NFRC 100", which will be used to fill the entire cavity. The figure below illustrates this.

Model a cavity open to the exterior environment as slightly ventilated when:

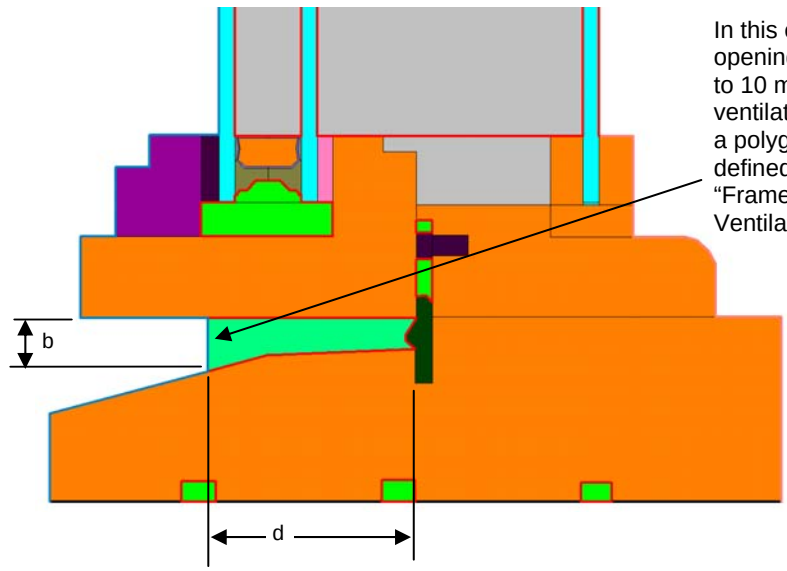
$d \geq b$

and

$2 \text{ mm} < b \leq 10 \text{ mm}$

For cavities < 2 mm, use the standard "Frame Cavity NFRC 100"

For cavities > 10 mm, do not model a frame cavity



In this example, where the opening to the outside narrows to 10 mm is where the slightly ventilated cavity would start – a polygon is created and defined with the material "Frame Cavity Slightly Ventilated NFRC 100".

Figure 6-11. Slightly Ventilated exterior cavities.

If there are openings ≤ 2 mm that open into a frame cavity defined as "Frame Cavity Slightly Ventilated NFRC 100" , these small cavities shall be defined as the standard "Frame Cavity NFRC 100" .

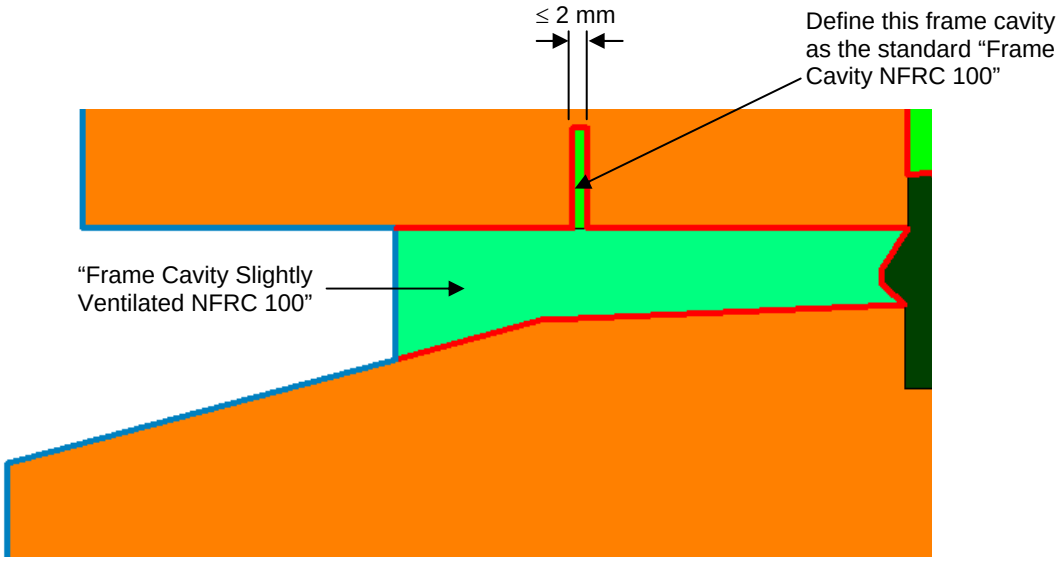


Figure 6-12. Small cavities adjoining slightly ventilated cavities.

If during testing, the product is sealed at the inside surface with tape, those cavities must be simulated with the standard "Frame Cavity NFRC 100" material.

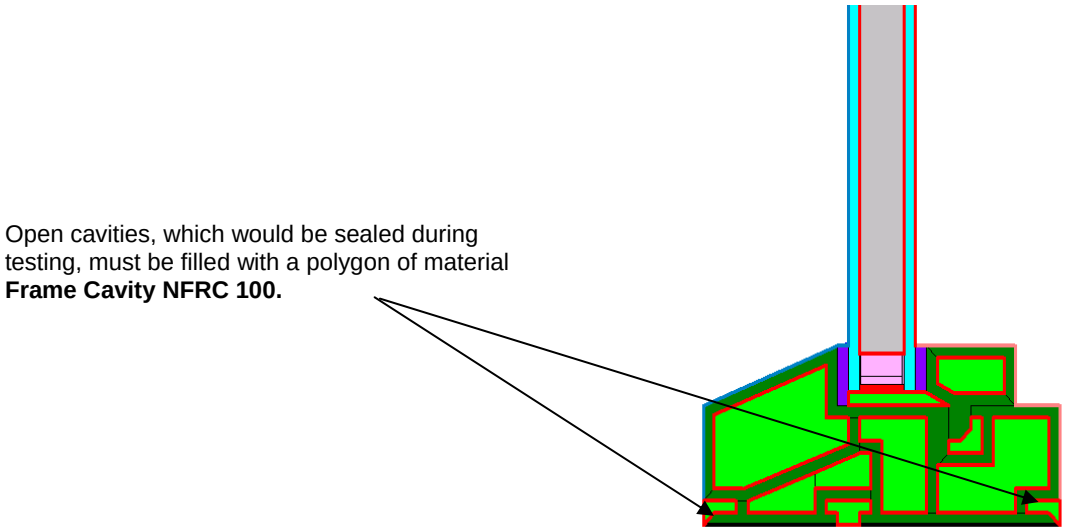


Figure 6-13. Cavities open to the interior are filled with Frame Cavity NFRC 100 material .

6.3.8. Modeling Sloped and Curved Surfaces

Because the exact geometry of sloped surfaces can be modeled in THERM, there is no need to change the boundary conditions for sloped surfaces.

For curved surfaces, THERM approximates curves with line segments. The number of line segments used in the curve will determine how close the final model is to the original geometry of the product. When importing a DXF file, the number of line segments is set using the **Arc to Polygon** setting in the **Options** menu. See the section on "Interpreting Arcs" in the **Drawing Tips document** on the LBNL THERM Documentation website for a detailed discussion of this procedure. In general, an **Arc to Polygon** setting of 45 degrees for small rounds and fillets in extrusions will give great enough accuracy without introducing unnecessary detail. For larger curved details, all points on the represented line must be within 5 mm of the actual line or curve. The averaged distance (for all points) between the represented line and the actual line or curve must be not greater than 2.5 mm (ISO 15099 Standard).

6.3.9. Modeling Sloped Sills

A product with a sloped sill must be modeled in the same way that it was tested. When a vertical sliding or fixed window is tested, the air space underneath the sloped portion of the sill is filled with expanded polystyrene insulating material. For the simulation of the sill section this window must have the insulating material modeled underneath the sloped portion of the sill as well, as shown in the figure below. The bottom surface of the insulating material will have an adiabatic boundary condition applied. The surface of the insulating material that faces to the interior will have a boundary condition applied that is the same as the condition applied to the frame above the insulating material. The U-factor surface tag for the interior facing surface of the insulating material will be defined as **Frame**, which ensures the correct projected frame dimension will be used in the area weighting of the total window U-factor.

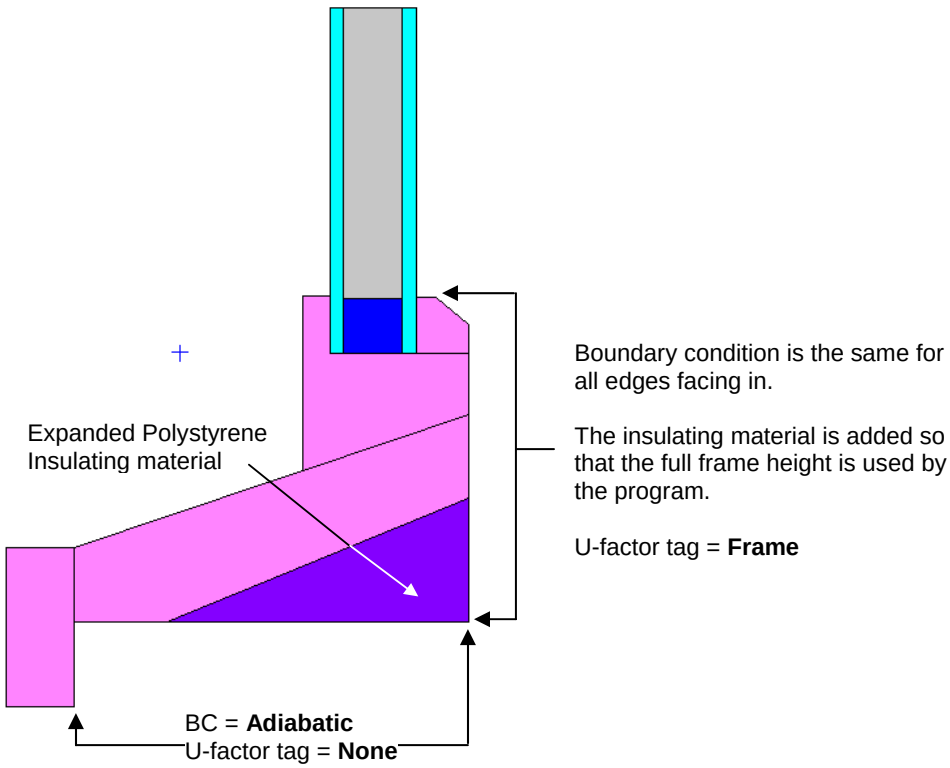


Figure 6-14. Model the sloped sill as it was tested, with insulating material under the sill.

6.4 Importing Glazing Systems

When the frame cross section has been drawn, and rotated into a vertical orientation if necessary, the next step is to import a glazing system. Section 5.9, "Inserting a Glazing System" in the *THERM User's Manual* contains detailed information about this step. The discussion in this manual is added information about glazing systems.

6.4.1. Overview

For NFRC simulations, a glazing system shall be imported into THERM from the **Glazing System Library** in the WINDOW program. When THERM imports the glazing system from the WINDOW library, it obtains the following information from the glazing system:

- emittance of the glazing surfaces
- the effective conductivity of the glazing cavity
- the interior and exterior boundary conditions of the glazing system

As discussed in Section 6.5, glazing systems should always be imported into the cross section in a vertical (either up or down) orientation (it may be necessary to rotate the cross section in order to do this). The figure below shows where the **Locator** should be positioned based on the orientation of the glazing system when it is imported. *The orientation of the glazing system determines in part the gravity vector orientation so it is extremely important to model it correctly.*

NOTE: Although in general it is best to rotate and flip cross sections before the glazing systems are imported and boundary conditions are defined, the exception is skylights, which are modeled at a tilt. In that case, import the glazing system in a vertical orientation,define the boundary conditions, and then rotate the entire cross section.

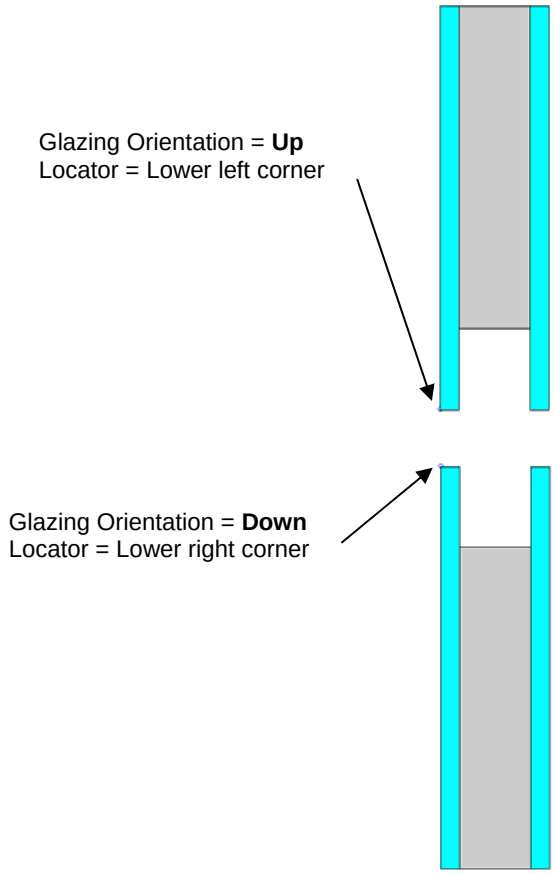


Figure 6-15. The Locator position when importing glazing systems in different orientations.

6.4.2. Inserting Glazing Systems

The *THERM User's Manual* contains a detailed description about how to insert glazing systems into a THERM file for U-factor and Condensation Resistance calculations. The figure below is a brief overview of the steps.

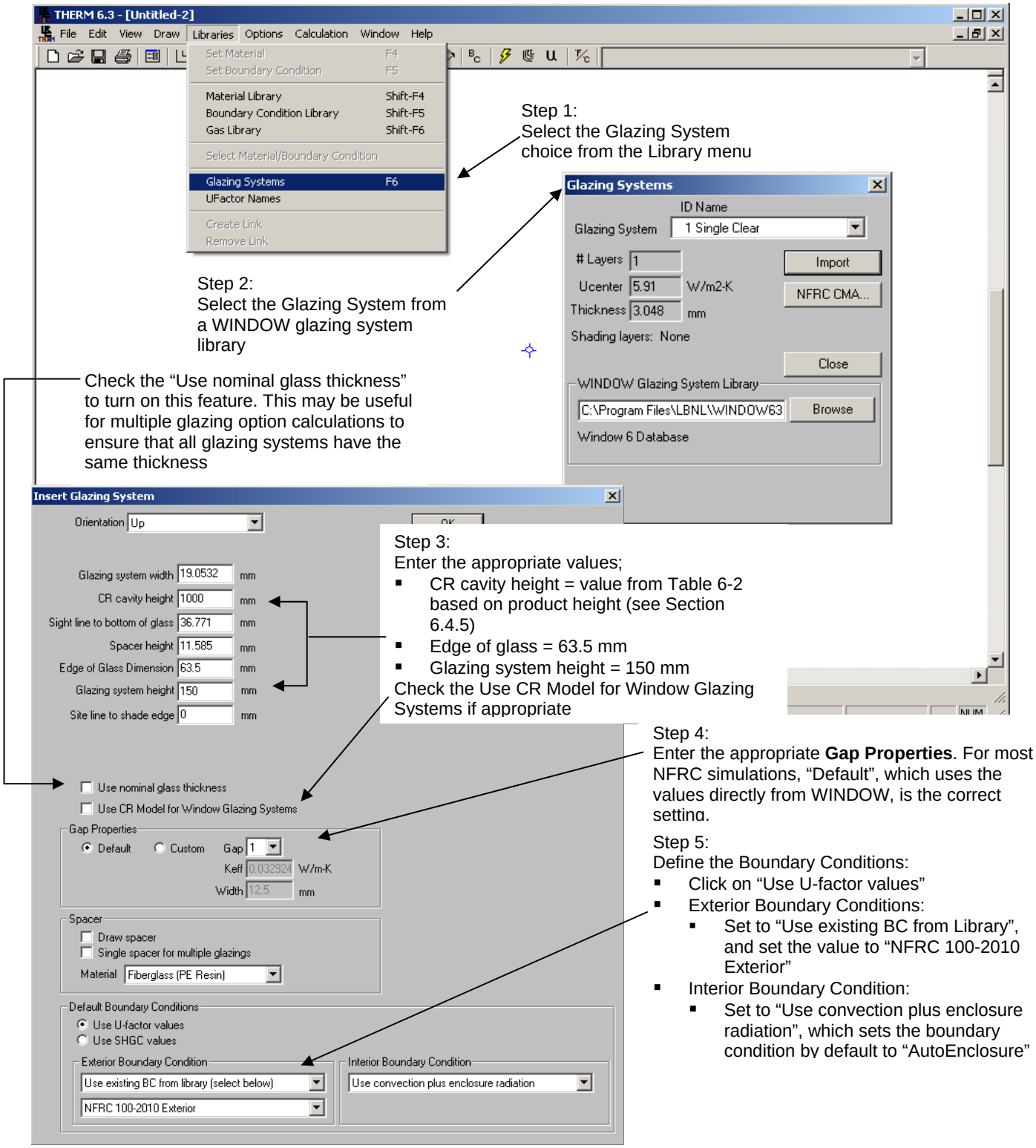


Figure 6-16. Inserting a Glazing System into a cross section.

The NFRC modeling requirements when inserting a glazing system are:

- **CR cavity height:** See table 6-2, Section 6.4.5 for values. Only used if the Condensation Resistance model is activated.
- **Edge of Glass:** 63.5 mm (2.5 inches)
- **Glazing System Height:** 150 mm (6.0 inches) for all products
- **Exterior Boundary Condition:** Set to "Use existing BC from library" and select "NFRC 100-2010 Exterior". This will be applied automatically by the program on the exterior surfaces of the glazing system and frame.
- **Interior Boundary Condition:** Set to "Use convection plus enclosure radiation" . This will cause the program to automatically calculate the boundary conditions for the glazing system to the "Autoenclosure" radiation model, which does not require the Radiation Enclosure geometry to be drawn.

The nominal thickness feature, turned on by checking the "Use nominal glass thickness" when importing a glazing system, can be useful for multiple glazing options, where THERM expects all the glazing system options to have identical thicknesses. This feature is explained in more detail in the *THERM User's Manual*.

6.4.3. Multiple Glazing Options

THERM allows multiple glazing options to be associated with a glazing system. This feature can be useful for simulations where many different glazing systems are to be modeled in the same frame cross section.

To use this feature, follow these steps:

1. **Determine the frame cross sections to be modeled:** The glazing options for a frame cross section must be identical in their geometry, including overall thickness, cavity thickness, spacer height, and sight line dimension. Therefore, the first step is to determine the number of frame cross sections, including dividers and meeting rails, that must be defined in THERM for each set of glazing options

2. **Create and Simulate the Base Case File: For each** frame/glazing option set, create a THERM file with the complete frame cross section and one of the glazing options. Create the boundary conditions for this model, making sure to check the "Use convection plus enclosure radiation" when importing the glazing system, and simulate it to make sure that the geometry is correct. This will be the "base cas**e" file, and will contain no results on**ce the multiple glazing options have been defined and simulated.

3. **Define the glazing options:** There are two ways to define the glazing options in a file:

- From the **Calculation** menu, select the **Glazing Options** menu choice.
  OR
- Double click on the glazing system geometry, and click on the **Glazing Options** button in the **Glazing System Info** dialog box.

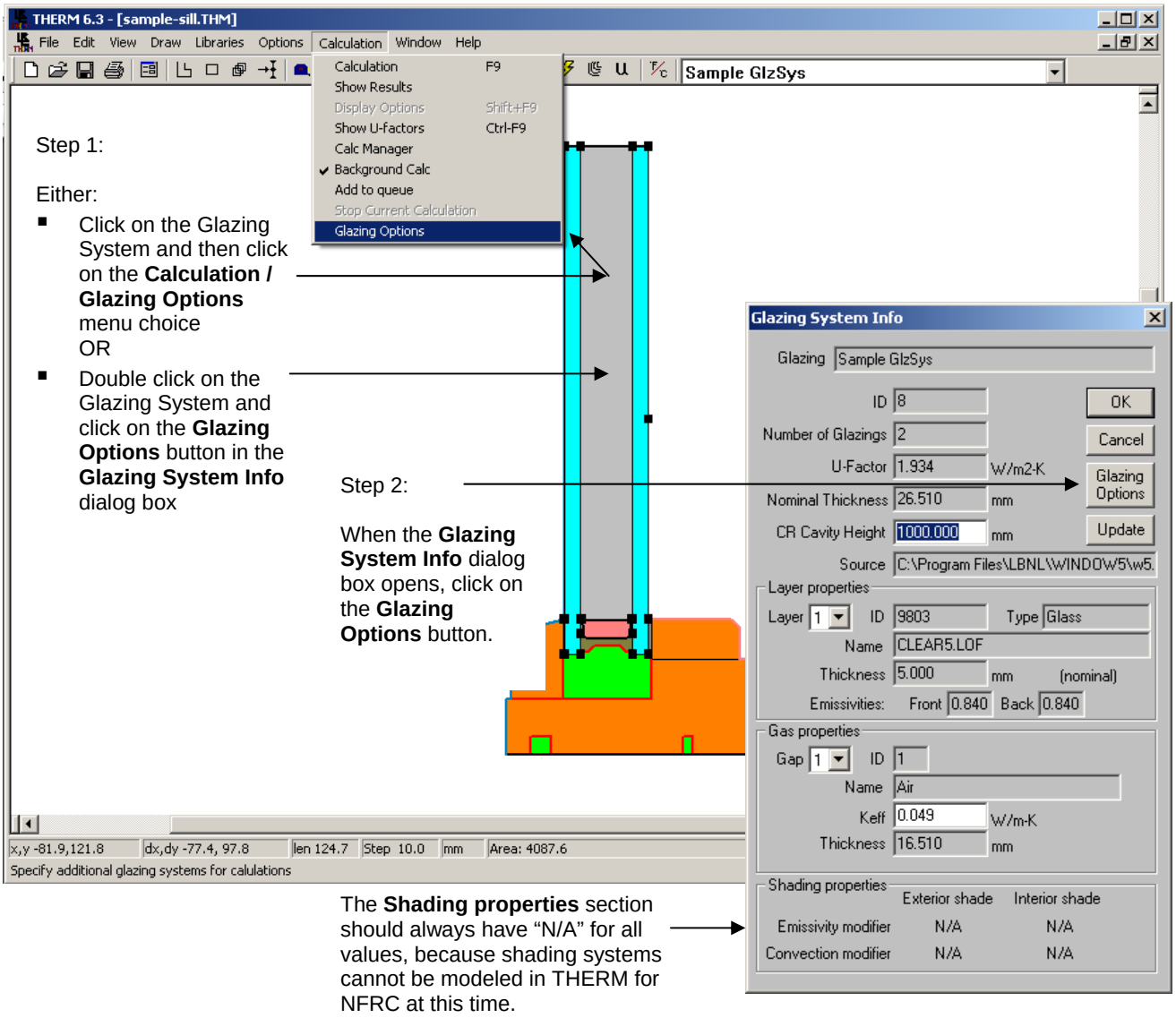


Figure 6-17. Define multiple glazing options.

- **Add glazing options:** From the **Glazing System Options** dialog box, click on the **Add** button to see a list of all the glazing systems in the currently selected **Glazing System Library** that have the same overall thickness and glass layer thickness as the base case glazing system. (Note: Use the nominal glass feature if necessary to make all the glazing systems a uniform thickness.) Click on the glazing systems in the **Add Glazing Options** dialog box that are to be associated with this cross section (use **Shift-click** or **Ctrl-click** to select multiple glazing systems) Click **OK** when all are selected.

4. THERM will make a separate file for each glazing option, and in the **Glazing System Options** dialog box, click on the radio button choice to determine how the program will automatically name each file. The options are either that the program will append the **Glazing System ID** (as a 3 character number, such as 001, 002) or **Name** to the base case filename.
5. **Boundary Conditions:** THERM will automatically calculate the boundary conditions for each separate glazing system option.

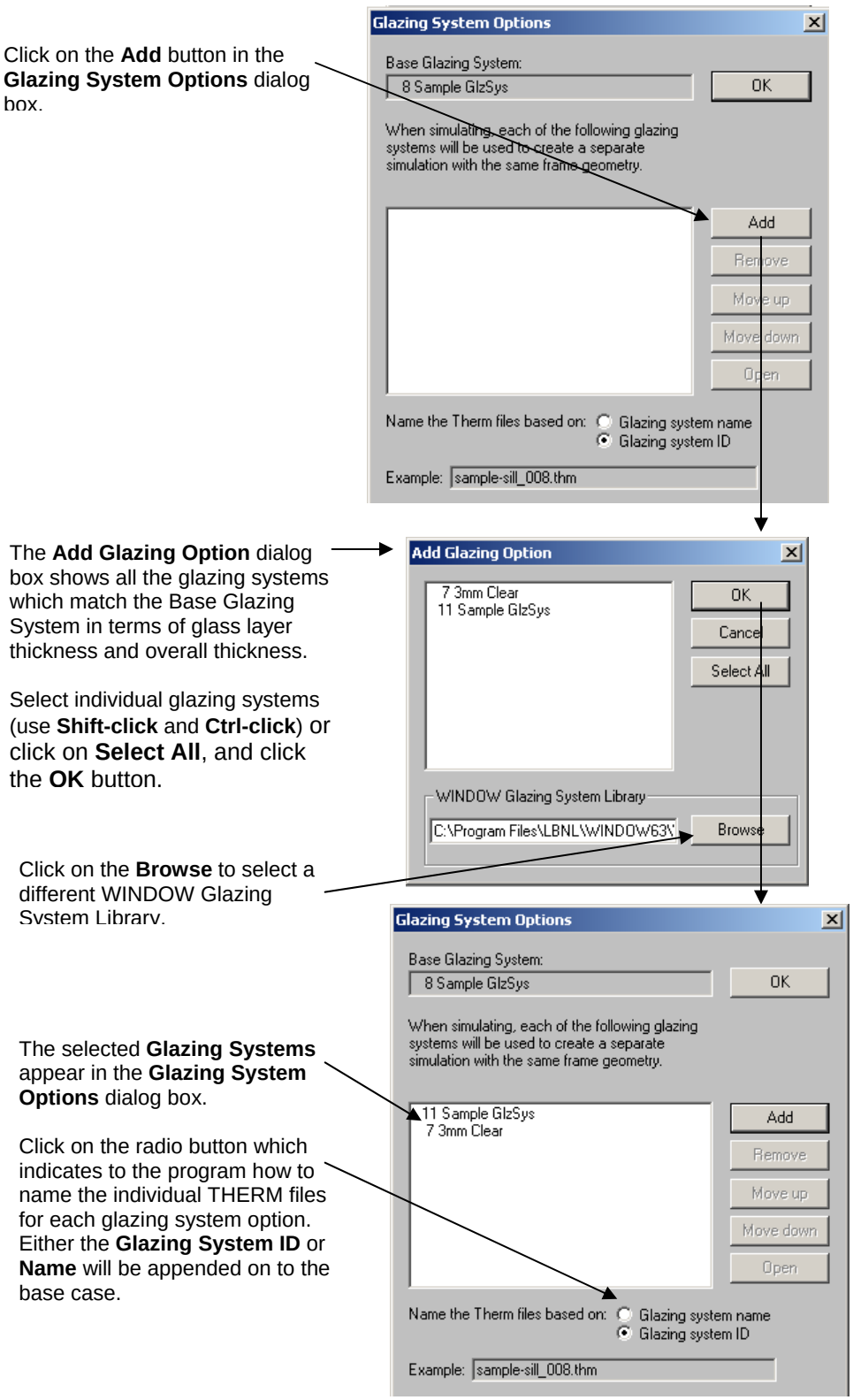


Figure 6-18. Select the glazing systems to be associated with the base case file.

6. **Calculate the Results:** the file can now be simulated, or more files can be created and all the files simulated through the **Calc Manager**. This is explained in more detail in *Section 6.6*, "Calculating the Results".

6.4.4. Condensation Resistance

There are two ways to activate the Condensation Resistance model in THERM:

- When importing the glazing system, check the "Use CR Model for Window Glazing System" checkbox.
- In the **Options** menu, **Preferences** choice, **Therm File Options** tab, check the "Use CR Model for Glazing Systems"

When inserting the glazing system into the model, as discussed in Section 6.4.2, the value for the "CR cavity height" shall come from the table below.

Table 6-2. Default Values for Actual Glazing Height Modeling for Condensation Resistance

Real Product Height	Default Glazing Height for Condensation Modeling (input as the "CR cavity height" in THERM)
2000 mm	1900 mm
1500 mm (vertical slider)	675 mm per sash
1500 mm (non-vertical slider)	1400 mm
1200 mm	1100 mm
600 mm	500 mm

Activating the Condensation Resistance model in THERM will cause boundary conditions to be drawn inside the glazing system cavity, as shown in the figure below. When this model is simulated, THERM will automatically calculate both the U-factor results and CR temperature data that will be be used, when this profile is imported into WINDOW, to generate the overall Condensation Resistance value for the whole product. During the simulation, two simulations will appear at the bottom of the screen, the first for the U-factor results and the second for the CR results.

The Condensation Resistance model is not used for vertical cross sections, such as a Jamb, a Vertical meeting rail, or a Vertical Divider. Even if the CR model is activated (i.e., the "Use CR Model for Window Glazing System" is checked) for these Cross Section Types, THERM will not perform the CR simulation for that file.

THERM generates temperature data from both the CR and U-factor simulations which WINDOW uses to calculate the frame CR values (shown in the Frame Library Detailed View) and also the whole product CR values (shown in the Window Library Detailed View). When the CR model is not appropriate for the whole product CR calculations, WINDOW will use the temperatures from the THERM U-factor calculation instead, as shown below.

Table 6-3. Temperatures used by WINDOW based on Product Type and Tilt

Product Type (From THERM)	WINDOW 5 Whole Product Tilt (input in Window Library Detailed View)	Temperatures Used by WINDOW for whole product CR calculations
Horizontal elements: Sill, Head, Horizontal Meeting Rail, Horizontal Divider	90	CR
Horizontal and Vertical elements: ▪ Sill, Head, Horizontal Meeting Rail, Horizontal Divider; ▪ Jamb, Vertical Meeting Rail, Vertical Divider	≥ 0, ≤ 20	U-factor
Vertical elements: Jamb, Vertical Meeting Rail, Vertical Divider	90	U-factor
Horizontal and Vertical elements: ▪ Sill, Head, Horizontal Meeting Rail, Horizontal Divider; ▪ Jamb, Vertical Meeting Rail, Vertical Divider	> 20, < 90	CR not calculated

The application of these rules happens when WINDOW performs a calculation in the Window Library. It is up to the simulator to have provided WINDOW with the appropriate simulations in THERM in order for WINDOW to be able to calculate the result. For example, if there are no CR results for a Sill or Head THERM file modeled in a window with a 90° tilt, then WINDOW will not calculate a whole product CR value because the needed CR temperature data does not exist. A message, shown below, will indicate which cross sections are missing the CR data.

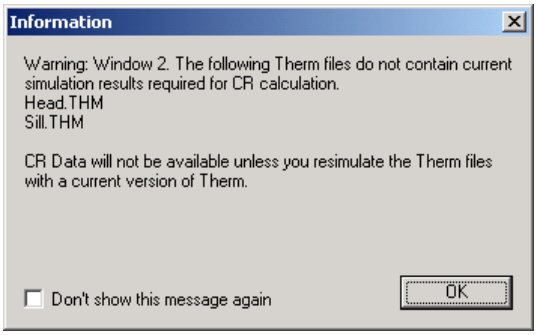


Figure 6-19. WINDOW will display a message if it determines that CR temperature data is not available from the THERM file.

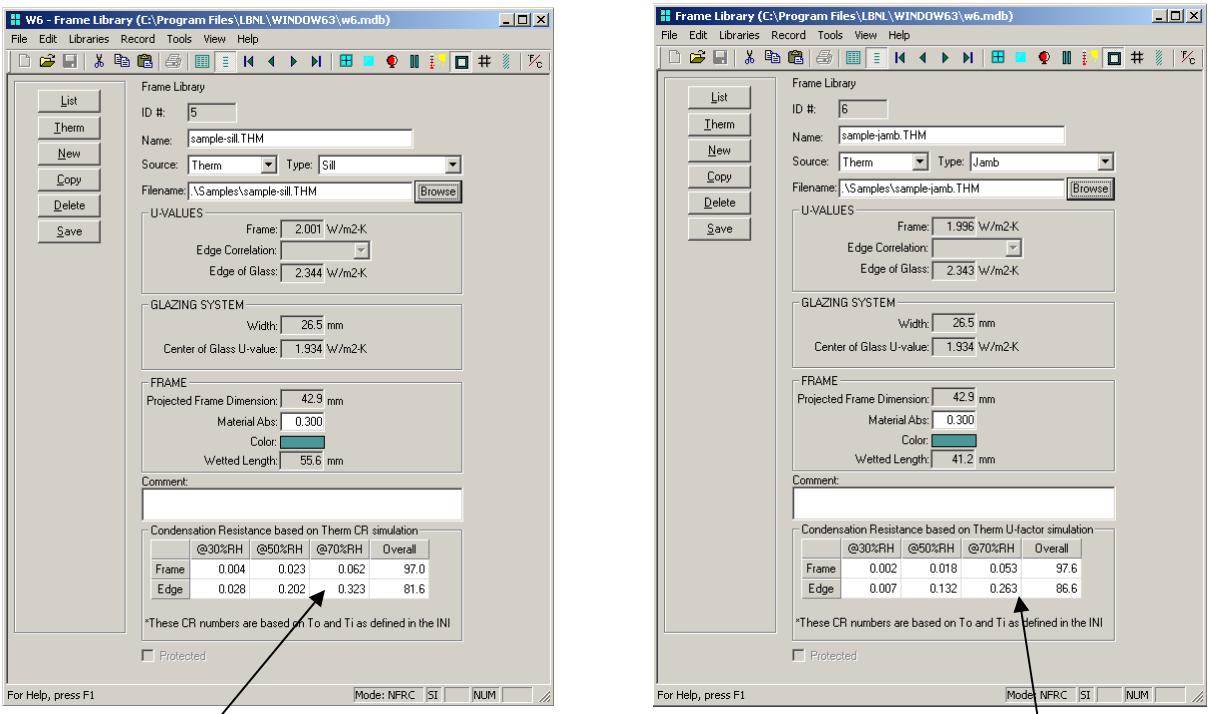


Figure 6-20. WINDOW Frame Library Detailed View displays the type of THERM temperature data to be used with the CR calculation, either U-fator or CR.

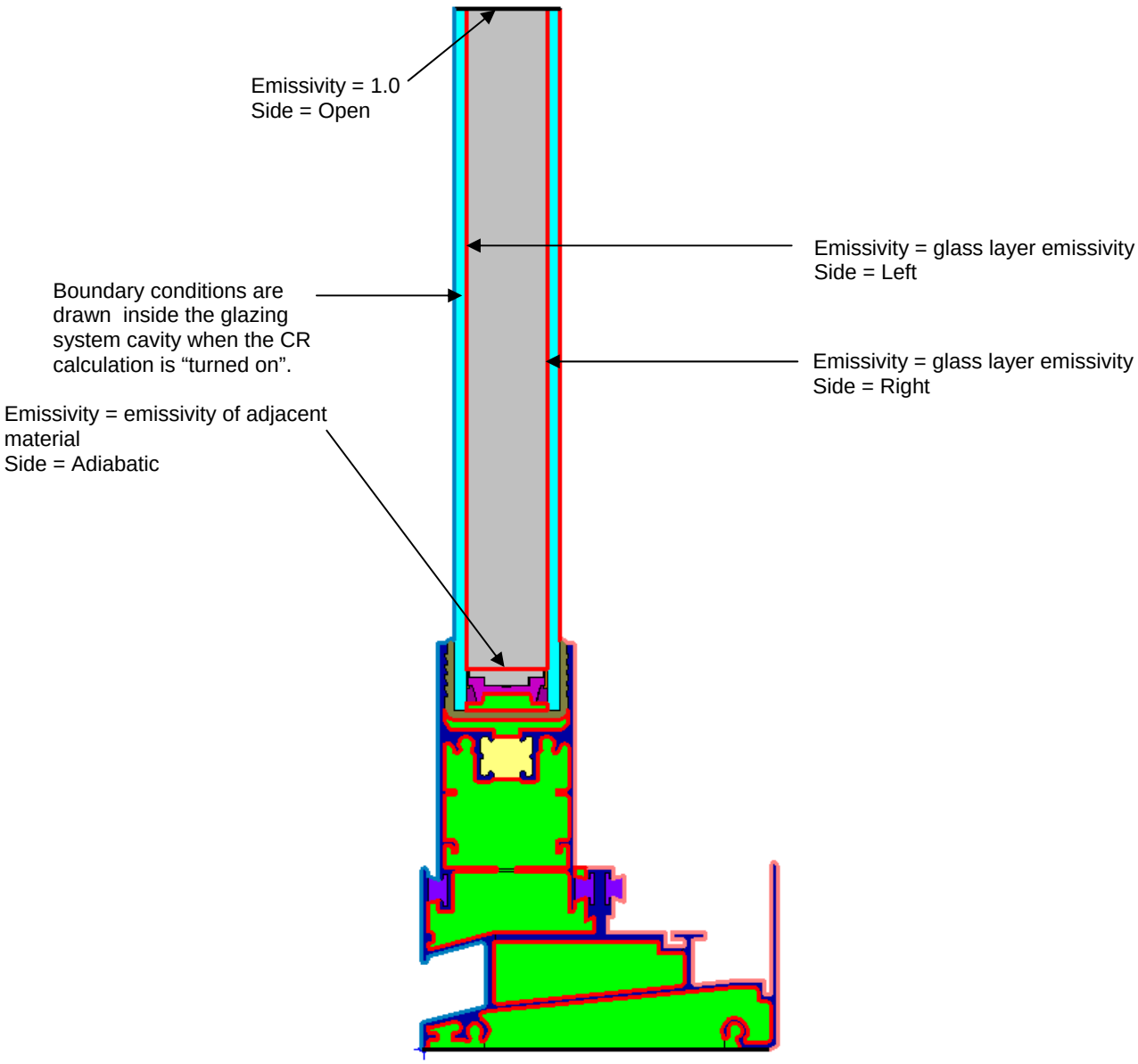


Figure 6-21. Modeling the profile with the CR model turned on.

6.5 Defining Boundary Conditions

Chapter 6 of the *THERM User's Manual* contains a detailed explanation of how to define boundary conditions in a model. The information found in this manual is supplemental to that discussion.

6.5.1. Overview

Boundary conditions must be defined for all the surfaces on the perimeter of the models, as well as at the surfaces adjacent to the radiation enclosure. These boundary conditions define the temperatures and film coefficients for each element of the perimeter. Different boundary conditions are defined for the surfaces on the interior and the exterior of the cross section. Surfaces which are assumed to have no heat transfer are assigned **Adiabatic** boundary conditions.

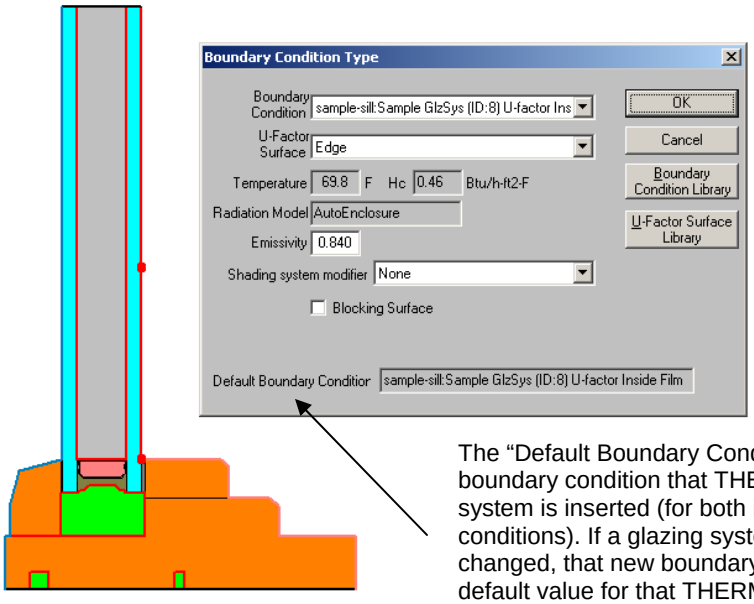
There are three main categories of boundary conditions:

- **Interior:** An interior boundary condition is used for all interior surfaces, and assumes that the surface is exposed to natural convection, and the heat transfer coefficient used depends on the temperature of the surface, which is a function of the material.
  - **For Glazing Systems:** The interior glazing system boundary conditions should be set to the boundary condition that is associated with the glazing system imported from WINDOW. (WINDOW calculates the center-of-glazing surface temperatures, and THERM uses these values to automatically calculate the edge-of-glazing boundary conditions for glazing systems imported from WINDOW). At the time the glazing system is imported from WINDOW, set the Interior Boundary Condition pulldown to "Use Convection plus enclosure radiation", which will cause the program to set the glazing system interior boundary condition **Radiation Mode**l to "AutoEnclosure". THERM will then model the cross section with the radiation enclosure feature (which is required by NFRC for all simulations) without the geometry of Radiation Enclosure being drawn. The boundary condition is named "<filename>:<glazing system name> U-factor Inside Film". Double click on an interior boundary conditions to see its characteristics, as shown in the figure below.
    - **For Frame Elements:** Set all non-glazing system interior boundary conditions according to the material, from the following predefined boundary conditions (which all have the **Radiation Model** set to "Autoenclosure"), one set for cross sections at a 90° tilt and another set for cross sections at a 20° tilt.**Interior Aluminum F**rame (Convection only)
    - Interior Thermally Broken Frame (Convection only)
    - Interior Thermally Improved Frame (Convection only)
    - Interior Wood/Vinyl Frame (Con**vection only)**
    - **I**nterior (20 tilt) Aluminum Frame (Convection only)
    - Interior (20 tilt) Thermally Broken Frame (Convection only)
    - Interior (20 tilt) Thermally Improved Frame (Convection only)
    - Interior (20 tilt) Wood/Vinyl Frame (Convection only)

    If there are frame materials that fall into more than one category, a single boundary condition must be applied to the entire interior surface of a given frame section, even if it contains different material components (i.e. vinyl sash and aluminum frame). The surface condition applied shall be the component with the greatest interior exposed area of that section.

    For steel skin door boundary conditions, see Section 8.7, Doors.

- **Exterior:** The "NFRC 100-2010 Exterior " exterior boundary condition is used for all exterior surfaces, including the glazing system, and assumes that the surface is exposed to a 5.5 m/sec (12.3 mph) air velocity, which corresponds to a convective film coefficient of 26 W/m^2-^{o}C (4.58 Btu/h-ft^2-^{o}F).
- **Adiabatic:** The adiabatic boundary condition is used for any surface assumed to have no heat flow. This is used for the top of the glazing system at the boundary between the edge-of-glazing and the center-of-glazing, because the assumption is that the heat transfer between the two sections are independent of each other. Adiabatic is also used for the bottom of the frame that would sit in the mask wall of the thermal chamber during testing.



The "Default Boundary Condition" field shows the default boundary condition that THERM will use when the glazing system is inserted (for both interior and exterior boundary conditions). If a glazing system boundary condition is changed, that new boundary condition will become the default value for that THERM session.

Figure 6-22. Double click on a boundary condition segment to see its characteristics..

THERM has a **Boundary Condition Library** (accessed from the **Library/Boundary Conditions** menu, or by double clicking on a boundary condition) which has the standard boundary conditions defined by NFRC, shown in Table 6-3, as well as **Adiabatic**. By default, the exterior boundary conditions are blue, interior boundary conditions are red, and the adiabatic boundary condition is black.

Table 6-4. Boundary condition definitions

Boundary Condition	**Radiation Model**	**Convective Film Coefficient**			
		Tilt = 90°		**Tilt = 20°**	
		W/m²-°K	**Btu/h-ft²-°F**	**W/m²-°K**	**Btu/h-ft²-°F**
NFRC 100-2010 Exterior	Blackbody	26	4.578	26	4.578
Interior Aluminum Frame (convection only)	Automatic Enclosure Model	3.29	0.579	4.65	0.819
Interior Thermally Broken Frame (convection only)	Automatic Enclosure Model	3.00	0.528	4.09	0.72
Interior Thermally Improved Frame (convection only)	Automatic Enclosure Model	3.12	0.549	4.32	0.761
Interior Wood/Vinyl Frame (convection only)	Automatic Enclosure Model	2.44	0.429	3.09	0.544
WINDOW Glazing System boundary condition <filename>:<glazing system name> U-factor Inside Film	Automatic Enclosure Model	Depends on the WINDOW calculations for the imported glazing system			

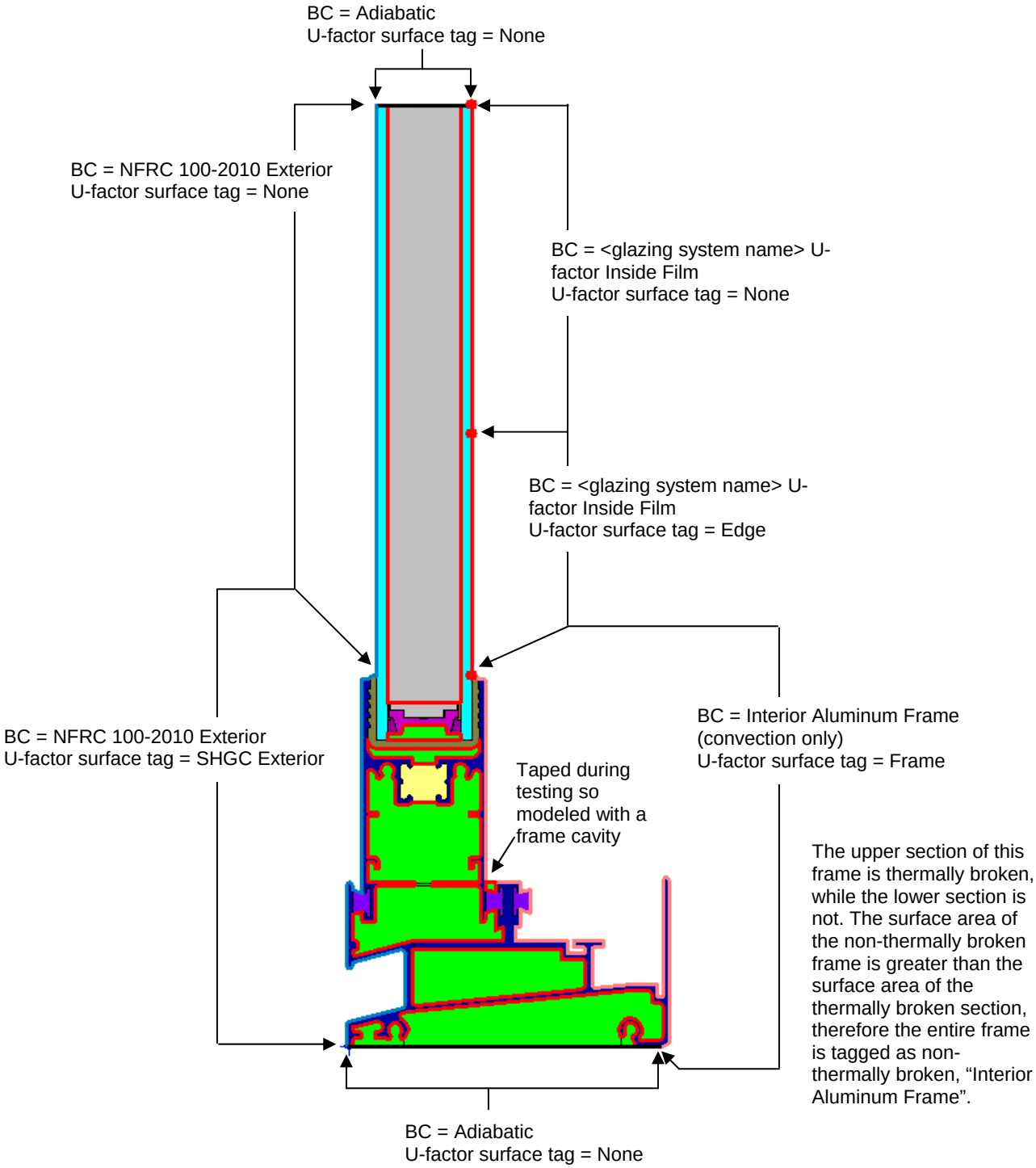


Figure 6-23. Defining the boundary conditions for a cross section.

6.5.2. Assigning Boundary Conditions and U-factor Surface Tags

Boundary conditions for a cross section are created in THERM by pressing the **Boundary Condition** toolbar button, clicking on the **Draw/Boundary Conditions** menu option, or pressing the **F10** key.

THERM will automatically assign boundary conditions, both interior and exterior, to a glazing system imported from WINDOW, as discussed above. However, the frame boundary conditions must be assigned in most cases.

- **NFRC 100-**2010 **Exterior** for the entire exterior surface of the glazing system and frame
- **Adiabatic** for bottom of the frame
- **Interior Frame Components:** The appropriate interior convection-only boundary condition for all other interior surfaces, from the choices in Table 6-3, found in the THERM Boundary Condition Library.

The technique for doing this is described in detail in Chapter 6, "Defining Boundary Conditions" of the *THERM User's Manual*.

In THERM, in addition to assigning boundary conditions to a boundary segment, the **U-factor Surface Tags** must also be assigned for each boundary condition. The **U-factor Surface Tags**, which are selected from the **U-factor Names** library, are used by THERM to calculate the component U-factors. For a THERM U-factor calculation that will be used in WINDOW, it is necessary to use the following **U-factor Surface Tags**, with the same capitalization (WINDOW will not recognize any other values):

- **Frame:** Use this tag for all interior boundary conditions that are part of the frame U-factor calculation, including the boundaries of the glazing system below the sight line. See *NFRC 100*, "Figure 2, Fenestration Product Schematic -- Vertical Section". THERM will automatically assign the U-factor tag of **Frame** to the portion of the glazing system that is below the sight line, based on the **Site Line to Bottom of Glass** value entered when the glazing system is inserted from WINDOW.
- **Edge:** Use this tag for all interior boundary conditions that are to be used in the edge-of-glazing calculation. THERM will automatically assign the U-factor tag of **Edge** based on the dimension entered in the **Edge of Glass Dimension** when importing the glazing system, which for NFRC modeling should be 63.5 mm (2.5 inches). This dimension will be added above the sight line, defined by the **Sight line to bottom of glass dimension** when importing the glazing system.
- **None:** Use this tag for the 86.5 mm (3.5 inches) of glazing system that is modeled above the Edge-of-glazing, and for the glazing system exterior boundary condition. This is the default U-factor tag automatically assigned by THERM for all surfaces except the glazing system.
- **SHGC Exterior:** Use this tag for all exterior non-glazing surfaces. This tag is used to calculate the wetted length of the exterior frame to be used in WINDOW for the Solar Heat Gain Coefficient (SHGC) calculation.

The **Blocking Surface** checkbox should be checked for frames, but not for glazing systems.

To change the boundary condition for one boundary segment, **double click** on the segment, or **single click** and press **Enter**, and the **Boundary Condition Type** dialog box will appear. This dialog box allows specification of both the boundary condition and the U-factor tag at the same time. To change the boundary condition for multiple boundary segments, cl ick on the first segment and **double click** (or **single click** and press **Enter**) on the last segment in a *counterclockwise* direction. The choices made in the **Boundary Condition Type** dialog box will then be applied to all the selected boundary segments. It is also possible to change the boundary condition definition for boundary segments using the **Select Material/BC** toolbar button. Click on the **Eye Dropper** tool, click on a boundary segment whose definition is to be duplicated to other segments, then click on the boundary segment(s) which need that boundary condition definition. The program will

assign both the boundary condition and U-factor tag from the copied segment. There is also one level of "undo" for boundary conditions, accessed through the **Edit/Undo** file menu choice.

The Radiation Model of all interior boundary conditions should be set to "Automatic Enclosure Model". If for some reason the interior boundary conditions do not have the **Radiation Model** set to "AutoEnclosure" (double click on the boundary condition to open the **Boundary Condition Type** dialog box which displays the setting), they can be easily changed to that model. To change the **Radiation Model**, go to the **Boundary Condition Library**, either through the **Library** menu, **Boundary Condition Library** choice, or by double clicking on a boundary condition segment and clicking on the **Boundary Condition Library** button. In the **Boundary Condition Library**, under the **Radiation Model**, click on the "Automatic Enclosure Model" radio button.

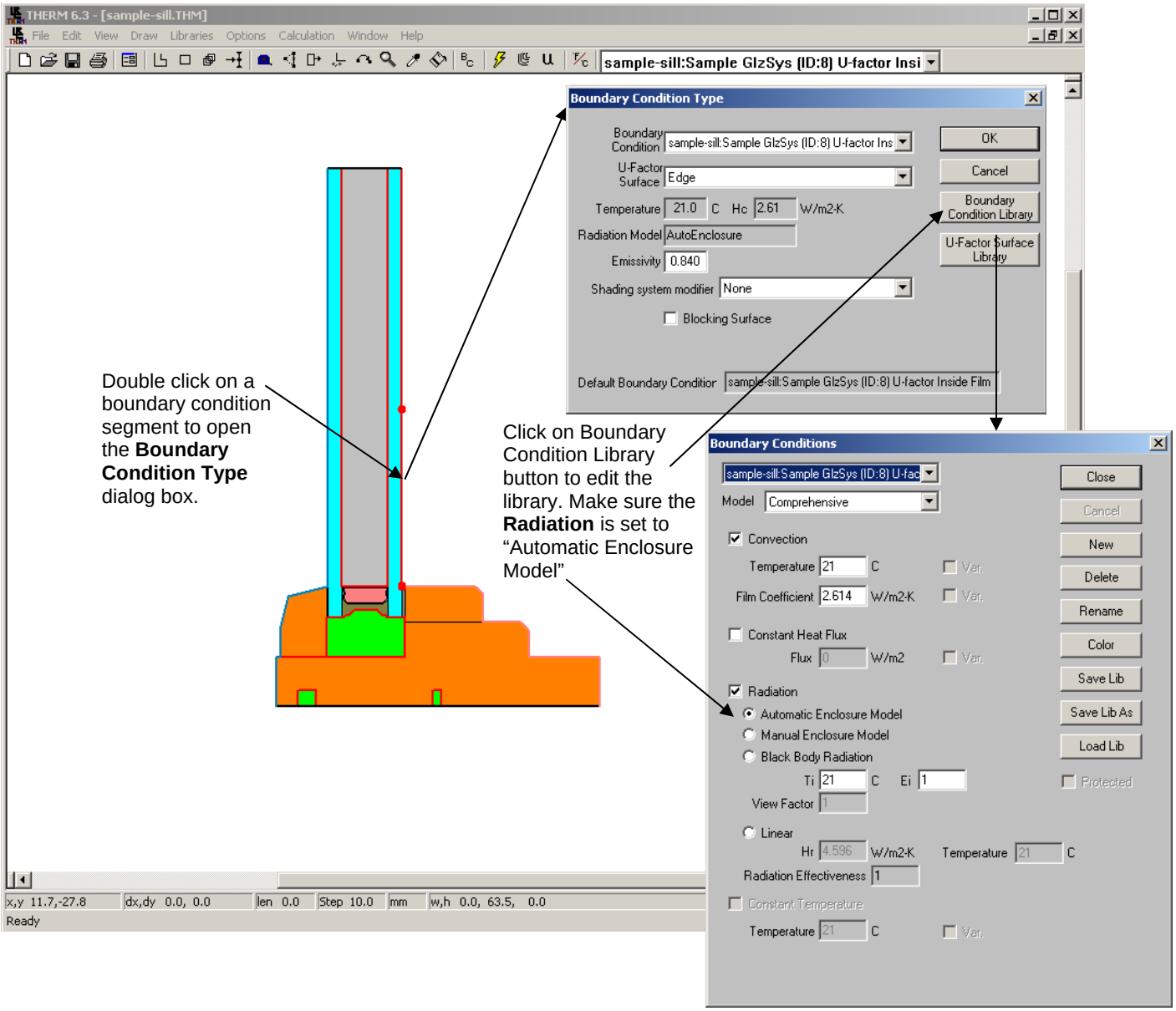


Figure 6-24. Make sure that the interior boundary conditions have set to "AutoEnclosure".

When boundary conditions are generated for a model, the program keeps them in the model until they are regnerated. If the boundary conditions are regenerated, the program will display a dialog box with three choices for how the program should generate them, as shown below.

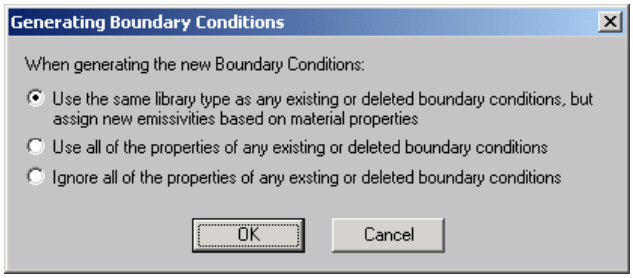


Figure 6-25. The dialog box displayed when boundary conditions are regenerated.

In general, pick the first option in “Generating Boundary Conditions” dialog box, which will pick up the emissivities of the materials in the model. However, do not select this option if you have edited the emissivities of material boundary conditions, such as frame cavities, by hand.

All the boundary conditions can be deleted by deleting one boundary segment.

Boundary conditions and U-factor tags are stored in libraries, and new entries can be defined for both using the **Libraries** menu choice. See *Section 6.2*, "Assigning Boundary Condition Definitions" in the *THERM User's Manual* for more detailed information.

Occasionally THERM loses track of the glazing system boundary conditions. If this happens they can be reassigned from the **Boundary Condition Library**.

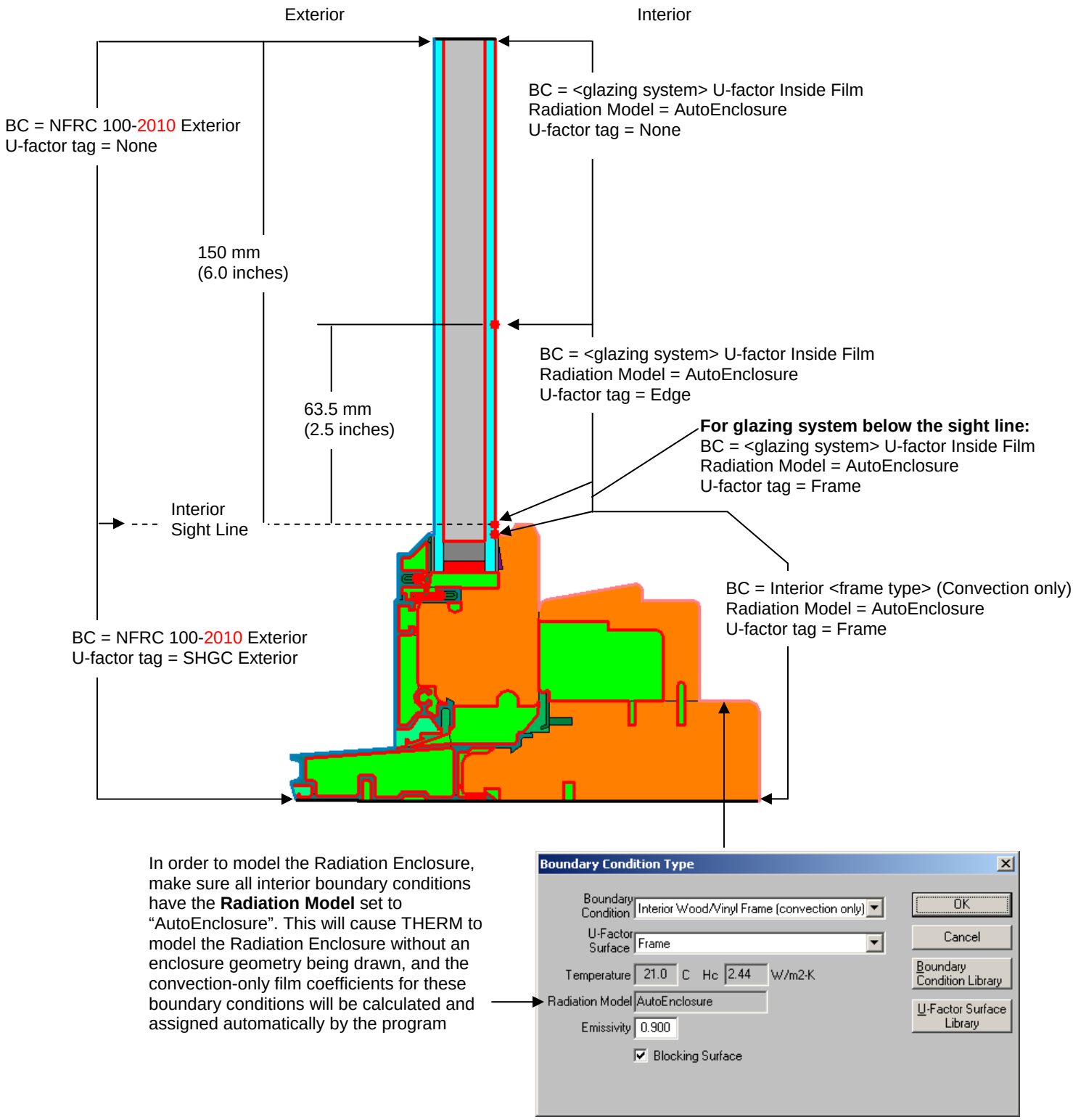


Figure 6-26. Standard boundary condition assignments for most models.

Boundary Conditions for Nailing Flanges

When modeling nailing flanges, assign the "NFRC Exterior" boundary condition, with U-factor tag set to "None", to the portion of the nailing flange that is facing the exterior condition, as shown in the figure below.

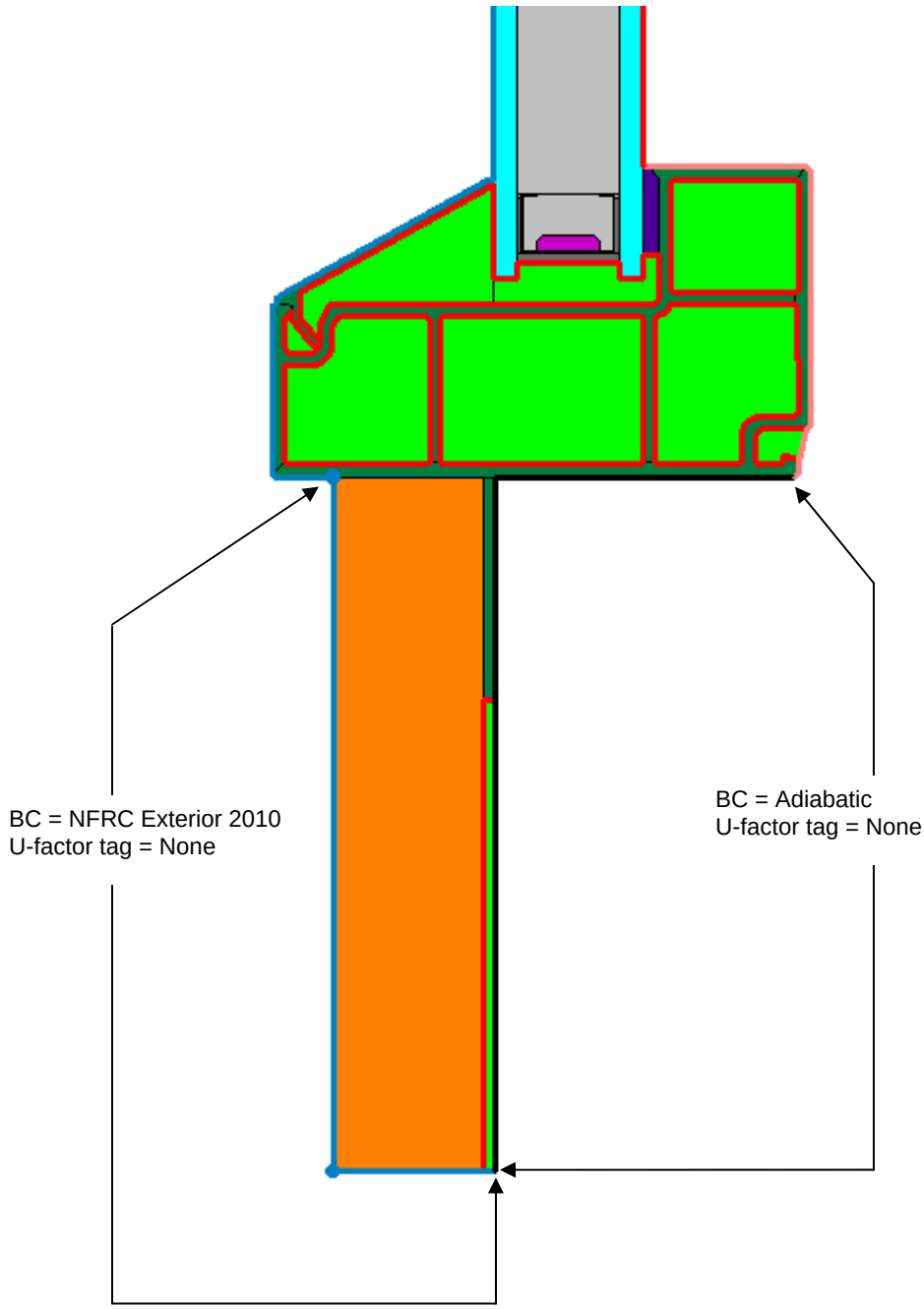


Figure 6-27. Boundary condition assignments for mailing flange.

6.5.3. Voids, Overlaps and Bad Points

In order to perform a simulation, the geometry of the cross section must be correctly defined, i.e., there must not be any voids, overlapping polygons, or points that cannot be resolved by THERM.

While drawing, there are a number of features in THERM to help avoid creating voids, overlapping polygons, and bad points. The **Always Check for Overlapping Polygons** feature (in **Options/Preferences/Drawing Options**) is the main tool used to avoid drawing overlaps and voids. This option can be turned off, but this is NOT recommended for most situations. The **View Voids and Overlaps** (from the **Draw** menu) feature is also a good tool for visual inspection to find voids and overlapping polygons in a cross section.

In addition to the features that attempt to prevent the creation of bad geometry during the drawing process, a number of error checks are performed when THERM calculates the boundary conditions in order to make sure the model geometry is correct.

For example, when the boundary conditions are calculated THERM identifies all points within 0.1 mm (0.004 inches) and 0.01 mm (0.0004 inches) of each other (points closer together than 0.01 mm are automatically merged). A message box appears saying that there are points closer than the program tolerance, as shown in Figure 6-27. In general, select the option **Automatically adjust points within tolerance option**, in which case THERM will fix all of the points automatically. This now works even for models with thin films in glazing systems. If you are unsure about whether to let the program adjust the points automatically, select the **Mark the points but don't adjust them** option, which causes THERM to draw red circles in the problem areas. Then you can examine all the circled points and fix them if appropriate, or regenerate the boundary conditions and let the program automatically adjust them. If the marked points are actual details in the drawing that need to be kept, they do not have to be fixed, although they might cause meshing problems during the simulation because of too much detail. Once all the circled areas in the drawing have been examined, press the Boundary Conditions toolbar again – if the program identifies “bad points’ but you wish to keep the detail, just click OK and the boundary conditions will be generated. (Having THERM adjust the points is an "all or nothing" proposition -- which is why all the points should be examined first before having the program adjust them. Also keep in mind that the automatic fixing of points cannot be reversed by THERM.)

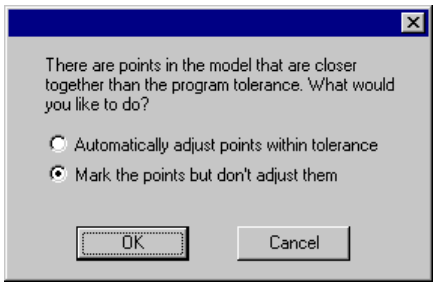


Figure 6-28. Message when trying to define boundary conditions indicating that there is a problem in the geometry.

The best way to fix points that are too close together is to delete or move the offending point. Many times, the point in question is in all the adjacent polygons, so it is best to delete the point in all the polygons at the same time by selecting all the polygons using the **Shift** key, then delete the point; it will be deleted from all the selected polygons.

THERM also marks **Voids and Overlaps** by checking for "lonely edges" -- two adjacent edges with a different number of points on each edge. THERM marks voids and overlapping polygons with red circles also. One way to eliminate these two conditions is by "jiggling" the points -- moving the points away from the adjacent polygon, then moving them back within the sticky distance and letting the program "snap" them to the polygon. Another way is to delete the offending polygon, and use the **Fill Void** toolbar button to create it again, which means that THERM will automatically align all points and ensure that no voids are created.

THERM can also find invalid polygons caused by points collapsing on each other, creating a zero-area extension. In this case both the point at the tip of the extension and the extra point at its base must be deleted.

Turning off the **Material Color** and the **Boundary Conditions** from the **View** menu can sometimes help to find the problems.

THERM will simulate a problem even if "bad points" have been marked and intentionally left in the cross section, because in some cases details are drawn that give bad points but which need to be modeled.

If changes are made to polygons on the boundary of the cross section, the boundary conditions must be generated again. If all the corrections are on internal polygons, the boundary conditions will not be automatically deleted. However, in this case, it is still a good idea to press the **Boundary Conditions** toolbar button again, to ensure that all points on all surfaces have boundary segments defined between them.

6.6 Calculating Results

When the boundary conditions have been correctly defined for the cross section, the model can be simulated. Begin the calculation by either clicking on the **Lightning Bolt** toolbar button, selecting the **Calculation/Calculation** menu option, or pressing **F9**.

6.6.1. Meshing

The first step performed by THERM in the simulation is to generate a mesh from the geometry on which the thermal analysis is based. This mesh is generated automatically, and a summary of how it works is found in "Appendix C" in the *THERM User's Manual*.

The one variable in the mesh generation that the user can control is the **Quadtree Mesh Parameter**, which determines how fine the mesh is. The larger the mesh parameter value, the smaller the largest element in the mesh is. The NFRC required default value for the mesh parameter is 6, as shown in Table 6-4.

Occasionally the mesh generator cannot create a closed mesh with the geometry that has been drawn, usually created because of extremely fine detail in the cross section. THERM circles the point(s) where the mesher failed. If this happens, first:

- **Rerun the problem with a higher mesh parameter value.** This causes the program to generate a finer mesh, and results in longer run times. The default mesh parameter value is 6. Mesh parameter values greater than 8 are rarely needed for single cross sections, but may be needed for full height product simulations. Options/Preferences/Simulation has a setting to "Automatically increment mesh parameter". If this option is checked the program will increase the mesh parameter until the problem meshes.

If this doesn't work:

- **Simplify any unnecessarily complicated details.** Keep in mind that the circled point often lies on the boundary between two polygons; the detail that is causing the problem could be anywhere in those two polygons and is often not at the place that is circled. One method to try is to break the problem polygon into multiple polygons, while keeping the geometry otherwise unchanged. Another option is to delete unnecessary points, such as in curves, because each point generates a mesh node.

6.6.2. Error Estimator

THERM has a built-in error estimator, and automatically refines the mesh in the areas where it is needed. The details of the error estimation algorithm are found in "Appendix C" of the *THERM User's Manual*. The error estimator returns the **Percent Error Energy Norm**, which is related to the gradient of heat flux (energy). If the

returned value is greater than the target value, THERM refines the mesh in areas with a high rate of change in the heat flux.

The default value for the **Percent Error Energy Norm** in THERM to 10%, as shown in Figure 6-28. This setting forces THERM to do the error estimator calculation and return a value for the error estimate (recorded with the U-factor results) and the program may or may not refine the mesh, depending on the result of the Error Energy Norm. If an error message is displayed saying that the error energy norm cannot be reached, increase the **Maximum Iterations** value (set by default to three iterations). An Error Energy Norm of less than 10% is equivalent to an uncertainty of less than 1% in the U-factor.

6.6.3. Required Settings for NFRC Simulations

In the **THERM File Options** tab found in the **Options/Preferences** menu, the following values must be set:

Table 6-5. Options/Preferences settings for THERM NFRC modeling

Setting	Value for NFRC Modeling
Quad Tree Mesh Parameter	6 or greater
Maximum % Error Energy Norm	10%
Run Error Estimator	must be checked

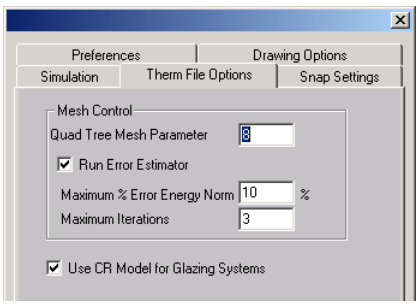


Figure 6-29. NFRC required THERM File Options settings.

In the **Simulation** tab found in the **Options/Preferences** menu, the Relaxation Parameter can be set to **1.0**, and the feature to "Automatically adjust relaxation parameter" should be set, as shown in the figure below.

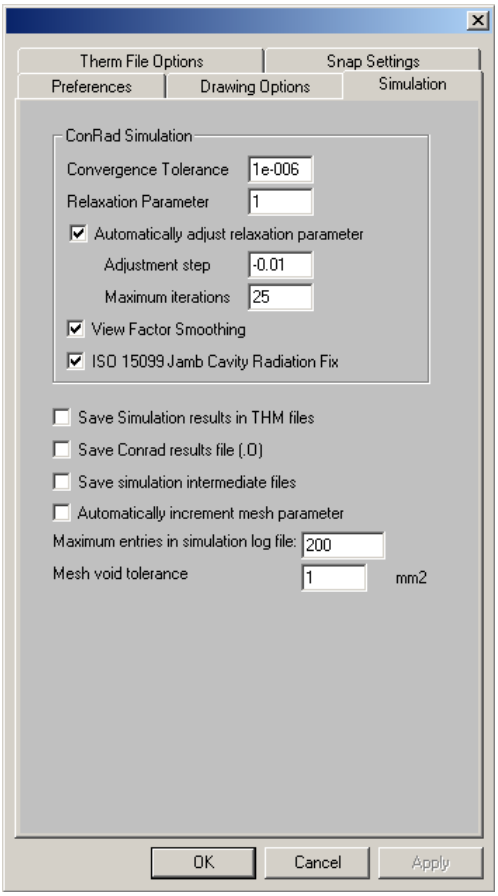


Figure 6-30. Simulation option settings.

6.6.4. Calculations

When a calculation is started, THERM can do the calculations in the background while another model is being worked on. There is also a **Calculation Manager**, accessed from the **Calculation/Calc Manager** menu option that allows the submittal of many files at one time to be calculated in the order they are added. The **Calc Manager Log** shows whether the jobs ran or not.

Calculating Multiple Glazing Options

If a base case file has been created with multiple glazing options (see Section 6.4.3, "Multiple Glazing Options"), when the file is simulated using the **Calc** toolbar, the **Calculation/Calculation** menu option, or the **F9** shortcut key, the **Glazing Option Simulation** dialog box will appear with the following options , as shown in Figure 6-30:

- **Create the glazing option files and perform all simulations:** This choice is the default, and it creates and runs all the THERM files for the multiple glazing options defined in the base case file.
- **Simulate the current file (base case) only:** This choice is useful when setting up the base case file to make sure there are no geometry errors before running the entire multiple glazing options.
- **Create the glazing option files but do not perform the simulations:** This choice will cause the program to make individual THERM files for each of the glazing options associated with the base case file, with either the Glazing System ID or Name appended on to the base case filename, but it will not simulate the files. These files can then be opened and simulated individually, or simulated through the Calc Manager.

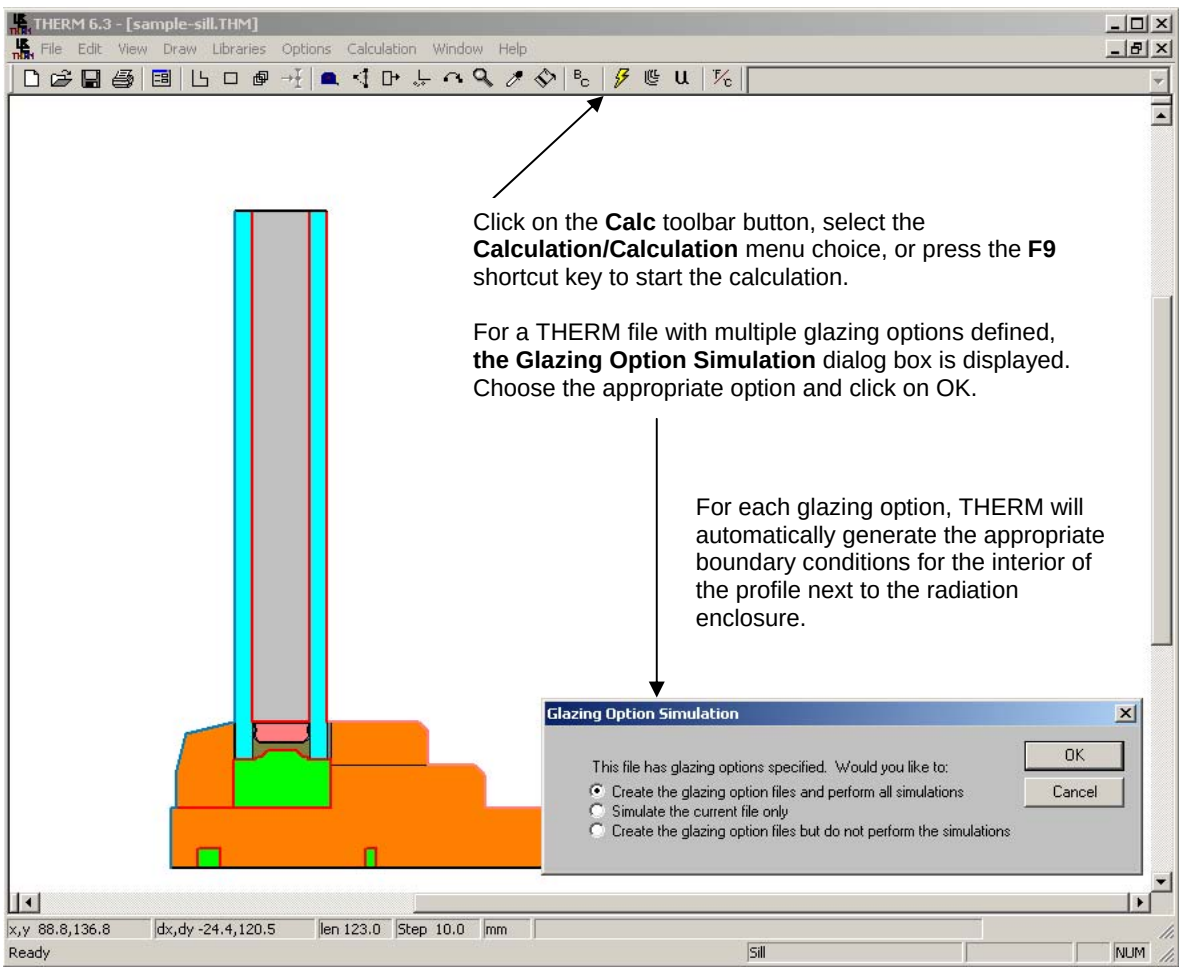


Figure 6-31. When a file w ith multiple glazing options is calculated, THERM gives several calculation options.

Multiple base case files with multiple glazing options in each file can be added to the **Calc Manager**, as shown in the figure below. The **Calc Manager** does not ask the three simulation-option questions; it implements the first choice, which is that to make all the files and then simulate them. The **Calculation Log** can be viewed to see the status of the runs. The information in the **Calculation Log** can be sorted by clicking on a column heading.

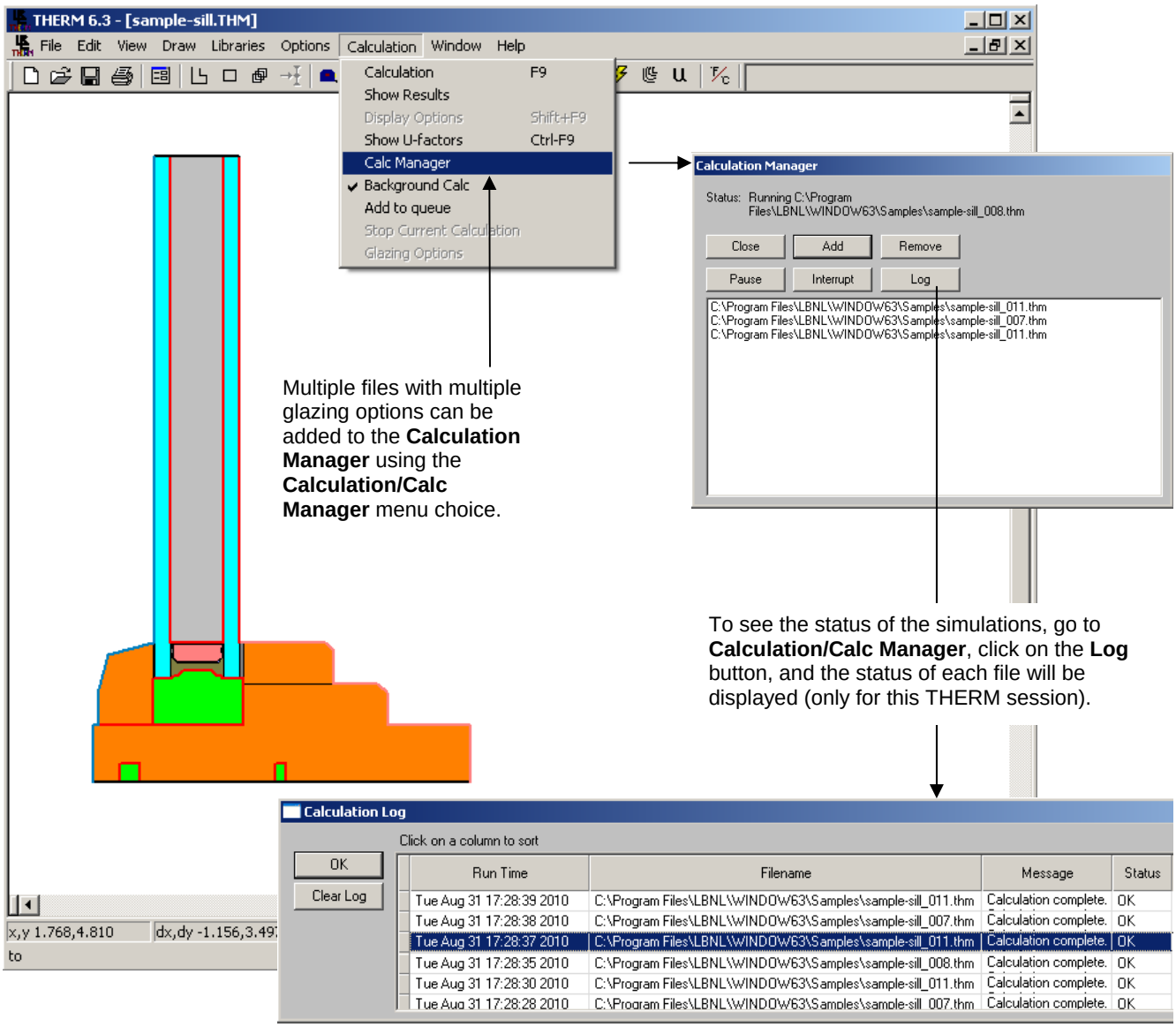


*Figure 6-32. The **Calc Manager** can be used to simulate multiple files with multiple glazing options in each file.*

6.6.5. Results

When the calculation is finished, the U-factors (shown in the figure below) can be viewed using the **Calculation/Show U-factor** menu choice or the **Show U-factor** toolbar button.

In addition, the graphic display of the results can be controlled using either the **Calculation/Show Results** menu choice or the **Show Results** toolbar button.

The U-factors can be viewed for **Projected X**, **Projected Y**, **Total Length, Custom Length, Projected in Glass Plane** or **Custom Rotation**. U-factors are generally calculated as Project in Glass Plane, but there are a few special cases where the **Custom Frame Length** feature must be used for an NFRC simulation. (See the following discussion in *Section 6.6.6*, "Custom Frame Length" for an example using **Custom Frame Length**.)

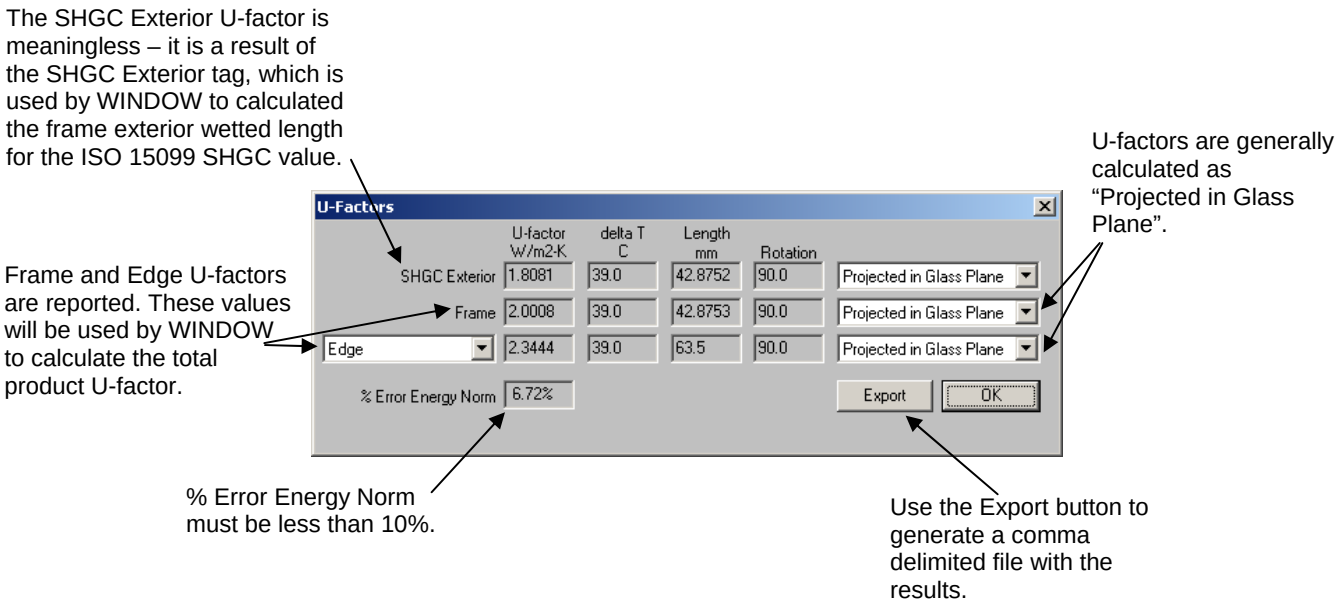


*Figure 6-33. U-factor results from the **Calculation/Show U-factors** menu choice.*

Local temperatures can be displayed at the cursor (from the **View/Temperature at Cursor** menu choice) and average temperatures can be displayed with the tape measure (from the **Options/Preferences** menu, **Drawing Options** tab, check the **Tape Measure Average Temperature** checkbox).

THERM has a report which summarizes all the details of a THERM file, including the polygon ID numbers for all cavities. This report can be viewed and printed from the **File/Report** menu choice.

THERM files (*.THM) can be saved without the detailed temperature data by selecting the **Options/Preferences** menu, going to the **Simulation tab**, and *unchecking* **Save Simulation results in THM files**. The THERM file will then contain only the geometry and boundary conditions used to run the simulation, the U-factor results, and the report, thus making the file much smaller.

6.6.6. Custom Frame Length

There is a case where THERM will not calculate the project frame length correctly. This happens when a section of an adiabatic boundary "overlaps" a boundary with a U-factor tag in the projected dimension over which the length is being calculated. The figure below illustrates this. This incorrect frame length will cause the U-factor over the projected length to be calculated incorrectly. The U-factors results dialog box has a feature which allows a custom frame length to be entered, in order for THERM to calculate the correct U-factor. This situation happens in some skylight files, although it potentially could happen in any model. The figure below describes the steps required to use the Custom Frame Length feature.

For multiple glazing options, setting the custom frame length for each option can be quite cumbersome. One technique is to set the custom frame length in the base file first, and then the program will pick up for custom length values for each multiple glazing option.

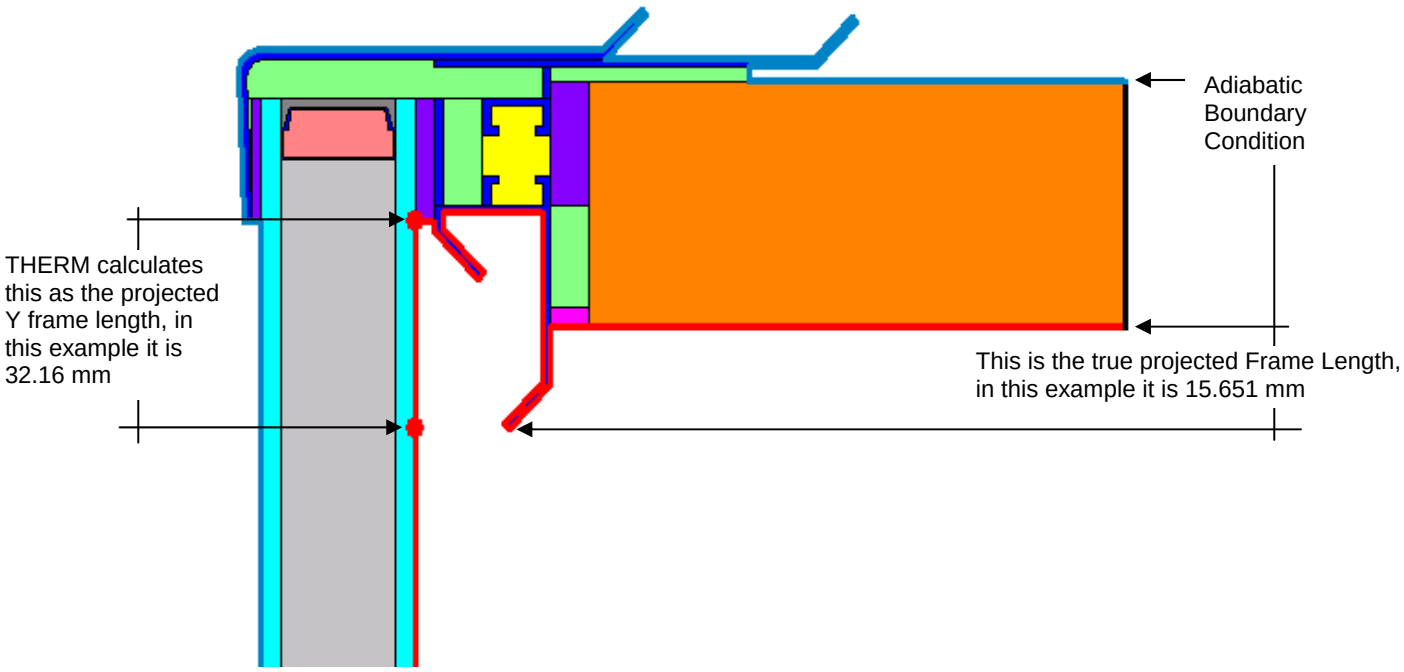


Figure 6-34 Example of a case where THERM does not calculate the projected Y frame length correctly because of an adiabatic boundary condition that "overlaps" an interior boundary condition.

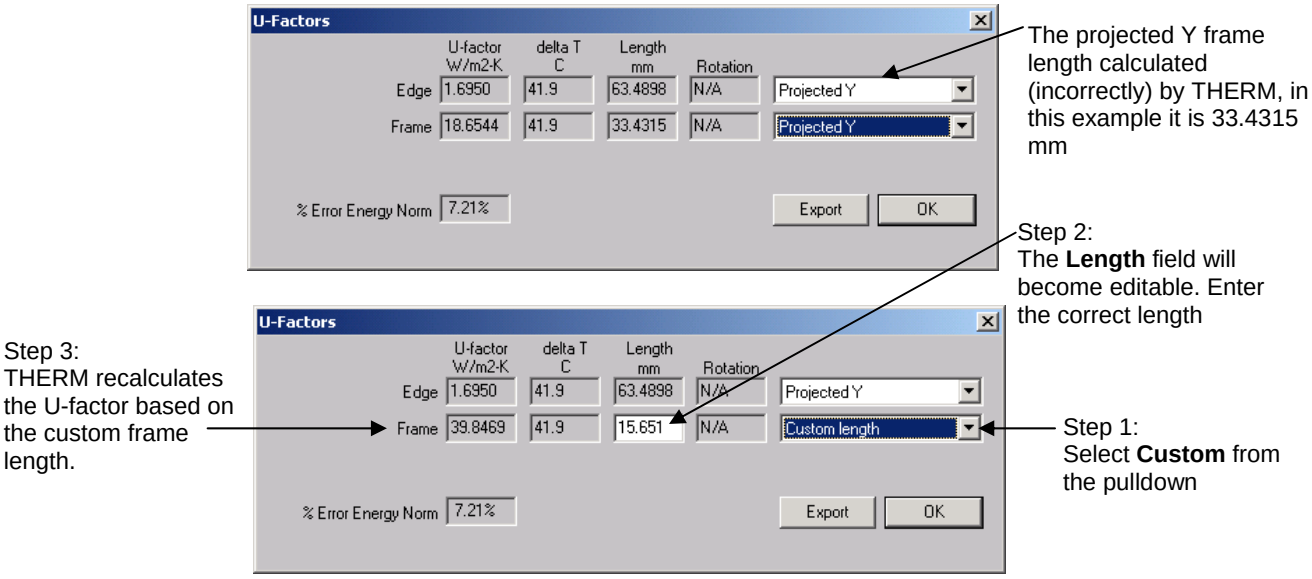
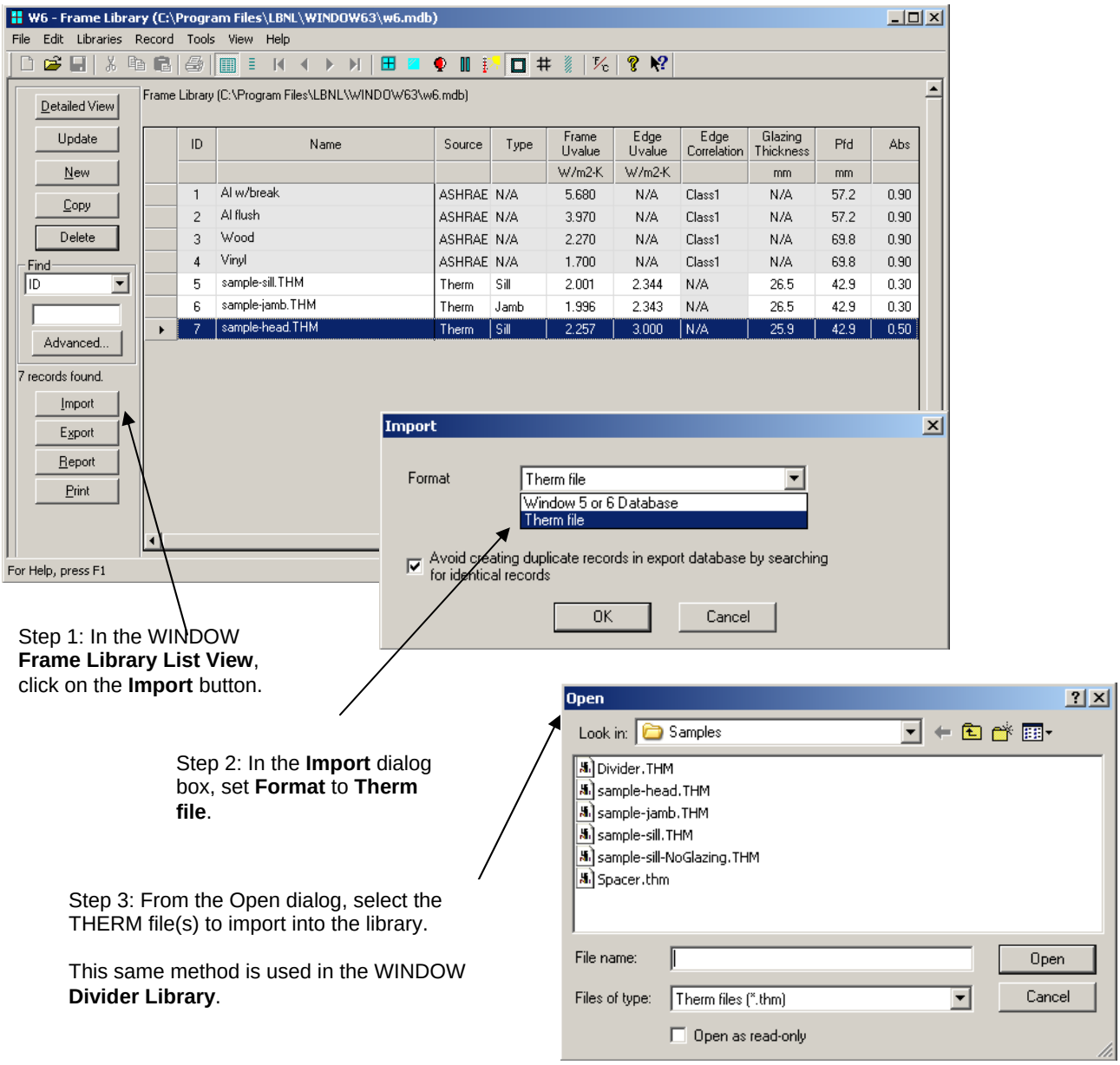


Figure 6-35 The Custom Frame Length feature allows the correct frame length to be entered.

6.6.7. Importing Results into WINDOW

Because the U-factors and temperatures from individual THERM cross sections will be used for the whole product calculations in WINDOW, it is necessary to import the THERM files with U-factor and simulation temperature results into the WINDOW program. This is explained in detail in the *WINDOW User's Manual,* Section 4.7.3, "Importing THERM Files". The basic steps are:

- Create the THERM models, calculate the results, and save and close the files.
- Open WINDOW and go to the **Frame Library List View**.
- Click on the **Import** button, select the "Therm Files" option from the pulldown, then THERM files to import (select multiple files using either **Shift** or **Ctrl** keys).
- WINDOW will ask how to number the new **Frame Library** records, either sequentially starting from the last existing record, or overwriting existing records.
- WINDOW will add each THERM file to the **Frame Library** as a separate record, assigning the THERM file name as the record name by default.
- If necessary, set (in WINDOW **File/Preferences/Calculation Options**) the "Default Frame Absorptance" to 0.30 or 0.50, according to the NFRC 200 specifications.



Step 1: In the WINDOW **Frame Library List View**, click on the **Import** button.

Step 2: In the **Import** dialog box, set **Format** to **Therm file**.

Step 3: From the Open dialog, select the THERM file(s) to import into the library.

This same method is used in the WINDOW **Divider Library**.

Figure 6-36 Importing THERM files into the WINDOW ***Frame Library****.*

7. TOTAL PRODUCT CALCULATIONS USING WINDOW

7.1. Overview

WINDOW determines the total product U-factor according to *NFRC 100* and *ISO 15099* by calculating an area-weighted average of the U-factors of the product components and accounting for product height:

- Frame and edge values for each cross section (frames and dividers) calculated in THERM: The U-factors are area-weighted based on the projected area on a plane parallel to the glass (the **Projected in the Glass Plane** choice in the THERM U-factors dialog box), not the total surface area of the frame and edge.
- Center-of-glazing values from WINDOW

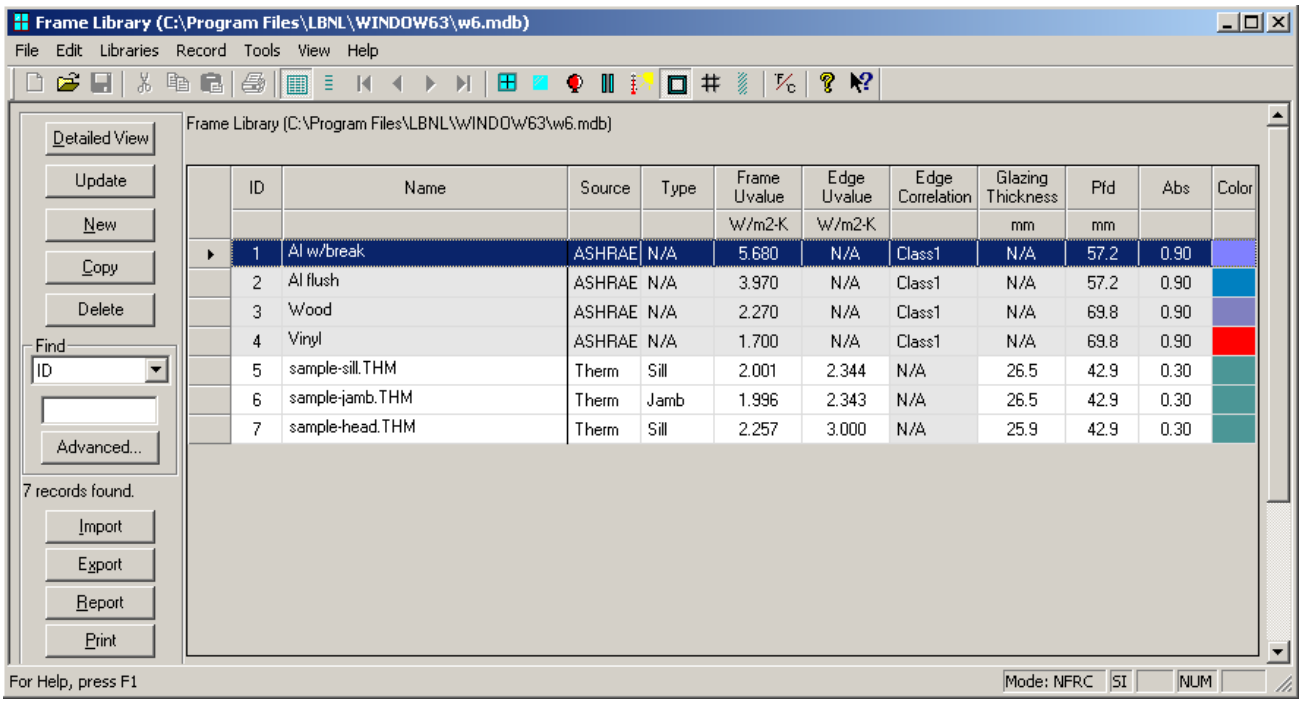
WINDOW calculates the total product area-weighted solar heat gain coefficient (SHGC) and visible transmittance (VT) according to the *NFRC 200* procedures and the total product Condensation Resistance (CR) according to the *NFRC 500* procedures.

WINDOW cannot calculate the total product area-weighted properties for some fenestration products. These include entry doors (see Chapter 8, Section 8.7. Doors), Vehicular Access Garage/Rolling Doors (see Chapter 8, Section 8.12. Garage and Rolling Doors). For these cases, a spreadsheet can be used to calculate the total product area-weighted values.

7.2 Frame and Edge U-factors from THERM

As discussed in Section 6.6.7, "Importing Results into WINDOW", THERM files are imported into the WINDOW Frame and Divider Libraries in order to calculate the whole product values in WINDOW.

When the THERM files are imported into the WINDOW **Frame** and **Divider Libraries**, they can be used in whole product calculations. The **Source** field in the **Frame Library** indicates whether the files were imported from THERM, as shown in the following figure.



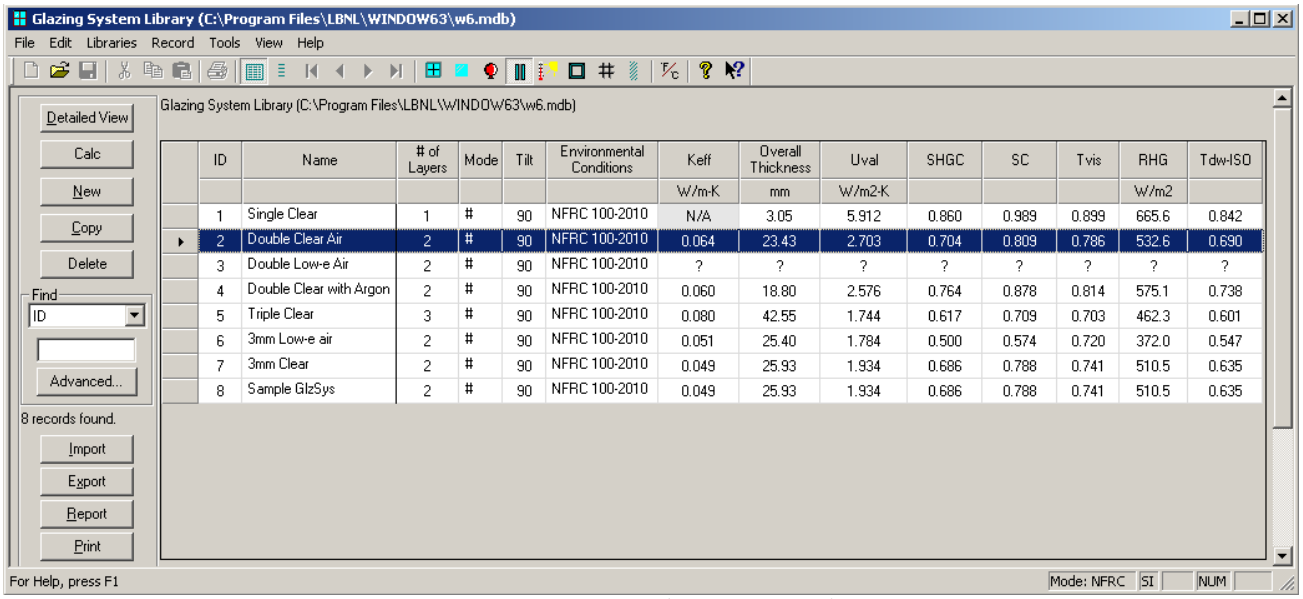
ID	Name	Source	Type	Frame Uvalue	Edge Uvalue	Edge Correlation	Glazing Thickness	Pfd	Abs	Color
				W/m2-K	W/m2-K		mm	mm		
1	Al w/break	ASHRAE	N/A	5.680	N/A	Class1	N/A	57.2	0.90	
2	Al flush	ASHRAE	N/A	3.970	N/A	Class1	N/A	57.2	0.90	
3	Wood	ASHRAE	N/A	2.270	N/A	Class1	N/A	69.8	0.90	
4	Vinyl	ASHRAE	N/A	1.700	N/A	Class1	N/A	69.8	0.90	
5	sample-sill.THM	Therm	Sill	2.001	2.344	N/A	26.5	42.9	0.30	
6	sample-jamb.THM	Therm	Jamb	1.996	2.343	N/A	26.5	42.9	0.30	
7	sample-head.THM	Therm	Sill	2.257	3.000	N/A	25.9	42.9	0.30	

Figure 7-1. WINDOW Frame Library with records imported from THERM.

7.3 Center-of-Glazing U-factors from WINDOW

The *WINDOW User's Manual* contains detailed information about calculating the center-of-glazing U-factors.

For an NFRC simulation, create glazing systems that represent all the glazing types to be modeled from the glass matrix provided by the manufacturer. In WINDOW, access the **Glazing System Library List View** either from the **Libraries/Glazing System** menu, by clicking on the **Glazing System Library** toolbar button, or by pressing **F5**.



	ID	Name	# of Layers	Mode	Tilt	Environmental Conditions	Keff	Overall Thickness	Uval	SHGC	SC	Tvis	RHG	Tdw-ISO
							W/m-K	mm	W/m2-K				W/m2	
	1	Single Clear	1	#	90	NFRC 100-2010	N/A	3.05	5.912	0.860	0.989	0.899	665.6	0.842
▸	2	Double Clear Air	2	#	90	NFRC 100-2010	0.064	23.43	2.703	0.704	0.809	0.786	532.6	0.690
	3	Double Low-e Air	2	#	90	NFRC 100-2010	?	?	?	?	?	?	?	?
	4	Double Clear with Argon	2	#	90	NFRC 100-2010	0.060	18.80	2.576	0.764	0.878	0.814	575.1	0.738
	5	Triple Clear	3	#	90	NFRC 100-2010	0.080	42.55	1.744	0.617	0.709	0.703	462.3	0.601
	6	3mm Low-e air	2	#	90	NFRC 100-2010	0.051	25.40	1.784	0.500	0.574	0.720	372.0	0.547
	7	3mm Clear	2	#	90	NFRC 100-2010	0.049	25.93	1.934	0.686	0.788	0.741	510.5	0.635
	8	Sample GlzSys	2	#	90	NFRC 100-2010	0.049	25.93	1.934	0.686	0.788	0.741	510.5	0.635

Figure 7-2. WINDOW Glazing System Library.

For NFRC certified simulations, use the currently approved International Glazing Database (IGDB) spectral data, imported into the WINDOW **Glass Library**. Glazing Systems that use approved spectral data will have a "#" in the **Mode** field, as shown in the figure above, with the exception of laminates and applied films (see Section 8 for more information).

The U-factors shown in the **Glazing System Library** are based on a one meter default height. When these glazing systems are used in whole products, in the **Window Library**, the center-of-glazing U-factors will be recalculated based on the actual product height specified in the **Window Library**. Therefore, the U-factors in the **Glazing System** and **Window Libraries** will probably be slightly different.

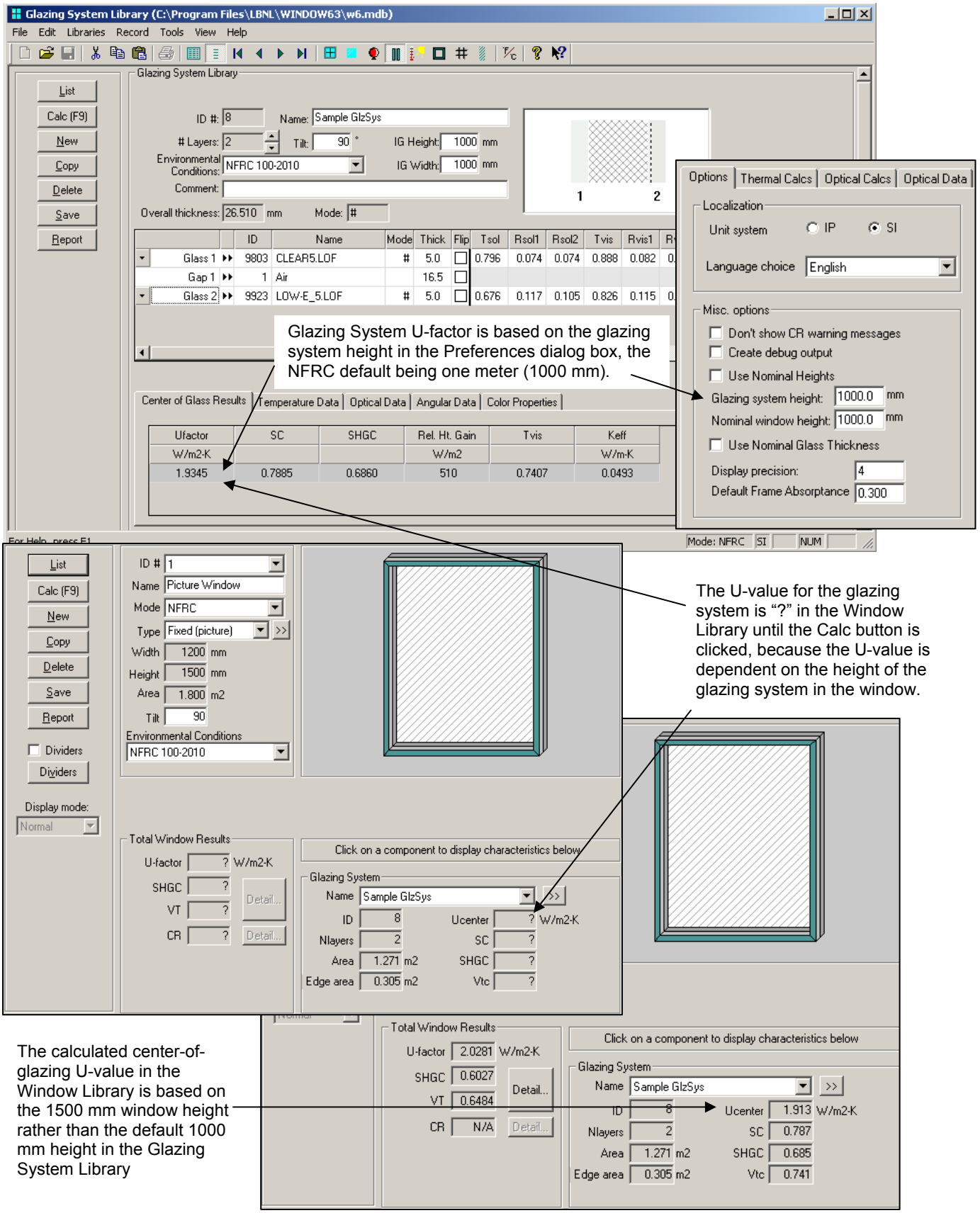


Figure 7-3. WINDOW Glazing System Library.

7.4 Overall Product U-factor, SHGC, VT, and CR Calculations

When the THERM results have been imported into the WINDOW **Frame** and **Divider Libraries**, and the needed glazing systems have been defined in the **Glazing System Library** (also needed for the THERM simulations), the whole product values for U-factor, SHGC, VT and CR can be calculated in the **Window Library**. Calculating these values is explained briefly below and in more detail in the *WINDOW User Manual.*

In the **Window Library Detail View**, set the appropriate values on the left-hand side of the screen, which depend on the type of fenestration product. The **Mode** field should be set to "NFRC", and the **Type** field should be set to the appropriate choice for the fenestration product being modeled. The complete list of choices can be viewed by clicking on the double arrow next to the **Type** pulldown list. The choices with the **Size** field set to "NFRC" are the official NFRC sizes. The **Environmental Conditions** field should be set to "NFRC 100-2010".

On the right-hand side of the screen, for each cross section component, select the appropriate records from the **Frame** and **Divider** libraries. When the frame cross sections and the glazing systems are specified, click on the **Calc** button and WINDOW will calculate the total product U-factor, SHGC, VT and CR, shown in the lower left corner of the main screen. In addition, for obtaining NFRC rating values, the program calculates the $SHGC_0$, $SHGC_1$, VT_0 and VT_1, discussed in detail in the following section.

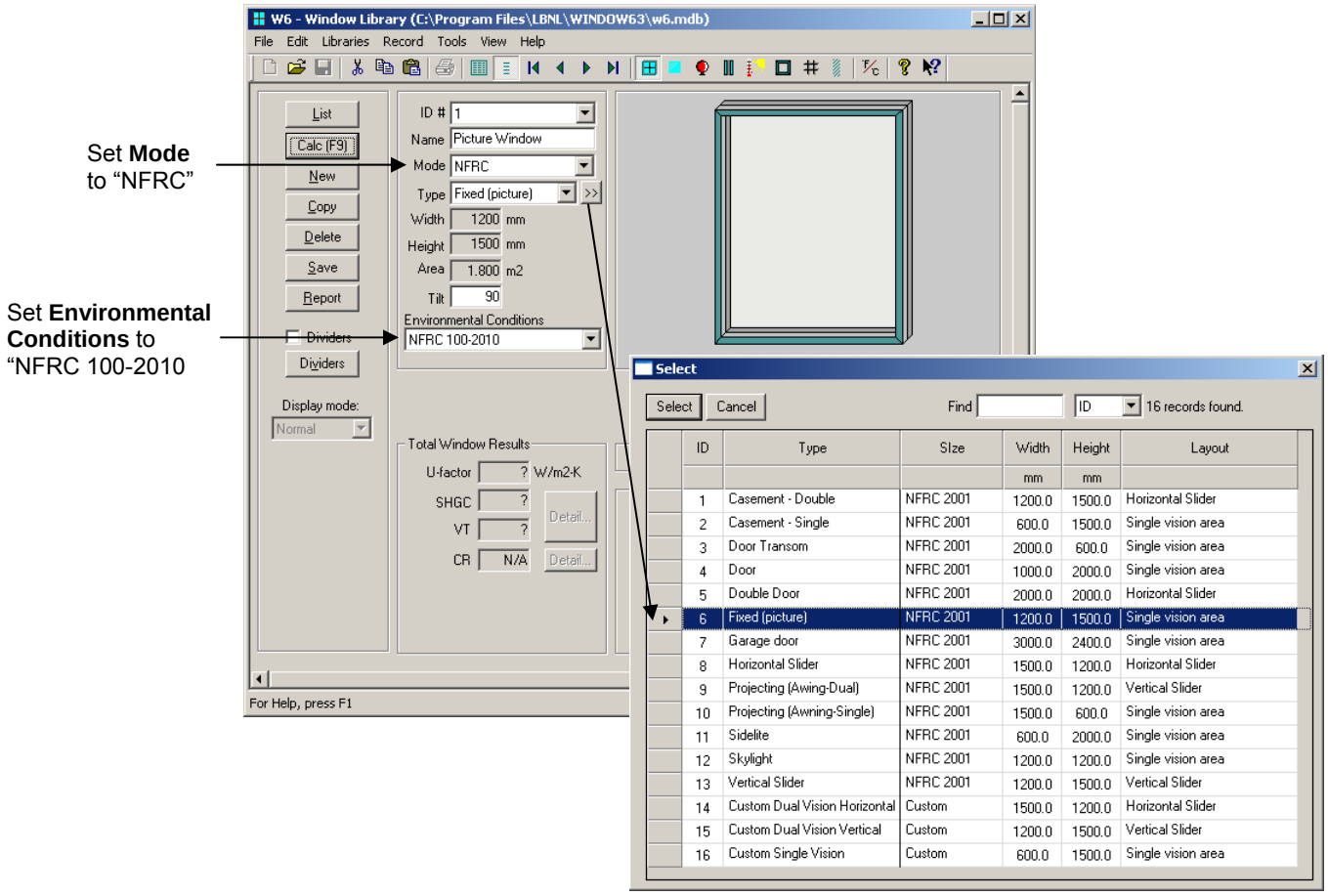
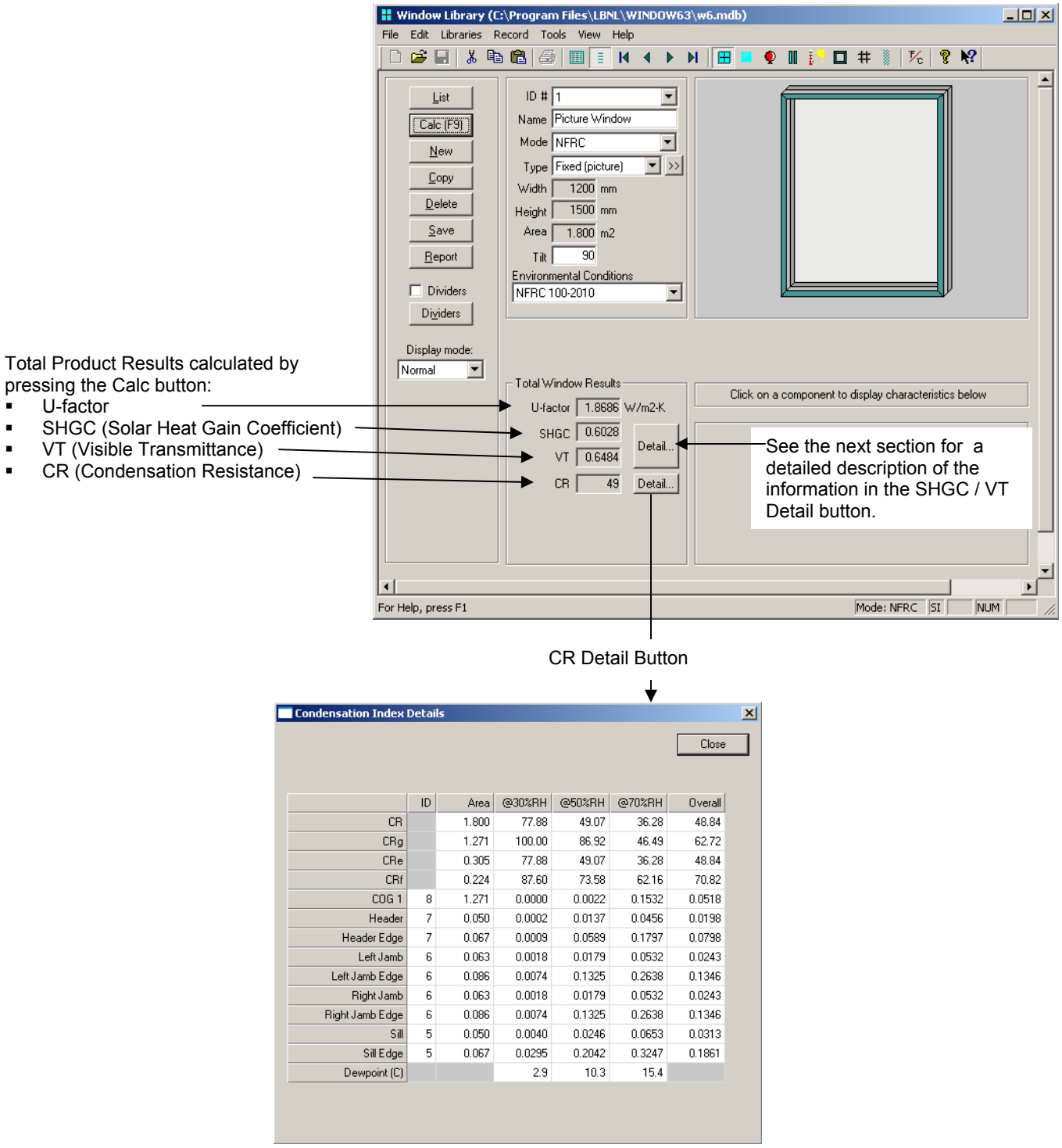


Figure 7-4. Window Library Detail View where the whole product is defined.

Once the values have been calculated, the results are displayed in the **Total Window Results section**, as shown below. The **Detail** button next to the **SHGC** and **VT** results can be used to view the $SHGC_0$, $SHGC_1$, VT_0 and VT_1 values, and the **Detail** button next to the **CR** result is used to view the intermediate values used to determine the overall CR result.



	ID	Area	@30%RH	@50%RH	@70%RH	Overall
CR		1.800	77.88	49.07	36.28	48.84
CRg		1.271	100.00	86.92	46.49	62.72
CRe		0.305	77.88	49.07	36.28	48.84
CRf		0.224	87.60	73.58	62.16	70.82
COG 1	8	1.271	0.0000	0.0022	0.1532	0.0518
Header	7	0.050	0.0002	0.0137	0.0456	0.0198
Header Edge	7	0.067	0.0009	0.0589	0.1797	0.0798
Left Jamb	6	0.063	0.0018	0.0179	0.0532	0.0243
Left Jamb Edge	6	0.086	0.0074	0.1325	0.2638	0.1346
Right Jamb	6	0.063	0.0018	0.0179	0.0532	0.0243
Right Jamb Edge	6	0.086	0.0074	0.1325	0.2638	0.1346
Sill	5	0.050	0.0040	0.0246	0.0653	0.0313
Sill Edge	5	0.067	0.0295	0.2042	0.3247	0.1861
Dewpoint (C)			2.9	10.3	15.4	

Figure 7-5. Window Library Detail View where the whole product results are calculated and displayed.

7.4.1. Individual Product SHGC and VT (SHGC 0 & 1, VT 0 & 1)

It is not necessary to calculate the SHGC and VT for all individual products and associated model sizes. *NFRC 200*- outlines a procedure for determining $SHGC_0$, $SHGC_1$, VT_0, VT_1 values which can then be used to calculate the SHGC and VT of any individual product. This procedure is used to obtain NFRC rating values.

These values are calculated in WINDOW for the best glazing option modelled with the highest combined frame and edge heat loss (i.e., the option with the lowest center-of-glass –factor and the highest total product U-factor), as outlined in *NFRC 200*, Section 4.5B. The values calculated from that one case are then used to calculate the SHGC for any other glazing options using Equations 4-3 and 4-4 in *NFRC 200*.

For domed skylights (see Chapter 8 of this manual), it is necessary to use the tested value for the center-of-glass value, with the modelled frame and edge values.

The values are calculated for the product using the best glazing system, for three cases:

- No dividers
- Dividers < 25.4 mm (1″), modelled at 19 mm (0.75″)
- Dividers ≥ 25.4 mm (1″), modeled at 38 mm (1.50″)

WINDOW automatically calculates these values for all records in the Window Library, using the U-factor for the default divider as defined in NFRC 200. The values can be displayed by clicking on the Details button next to the whole product results for SHGC and VT, as shown in the figure below.

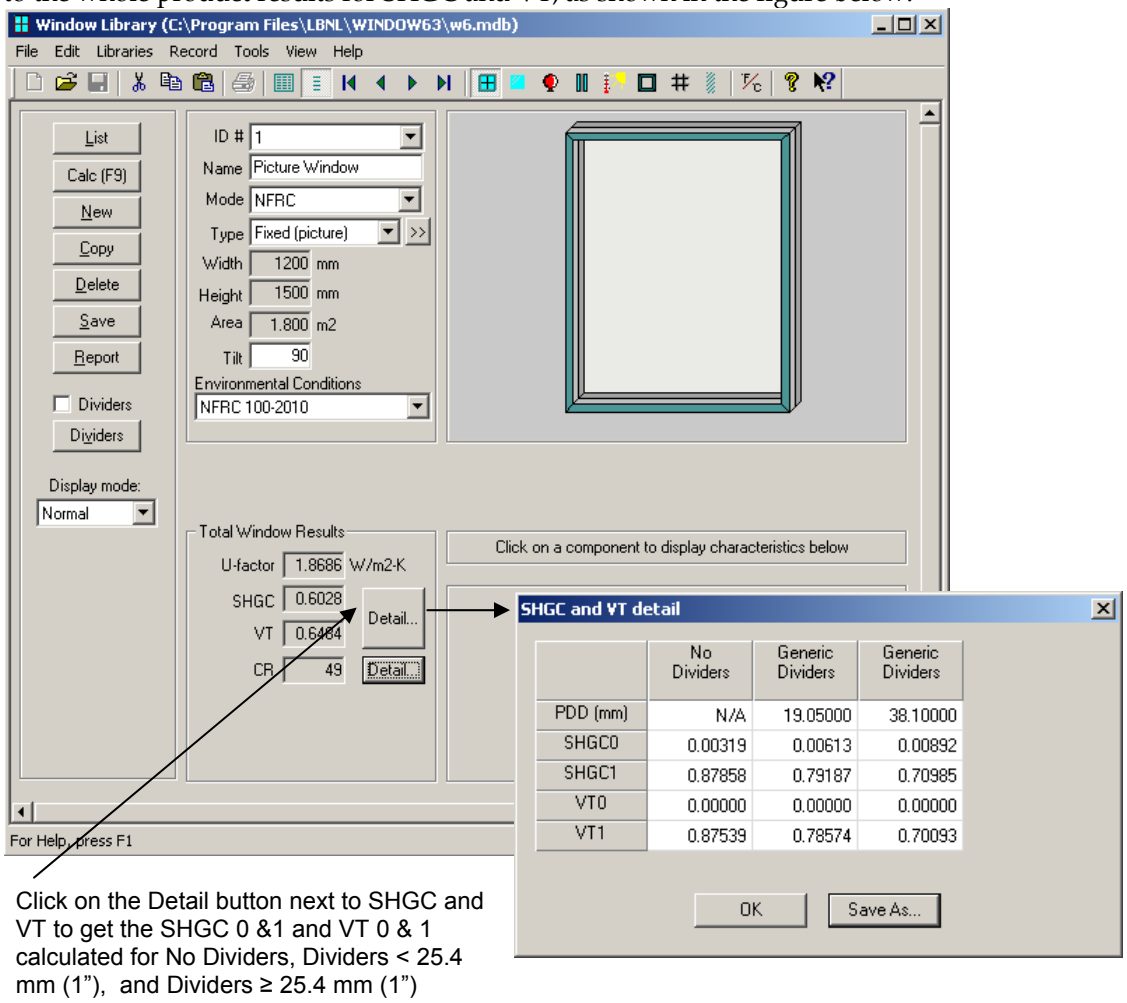
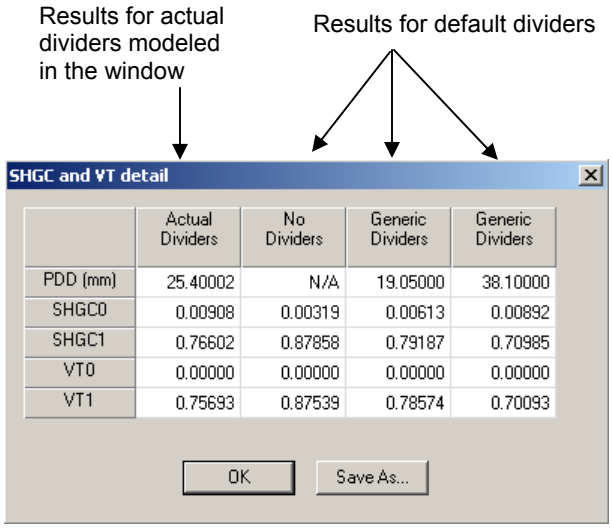


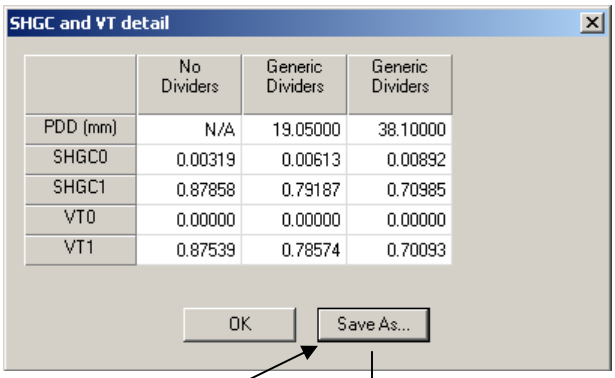
Figure 7-6. Click on the Detail button to get the SHGC 0 & 1 and VT 0 & 1 results.

If the product has real dividers, the program will calculate the SHGC 0 & 1 and VT 0 & 1 values for the generic dividers as well as for the actual dividers, as shown below. For NFRC simulations, the default divider results should always be used.



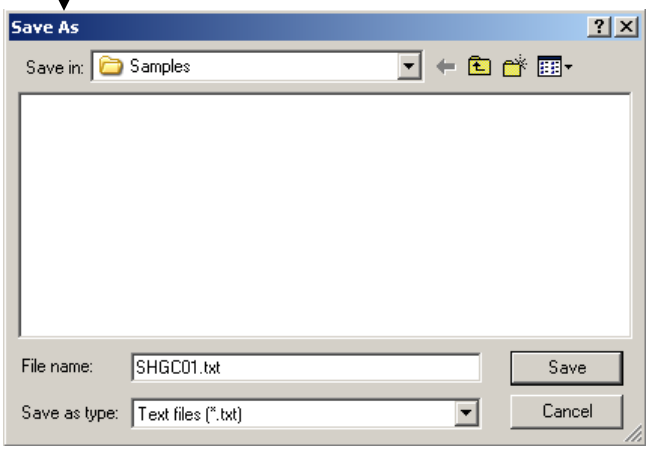
	Actual Dividers	No Dividers	Generic Dividers	Generic Dividers
PDD (mm)	25.40002	N/A	19.05000	38.10000
SHGC0	0.00908	0.00319	0.00613	0.00892
SHGC1	0.76602	0.87858	0.79187	0.70985
VT0	0.00000	0.00000	0.00000	0.00000
VT1	0.75693	0.87539	0.78574	0.70093

Figure 7-7. The SHGC 0 & 1 and VT 0 & 1 results are shown for the actual dividers if they are modeled.

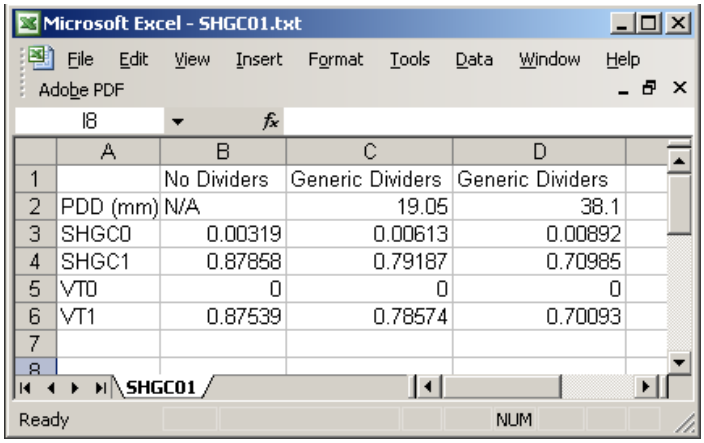


	No Dividers	Generic Dividers	Generic Dividers
PDD (mm)	N/A	19.05000	38.10000
SHGC0	0.00319	0.00613	0.00892
SHGC1	0.87858	0.79187	0.70985
VT0	0.00000	0.00000	0.00000
VT1	0.87539	0.78574	0.70093

Click on the Save As button to save the results into a text file.



The text file can be imported into other software, such as a spreadsheet.



	A	B	C	D
1		No Dividers	Generic Dividers	Generic Dividers
2	PDD (mm)	N/A	19.05	38.1
3	SHGC0	0.00319	0.00613	0.00892
4	SHGC1	0.87858	0.79187	0.70985
5	VT0	0	0	0
6	VT1	0.87539	0.78574	0.70093
7				
8				

Figure 7-8. The SHGC 0 & 1 and VT 0 & 1 results can be saved to a text file which can be imported into other applications, such as a spreadsheet or word processing program.

7.4.2. Whole Product U-factor With Dividers

The generic dividers used to calculate the $SHGC_0$, $SHGC_1$, VT_0, and VT_1 values are NOT used to calculate the whole product U-factor, if the whole product is manufactured with dividers. In that case, the actual divider geometry is modeled in THERM, the THERM file is imported into the WINDOW Divider Library, and used in a record (different from those used for the $SHGC_0$, $SHGC_1$, VT_0, VT_1 calculations) in the Window Library. This is shown in the following figures.

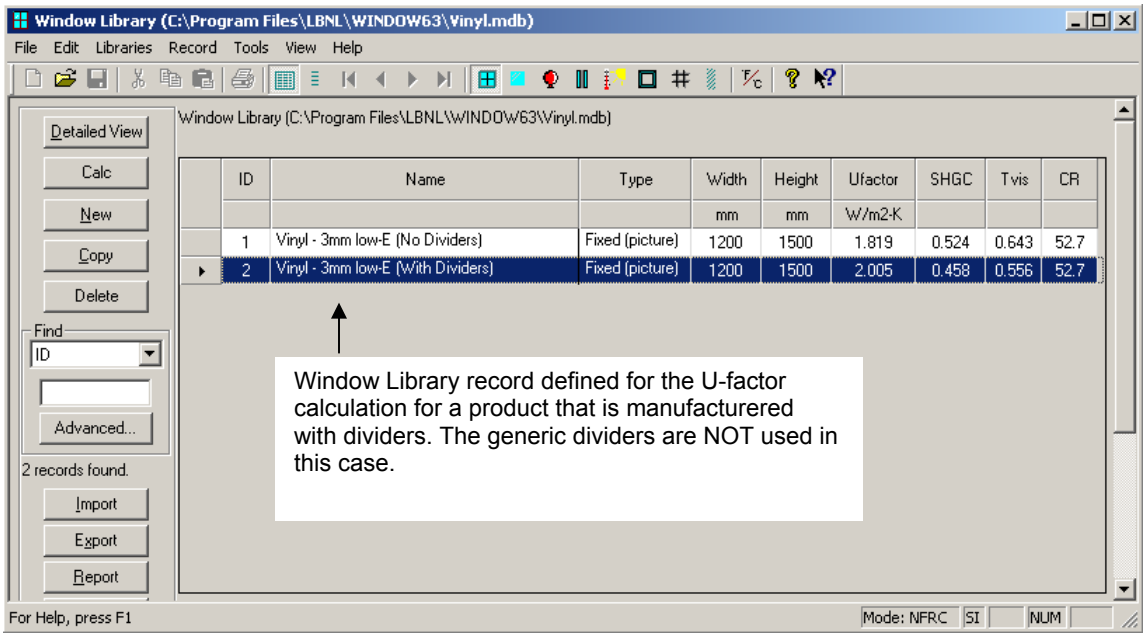


Figure 7-9. Window Library List View for the "U-factor with Dividers" case.

The Window Library Detailed View shows that the divider used for this product is from a THERM file, rather than one of the generic dividers.

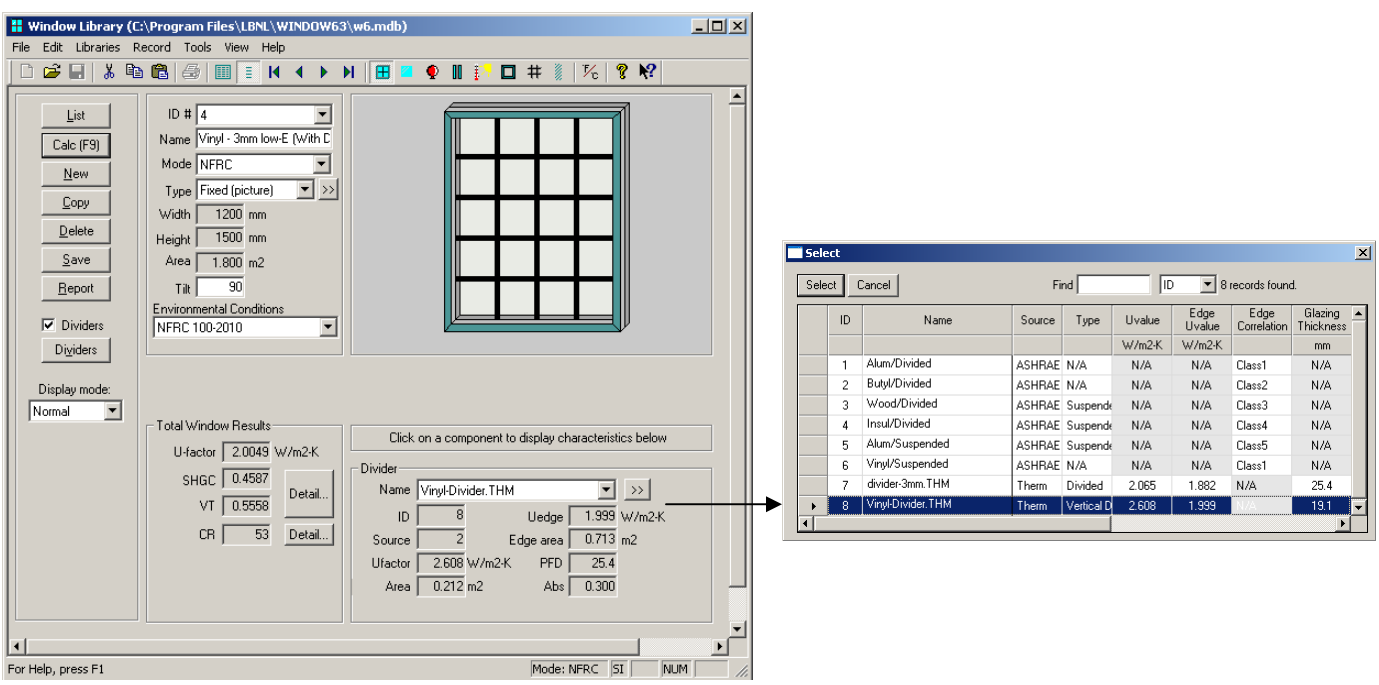


Figure 7-10. Window Library List View for the "U-factor with Dividers" case.

7.5 Project Databases

WINDOW 6 databases can be quite large. For example, the default database, w6.mdb, that is included in the program installation package, is approximately 27 MB. One of the main reasons for the large size is the records in the Glass Library – there are 3500+ records in that library as of this writing. Each entry in the Glass Library contains spectral data for that glass layer, hence the large database size. For any given modeling project, only a few of these glass layers are used.

It is possible to make a much smaller WINDOW6 project database by saving only the records in each library (particularly the Glass Library) that are used in the defined glazing systems and windows. For example, saving a project database in this fashion would mean that only the glass layers referenced by the glazing system would be saved in the Glass Library, rather than the entire Glass Library that is installed with the program. A database with only the referenced glass layers can be less than 1 MB.

Saving a smaller database in this manner is referred to in this manual as a "Project Database", meaning it contains only the needed entries for the project being modeled. In the List View of each library there is an "Export" button, which can be used to export selected records to another database. This "Export" feature is what can be used to generate a Project Database.

Many of the libraries reference other libraries for some of their values. Therefore, when a record is Exported from a library, WINDOW also has to export any other records that are referenced from the exported record. Figure 7-10 shows how each library is referenced from other libraries. The Gas, Glass, Frame, Divider and Environmental Conditions libraries are stand-alone libraries, meaning they do not reference any other libraries. However, the Glazing System and Window Libraries reference many of the other libraries.

So, for example, in order to export to another database all the information for a glazing system, WINDOW6 must also import the referenced records from the Gas Library, Glass Library and Environmental Conditions Library. But the important point is that only the needed records in each of these referenced libraries are needed in the exported database. So there might only be two or three entries in the Glass Library, i.e., those used in the Glazing System, instead of the 3500 entries that are in the entire database. This will then make the database these records are imported into much smaller.

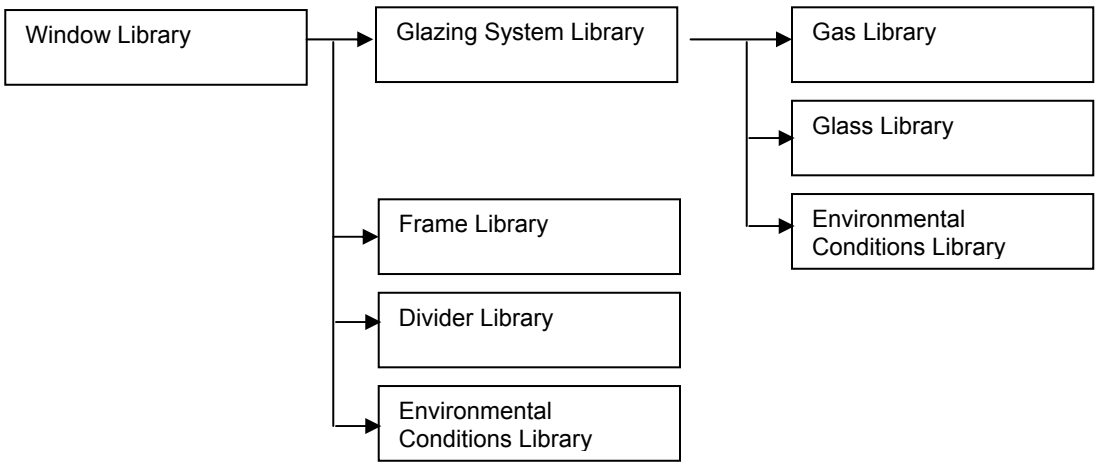


Figure 7-11. The database hierarchy in the WINDOW project database.

The steps to save a WINDOW database in this manner are the following:

- Select the Library "level" that the export should start from – in general, the most complete "level" to export from will be the Window Library.

  Start from the Window Library: this will mean that records from all the libraries that are used either directly or indirectly from those libraries will be included in the project database:

  - **Glazing System Library:** All the glazing systems referenced in the Window Library entries
  - **Frame Library:** All the frames referenced in the Window Library entries
  - **Divider Library:** All the dividers referenced in the Window Library entries, if dividers are modeled.
  - **Glass Library:** All the glass layers referenced from the glazing systems used in the Window Library entries
  - **Gas Library:** All the gases referenced from the glazing systems used in the Window Library entries
  - **Environmental Conditions Library:** All the environmental conditions referenced from the glazing systems and the Window Library entries.

  Start from the Glazing System Library: this will mean that records from the libraries used to define the glazing systems will be written into the project database, and no other entries:

  - **Glazing System Library:** All the glazing systems referenced in the Window Library entries
  - **Glass Library:** All the glass layers referenced from the glazing systems used in the Window Library entries
  - **Gas Library:** All the gases referenced from the glazing systems used in the Window Library entries
  - **Environmental Conditions Library:** All the environmental conditions referenced from the glazing systems and the Window Library entries.

Note that when you create a project database the program may display a message saying that some record already exists (based on detecting duplicate record ID numbers), and ask if you want to overwrite it, as shown below.

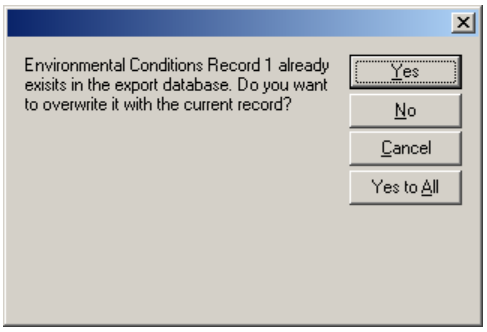


Figure 7-12. Export only referenced records into a new WINDOW5 database.

This message will always appear for a New Project Database for Record 1 of the Environmental Conditions Library, because the default "blank" database that the program writes into contains one default Environmental Conditions record. For new project databases, click the Yes button for overwriting existing records. If you are importing records into an existing database, you should determine what

record ID numbers are already defined in the existing database, and determine whether or not you should overwrite those records with records you are going to import into that database.

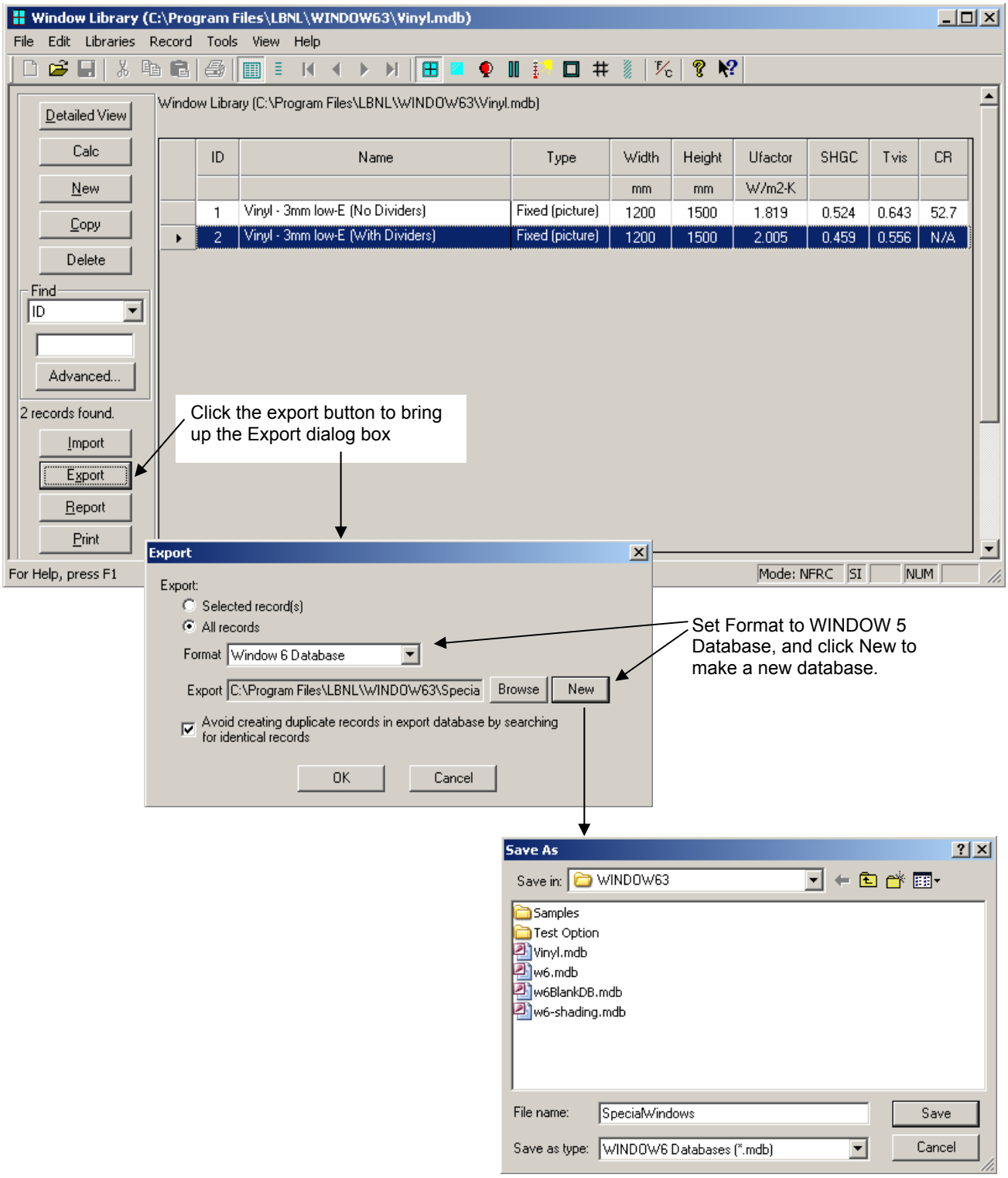


Figure 7-13. Export only referenced records into a new WINDOW5 database.

8. SPECIAL CASES

8.1. Overview

The following special cases are covered in this section:

8.2.	Meeting Rails	page 8-2
8.3.	Dividers	page 8-10
8.4.	Storm Windows	page 8-45
8.5.	Skylights	page 8-54
8.6.	Tubular Daylighting Devices	page 8-70
8.7.	Doors	page 8-89
8.8.	Spacers	page 8-90
8.9.	Non Continuous Thermal Bridge Elements	page 8-92
8.10.	Site Built Fenestration Products Curtain Walls, Window Walls and Sloped Glazing	page 8-105
8.11.	Retractable Venetian Blinds in Fully Open Position	page 8-119
8.12.	Garage / Rolling Doors	page 8-130
8.13.	Creating a Laminate in Optics for NFRC	page 8-143
8.14.	Creating an Applied Film Layer in Optics for NFRC Certification	page 8-157
8.15.	Framed Intermediate Pane	page 8-167

8.2 Meeting Rails

Meeting rail cross sections are the stiles or rails that meet in the middle of a sliding window. In this manual, the term "meeting rail' is used generically to describe meeting rails, meeting stiles, interlock stiles, interlocking stiles, sliding stiles, check rails, and check stiles.

8.2.1. Modeling Meeting Rails

When modeling a meeting rail, both the sashes and their associated glazing systems are modeled. Figure 8-1 shows an example of the meeting rail from a horizontal aluminum slider.

Creating the cross section for a meeting rail is no different than any other model in THERM. A few things to keep in mind are:

- Two glazing systems are imported, one facing up and one facing down
- Interior boundary conditions for each of the glazing systems are labeled with the **Edge** U-factor tag, and the program averages the values for both to derive one Edge U-factor.
- Model the meeting rail with the glazing systems facing up and down (see Section 6.3.2, "Cross Section Orientation" in this manual). If the DXF file is drawn with them in a horizontal position, draw the frame cross section, and then rotate it before inserting the glazing system.

The following discussion lists the steps for making a cross section with two glazing systems and assigning the correct boundary conditions.

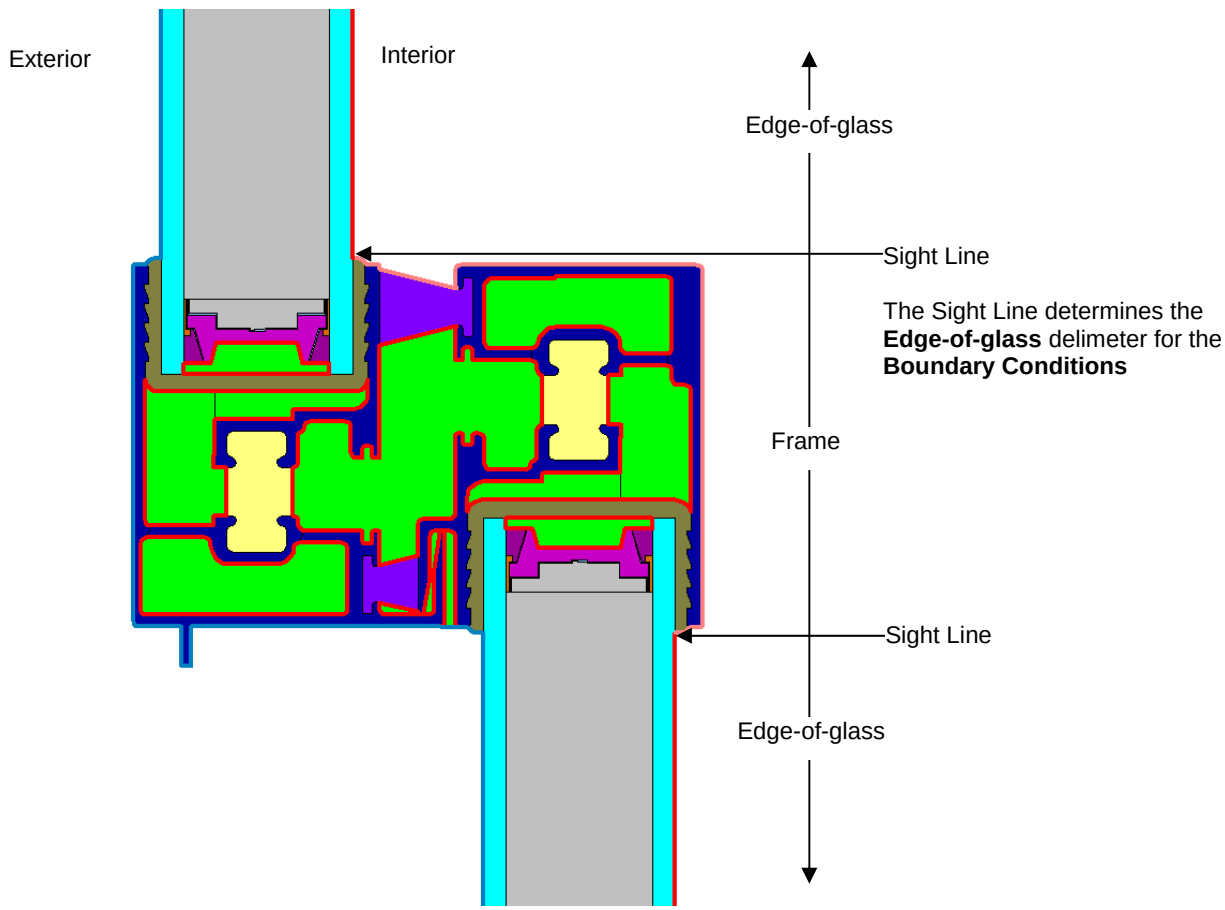


Figure 8-1. Meeting rail cross section.

8.2.2. Steps for Meeting Rail U-factor Calculation

1. Using dimensioned drawings or a DXF file, create the cross section for the frame portion of the meeting rail. In Figure 8-2, the frame for the horizontal aluminum slider meeting rail has been created.

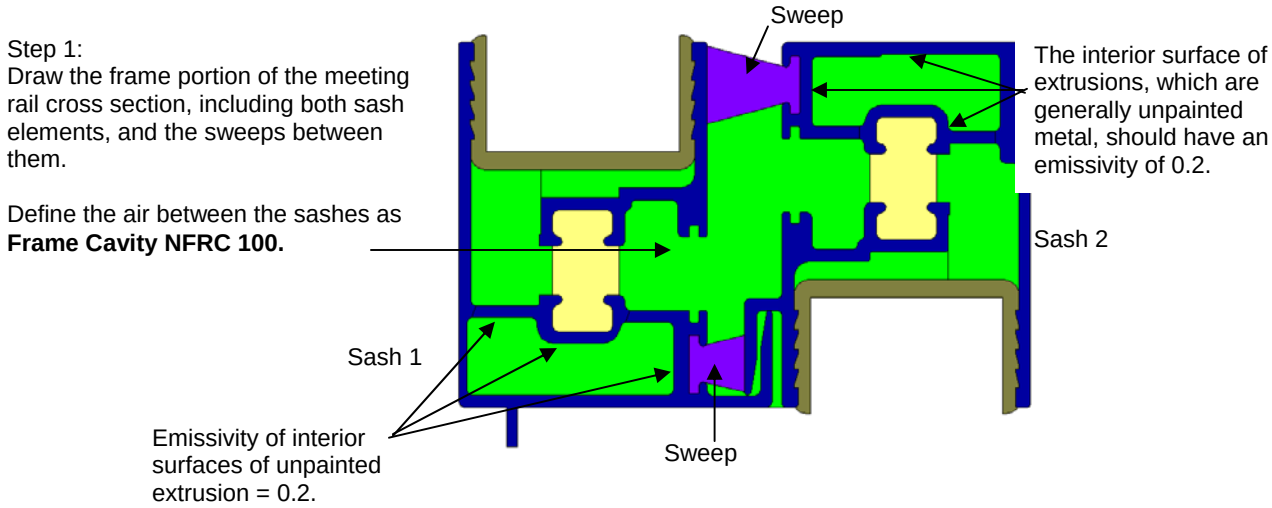


Figure 8-2. Frame portion of meeting rail cross section.

2. Position the **Locator** (using the **Draw/Locator** menu choice, or pressing **Shift F2**) in the lower left corner of the frame where the first glazing system will be inserted, as shown in Figure 8-3.

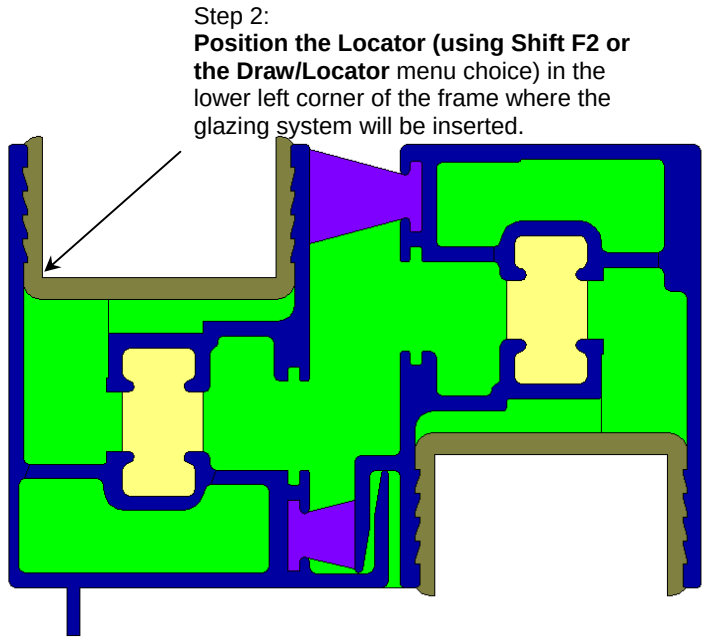


Figure 8-3. Position the Locator for the first glazing system.

3. Using the **Libraries/Glazing Systems** menu option (or the **F6** key), insert the upper glazing system, as shown in Figure 8-4. In this example, the spacer will be copied and pasted into the cross section later. Add a spacer and use the Material Link (Library/Create Link) to link the glazing system cavity conductivity with adjacent cavities in a spacer which is open to the glazing system cavity, if necessary.

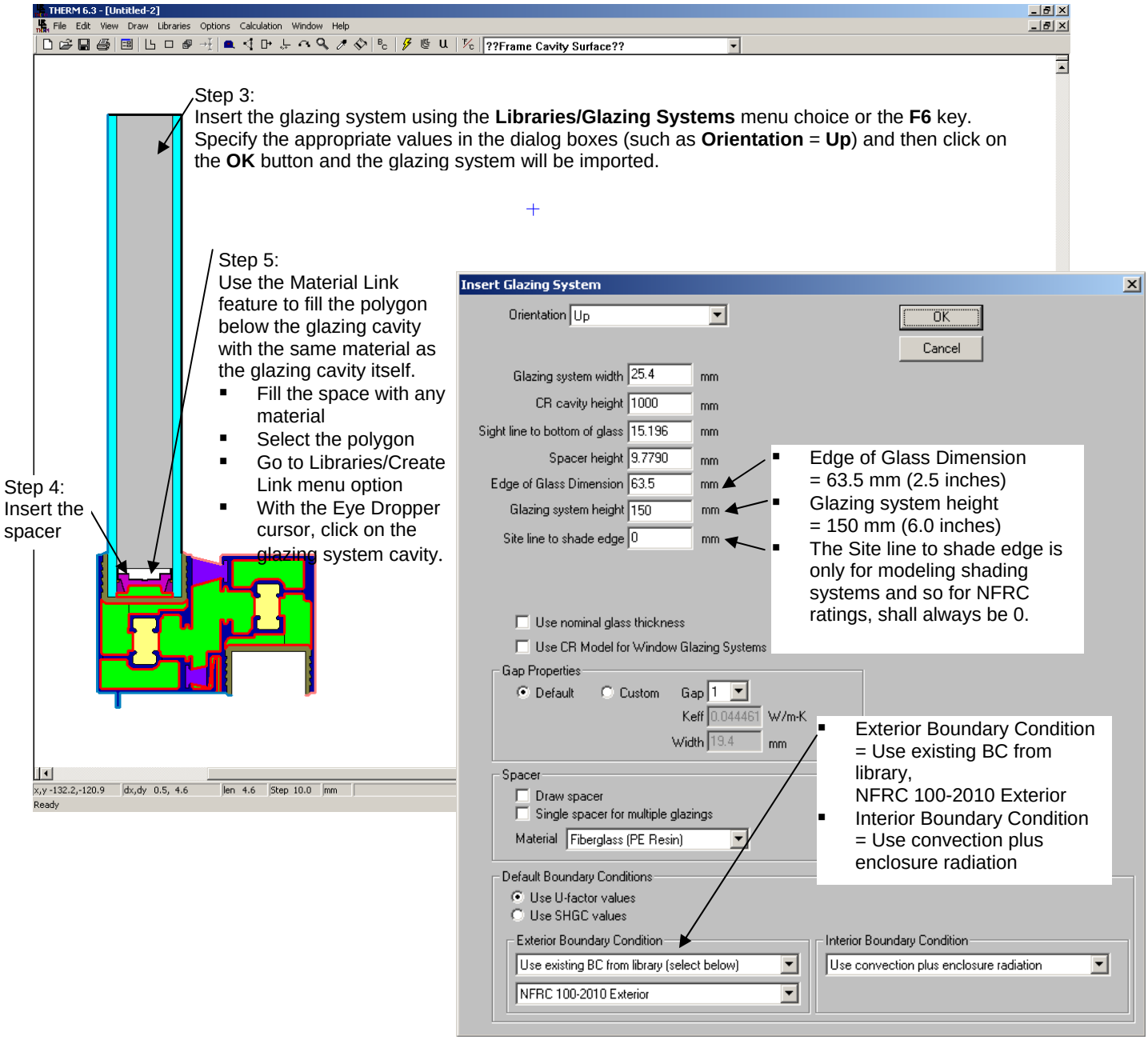


Figure 8-4. Insert the first glazing system.

4. Reposition the locator to the upper left corner for the 2nd glazing system.

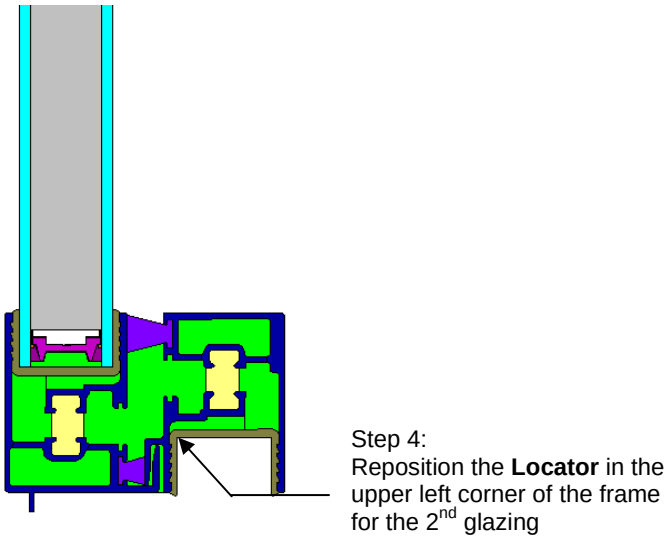


Figure 8-5. Reposition the Locator for the 2nd glazing system.

5. Insert the 2nd glazing system, setting the **Orientation** to "Down", and entering the correct values for **Sight line to bottom of glass** and **Spacer height**.

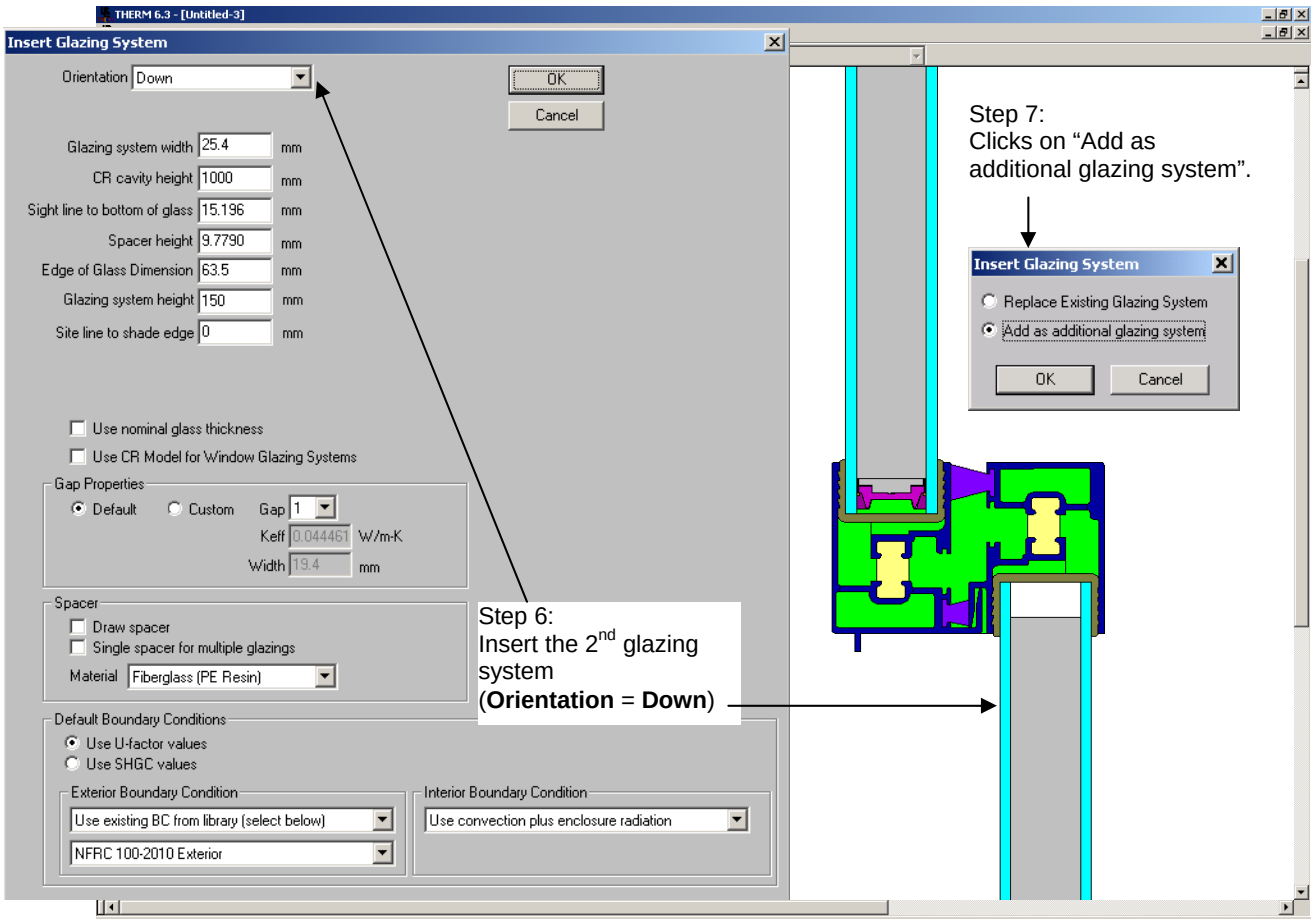


Figure 8-6. Insert the 2nd glazing system.

6. Add spacers and create materials linked to the glazing system cavity if necessary.

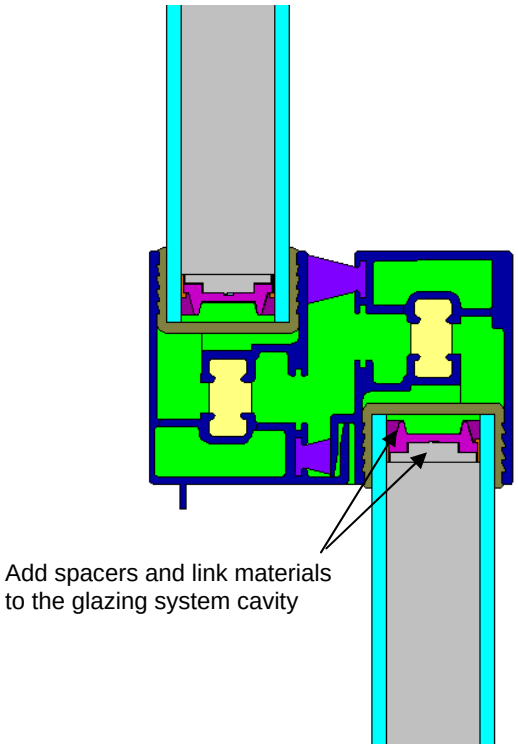


Figure 8-7. Add custom spacers.

7. Define the boundary conditions by pressing the **Boundary Conditions** toolbar button, or clicking on the **Draw/Boundary Conditions** menu choice, or pressing the **F10** key. Make sure that the interior boundary conditions are set to **Radiation Model** = "AutoEnclosure". Assign the **Edge U-factor tag** to each of the interior glazing system boundary conditions, as shown in Figure 8-8.

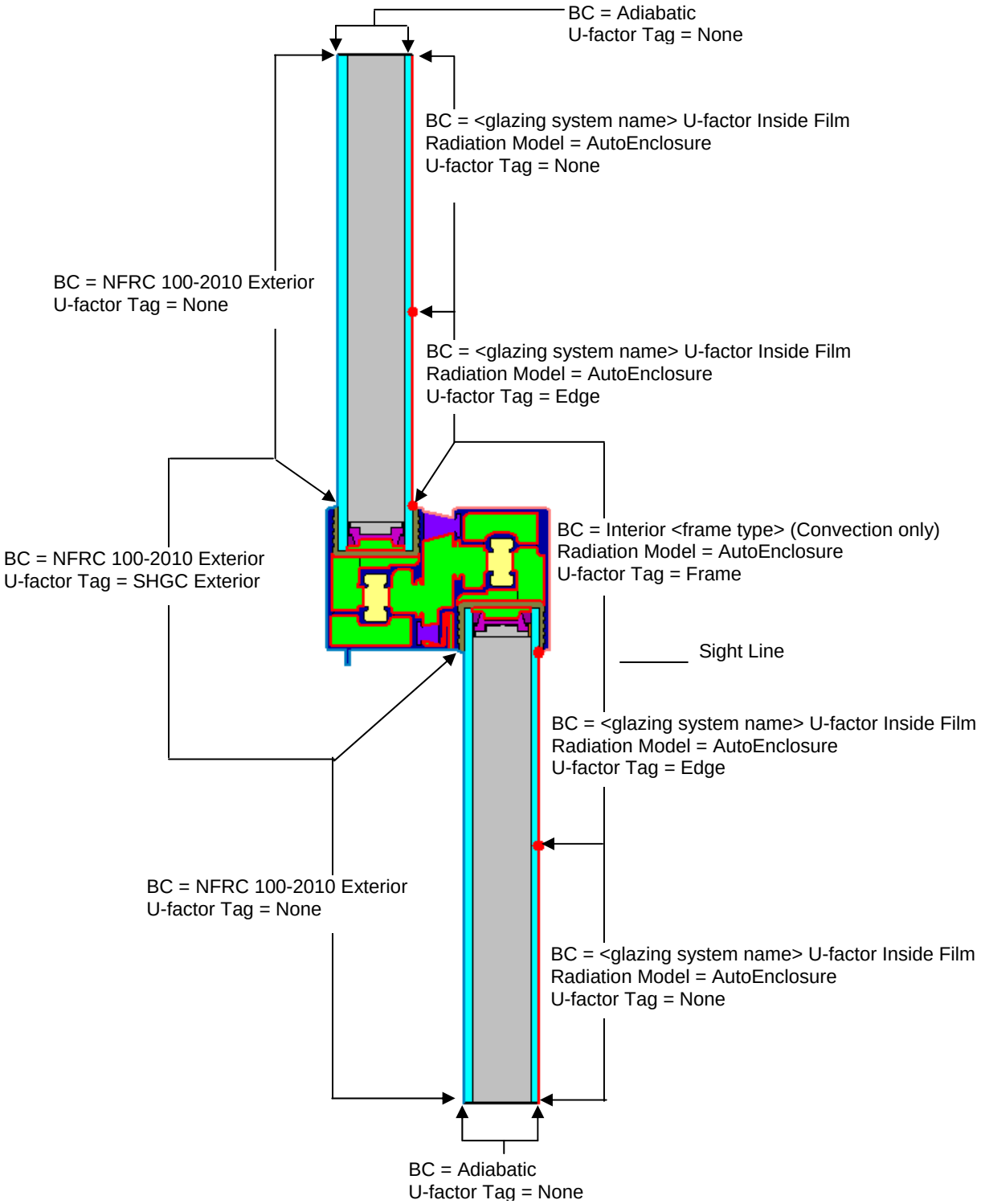


Figure 8-8. Define the Boundary Conditions for the meeting rail.

8. Run the simulation, by pressing the **Calc** toolbar button, clicking on the **Calculation/Calculation** menu choice, or pressing the **F9** key. The U-factor results are calculated for the **Frame** and **Edge U-factor tags**, as shown in the figure below.

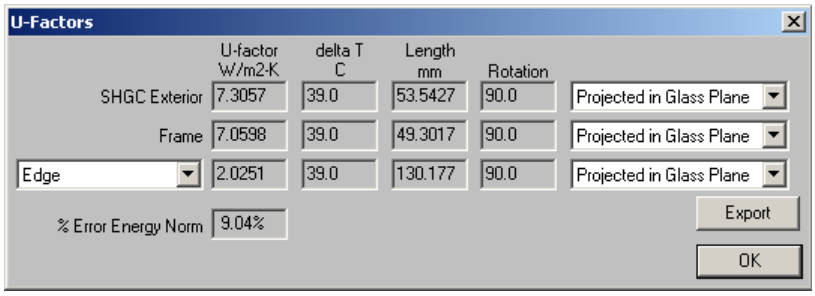


Figure 8-9. Calculate the results.

9. Import the THERM file into the WINDOW Frame Library.

8.2.3. Steps for Meeting Rail Condensation Resistance Calculation

The Condensation Resistance model is only appropriate for *horizontal meeting rails* (found in vertical sliding products) – THERM will not calculate the Condensation Resistance for a file with the **Cross Section Type** set to "Vertical Meeting Rail".

There are two methods for calculating the Condensation Resistance information in THERM, which will be used in WINDOW to calculate the total Condensation Resistance of the product:

- Check the "Use CR Model for Window Glazing System" checkbox when importing a glazing system

  OR

- In the Options menu, Preferences choice, THERM File Options tab, check the "Use CR Model for Glazing Systems", as shown in the figure below.

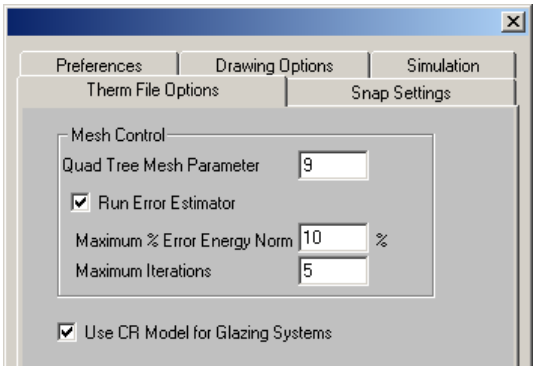


Figure 8-10 In Options/Preferences/Therm File Options, check the "Use CR Model for Glazing Systems" checkbox.

When the CR model has been "turned on", red boundary conditions will appear inside the glazing system, and the following steps should be taken to simulate the file:

1. Check the emissivities of these boundary conditions. They should be the following:
   - Emissivity of the surrounding surface, such as 0.84 for standard glass, 0.90 for most frame materials, 0.20 for metal, and so forth.
   - 1.0 for the adiabatic (open end) of the glazing cavity.
   - Actual cavity height per Table 6-2, Section 6.4.5

2. Simulate the model. The program will calculate both U-factor results and the Condensation Resistance results.
3. Import the results into the WINDOW **Frame Library** and use the meeting rail file to create the whole product in the **Window Library** as applicable.

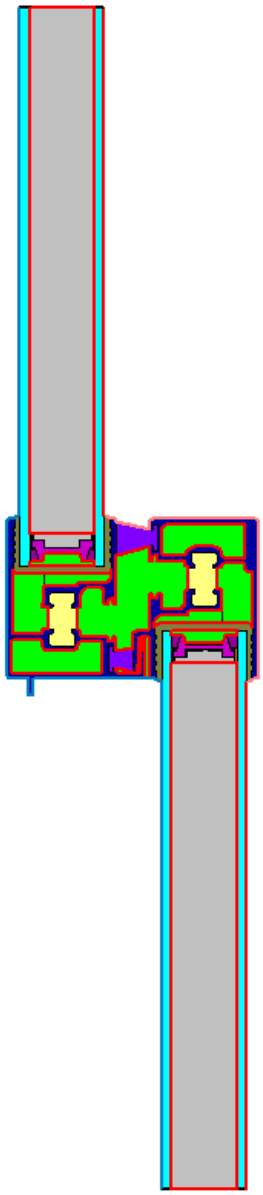


Figure 8-11 Red boundary conditions will appear inside the glazing system when the Condensation Resistance feature is activated. Check the emissivities of each of these boundaries. Note that Condensation Resistance is only modeled for horizontal meeting rails (such as in a double hung window).

8.3 Dividers

8.3.1. Internal Dividers (Suspended Grilles)

The criteria for when dividers are modeled can be found in *NFRC 100*, Section 1.4.4, "Simplifications to a Product Line". The discussion below describes the methodologies in WINDOW and THERM for modeling dividers when that criteria is met.

8.3.1.1. Modeling Steps

The modeling steps in THERM6 and WINDOW6 are the same for all divider shapes and all possible gas fills, in contrast to modeling steps in previous versions of THERM. These steps are the following:

In WINDOW:

- No new work is required, because the same glazing system that is used to model the rest of the product is used in the divider model.

In THERM:

- The new ISO 15099 modeling assumptions would theoretically warrant modeling horizontal and vertical dividers separately. However, a conservative simplification is to model all dividers, including horizontal ones, as vertical dividers. Therefore, only one divider model is created in THERM and referenced in WINDOW.
- Set the **Cross Section Type** to "Vertical Divider" for all dividers.
- Insert the glazing system twice, once facing up, with a spacer height defined as the same height as the divider height, and once facing down with the spacer height set to zero.
- *NOTE: Because all dividers are modeled as "Vertical Dividers" the CR model is not run in THERM for these files.* However, WINDOW will still calculate a whole product CR value when these dividers are used in a product, by using the U-factor temperatures for the dividers.
- Draw the true geometry of the divider in the upper glazing system, in the "spacer" area.
- Depending on the fill of the glazing system, assign the appropriate frame cavity material to the cavities between the glazing system and the divider, as well the cavity inside the divider, as follows:
  - For air-filled dividers: Assign "Frame Cavity NFRC 100-2010" material
  - For gas-filled dividers: Create a new material in the **Material Library** that is identical to the "Frame Cavity NFRC 100-2010" material, except that the gas used in the glazing system, found in the **Gas Library,** is referenced in the **Gas Fill** field. Assign this new material to the cavities in the divider. (See the example below)
- Assign Boundary Conditions.
- Simulate the results.

Import the file into the WINDOW Divider Library. Reference the Divider as appropriate from the Window Library when constructing the whole product.

8.3.1.2. Air Filled Glazing Systems

The modeling steps for a divider with an air-filled glazing system are explained in detail in the following pages.

In THERM:

1. Set the **Cross Section Type** to "Vertical Divider".
2. Import the glazing system for the divider, which is the same glazing system as the rest of the product, with the following settings:
   - **Orientation** = Up
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** = height of the divider (in this example it is 19.05 mm [0.75 inches])
   - **Spacer height** = height of the divider (in this example it is 19.05 mm [0.75 inches)
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

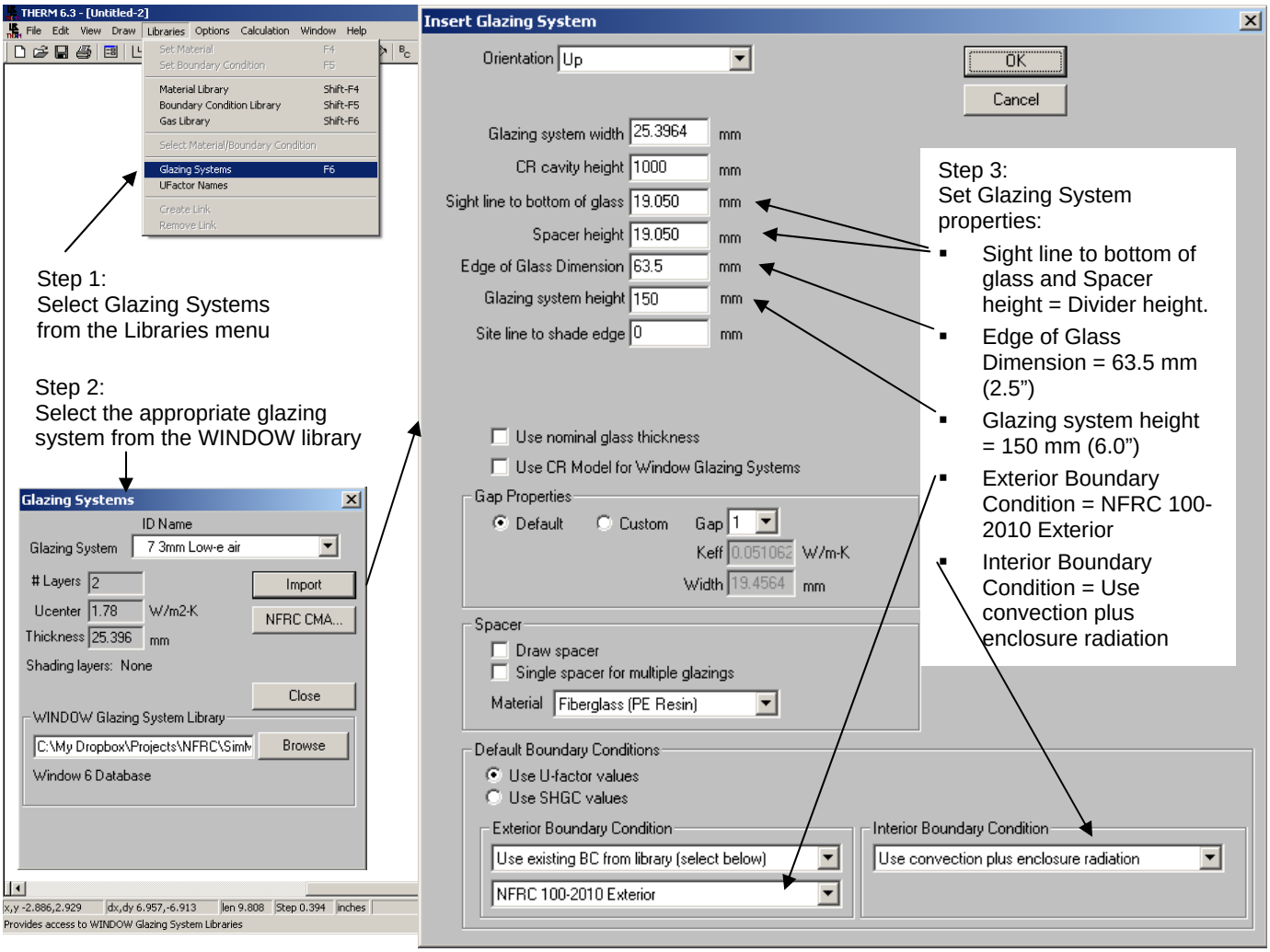


Figure 8-12. Import the first glazing system.

3. Import the glazing system again as an additional glazing system, below the first one (the locator does not have to be moved), but facing down this time. Use the following settings for this glazing system:
   - **Orientation** = Down
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** = 0
   - **Spacer height** = 0
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

   Insert the glazing system as an **Additional Glazing**.

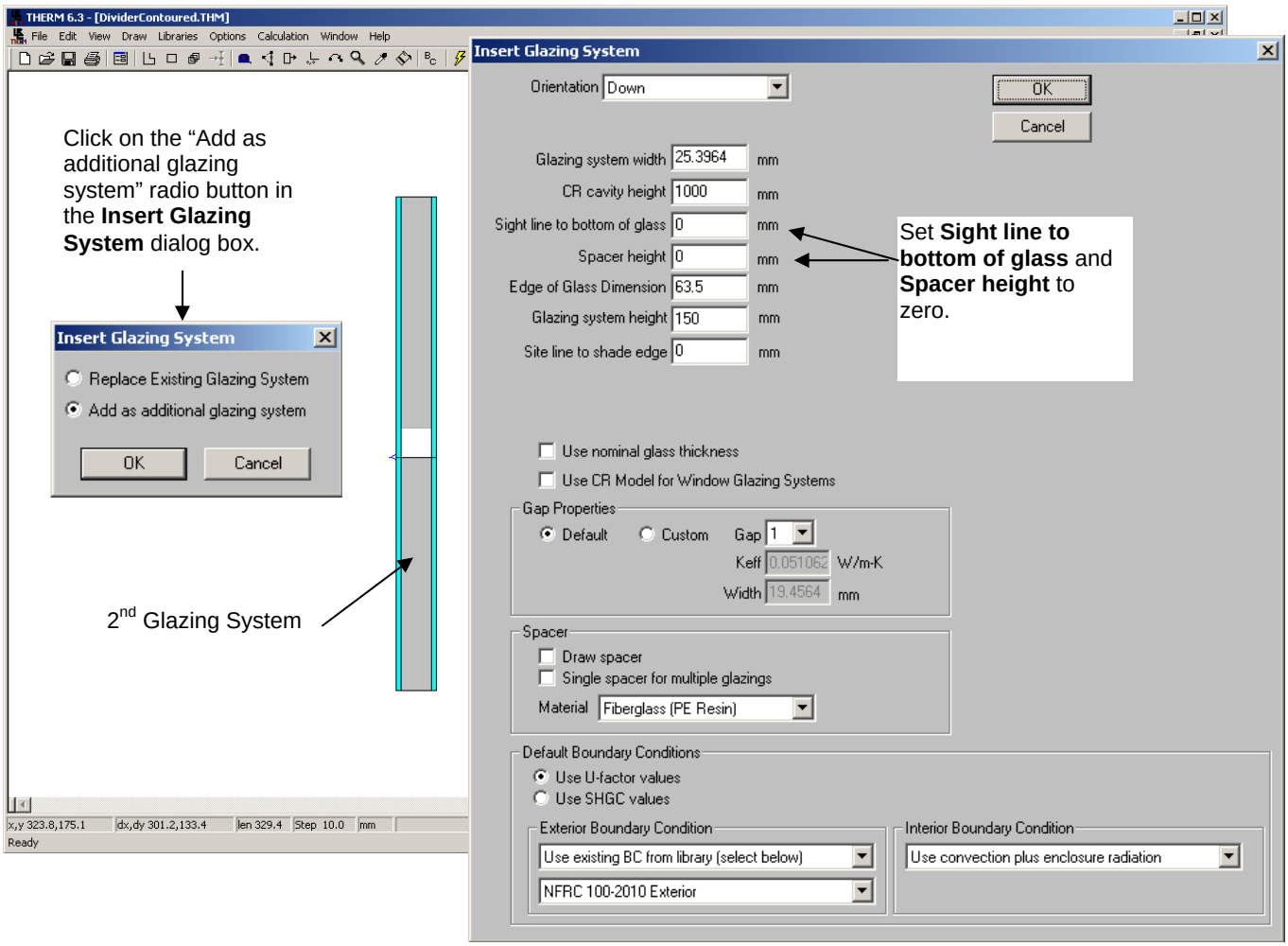


Figure 8-13. Import the second glazing system as an additional glazing system, facing down.

4. Draw (or copy and paste from another THERM file) the polygons in the cavity that represent the divider. The figure below shows the divider for this example drawn with the material set to Aluminum Alloy

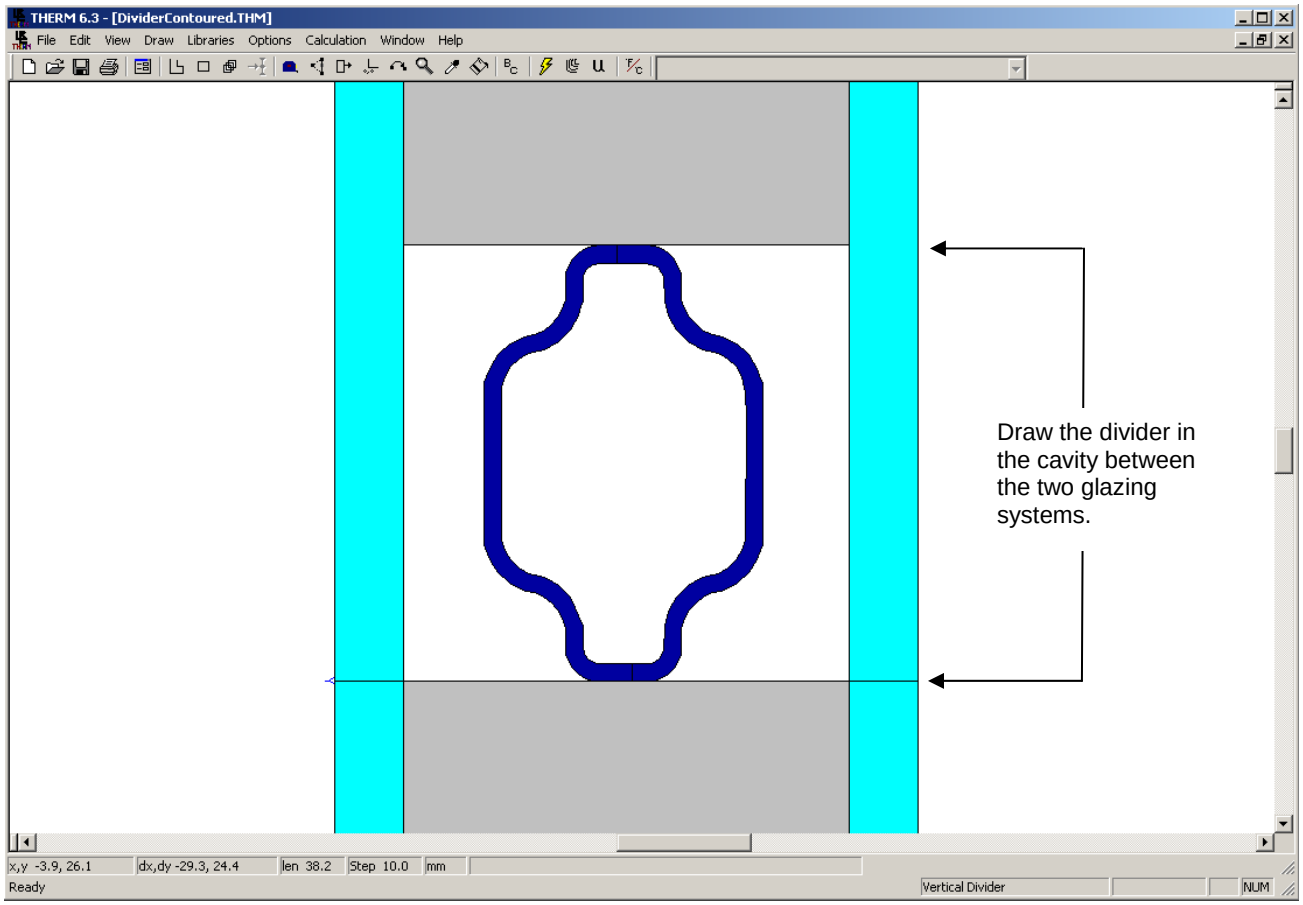


Figure 8-14. Draw the polygons to represent the divider.

5. Fill the cavities between the divider and the glass layers and inside the divider with the material "Frame Cavity NFRC 100". Divide the cavities up according to the 5 mm rule as necessary.

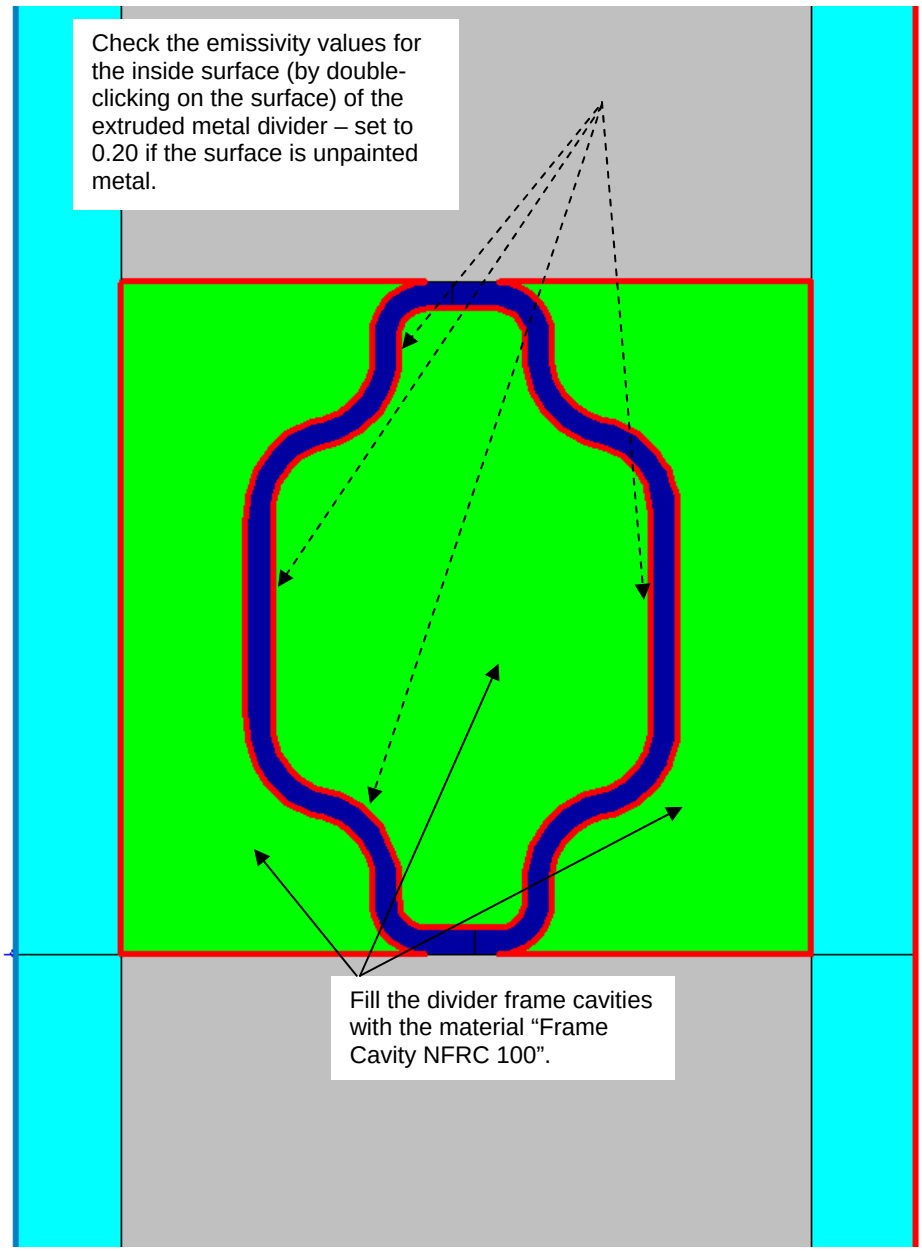


Figure 8-15 Fill the divider frame cavities with Frame Cavity NFRC 100.

6. Define the boundary conditions, using the "AutoEnclosure" choice for the Radiation Model.

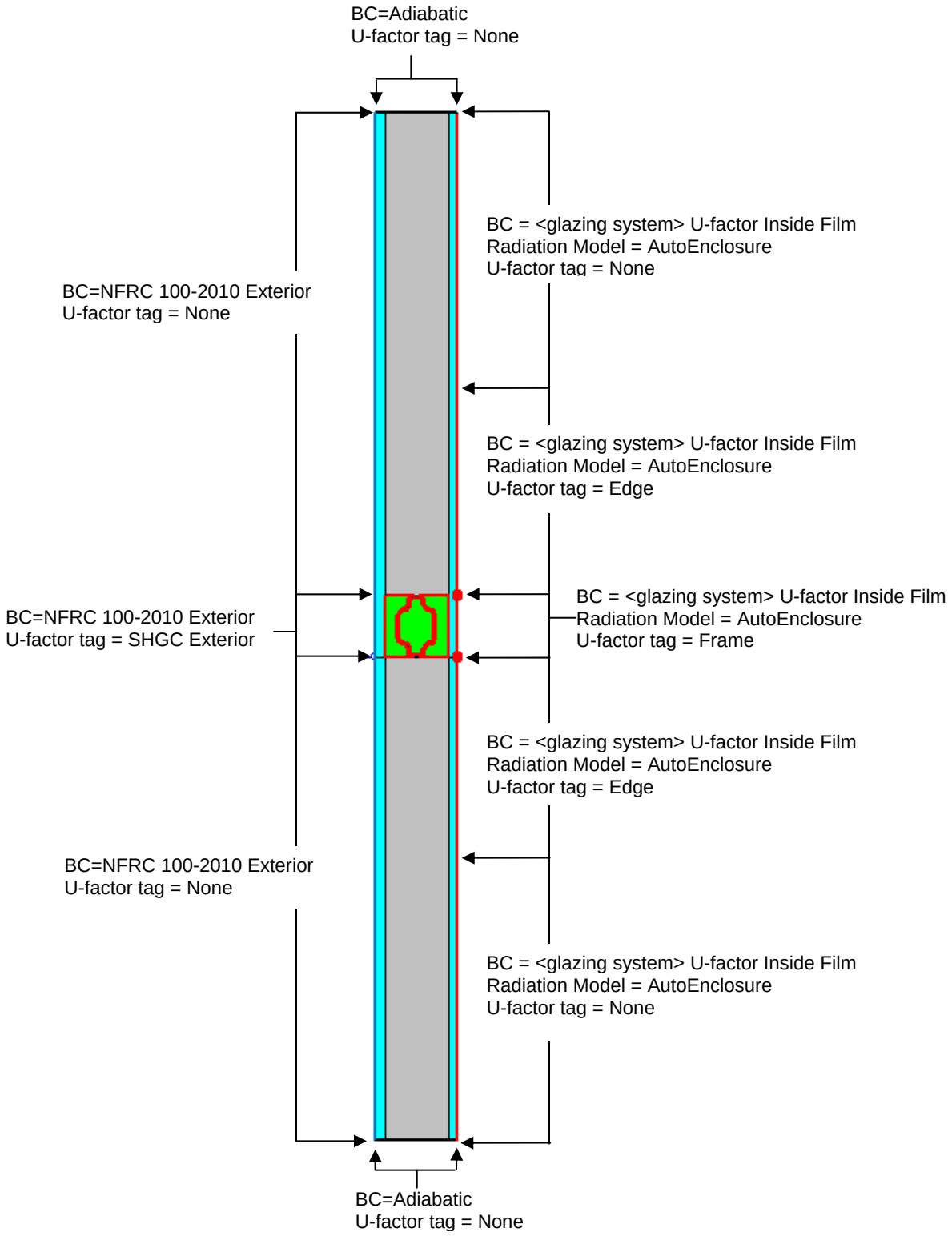


Figure 8-16 Assign the boundary conditions.

6. Calculate the results.

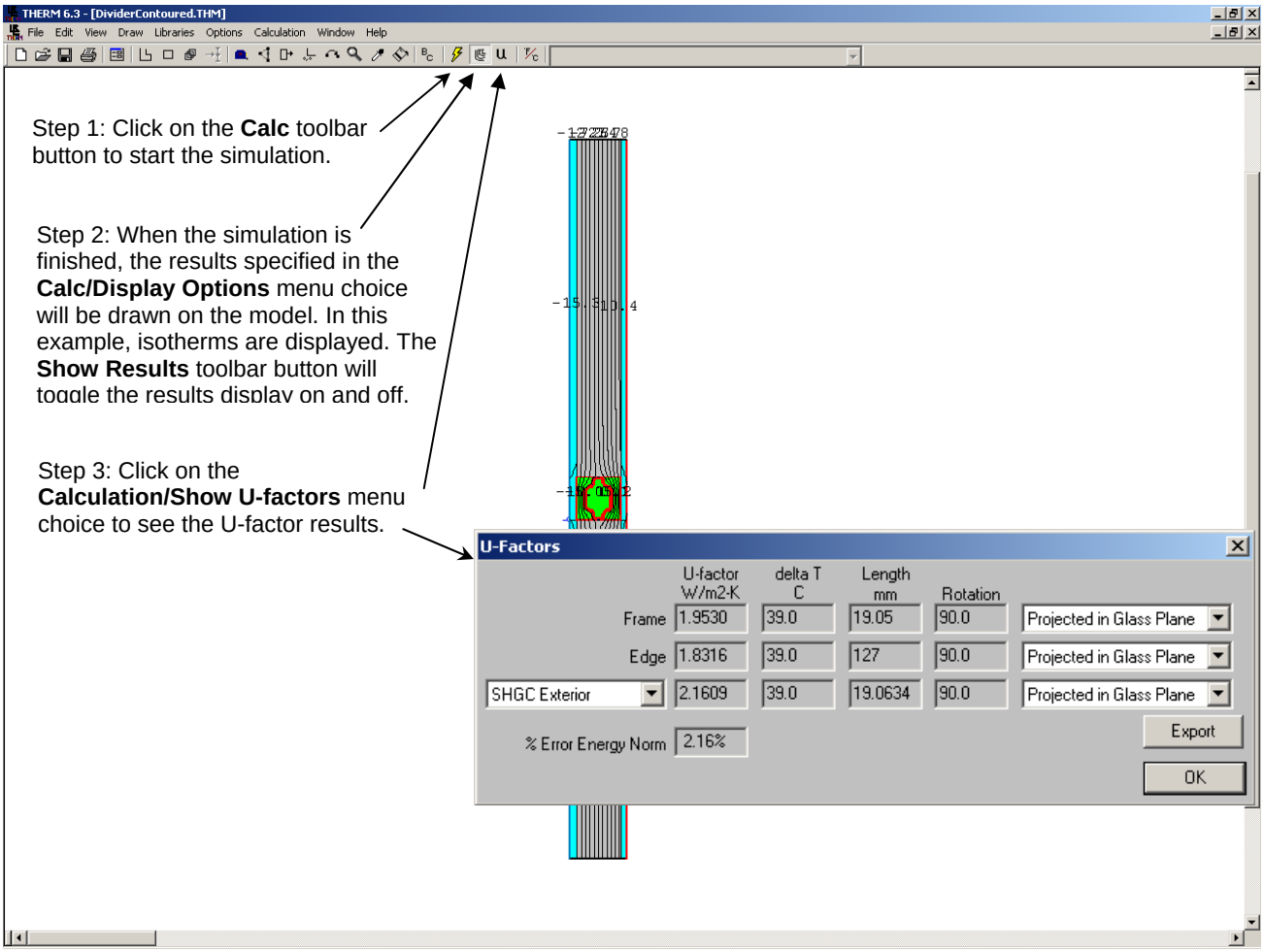


Figure 8-17 Calculate the results.

7. Save the file using the **File/Save As** menu choice.

8. Import the results to the WINDOW Divider Library, as shown below. See Section 4.7.3, "Importing THERM files" in the *WINDOW User's Manual* for more information about importing THERM files.

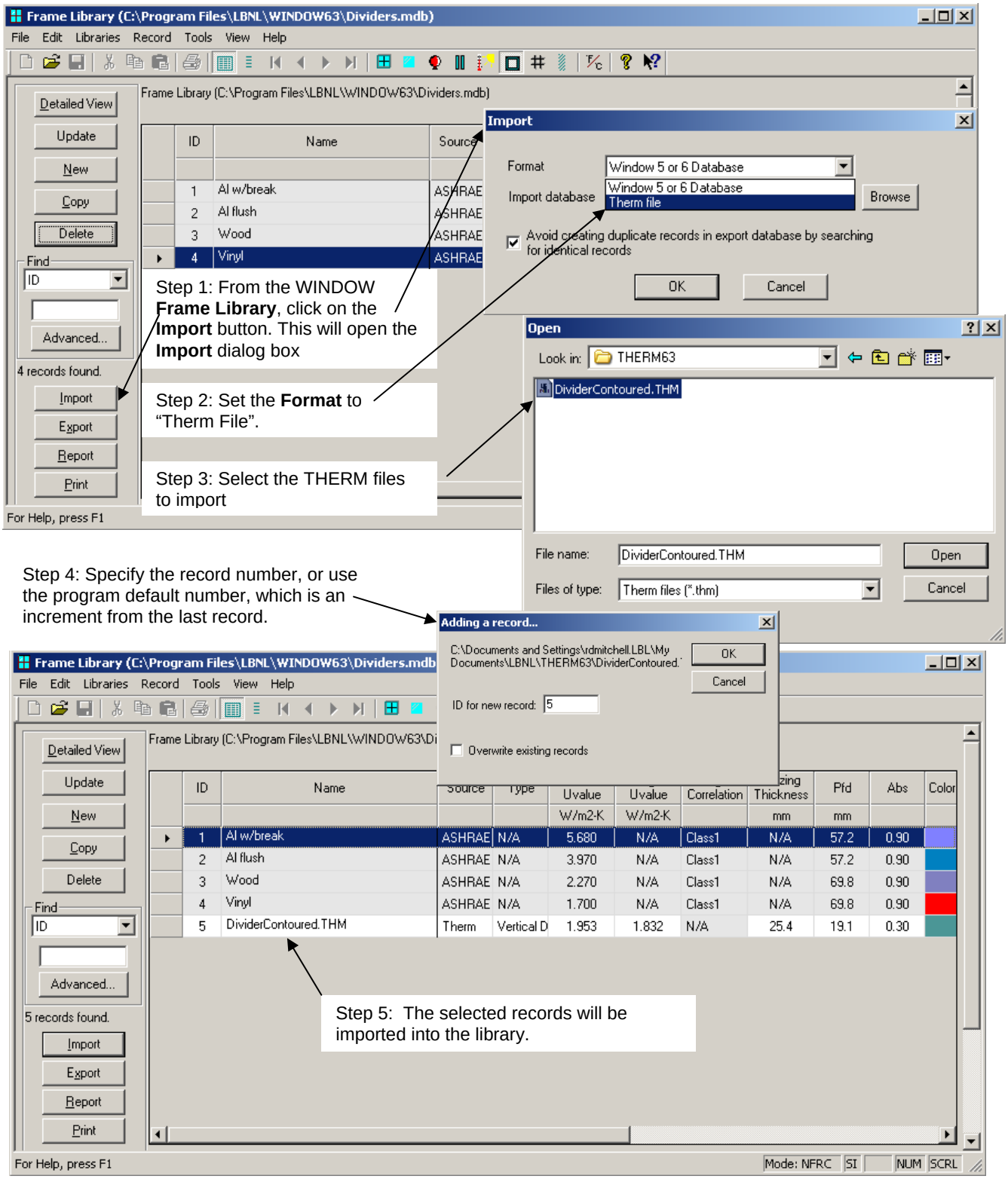


Figure 8-18 Import the THERM file into the WINDOW ***Divider Library****.*

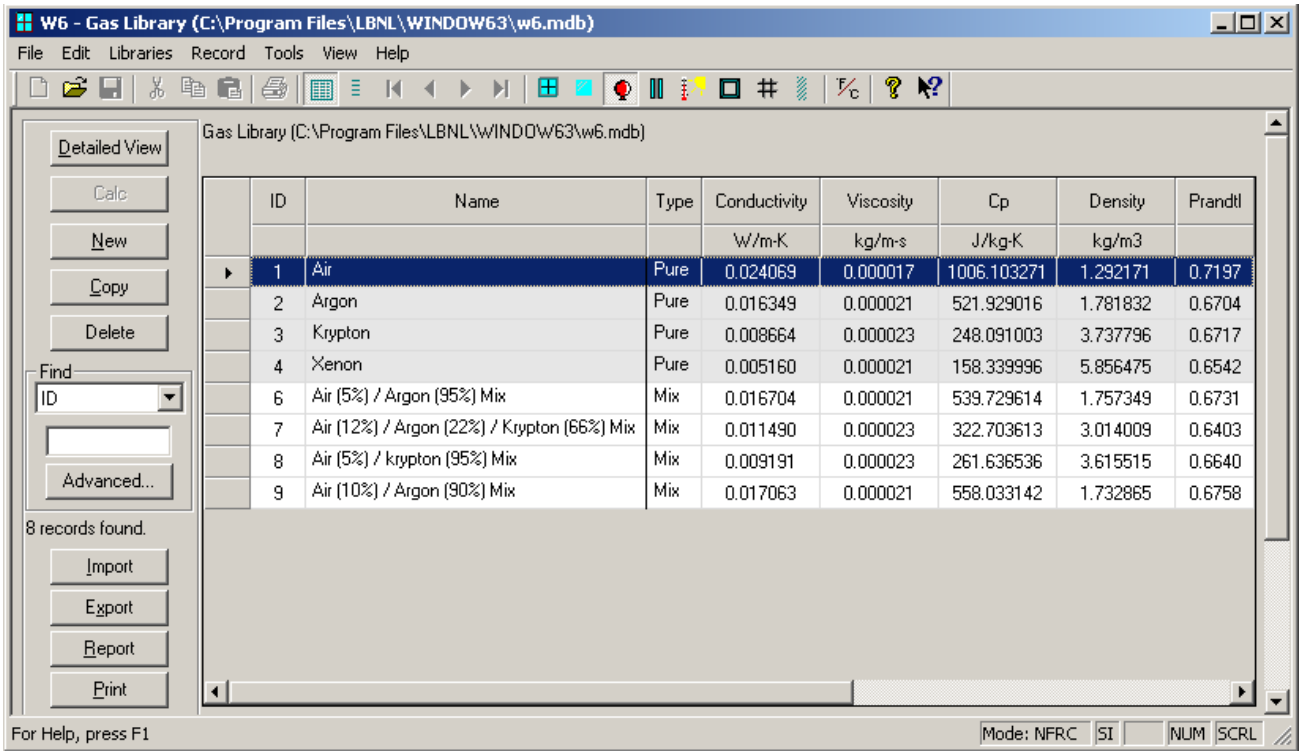
9. Use the new divider in the calculation of the complete product values in the main screen of WINDOW.

8.3.1.3. Gas Filled Glazing Systems

If the glazing system being modeled with a divider is gas-filled, it is necessary to model the divider with the same gas fill as the glazing system. This means a new material must be defined for the gas-filled frame cavities around and inside the divider.

The THERM **Gas Library** contains entries for standard gases, as well as examples of gas mixtures. These gases are not made in THERM; they are made in the WINDOW **Gas Library** and then imported into the THERM **Gas Library**. When the gas mixtures have been imported into THERM, they can be referenced from a new frame cavity material for the divider model, as shown below.

1. Create the gas mixture in the WINDOW **Gas Library**. Presumably it already exists for the product glazing system model. See Section 4.6, "Gas Library" in the *WINDOW User's Manual* for details about creating new entries in the **Gas Library**.



ID	Name	Type	Conductivity	Viscosity	Cp	Density	Prandtl
			W/m-K	kg/m-s	J/kg-K	kg/m3	
1	Air	Pure	0.024069	0.000017	1006.103271	1.292171	0.7197
2	Argon	Pure	0.016349	0.000021	521.929016	1.781832	0.6704
3	Krypton	Pure	0.008664	0.000023	248.091003	3.737796	0.6717
4	Xenon	Pure	0.005160	0.000021	158.339996	5.856475	0.6542
6	Air (5%) / Argon (95%) Mix	Mix	0.016704	0.000021	539.729614	1.757349	0.6731
7	Air (12%) / Argon (22%) / Krypton (66%) Mix	Mix	0.011490	0.000023	322.703613	3.014009	0.6403
8	Air (5%) / krypton (95%) Mix	Mix	0.009191	0.000023	261.636536	3.615515	0.6640
9	Air (10%) / Argon (90%) Mix	Mix	0.017063	0.000021	558.033142	1.732865	0.6758

Figure 8-19 Make the necessary gas mixture in the WINDOW Gas Library.

2. Import the WINDOW gas mixture into the THERM **Gas Library**, if it is not already there.

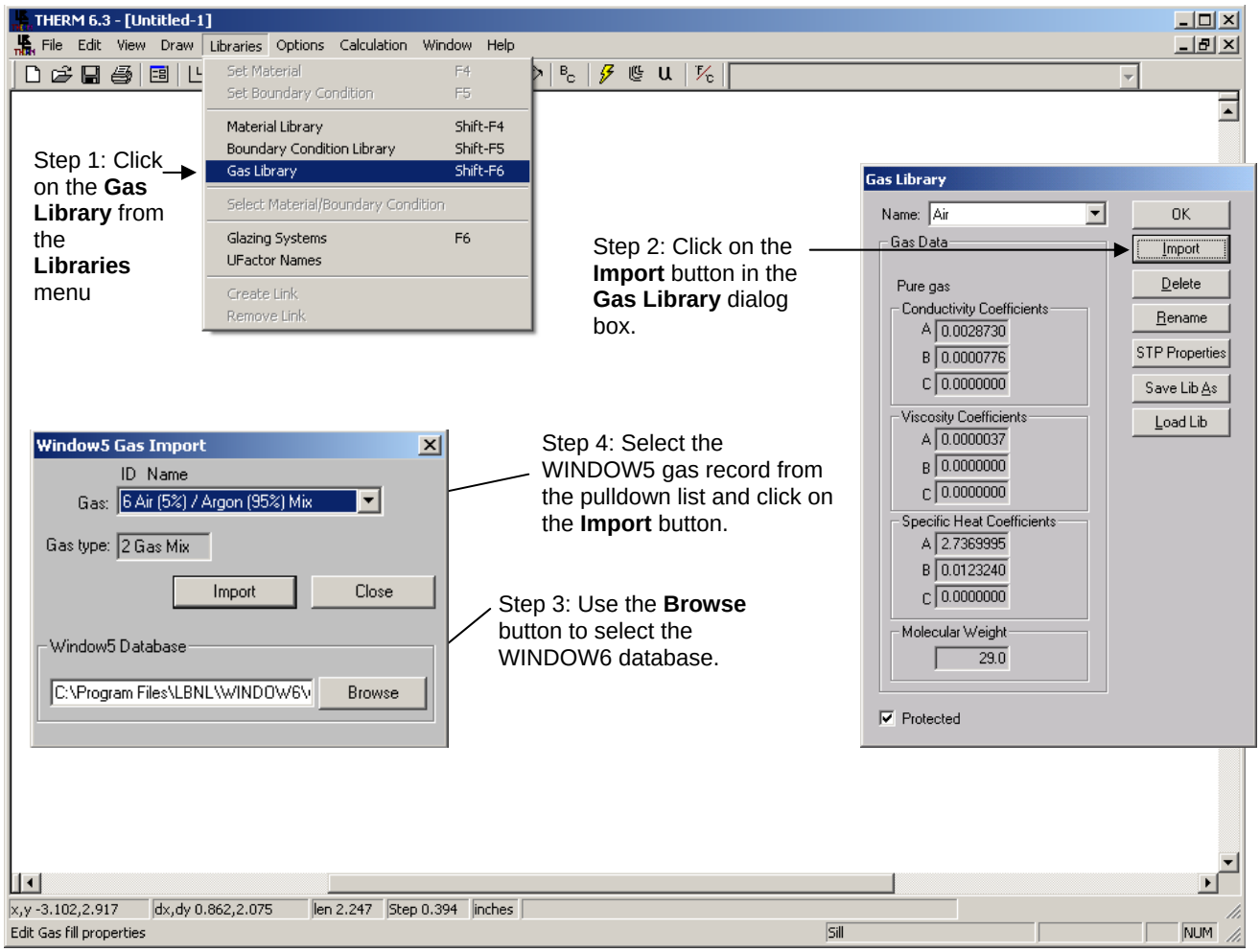


Figure 8-20 Import the gas mixture entries into the THERM Gas Library.

3. Make a new frame cavity material in the THERM **Material Library** based on "Frame Cavity NFRC 100" but with the **Gas Fill** field set to the correct gas mixture from the **Gas Library**.

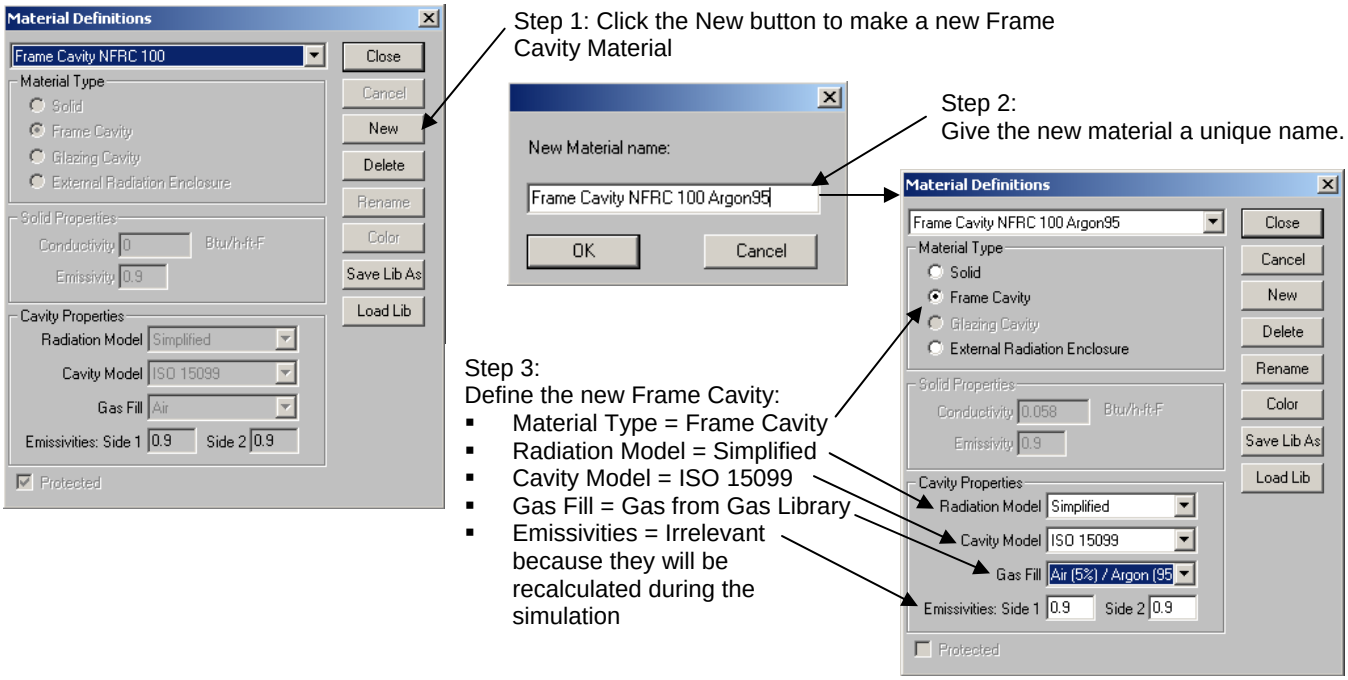


Figure 8-21 Import the gas mixture entries into the THERM Gas Library.

4. Use this new frame cavity material in the divider model cavities.

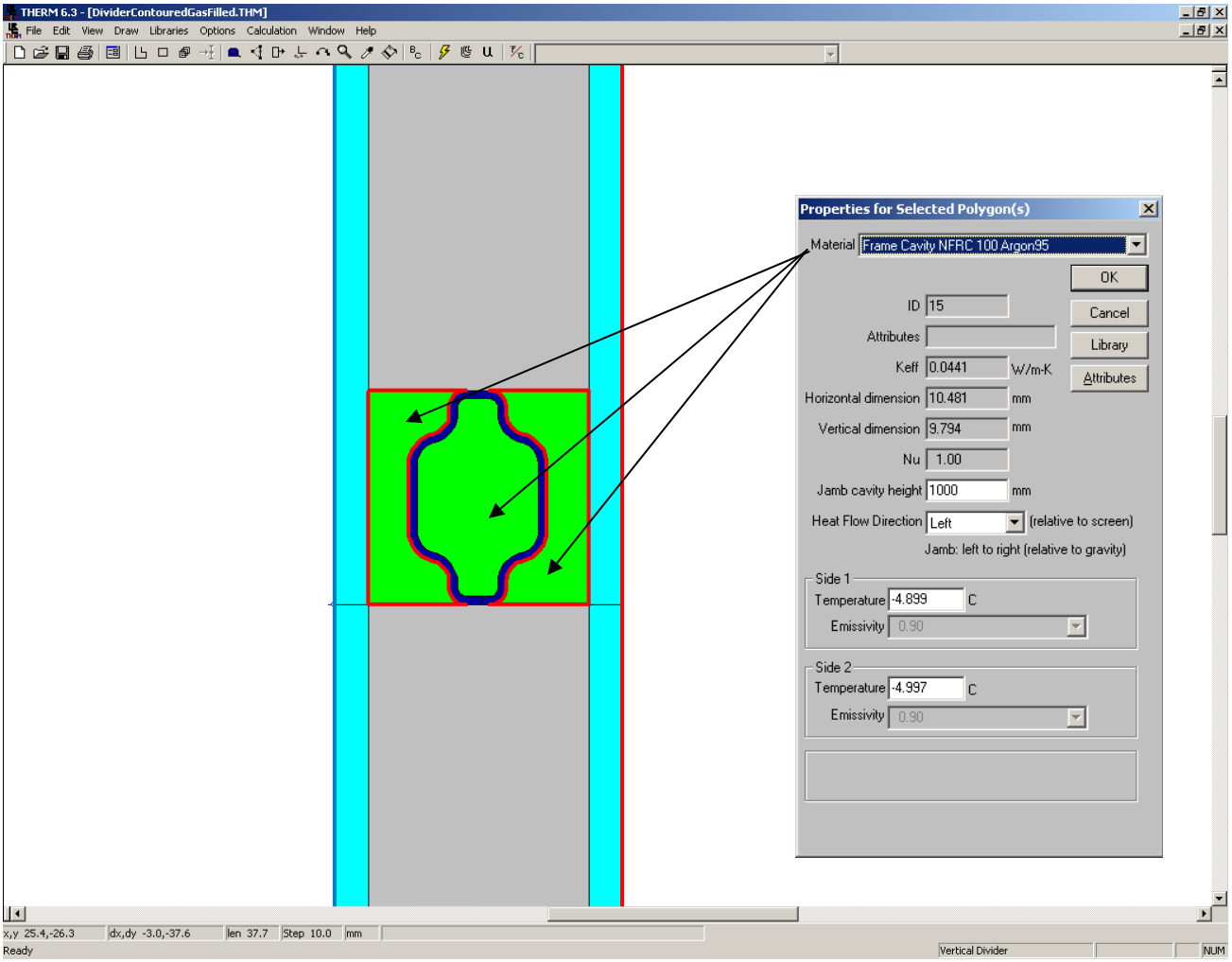


Figure 8-22. Use the new Frame Cavity material to fill the divider cavities.

8.3.2. Simulated Divided Lites

A simulated divided lite is a glazing system that has elements attached to the inside and outside of a glazing system to give the appearance of true divided lites. The glazing system has a metal internal reinforcement, but is all one system. The materials applied/adhered to the outside of the insulating glazing unit are not required to be modeled per NFRC 100. This is an option of the manufacturer and the following provides the details to model and simulate it correctly

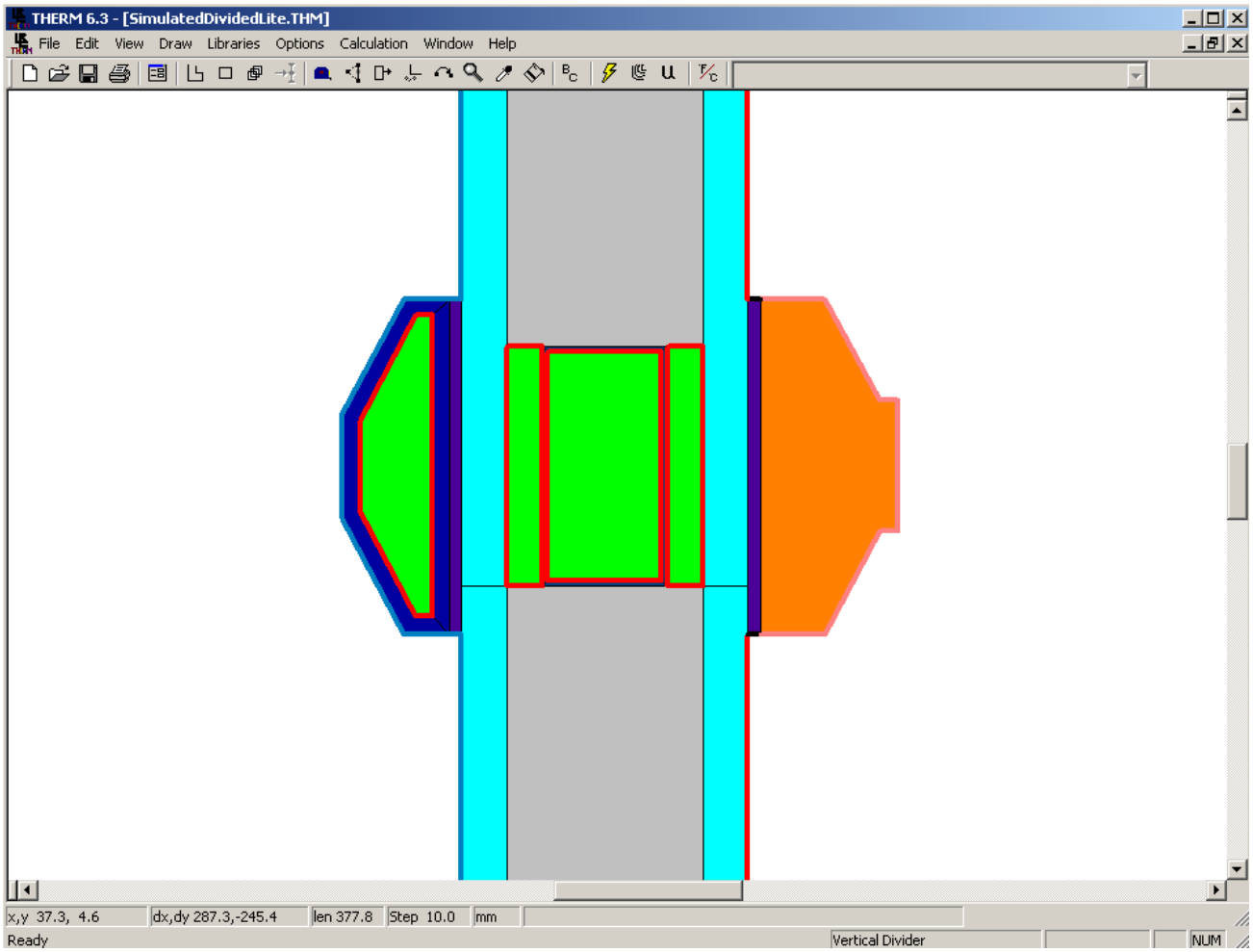


Figure 8-23. A simulated divided lite in THERM.

In THERM:

10. Set the **Cross Section Type** to "Vertical Divider".

11. Import the glazing system for the divider, which is the same glazing system as the rest of the product, with the following settings:
    - **Orientation** = Up
    - **Actual Cavity height** = 1000 mm (39 inches)
    - **Sight line to bottom of glass** = height of the divider (in this example it is 19.05 mm [0.75 inches])
    - **Spacer height** = height of the divider (in this example it is 19.05 mm [0.75 inches)
    - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
    - **Glazing System Height:** 150 mm (6.0 inches)
    - **Draw spacer** = Not checked

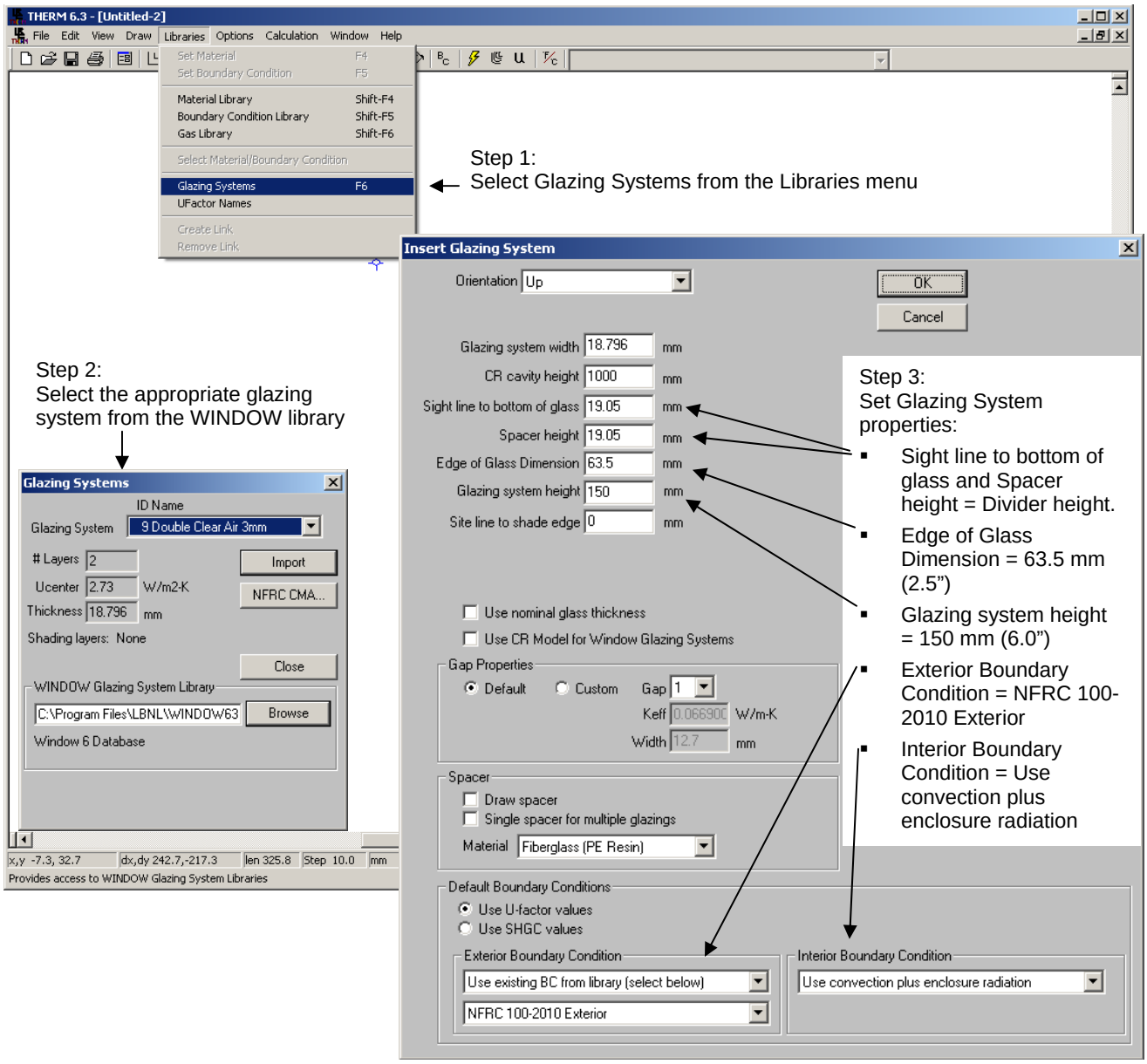


Figure 8-24. Import the first glazing system.

12. Import the glazing system again as an additional glazing system, below the first one (the locator does not have to be moved), but facing down this time. Use the following settings for this glazing system:
    - **Orientation** = Down
    - **Actual Cavity height** = 1000 mm (39 inches)
    - **Sight line to bottom of glass** = 0
    - **Spacer height** = 0
    - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
    - **Glazing System Height:** 150 mm (6.0 inches)
    - **Draw spacer** = Not checked

    Insert the glazing system as an **Additional Glazing**.

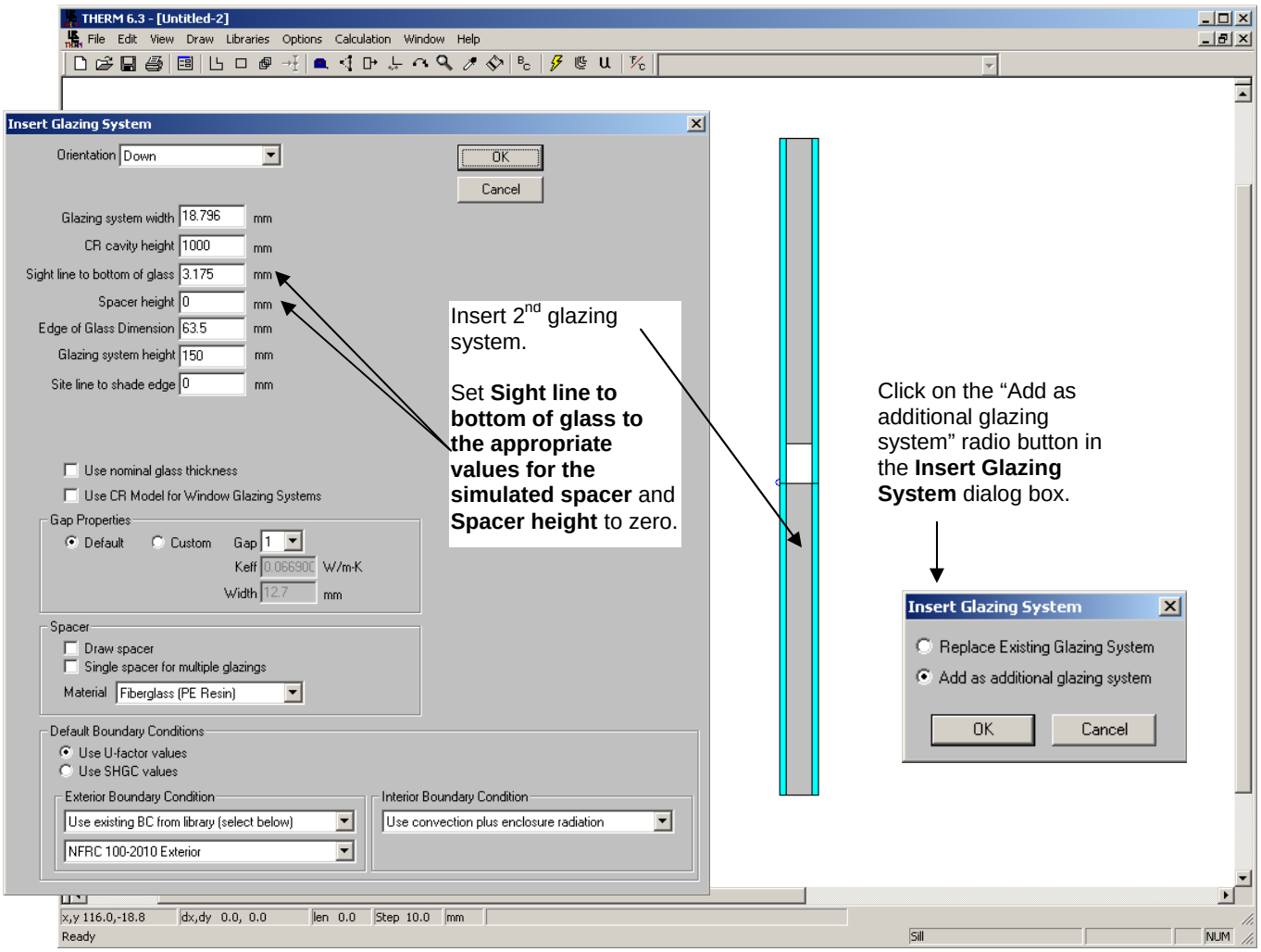


Figure 8-25. Import the second glazing system as an additional glazing system, facing down.

1. Draw (or copy and paste from another THERM file) the polygons in the cavity that represent the divider. The figure below shows the divider for this example drawn with the material set to Aluminum Alloy

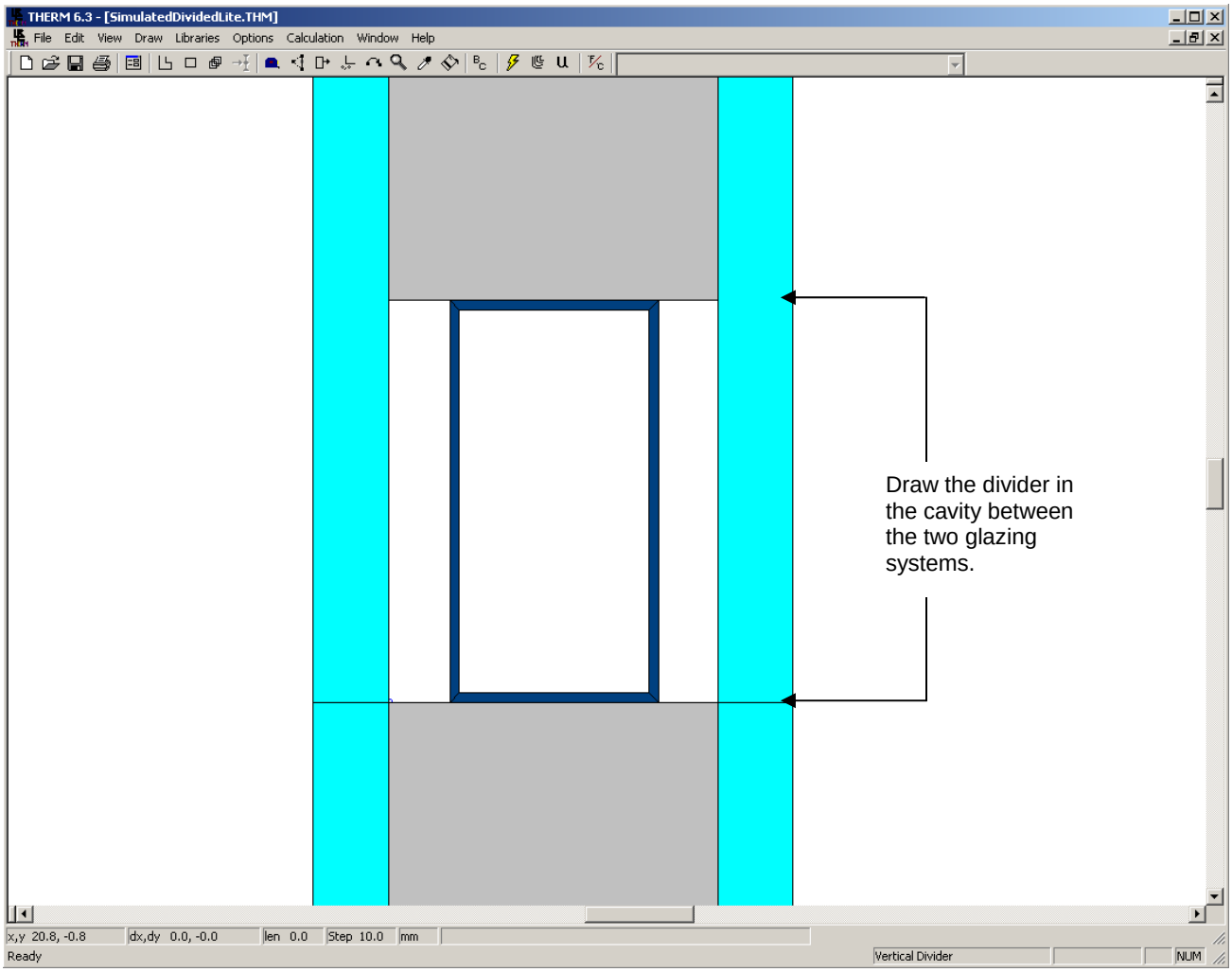


Figure 8-26. Draw the polygons to represent the divider.

2. Fill the cavities between the divider and the glass layers and inside the divider with the material "Frame Cavity NFRC 100". Divide the cavities up according to the 5 mm rule as necessary.

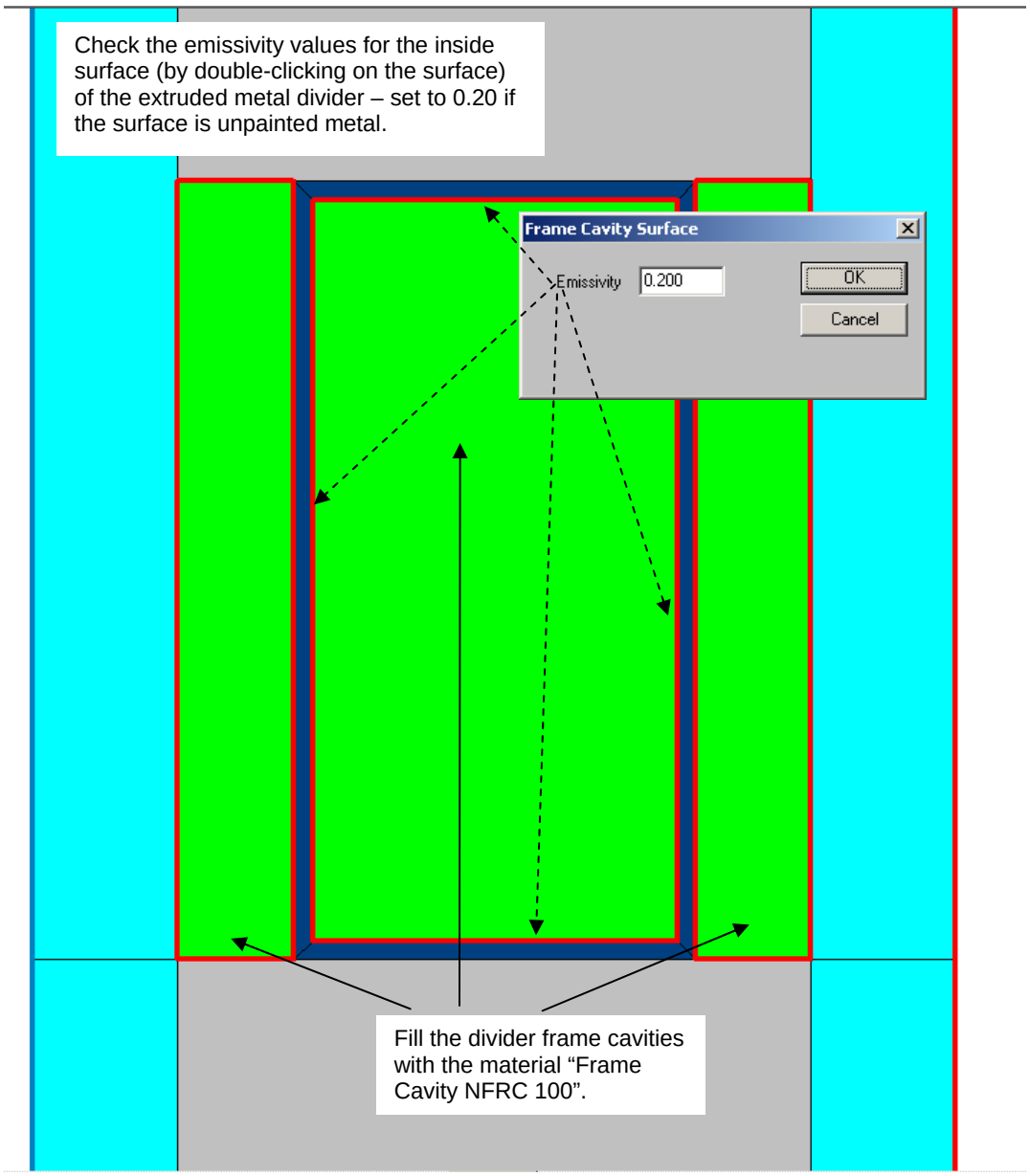


Figure 8--27 Fill the divider frame cavities with Frame Cavity NFRC 100.

7. Add the polygons for the simulated divided light elements on either side of the glazing system and assign the appropriate materials to them.

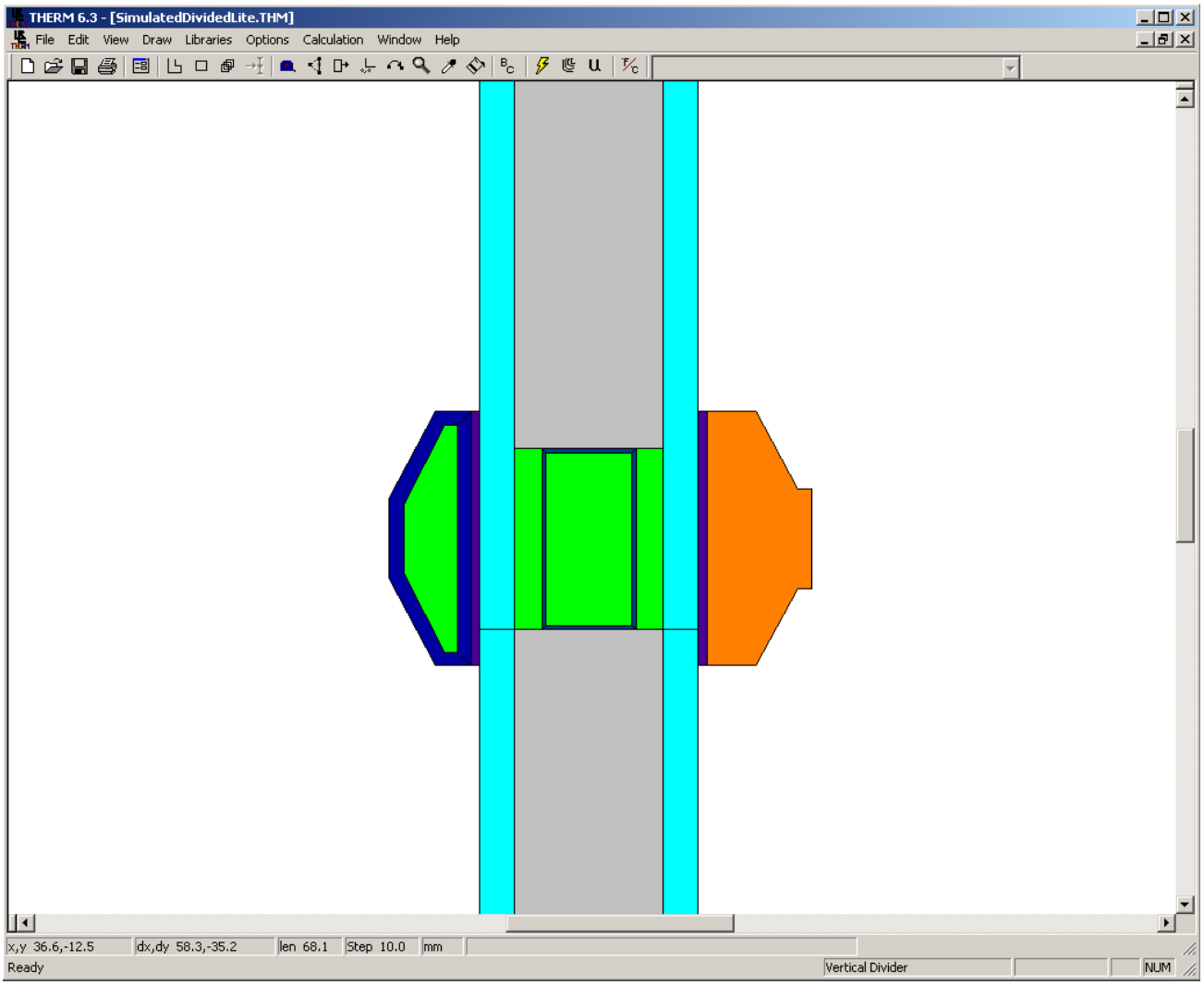


Figure 8--28 Add the polygons for the simulated divided lite elements on either side of the glazing system.

8. Define the boundary conditions, using the "AutoEnclosure" choice for the Radiation Model.

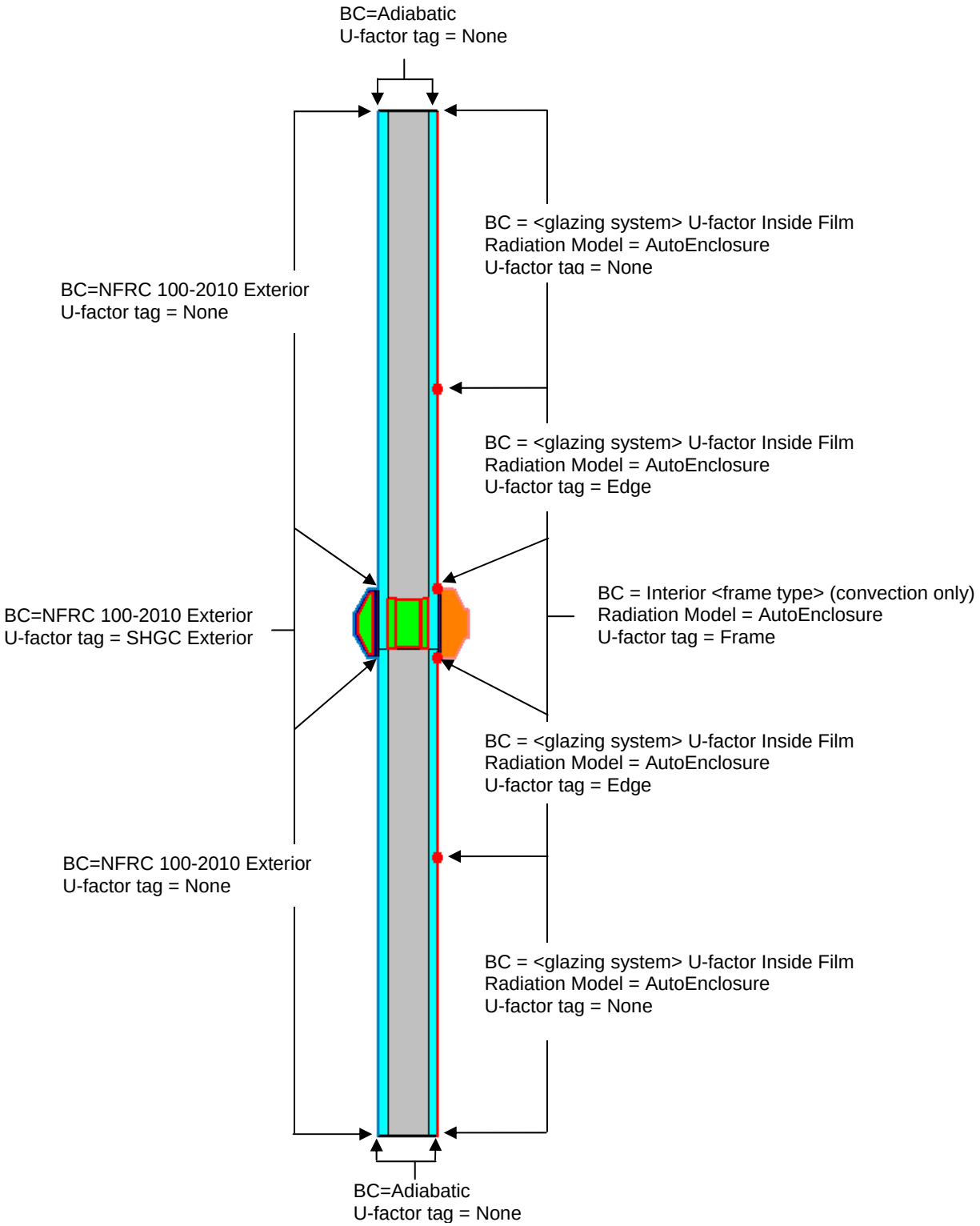


Figure 8-29 Assign the boundary conditions.

3. Calculate the results.

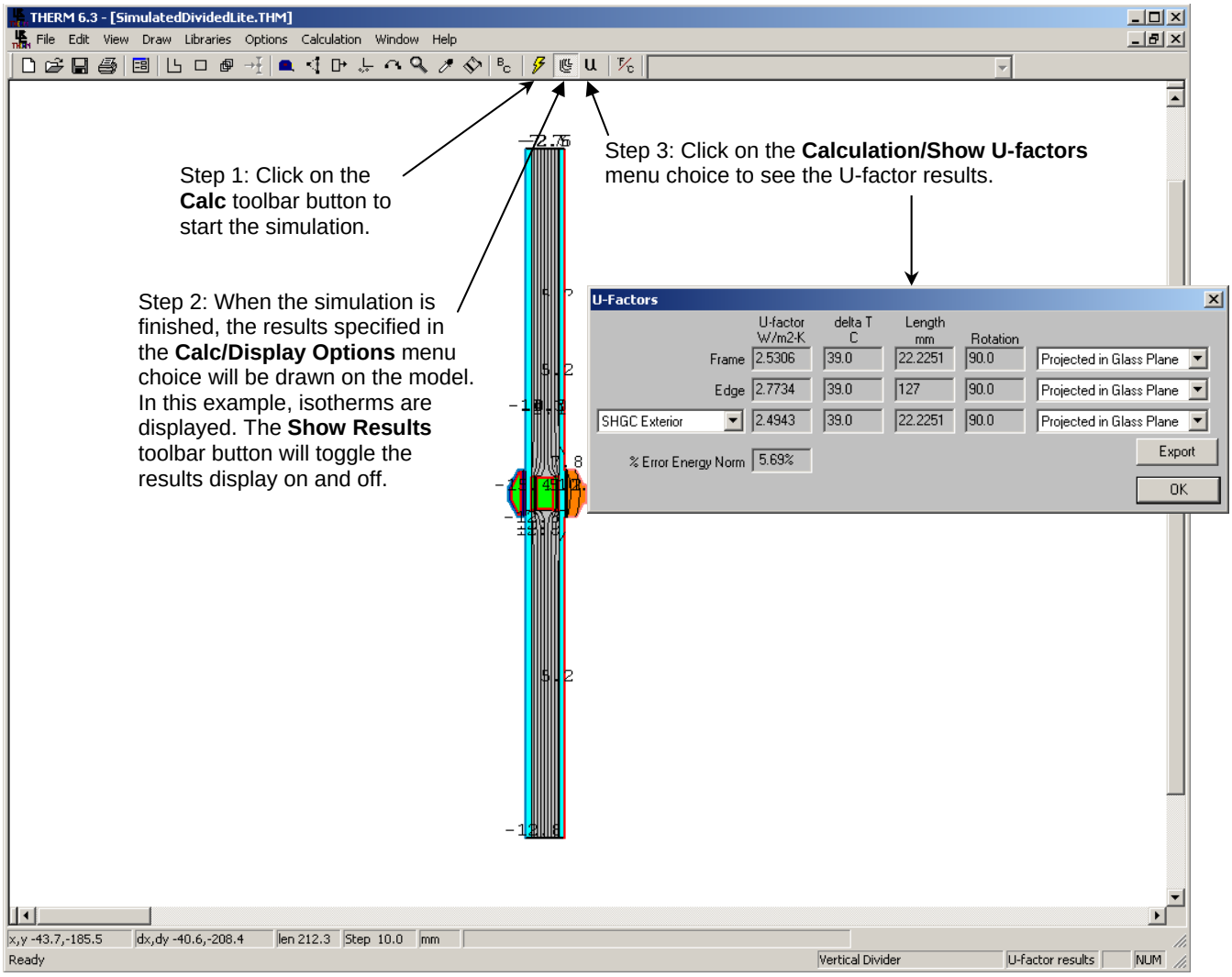
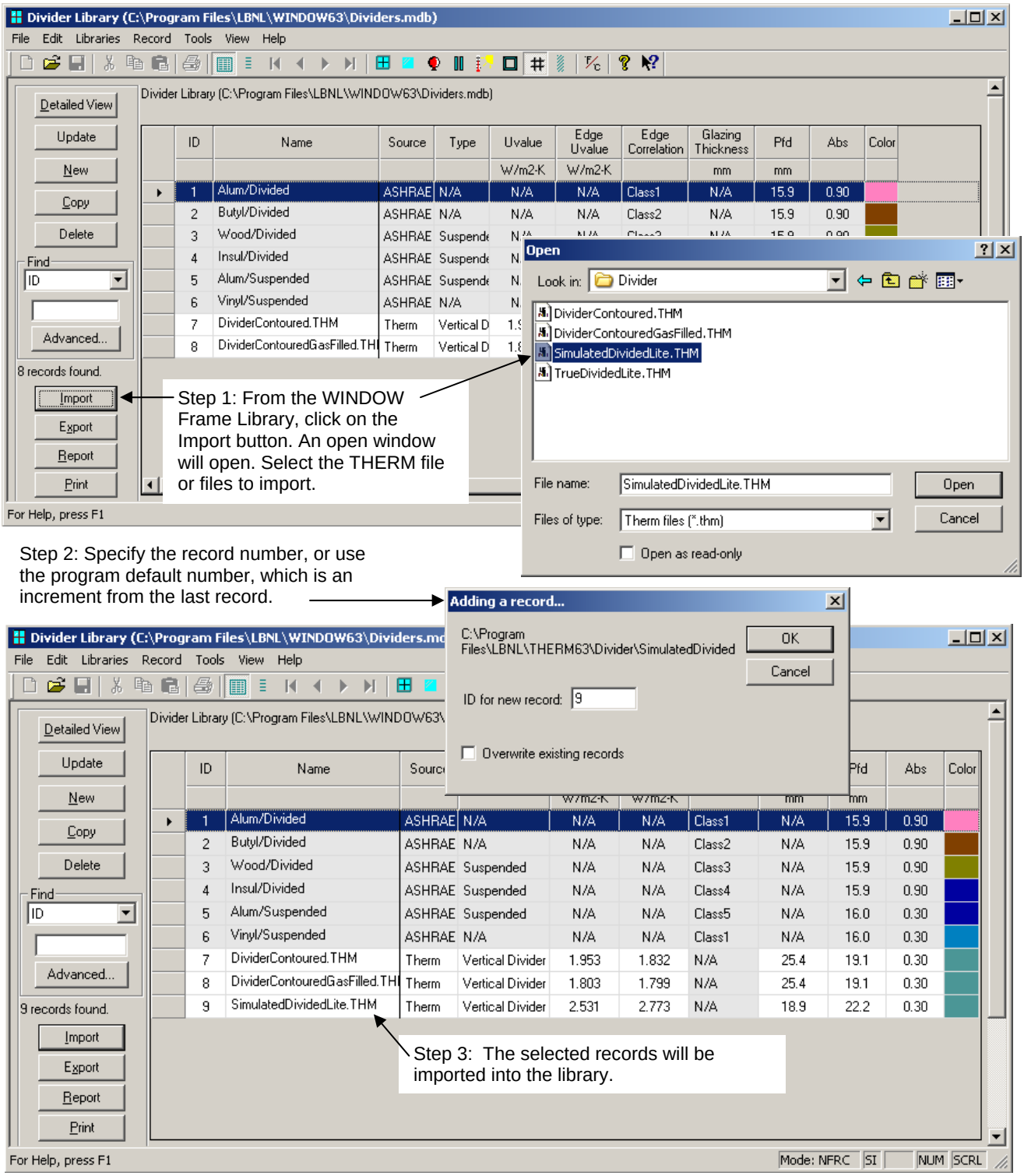


Figure 8-30 Calculate the results.

4. Save the file using the **File/Save As** menu choice.

5. Import the results to the WINDOW Divider Library, as shown below. See Section 4.7.3, "Importing THERM files" in the *WINDOW User's Manual* for more information about importing THERM files.



ID	Name	Source	Type	Uvalue	Edge Uvalue	Edge Correlation	Glazing Thickness	Pfd	Abs	Color
				W/m2-K	W/m2-K		mm	mm		
1	Alum/Divided	ASHRAE	N/A	N/A	N/A	Class1	N/A	15.9	0.90	
2	Butyl/Divided	ASHRAE	N/A	N/A	N/A	Class2	N/A	15.9	0.90	
3	Wood/Divided	ASHRAE	Suspende	N/A	N/A	Class3	N/A	15.9	0.90	
4	Insul/Divided	ASHRAE	Suspende	N/A	N/A	Class4	N/A	15.9	0.90	
5	Alum/Suspended	ASHRAE	Suspende	N/A	N/A	Class5	N/A	16.0	0.30	
6	Vinyl/Suspended	ASHRAE	N/A	N/A	N/A	Class1	N/A	16.0	0.30	
7	DividerContoured.THM	Therm	Vertical D	1.9	1.832	N/A	25.4	19.1	0.30	
8	DividerContouredGasFilled.TH	Therm	Vertical D	1.8	1.799	N/A	25.4	19.1	0.30	
9	SimulatedDividedLite.THM	Therm	Vertical Divider	2.531	2.773	N/A	18.9	22.2	0.30	

Figure 8-31 Import the THERM file into the WINDOW ***Divider Library****.*

6. Use the new divider in the calculation of the complete product values in the main screen of WINDOW.

8.3.3. True Divided Lites

The criteria for when dividers are modeled can be found in *NFRC 100*, Section 1.4.4, "Simplifications to a Product Line". The discussion below describes the methodologies in WINDOW and THERM for modeling dividers when that criteria is met.

A true divided lite means that the dividers have separate glazing systems between the divider elements, as shown in the figure below.

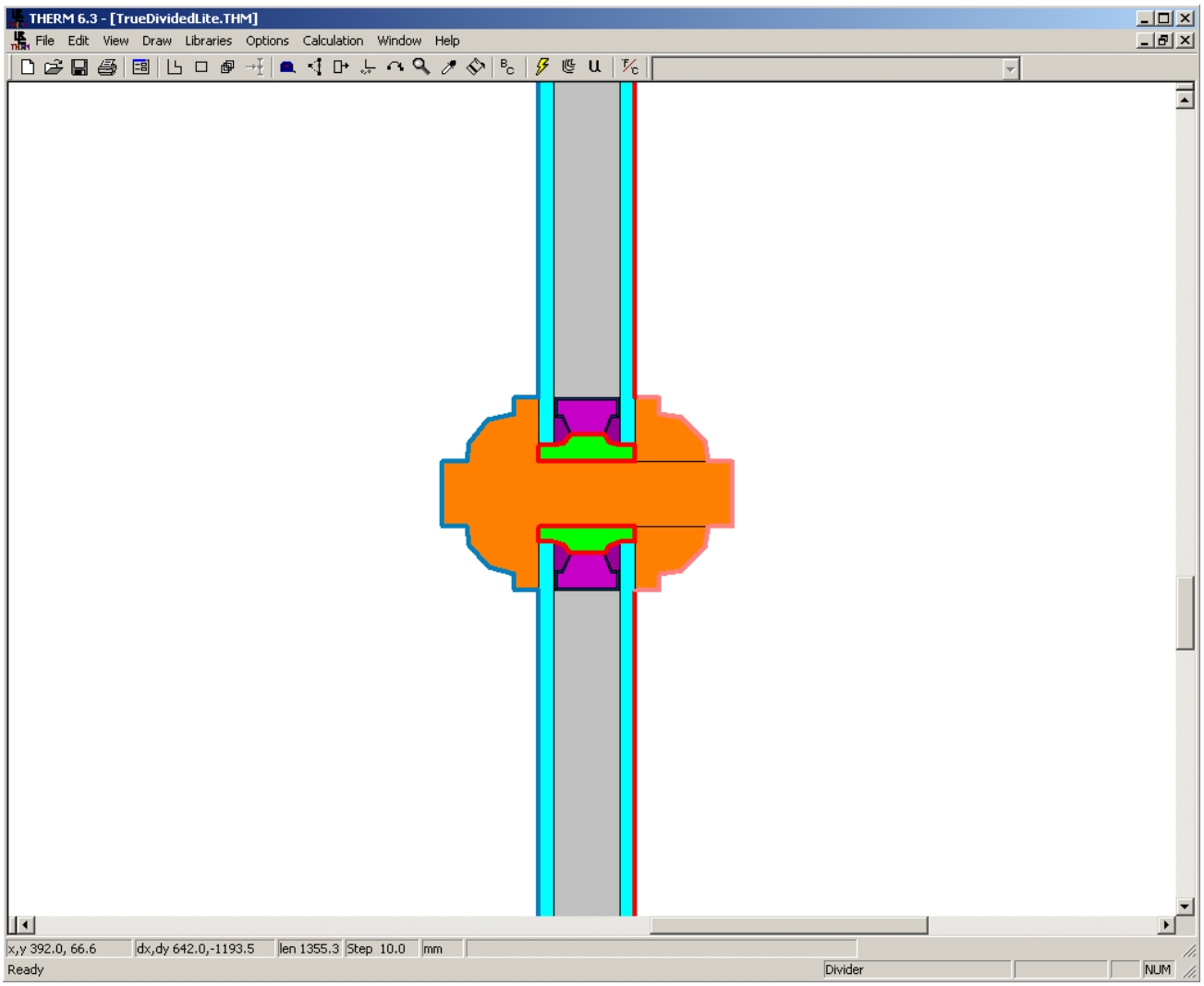


Figure 8-32. A true divided lite in THERM.

In THERM:

In this example, it is easier to start by drawing the polgyons that represent the divider, and then placing the glazing systems relative to those polygons.

1. Set the **Cross Section Type** to "Vertical Divider".
2. Draw the divider polygons as shown in the figure below.

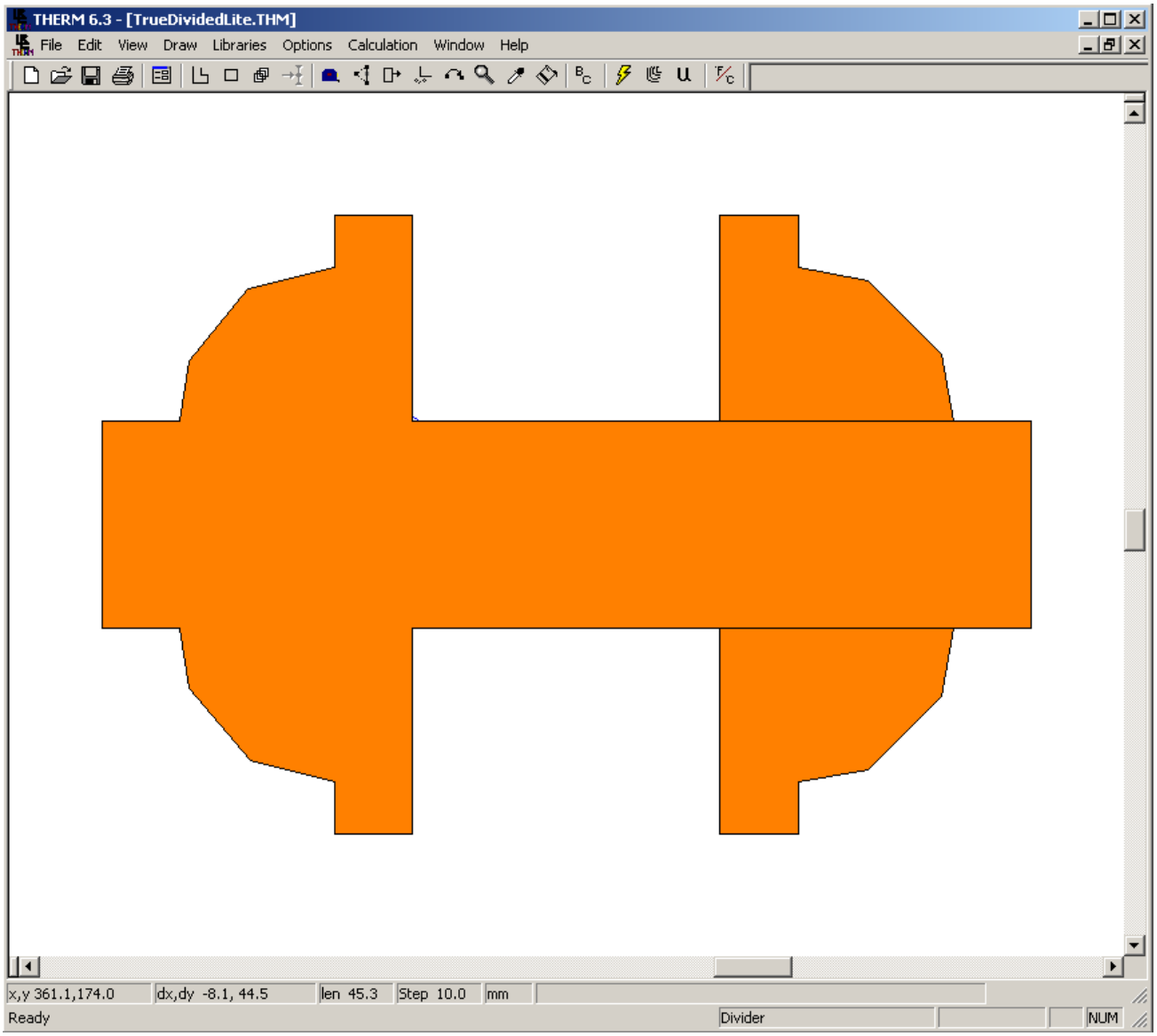


Figure 8-33. In THERM, draw the polygons for the divider elements that the glazing systems will fit into.

3. Import the first glazing system (in this case the top glazing system) for the divider, with the following settings:
   - Set the **Locator** in the appropriate location for where the glazing system will start, in this example 3.175 mm (0.125 inches) above the bottom of the divider
   - **Orientation** = Up
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** = height of the divider (in this example it is 9.525 mm (0.375 inches)
   - **Spacer height** = height of the divider (in this example it is 9.525 mm (0.375 inches)
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

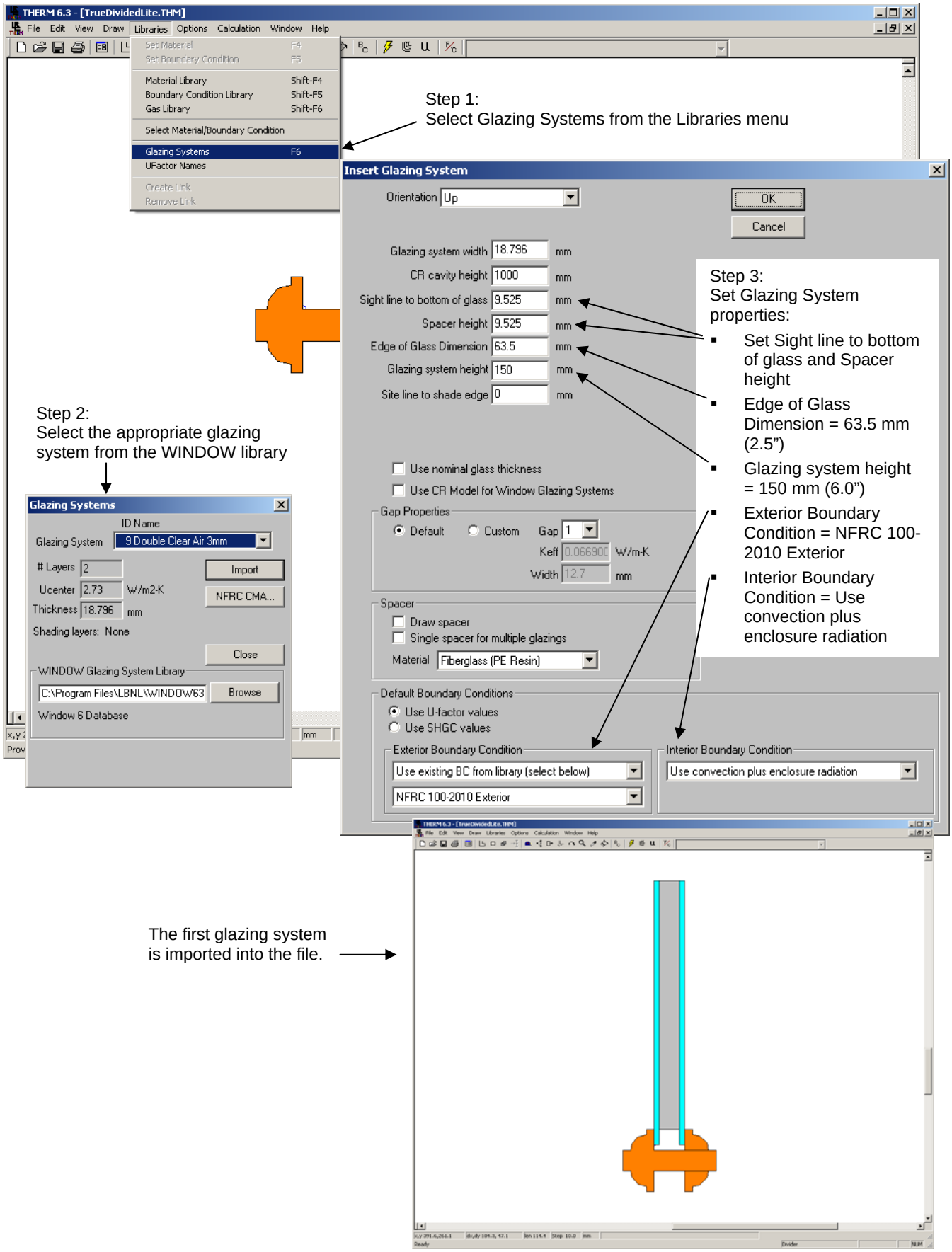


Figure 8-34. Import the first glazing system.

4. Import the glazing system again as an additional glazing system, facing down this time. Use the following settings for this glazing system:
   - Set the **Locator** in the appropriate location for where the glazing system will start, in this example 3.175 mm (0.125 inches) above the bottom of the divider
   - **Orientation** = Down
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** = height of the divider (in this example it is 9.525 mm (0.375 inches)
   - **Spacer height** = height of the divider (in this example it is 9.525 mm (0.375 inches)
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

   Insert the glazing system as an **Additional Glazing**.

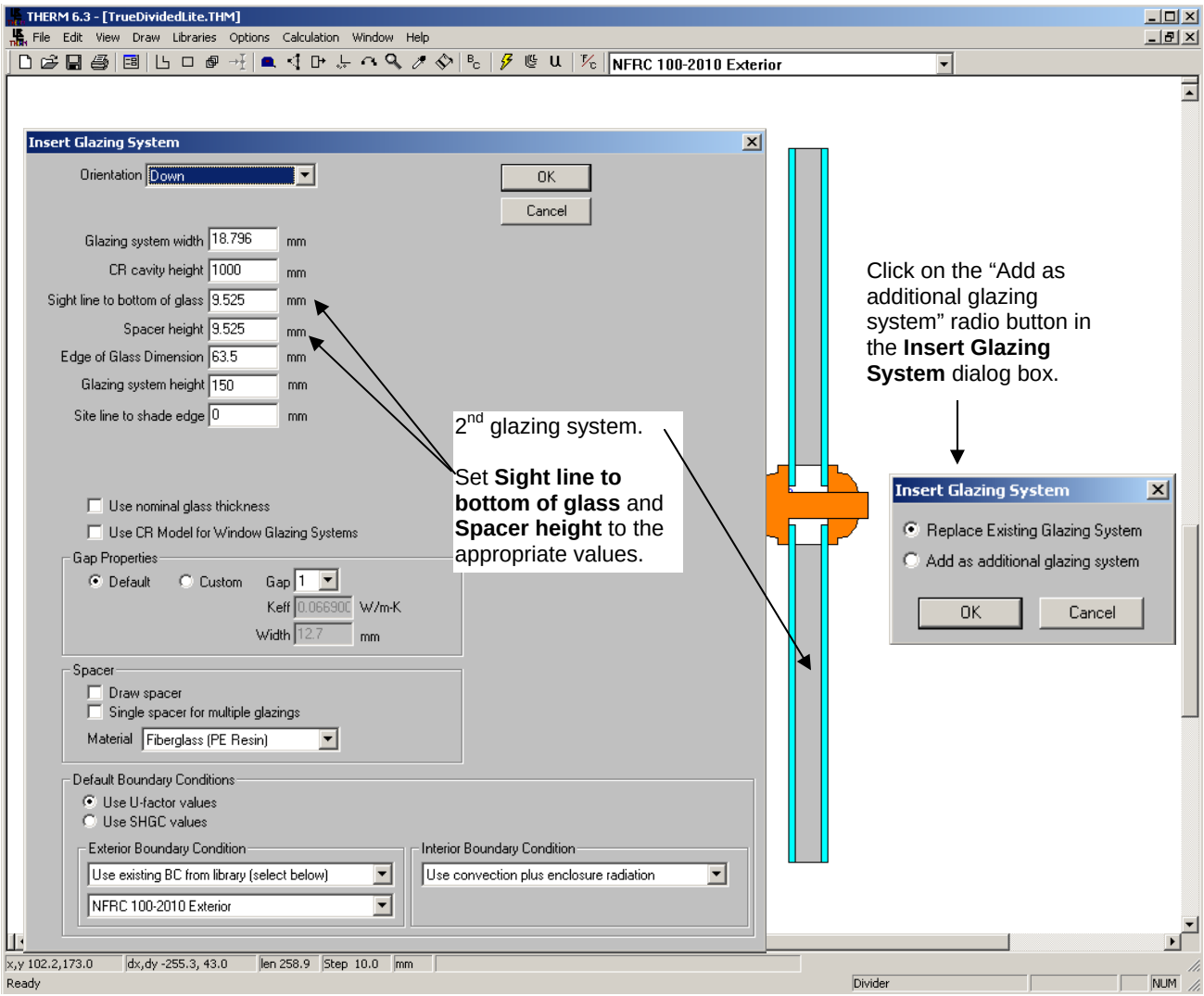


Figure 8-35. Import the second glazing system as an additional glazing system, facing down.

5. Add the spacers, sealants, desiccants, and frame cavities as appropriate.

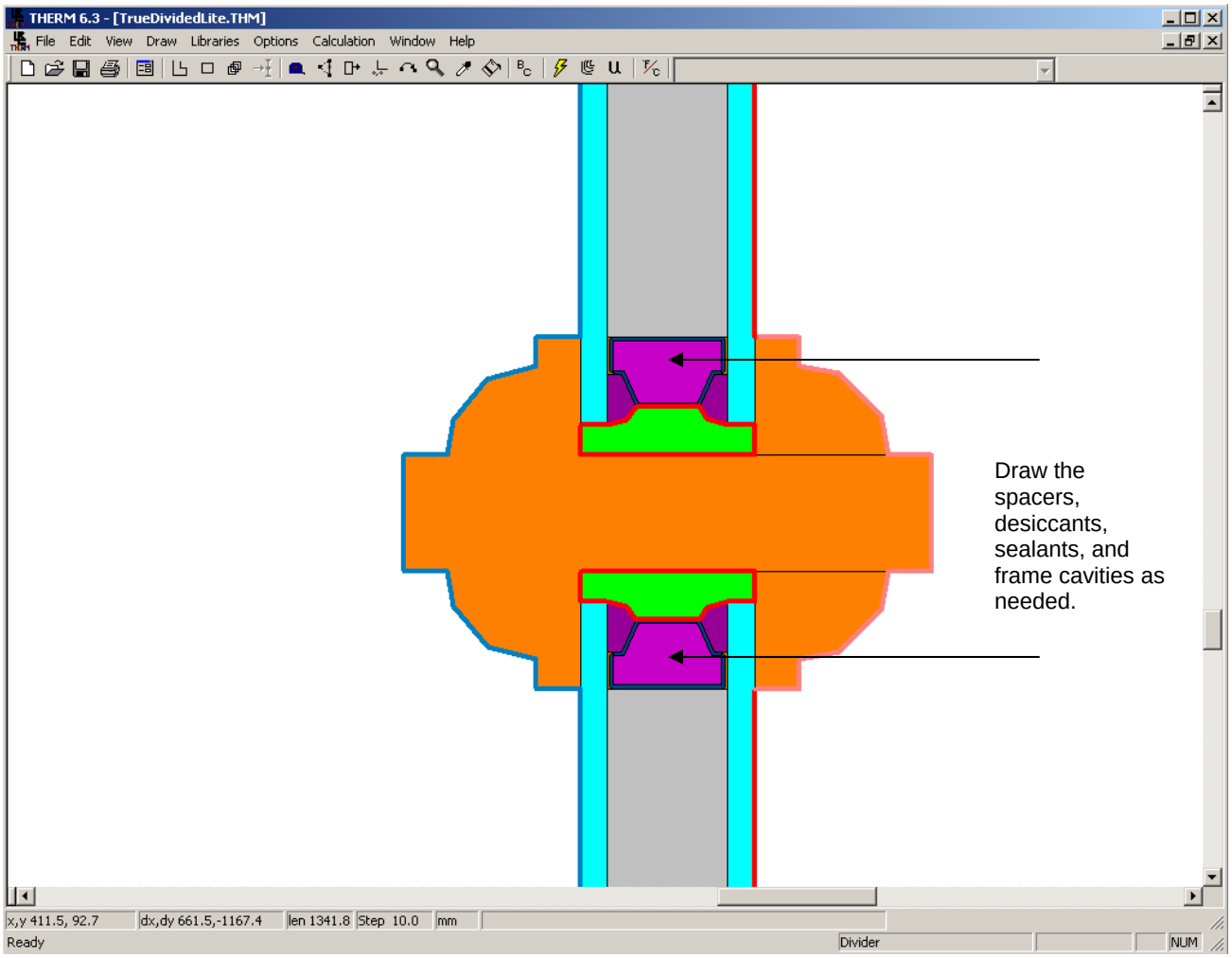


Figure 8-36. Draw the polygons to represent the divider.

6. Define the boundary conditions, using the "AutoEnclosure" choice for the Radiation Model.

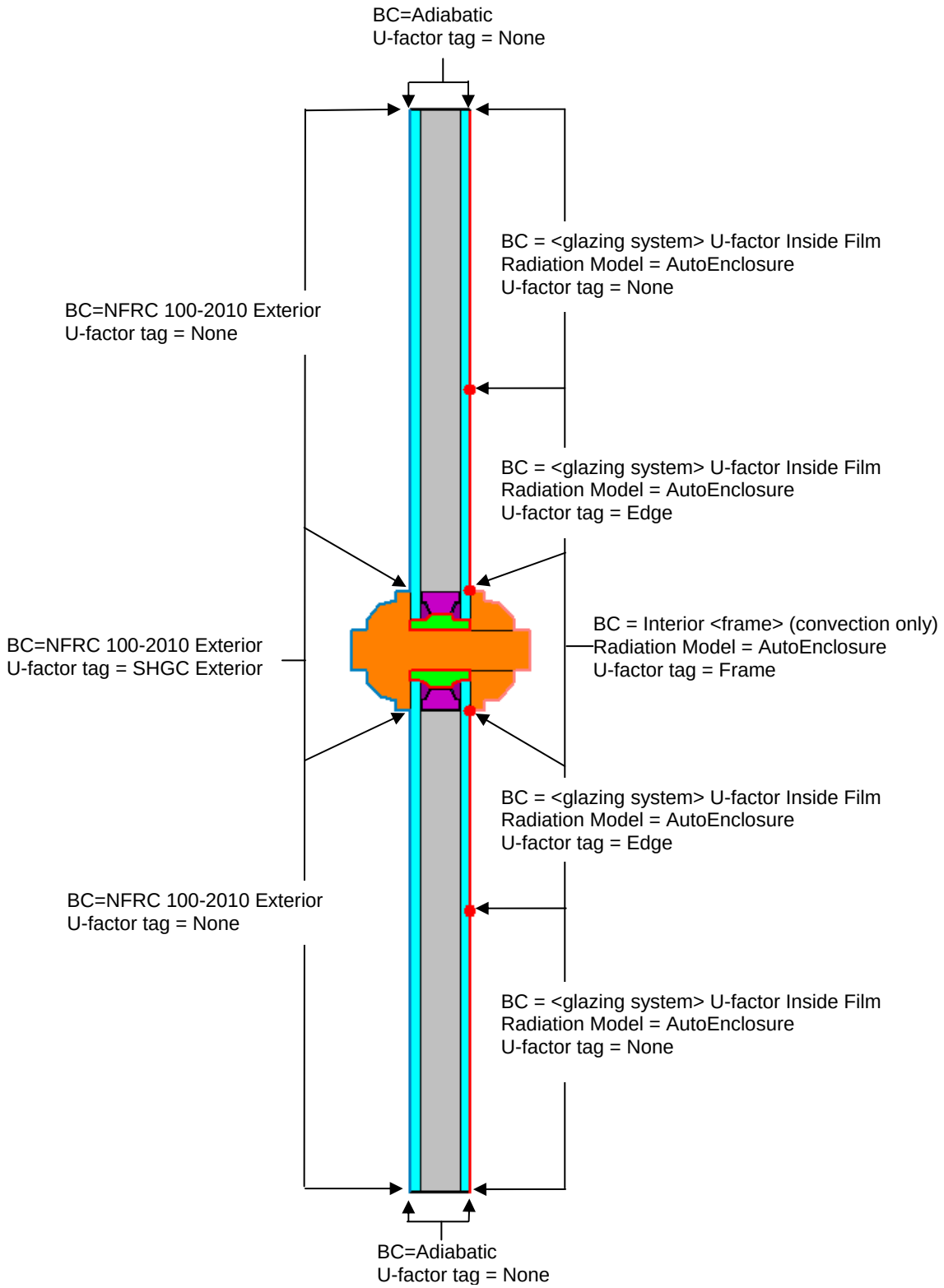


Figure 8-37. Assign the boundary conditions.

6. Calculate the results.

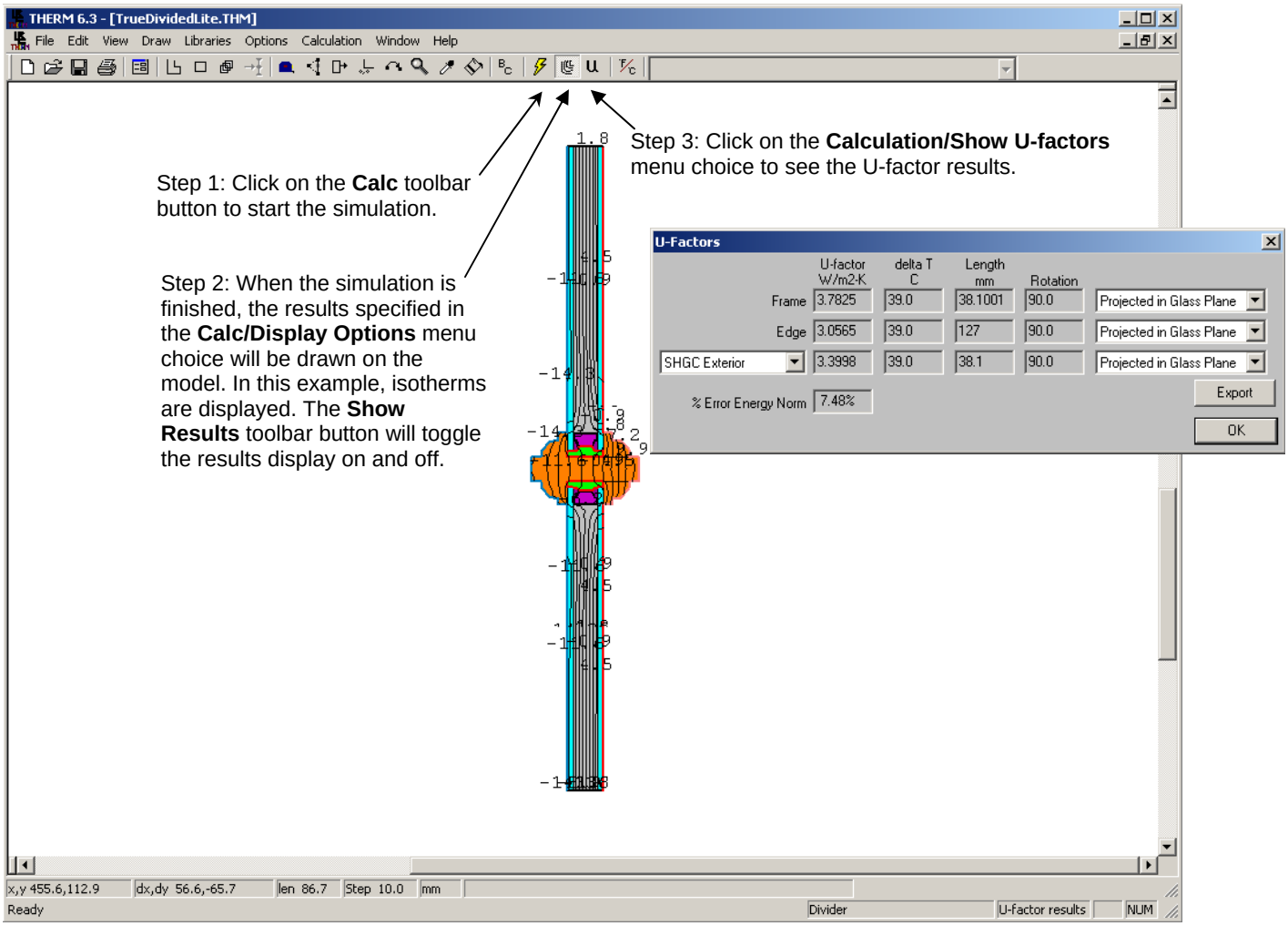
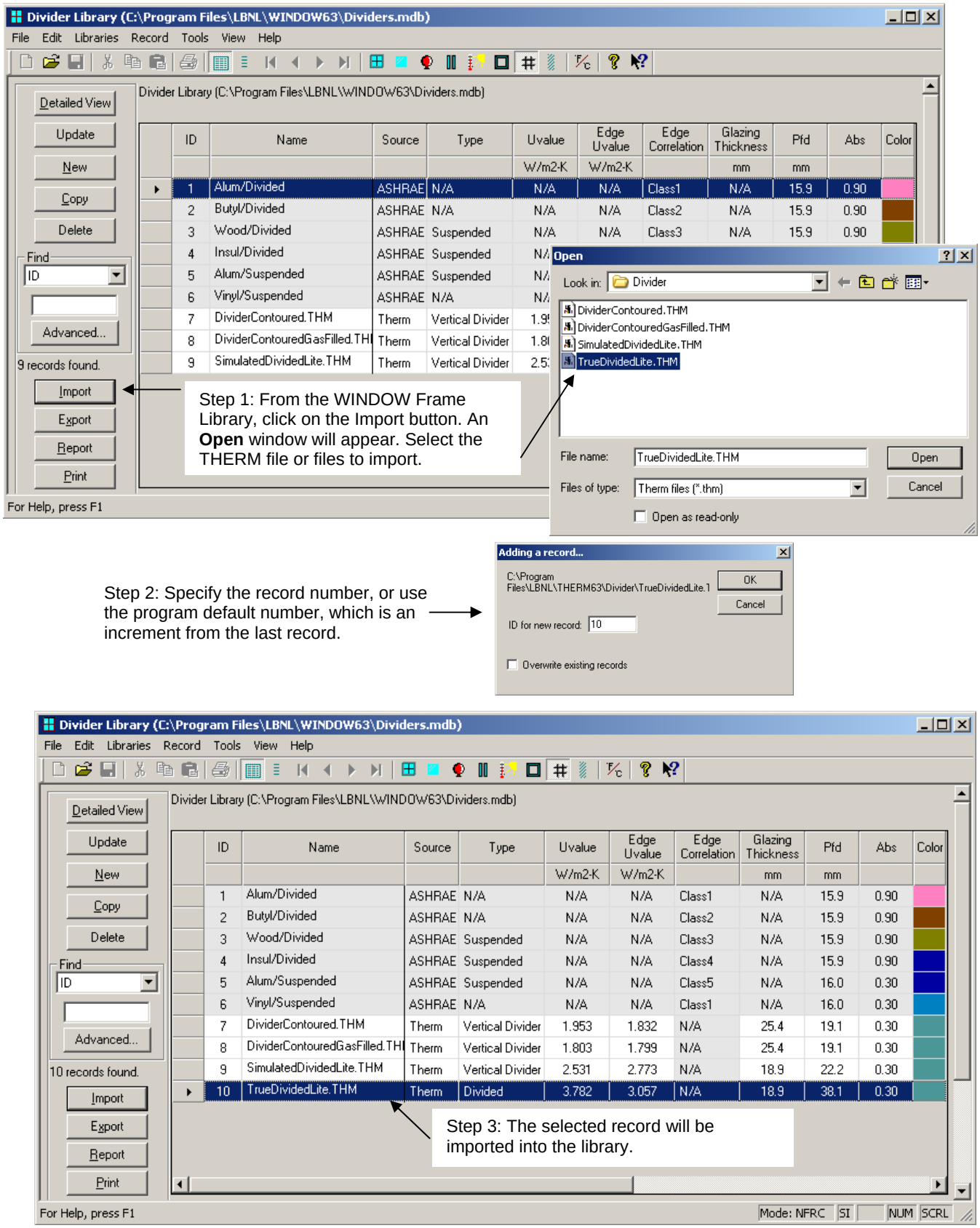


Figure 8-38. Calculate the results.

7. Save the file using the **File/Save As** menu choice.

8. Import the results to the WINDOW Divider Library, as shown below. See Section 4.7.3, "Importing THERM files" in the *WINDOW User's Manual* for more information about importing THERM files.



ID	Name	Source	Type	Uvalue	Edge Uvalue	Edge Correlation	Glazing Thickness	Pfd	Abs	Color
				W/m2-K	W/m2-K		mm	mm		
1	Alum/Divided	ASHRAE	N/A	N/A	N/A	Class1	N/A	15.9	0.90	
2	Butyl/Divided	ASHRAE	N/A	N/A	N/A	Class2	N/A	15.9	0.90	
3	Wood/Divided	ASHRAE	Suspended	N/A	N/A	Class3	N/A	15.9	0.90	
4	Insul/Divided	ASHRAE	Suspended	N/A	N/A	Class4	N/A	15.9	0.90	
5	Alum/Suspended	ASHRAE	Suspended	N/A	N/A	Class5	N/A	16.0	0.30	
6	Vinyl/Suspended	ASHRAE	N/A	N/A	N/A	Class1	N/A	16.0	0.30	
7	DividerContoured.THM	Therm	Vertical Divider	1.953	1.832	N/A	25.4	19.1	0.30	
8	DividerContouredGasFilled.THM	Therm	Vertical Divider	1.803	1.799	N/A	25.4	19.1	0.30	
9	SimulatedDividedLite.THM	Therm	Vertical Divider	2.531	2.773	N/A	18.9	22.2	0.30	
10	TrueDividedLite.THM	Therm	Divided	3.782	3.057	N/A	18.9	38.1	0.30	

Figure 8-39. Import the THERM file into the WINDOW ***Divider Library****.*

9. Use the new divider in the calculation of the complete product values in the main screen of WINDOW.

8.3.4. Door Caming

When modeling glazing options with caming, which are treated in a similar fashion to dividers, the NFRC default caming can be used. The flat caming (H-Bar) shall be used as the default shape. Brass conductivity and emissivity, per NFRC 101, Appendix B, shall be used as the default material. The caming drawing DXF file is available from the NFRC website.

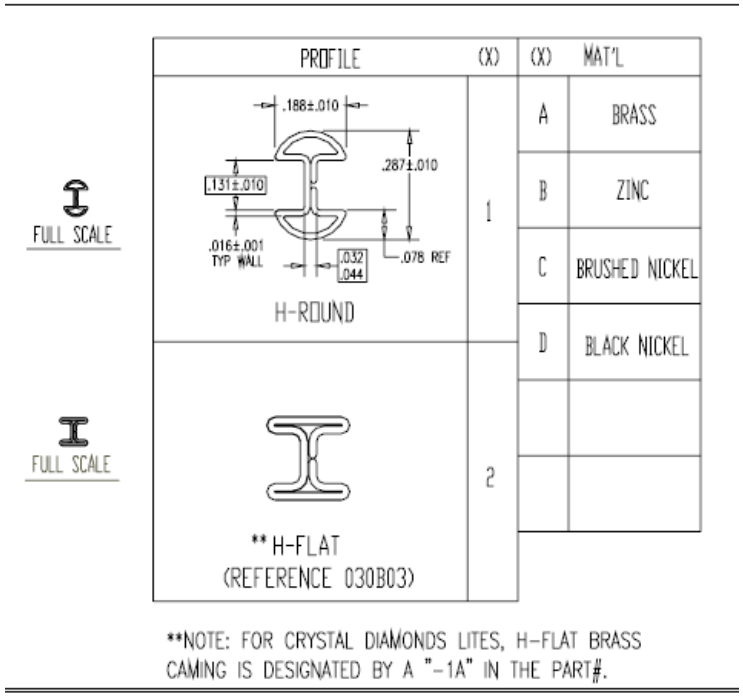


*Figure **8-40**. Standardized Caming Drawing*

In THERM:

In this example, which represents an intermediate pane in an IG unit with caming, it is easier to start by drawing the polgyons that represent the divider, and then placing the glazing systems relative to those polygons.

1. Set the **Cross Section Type** to "Vertical Divider".
2. Draw the caming polygons.

3. Insert the first glazing system (in this case the top glazing system which is a triple glazed unit made in WINDOW) for the divider, with the following settings:
   - Set the **Locator** in the appropriate location for where the glazing system will start
   - **Orientation** = Up
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** =0
   - **Spacer height** = 0
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

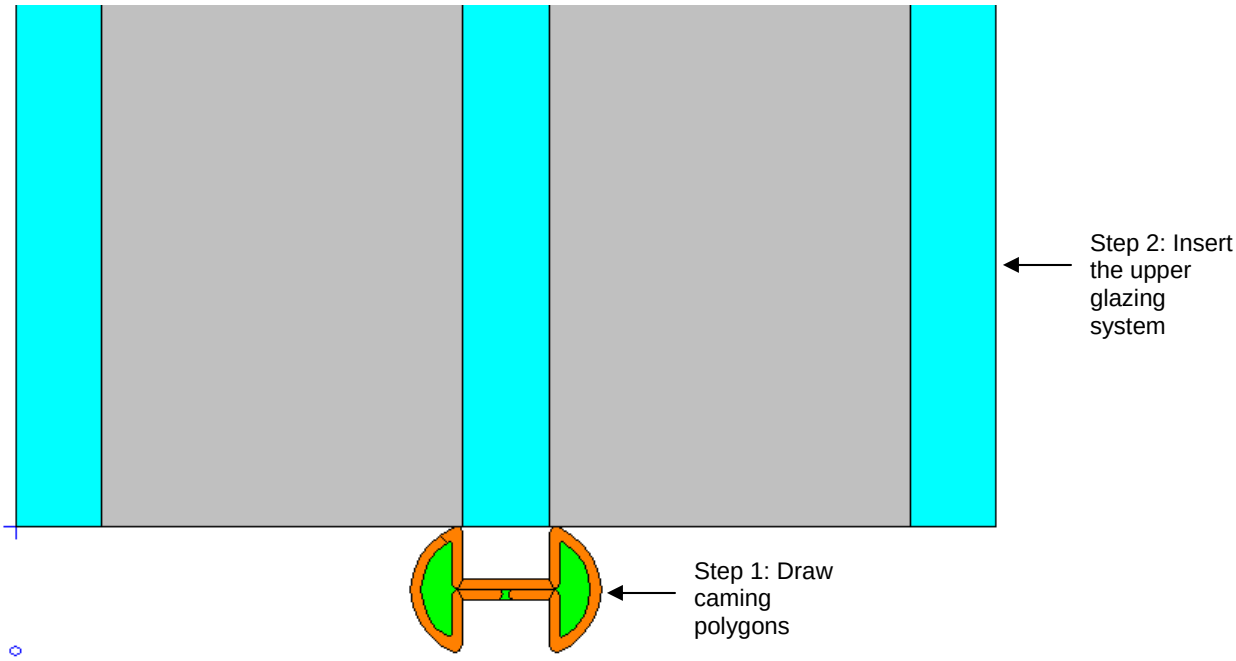


*Figure **8-41**. Draw the caming polygons and insert the upper glazing system*

4. Insert the second glazing system, with the following settings, and click the "Add as additional glazing system" radio button upon insert.
   - Set the **Locator** in the appropriate location for where the glazing system will start
   - **Orientation** = Down
   - **Actual Cavity height** = 1000 mm (39 inches)
   - **Sight line to bottom of glass** =0
   - **Spacer height** = 0
   - **Edge of Glass Dimension** = 63.5 mm (2.5 inches)
   - **Glazing System Height:** 150 mm (6.0 inches)
   - **Draw spacer** = Not checked

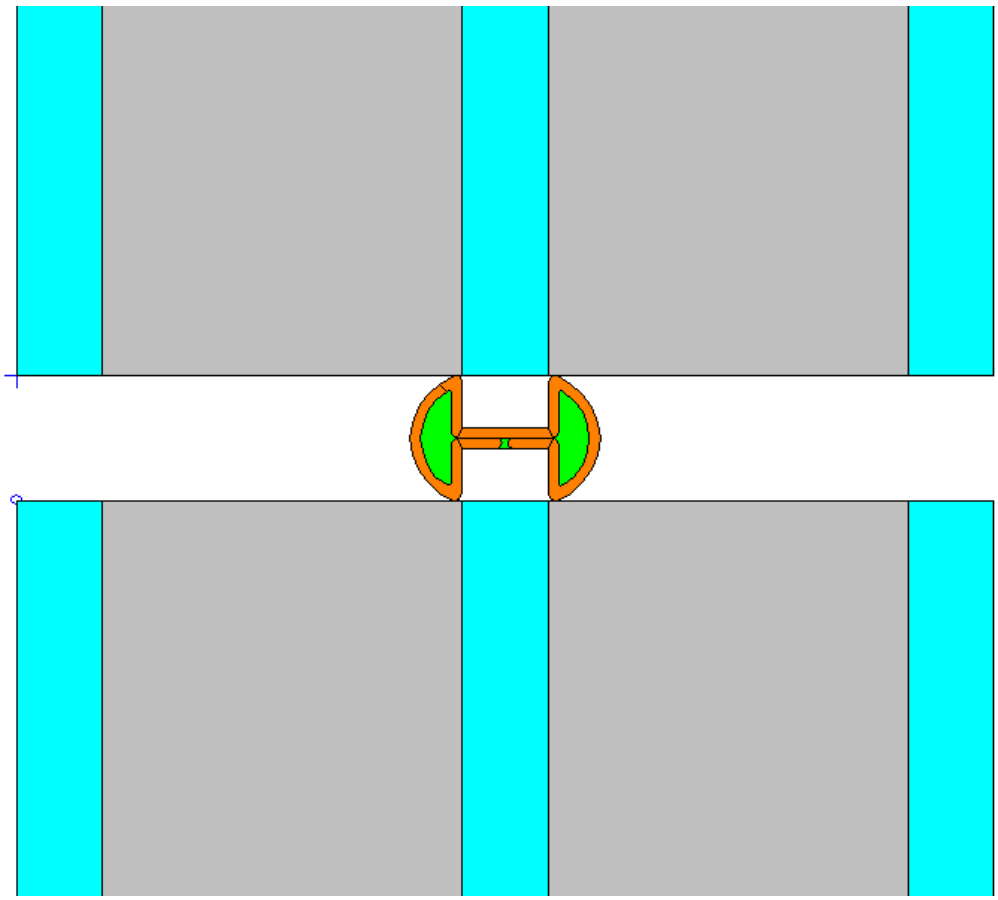


*Figure **8-42**. Insert the lower glazing system*

5. From the Options menu, select Preferences, then click on the Drawing Options tab and check "Allow editing of IG polygons" so that the glazing system geometry can be modified.
6. For both the upper and lower glazing systems, move the points of the center glass layer into the caming, as showin in the figure below.

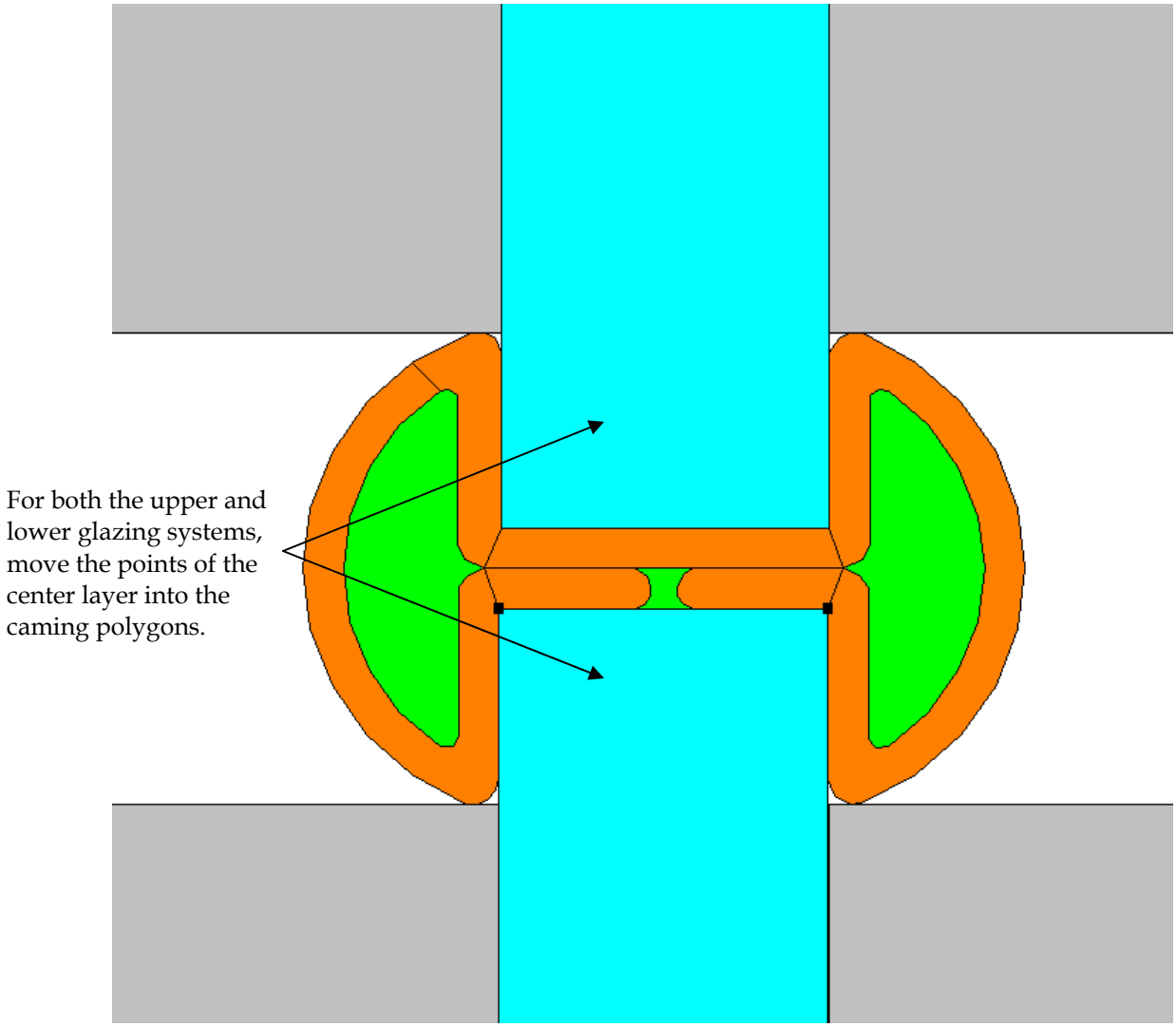


*Figure **8-43**. Move the points of the middle layer of the upper and lower glazing systems into the caming.*

7. For the either the upper or lower glazing system, move the points of the outer layers to meet the other glazing system, to enclose the IG.

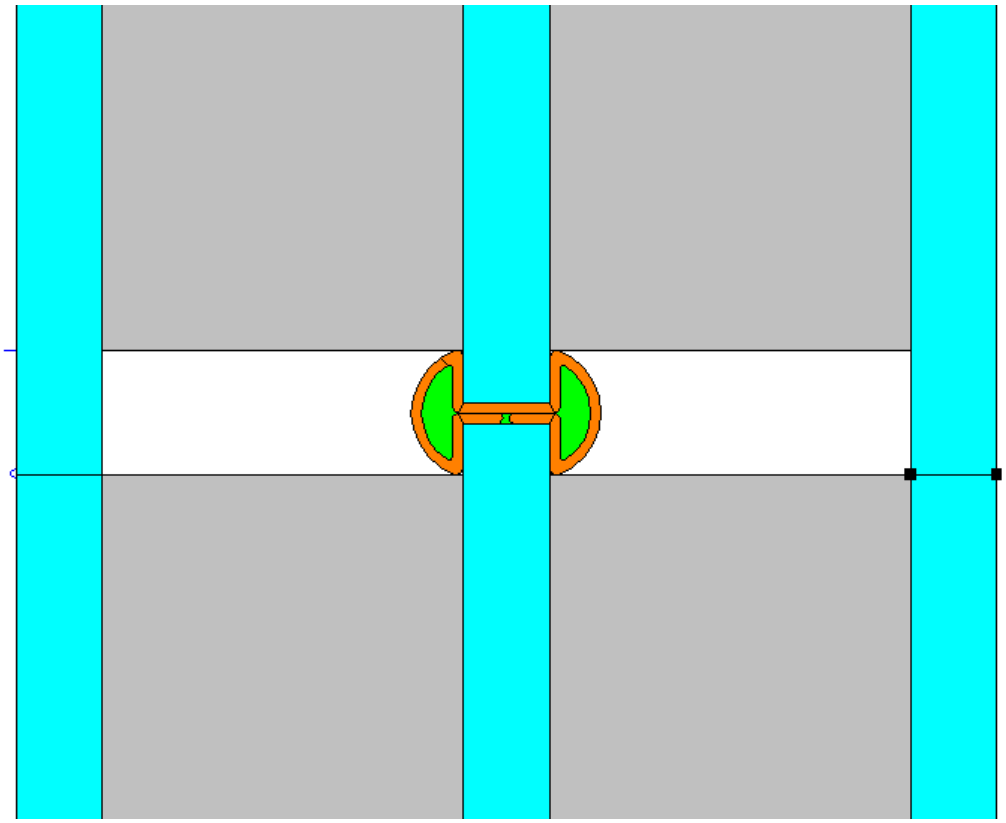


*Figure **8-44** Move the points of either the outside layers of either the upper or lower glazing system to meet the other glazing system, to enclose the IG*

8. If the IG Unit is air-filled, then fill the cavities with NFRC Frame Cavity 100, assign the normal boundary conditions, and simulate as usual. If the IG unit if gas-filled, follow the procedures for gas filling a divider per Section 8.3.1.3.

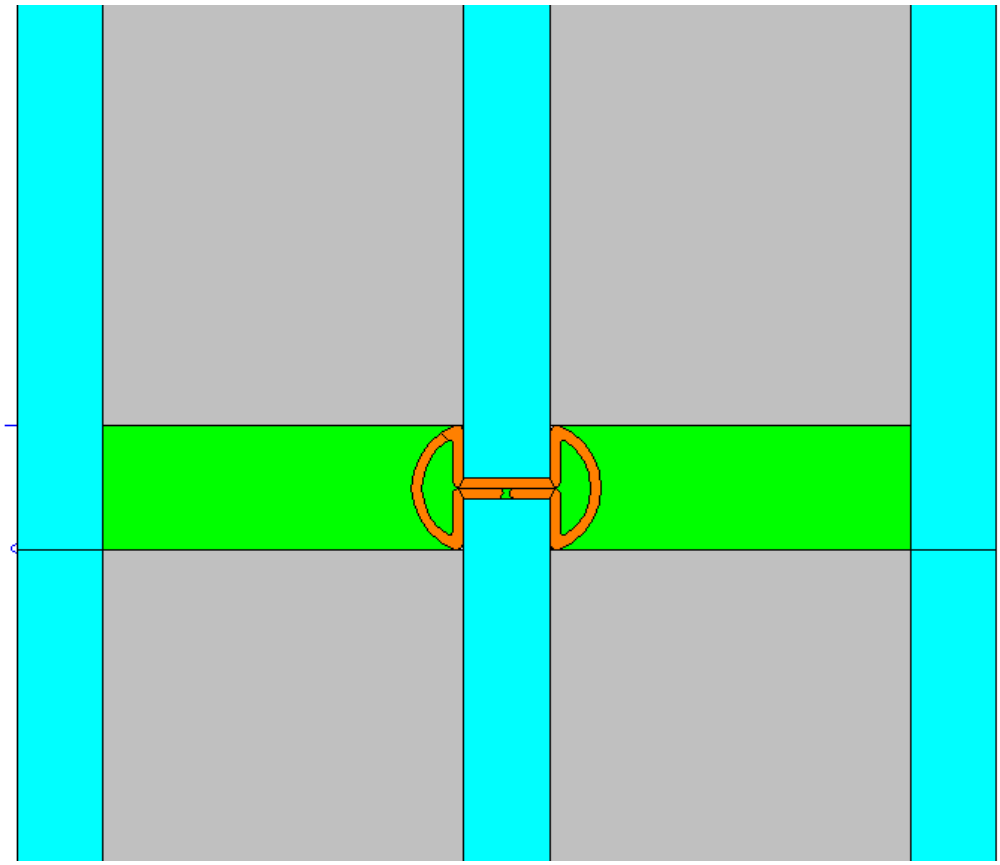


*Figure **8-45** Fill the cavities with Frame Cavity NFRC 100*

8.4 Storm Windows

Storm windows present a modeling problem different from most insulated glass (IG) units, because the spacing between the IG unit and the storm window is usually quite large, as shown in the figure below. As with all other product modeling, all relevant cross sections (head, sill, jambs, meeting rails and dividers) must be modeled in THERM.

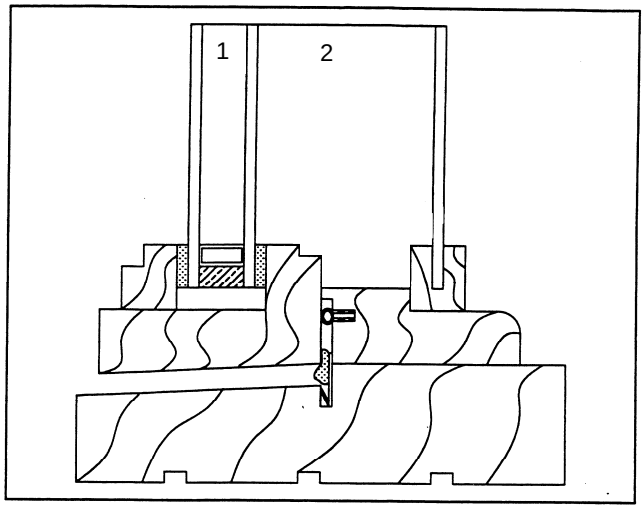


Figure 8-46 Product with an interior storm window.

8.4.1. Modeling Steps

The following steps can be used to model storm windows. These steps are discussed in more detail in the following sections.

If the product is *NOT* a single or double hung (i.e., it is a casement, fixed, picture, transom, awning, etc), do the following:

In WINDOW:

- Create a three-layer glazing system with the correct spacing between each of the glass layers in WINDOW.

In THERM

- Draw the frame components for the product in THERM.
- Import the glazing system into THERM
  Edge of Glass Dimension = 63.5 mm (2.5 inch)
  Glazing System Height = 150 mm (6.0 inch).
- Fill the air cavity below the glazing system and use the Library/Create Link feature to link that air cavity to the glazing cavity.
- Assign the boundary conditions
  Exterior Boundary Condition = **Use existing BC from library,** select "NFRC 100-2001 Exterior", and assign the **SHGC Exterior** U-factor tag to the exterior frame components
  Interior Boundary Condition = Use "convection plus enclosure radiation" for Glazing System, use appropriate "convection only" frame boundary condition for the frame components.
- Simulate the problem

If the product *IS* a hung or sliding window (i.e., a vertical or horizontal slider), where there will be a different gap width between the glazing system and the storm window for different frame profiles, do the following:

In WINDOW:

- Before starting the program, open the W6.INI file (usually found in the operating system directory – for example, in Microsoft Windows XP, that directory is c:\windows) and add the following line (if it does not already exist):
  - FrameToleranceGlazingSystemThickness=5

  Note: it is all one word, no spaces, and that it can go anywhere in the INI file. If this line already exists, but has some other value other than "5", change the value to "5". This represents the percentage tolerance between the frame and glazing system thickness. Setting it to one makes the thickness tolerance checking 500%, which should disable the WINDOW thickness tolerance checking, and therefore allowing the program to perform a calculation with glazing systems of different thicknesses.
- Create the two glazing systems with the actual thicknesses between the glazing system and the storm window, which will fit into the frame profiles that will be modeled in THERM.

In THERM

- Draw the frame components for the product in THERM.
- Import the glazing systems with the actual gap widths into the appropriate frame profiles with the following settings:
  Edge of Glass Dimension = 63.5 mm (2.5 inch)
  Glazing System Height = 150 mm (6.0 inch).
- Fill any air cavity between the bottom of the glazing system and the top of the frame profile as necessary, and use the Library/Create Link feature to link that air cavity to the glazing cavity.
- Assign the boundary conditions
  Exterior Boundary Condition = **Use existing BC from library,** select **"**NFRC 100-2001 Exterior", and assign the **SHGC Exterior** U-factor tag to the exterior frame components
  Interior Boundary Condition = Use "convection plus enclosure radiation" for Glazing System, use appropriate "convection only" frame boundary condition for the frame components.
- Simulate each model.

In WINDOW:

- Import the THERM frame profiles that have the correct geometry for the glazing systems into the Frame Library.
- In the Window Library, create the window, referencing the matching frames and glazing systems, including the meeting rail (you cannot "match" the glazing system thicknesses in the meeting rail, so just reference it).
- Calculate the overall product values from this combination of components.
- Close the program, open the W6.ini file, and do the following:
  - Delete the line FrameToleranceGlazingSystemThickness=5

  Or

  - Put a semicolon ";" in front of it which keeps it in the file, but makes it a comment instead of a command. This way it will be there the next time you need to use it.

    ; FrameToleranceGlazingSystemThickness=5

8.4.2. Storm Window Example

The following example problem, based on the product in Figure 8-23, is explained in detail in the following discussion.

8.4.2.1. Create Glazing System in WINDOW:

1. Make a glazing system consisting of three layers of glass, with the dimensions of the glazing cavity for the first gap, and the correct dimension from the glass to the storm window for the second gap.

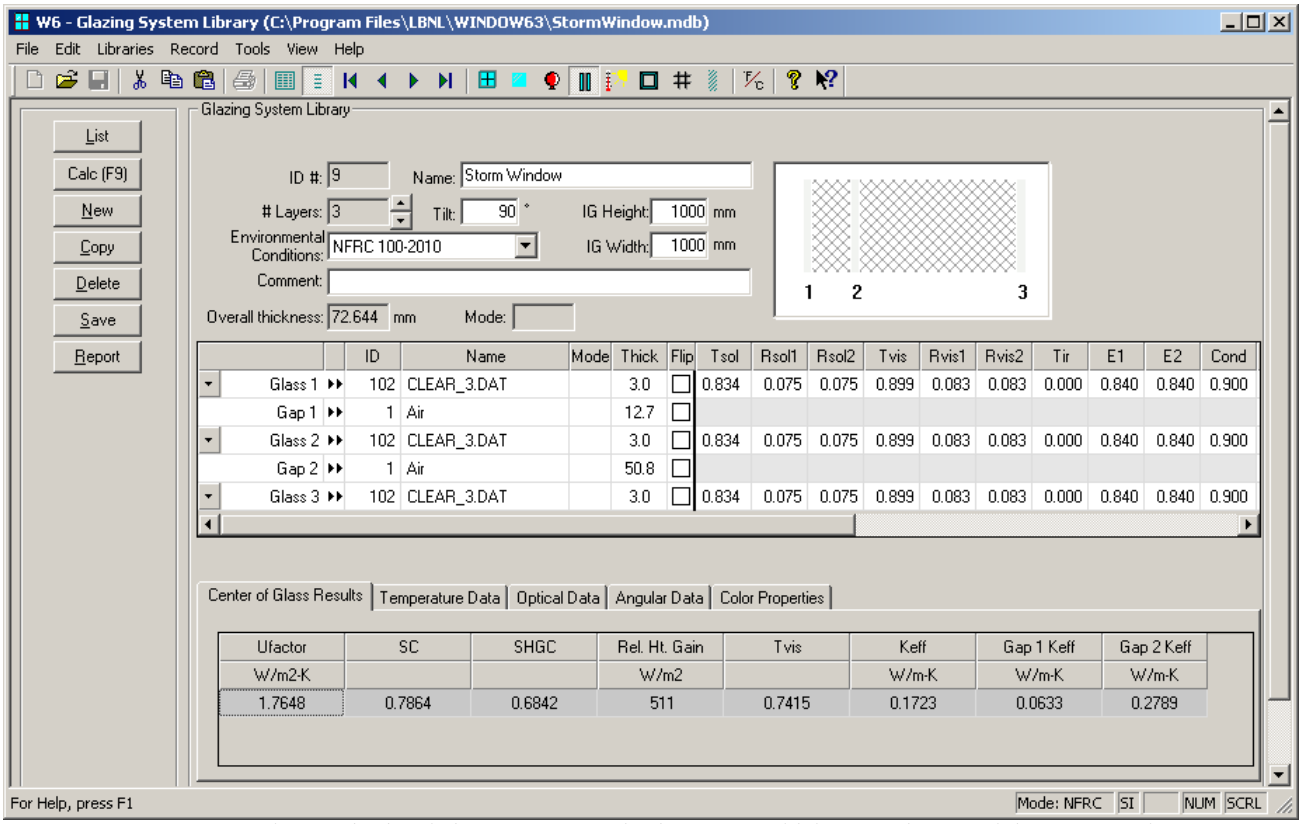


Figure 8-47 Make a triple glazed glazing system with a large gap width between the IG and the storm window.

8.4.2.2. Calculate U-factor in THERM

The steps for importing the glazing system into THERM are explained in more detail below.

1. Draw the required frame cross sections (such as head, sill, jambs, meeting rails, and dividers)
2. From the **File/Properties** menu, select the appropriate **Cross Section Type**, such as "Sill", "Head", "Jamb", and so forth.
3. Import the glazing system with the correct storm window cavity dimensions (created in WINDOW), in this case the glazing system with the 2" gap.
   Edge of Glass Dimension = 63.5 mm (2.5 inch)
   Glazing System Height = 150 mm (6.0 inch).
   Exterior Boundary Condition = **Use existing BC from library**, select "NFRC 100-2010 Exterior"
   Interior Boundary Condition = **Use convection plus enclosure radiation** for glazing system, and appropriate "convection only" boundary condition for the interior frame components.

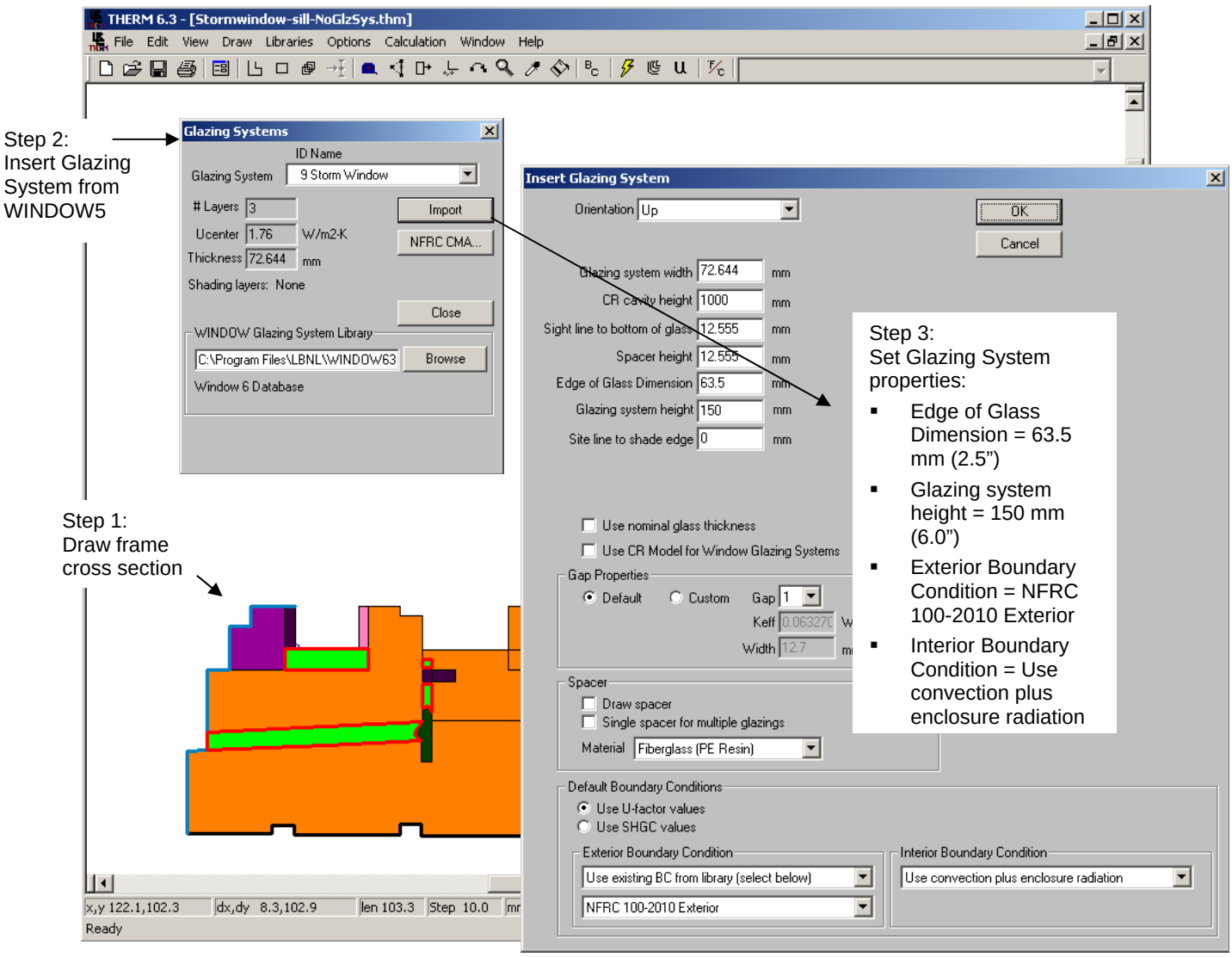


Figure 8-48 Insert the glazing system.

4. If necessary (as in this example because there is a gap between the bottom of the glazing cavity and the frame),use the material linker to create a separate polygon and link the properties to the 2″ glazing cavity.

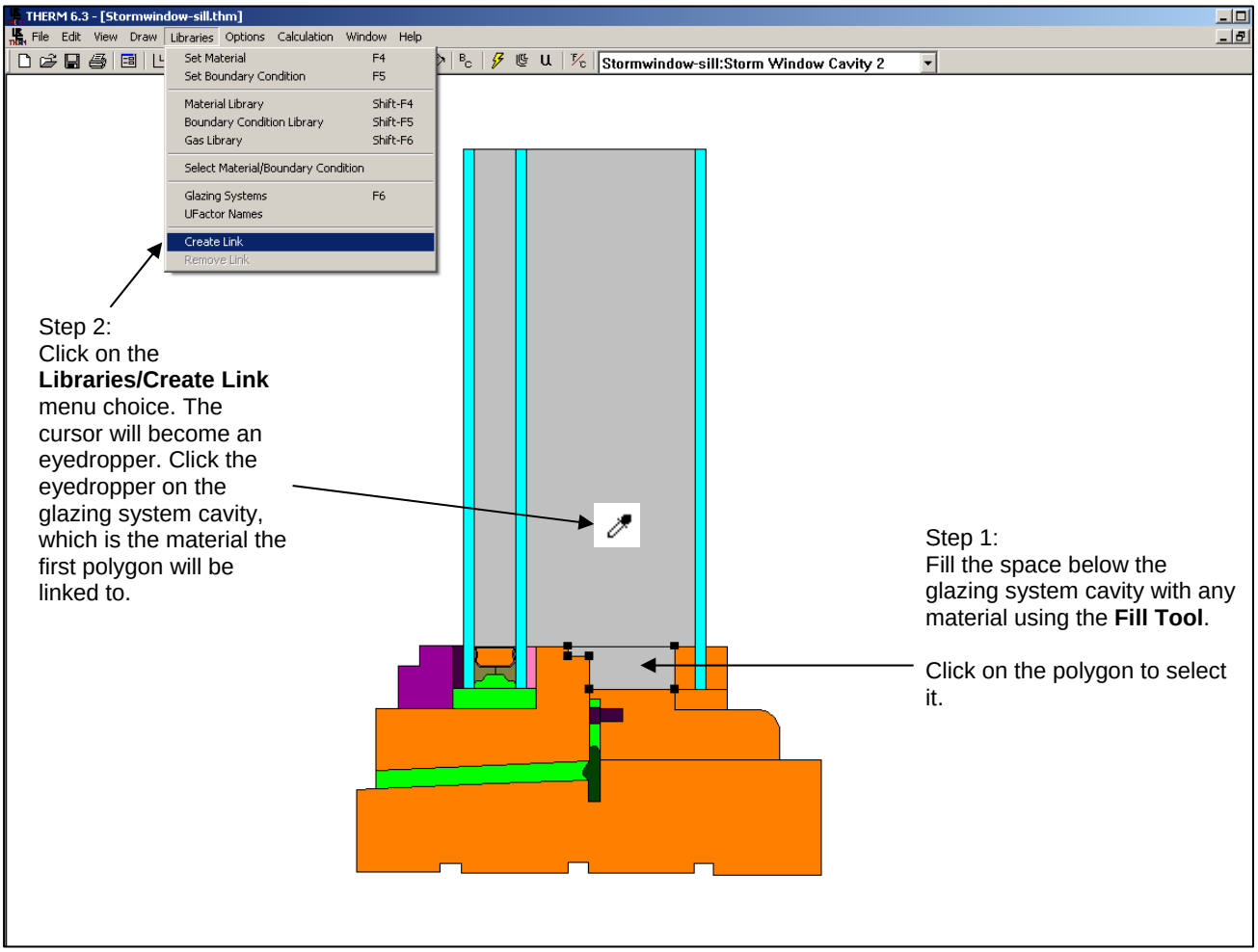


Figure 8-49 If needed, create a material link between the glazing system cavity.

5. Generate the **Boundary Conditions** by pressing the **BC** toolbar button. The figure below shows the boundary conditions for one storm window cross section. Make sure that the interior boundary conditions have the Radiation Model set to "AutoEnclosure".

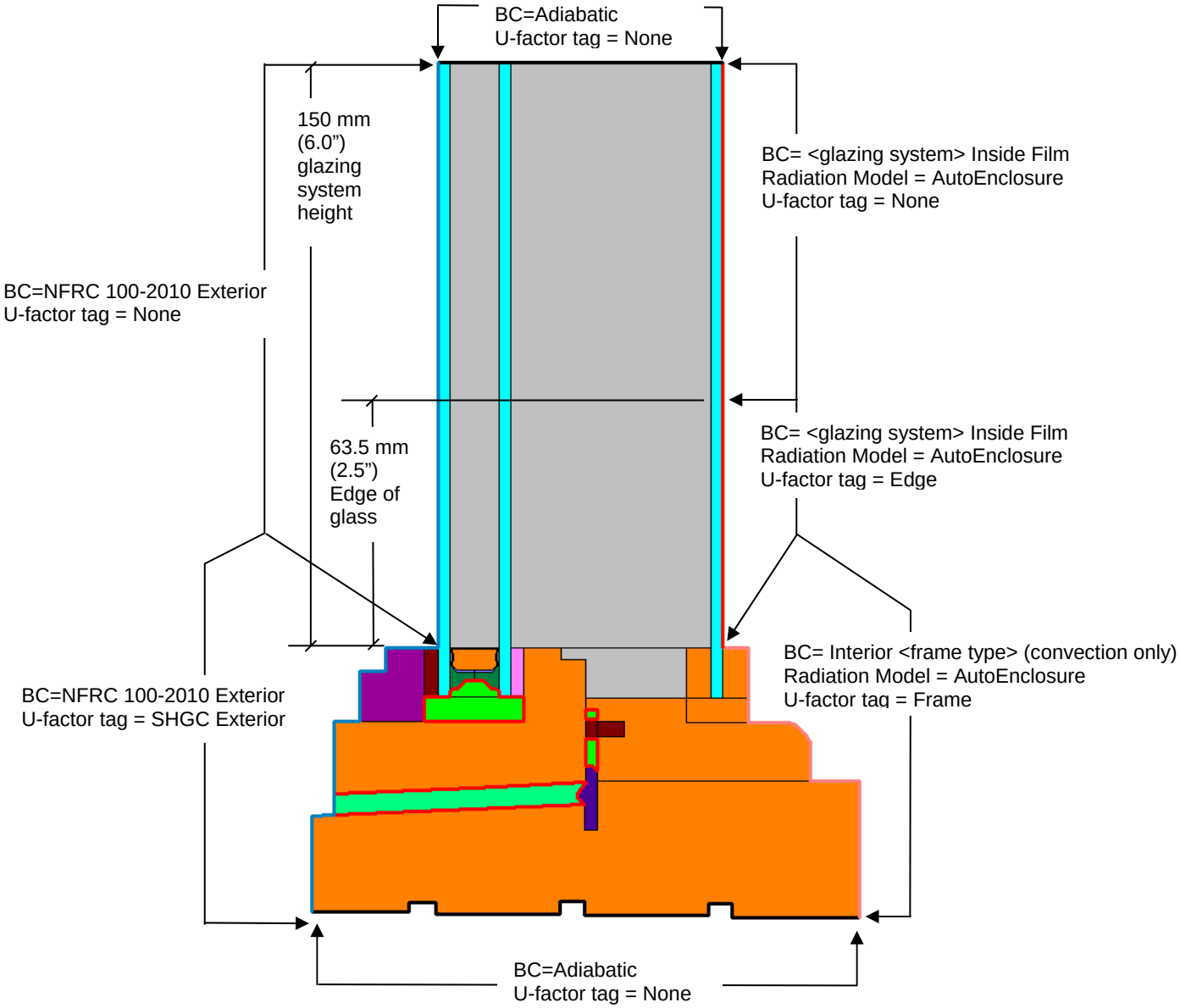


Figure 8-50 Define the boundary conditions.

6. Simulate the problem and save the file.

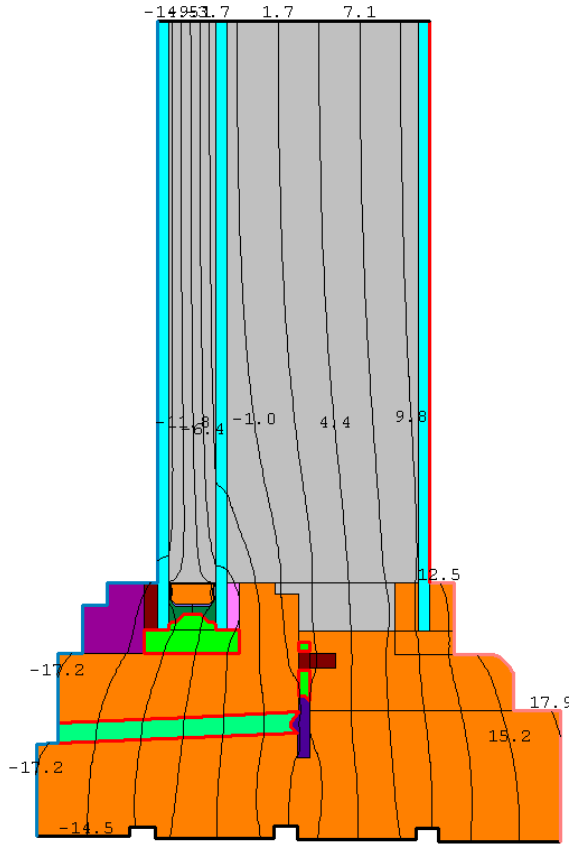


Figure 8-51 Simulate the file.

8.4.3. Steps for Storm Window Condensation Resistance Calculation

The Condensation Resistance model is only appropriate for *horizontal* frame components such as Head and Sill elements – THERM will not calculate the Condensation Resistance for a file with the **Cross Section Type** set to "Jamb" or "Vertical Meeting Rail".

There are two methods for calculating the Condensation Resistance information in THERM, which will be used in WINDOW to calculate the total Condensation Resistance of the product:

- Check the "Use CR Model for Window Glazing System" checkbox when importing a glazing system

  OR

- In the **Options** menu, **Preferences** choice, **THERM File Options** tab, check the "Use CR Model for Glazing Systems", as shown in the figure below.

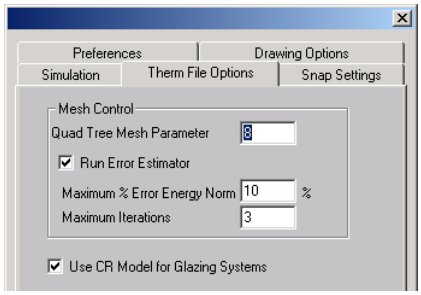


Figure 8-52 In Options/Preferences/Therm File Options, check the "Use CR Model for Glazing Systems" checkbox.

When the CR model has been "turned on", red boundary conditions will appear inside the glazing system, and the following steps should be taken to simulate the file:

1. Check the emissivities of these boundary conditions. They should be the following:
   - Emissivity of the surrounding surface, such as 0.84 for standard glass, 0.90 for painted metal and most other frame materials, 0.20 for mill finish metal, and so forth.
   - 1.0 for the adiabatic (open end) of the glazing cavity.
2. Simulate the model. The program will calculate both U-factor results and the Condensation Resistance results if the CR model is checked.
3. Import the results into the WINDOW **Frame Library** and use the file to create the whole product in the **Window Library** as applicable.

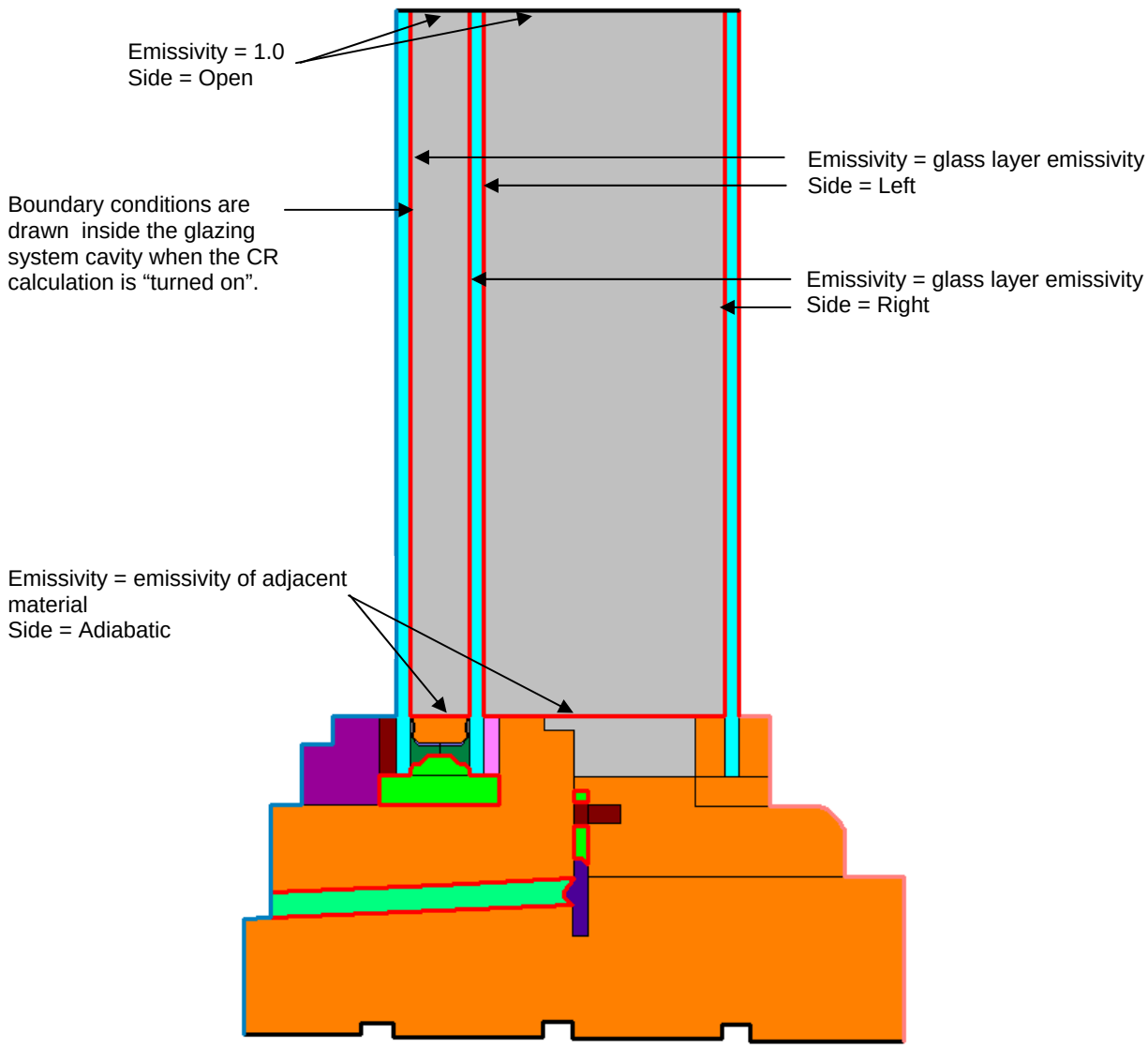


Figure 8-53 Red boundary conditions will appear inside the glazing system when the CondensationResistance option is turned on. Check the emissivities of each boundary condition.

8.4.3.3. Calculate the Total Product Values in WINDOW

The following discussion explains how to model the whole product values for the storm window in WINDOW.

- Import the THERM files into the WINDOW **Frame Library**.

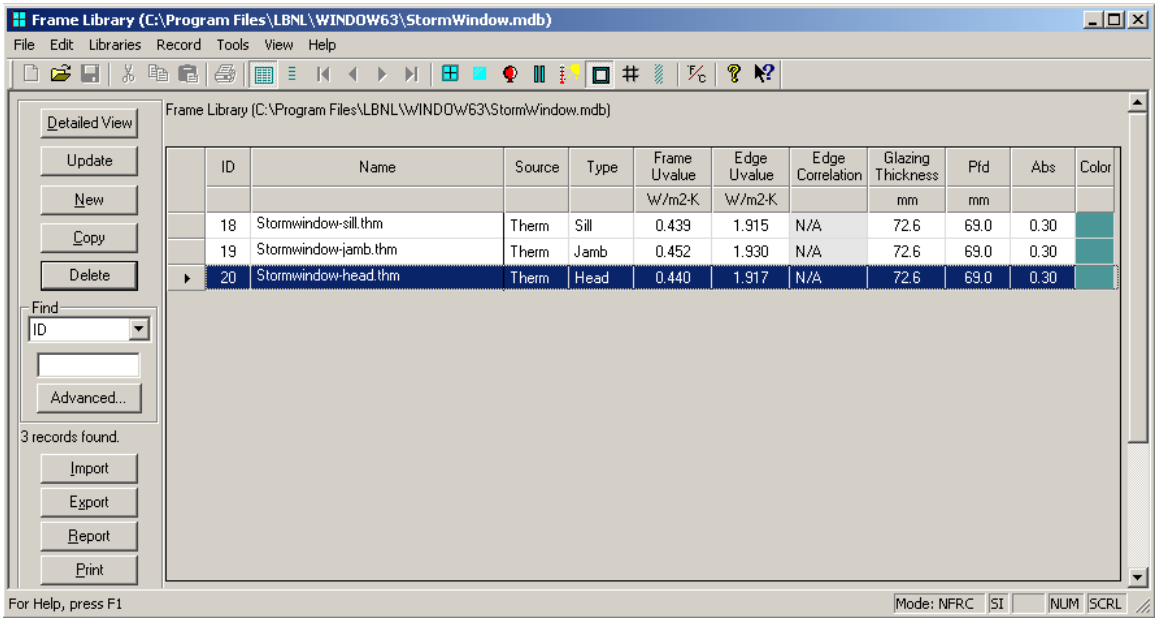


Figure 8-54 Import the storm window THERM files .

- In the WINDOW **Window Library**, construct the storm window from the THERM files and the glazing system previously defined, and calculate the total product values.

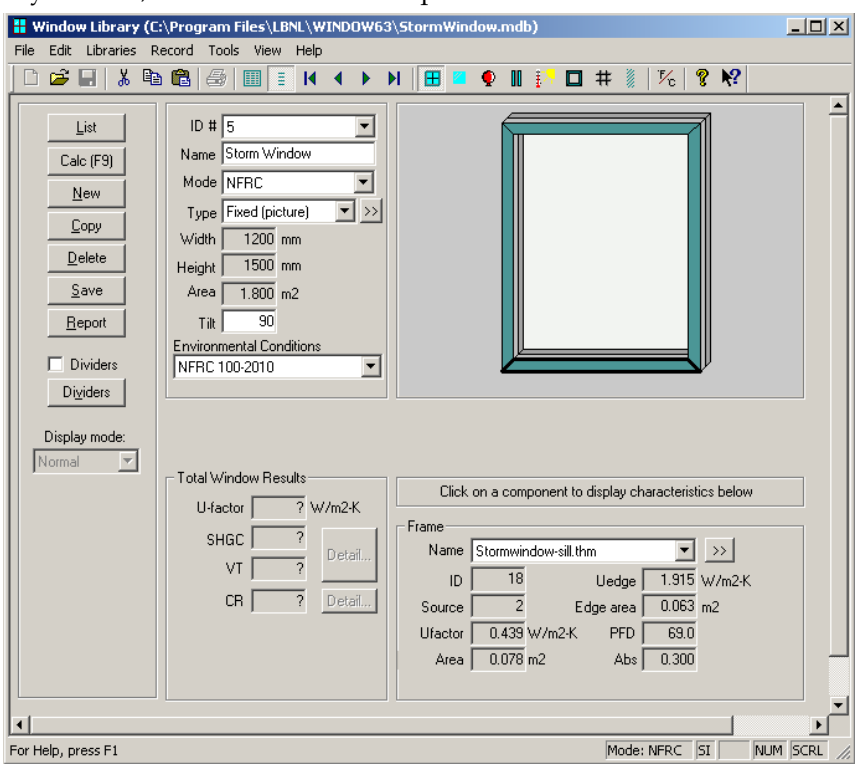


Figure 8-55 Storm window created in the Window Library to obtain total product results.

8.5 Skylights

This section discusses the modeling procedures for skylights, which are modeled in sections in a similar manner to other products. In addition, in accordance with *NFRC 100*, skylights are modeled at a 20° slope from horizontal.

8.5.1. Skylight Modeling Steps

The steps for modeling a skylight are as follows:

In WINDOW:

- Create the skylight glazing system in WINDOW:
  - Set **Tilt** to "20" degrees

In THERM:

- Draw the required frame cross sections in THERM, for example a head, sill, and jambs if they are all different, untilted. Because the tilt of the jambs will be in the z-direction, which is not possible to display in the two dimensional viewing of THERM, they will be drawn vertically and the gravity vector oriented properly to reflect the tilt in the z-direction.
- Do not use the Condensation Resistance Model on any of the THERM skylight cross sections. WINDOW will calculate the CR value based on the temperatures from the U-factor results. (Even if the THERM cross sections are modeled with CR enabled, WINDOW will use the U-factor temperature results rather than the CR temperature results when calculating the whole product CR value).
- Set the **Cross Section** value in **File/Properties** as follows:
  - For **Sill**: set **Cross Section** to "Sill", **Gravity Vector** should face "Down"
  - For **Head:** set **Cross Section** to "Head", **Gravity Vector** should face "Down"
  - For **Jambs:** set **Cross Section** to "Sill", set **Gravity Vector** to "Right"
- The Frame Cavity height is not used by the program for the skylight cross sections, as long as the Types are defined properly as shown above, so the default value of 1000 mm can be left unchanged.
- Insert the glazing system from WINDOW into the frame cross sections with the **Edge of Glass Dimension** field set to 150 mm (6.0 inches). The **CR cavity height** field can be set to any value (you can leave it set to the default of1000 mm) because the U-factor temperatures not the CR temperatures will be used in WINDOW to calculate the overall CR value).
  - Insert the **Sill** glazing system with orientation up
  - Insert the **Head** glazing system with orientation down
  - Insert the **Jamb** glazing system with orientation up
- Assign the boundary conditions. Interior Boundary conditions have the following settings:
  - **Radiation Model** set to "AutoEnclosure"
  - **Frame Boundary Conditions:** set to the appropriate "Interior (20 tilt) …" choices
- Tilt the cross section 20 degrees from horizontal:
  - For a **Sill** or **Head**, rotate the entire model 70 degrees clockwise
  - For **Jambs**, do not rotate the model at all

- Simulate the skylight cross sections and save them.
- View the U-factor for the cross section, and make sure the "Projected in Glass Plane" is selected from the Projection pulldown list, as shown in the figure below. This will ensure that the projection will be correct for the tilted cross section.

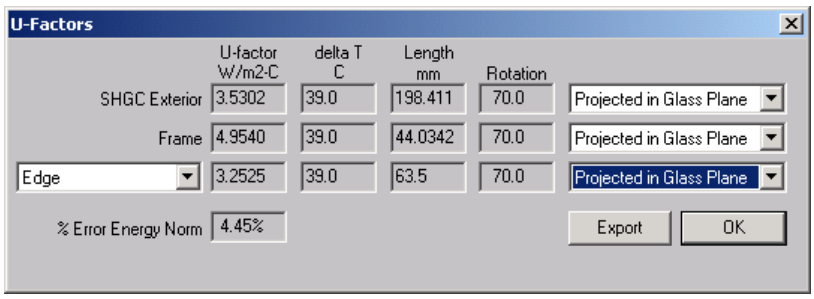


Figure 8-56 Make sure the "Projected in Glass Plane" projection option is selected for the tilted cross section.

There is a circumstance where THERM will not calculate the total frame length correctly, and it is necessary to enter a "Custom Frame Length" into the U-factor dialog box above. It occurs when a section of an adiabatic boundary "overlaps" a boundary with a U-factor tag in the projected dimension over which the length is being calculated. This is explained in detail in Chapter 6, Section 6.6.6.

- Import the components into the WINDOW Frame Library (and Divider Library if appropriate)
- Construct the whole product in the WINDOW Window Library to get the overall product results.

8.5.2. Skylight Mounting Details

There are two ways that skylights can be mounted into a roof system, either flush-mounted (also called inset-mounted) or curb-mounted. The figures below show these two different mounting styles. Each mounting style has a slightly different definition of the adiabatic boundary condition, and each will have a different projected frame length. The rules for modeling can be found in *NFRC 100* and the NFRC Technical Interpretations. To model curb mounted skylights, if the projected frame height is zero, define a Frame U-factor Surface Tag 0.25 mm (0.01 inches) up the interior of the glass, which will result in a non-zero frame height.

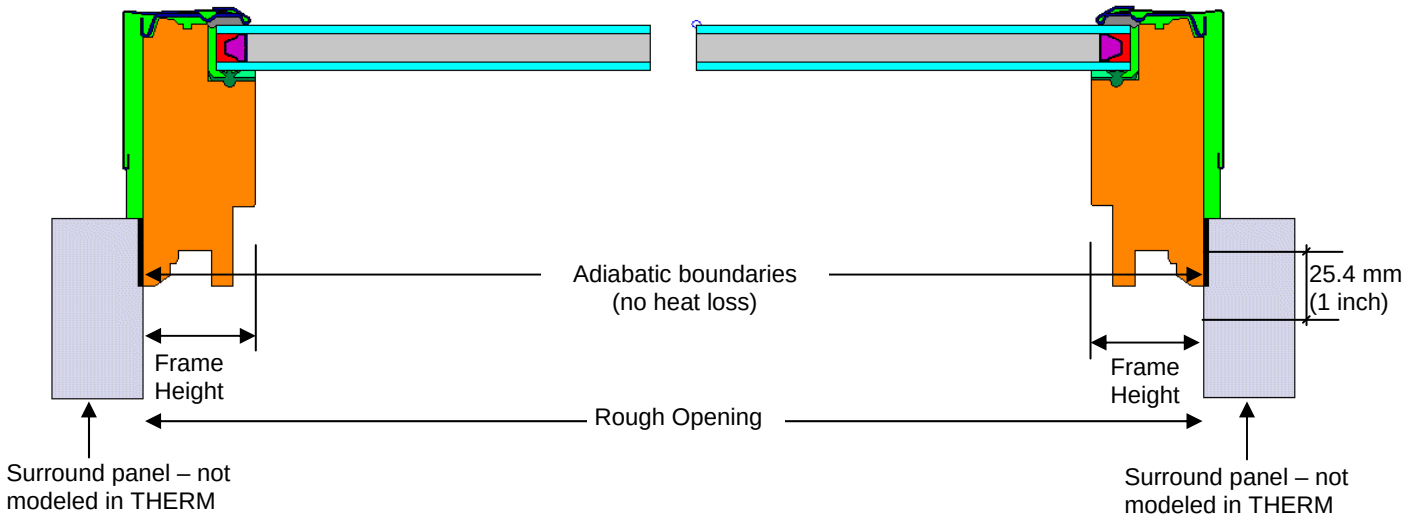


Figure 8-57 A flush-mounted (or inset-mounted) skylight.

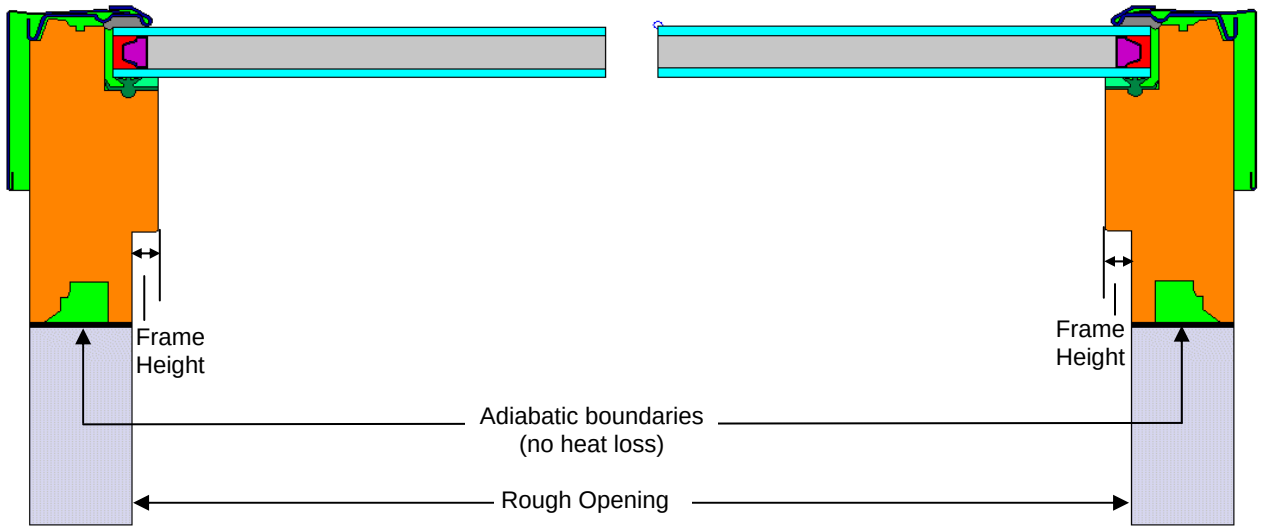


Figure 8-58 A curb-mounted skylight.

8.5.3. Example Flush Mounted Skylight Problem

This example assumes a flush-mounted skylight.

In WINDOW:

1. **Glazing System Library:** Make a glazing system with a tilt of 20° off horizontal. In this example, the glazing system is called **Skylight Double Glz** and is made up of generic glass layers.

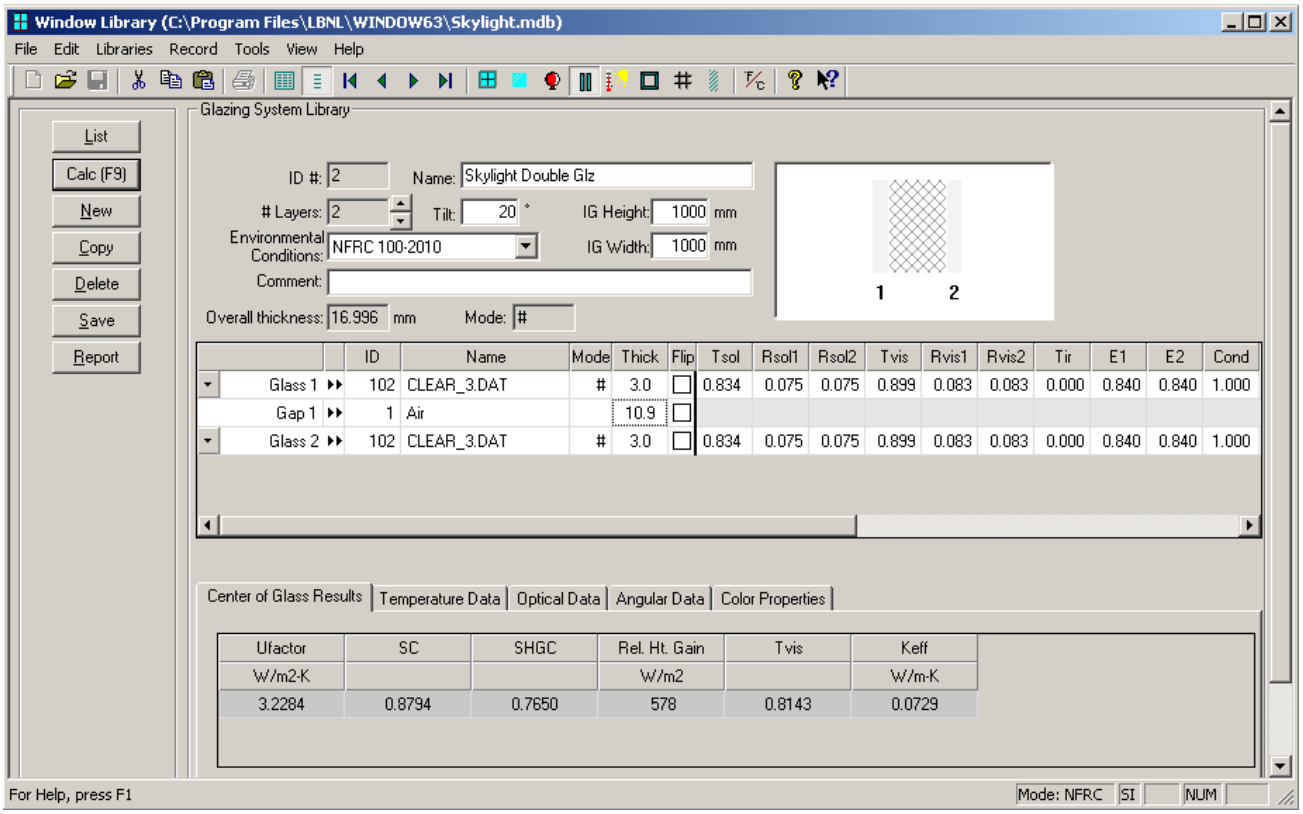


*Figure 8-59 Make new glazing system in the **Glazing System Library** with **Tilt** = 20 degrees.*

2. **Save the file:** Make sure to save the glazing system (**Record** menu**, Save** choice**.**).

In THERM, for Sill:

1. Draw the appropriate cross sections for the Sill.

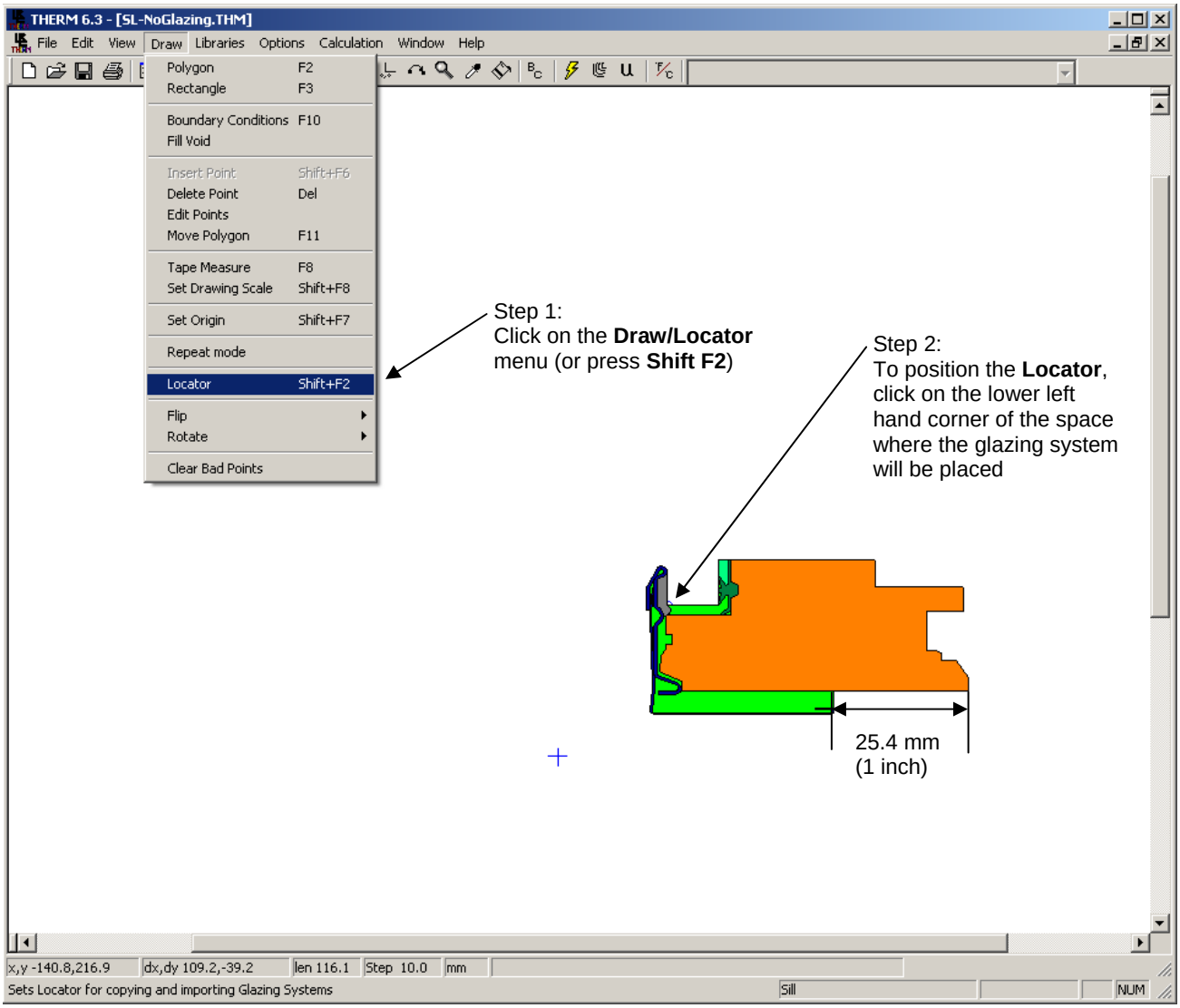


Figure 8-60 Position the locator so that the first glazing section can be inserted.

2. Insert the glazing system for the Sill, with the following settings:
   - **Orientation** = Up
   - **Cavity height** = 1000 mm
   - **Sight line to bottom of glass** = measure this value with the tape measure or get from dimensioned drawings
   - **Spacer height** = measure this value with the tape measure or get from dimensioned drawings
   - **Edge of Glass Dimension** = 150 mm (6.0 inches)
   - **Draw spacer** = not checked

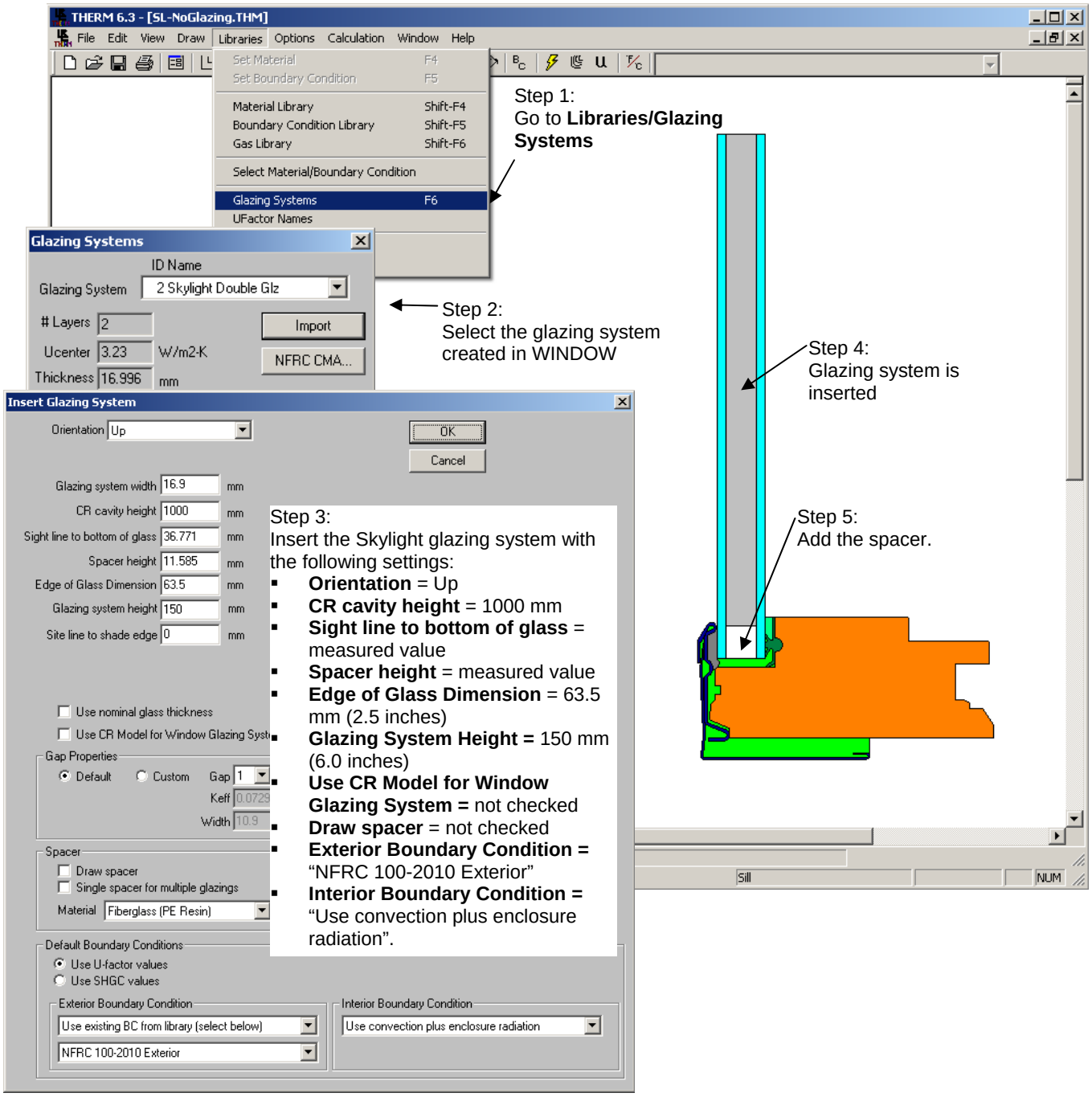


Figure 8-61 Insert the glazing system .

- Note: If using the Multiple Glazing Options feature of THERM, set up the multiple glazing options before tilting the profile, so that all the Boundary Conditions become defined automatically for the glazing options by THERM. Then tilt the cross-section.

3. **Assign Boundary Conditions and U-factor tags:** Click on the Boundary Conditions (BC) toolbar button and correct any problems encountered with the geometry (see Section 6.5.3, "Voids, Overlaps, and Bad Points" in this manual).

4. Tilt the cross section to be 20 degrees off the horizontal plane. For this example sill cross section, click on the **Draw** menu, **Rotate/Degree** choice, and enter **70** degrees **Clockwise**.

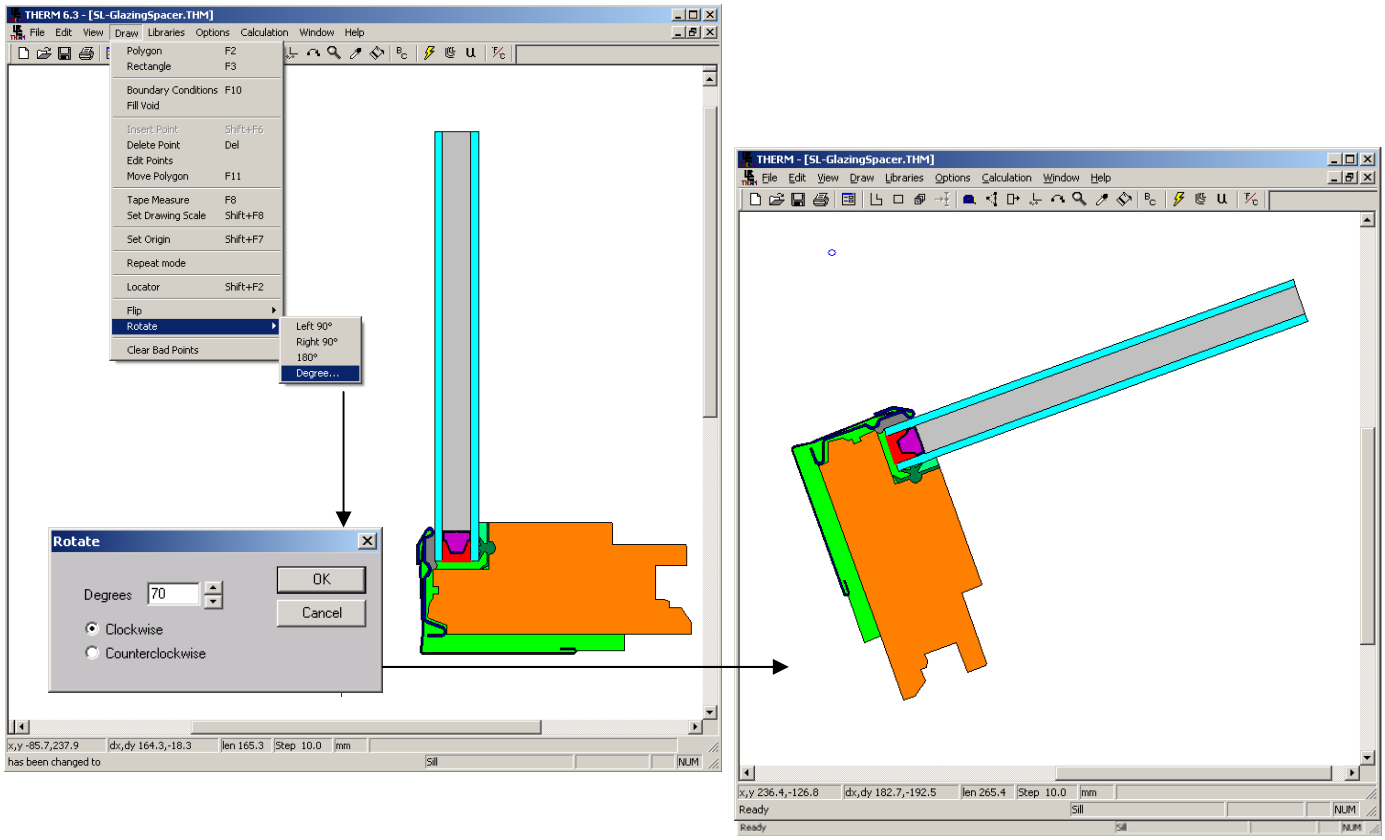


Figure 8-62 Rotate the sill cross section AFTER assigning Boundary Conditions.

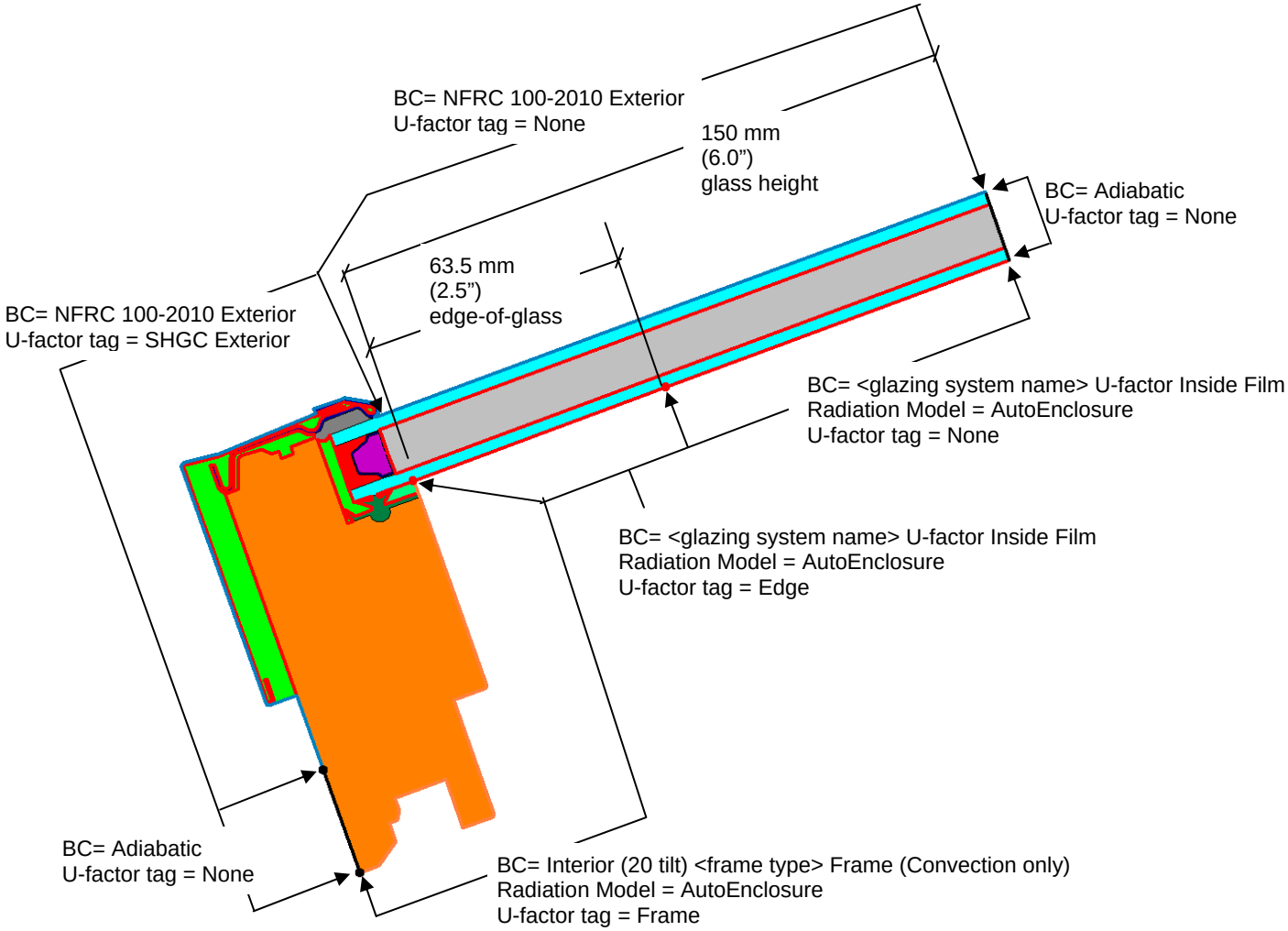


Figure 8-63 Boundary condition and U-factor tag settings for skylight Sill example.

6. Check the **Gravity Vector** for the Sill cross section (**View/Gravity Arrow**), which should point down.

7. Simulate the file.

8. Click on the Show U-factors button to view the U-factors dialog box. Make sure that the projection is set to "Projected in Glass Plane" which will allow the program to calculate the correct projected frame dimensions with a tilted cross section.

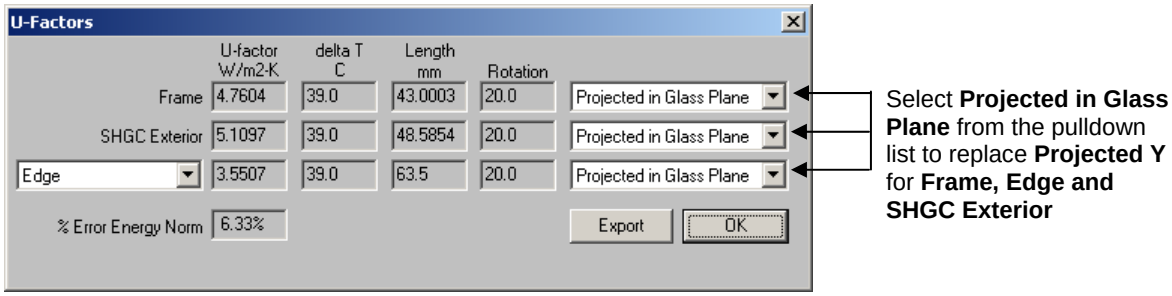


Figure 8-64 Select the Projected in Glass Plane for the projected frame dimension calculation.

In THERM, for Head:

1. Create the cross section for the Head, set the **Cross Section Type** to "Head", and import the glazing system facing **Down** (in order to get the Gravity Vector pointing in the proper direction).
2. Assign the Boundary Conditions as shown in the figure below.
3. Tilt the Head cross section so that it is 20 degrees off horizontal (click on the **Draw** menu, **Rotate/Degree** choice, and enter **70** degrees **Clockwise)**.
4. Check the Gravity Vector (**View/Gravity Arrow**), which should be pointed down.

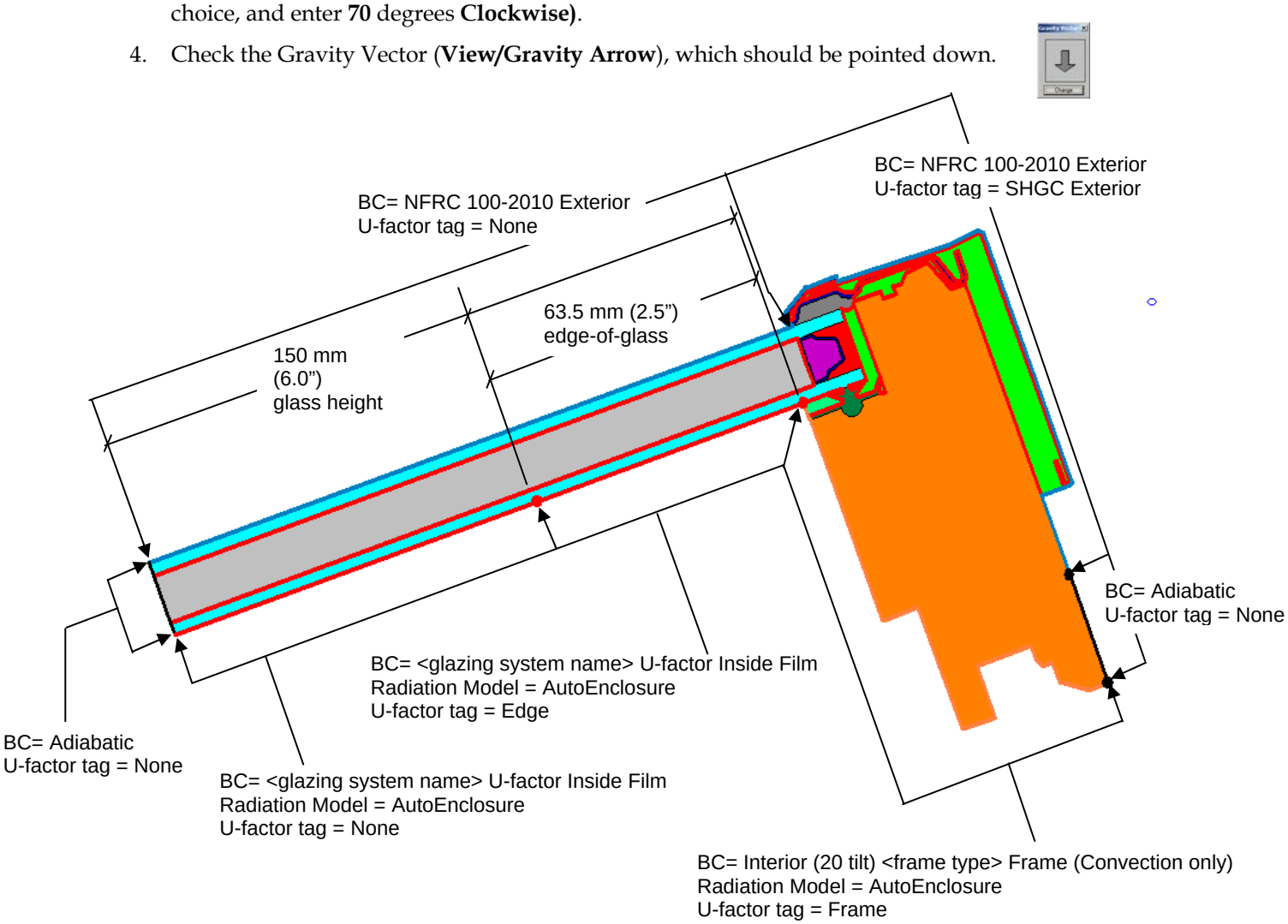


Figure 8-65 Boundary condition and U-factor tag settings for skylight Head example.

5. Simulate the file.

6. Click on the Show U-factors button to view the U-factors dialog box. Make sure that the projection is set to “Projected in Glass Plane” which will allow the program to calculate the correct projected frame dimensions with a tilted cross section.

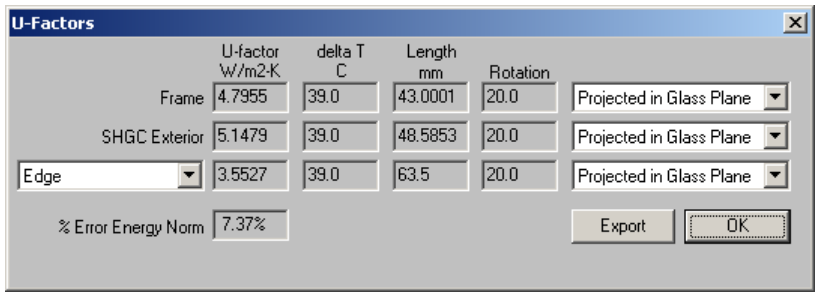


Figure 8-66 Select the Projected in Glass Plane for the projected frame dimension calculation.

In THERM, for Jamb:

1. Create the cross-section for the Jamb. The steps are similar to modeling the head and sill, except for the following:
   - Jambs are modeled in the vertical direction
   - The Cross Section Type is set to “Sill”
   - The glazing system is oriented “Up”
   - The gravity vector is set by hand to “Right”

2. Simulate the file.
   Because the cross section is not rotated, the projection in the U-factor dialog box can be set to either “Projected Y” or “Projected in Glass Plane”; both settings will result in the same answer.

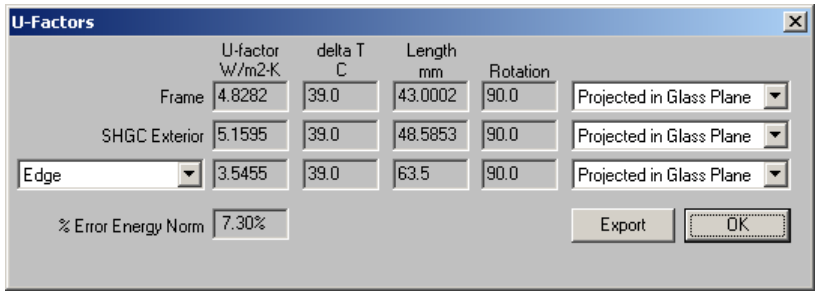


Figure 8-67 The projection can be set to either “Projected Y” or “Projected in Glass Plane”; both will result in the same answer.

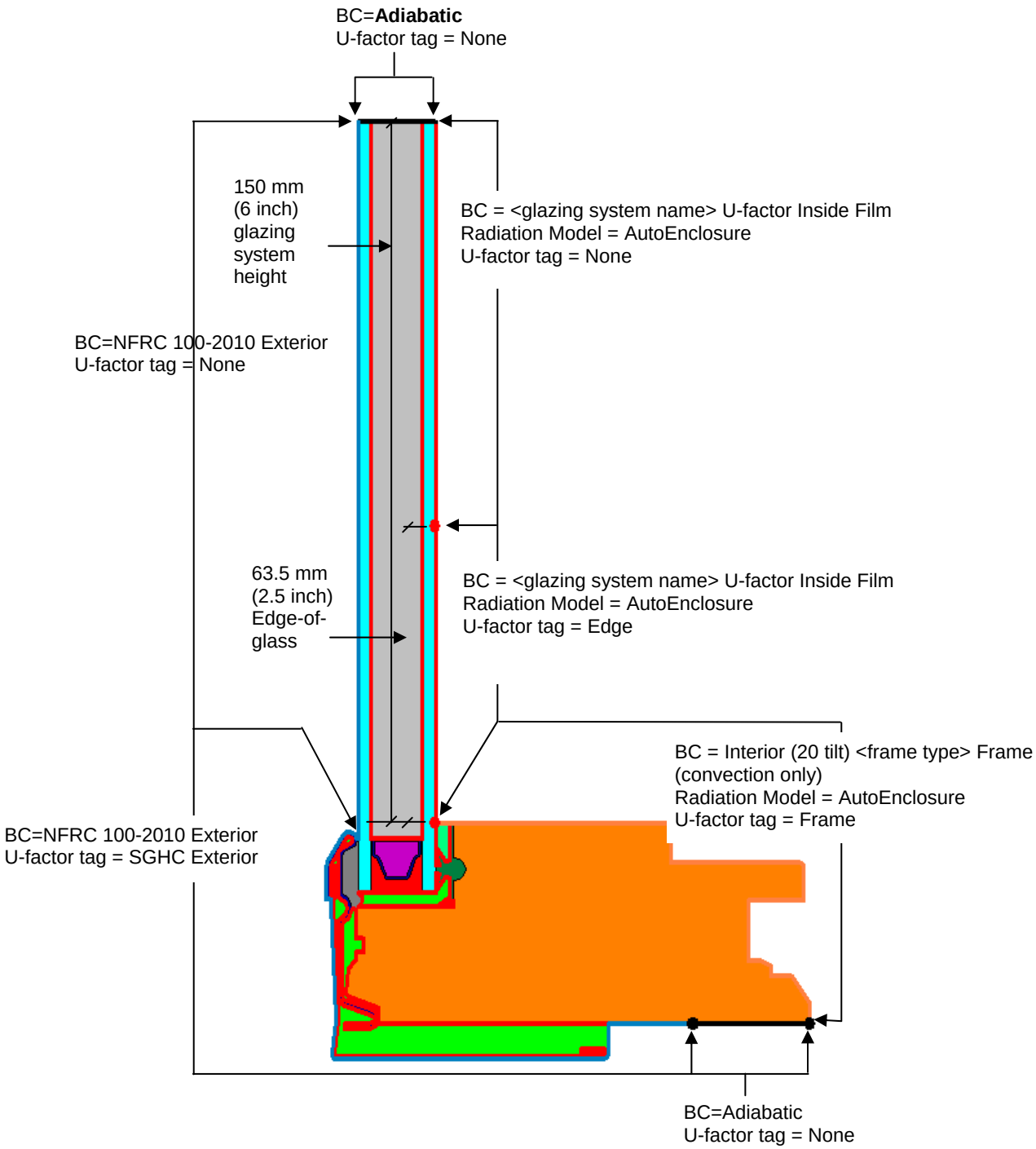


Figure 8-68 Boundary condition and U-factor tag settings for skylight jamb example.

In WINDOW, Calculate the Total Product U-factor:

1. In the WINDOW **Frame Library**, import the THERM files for the Head, Sill, Jamb and any other needed cross sections that were modeled.

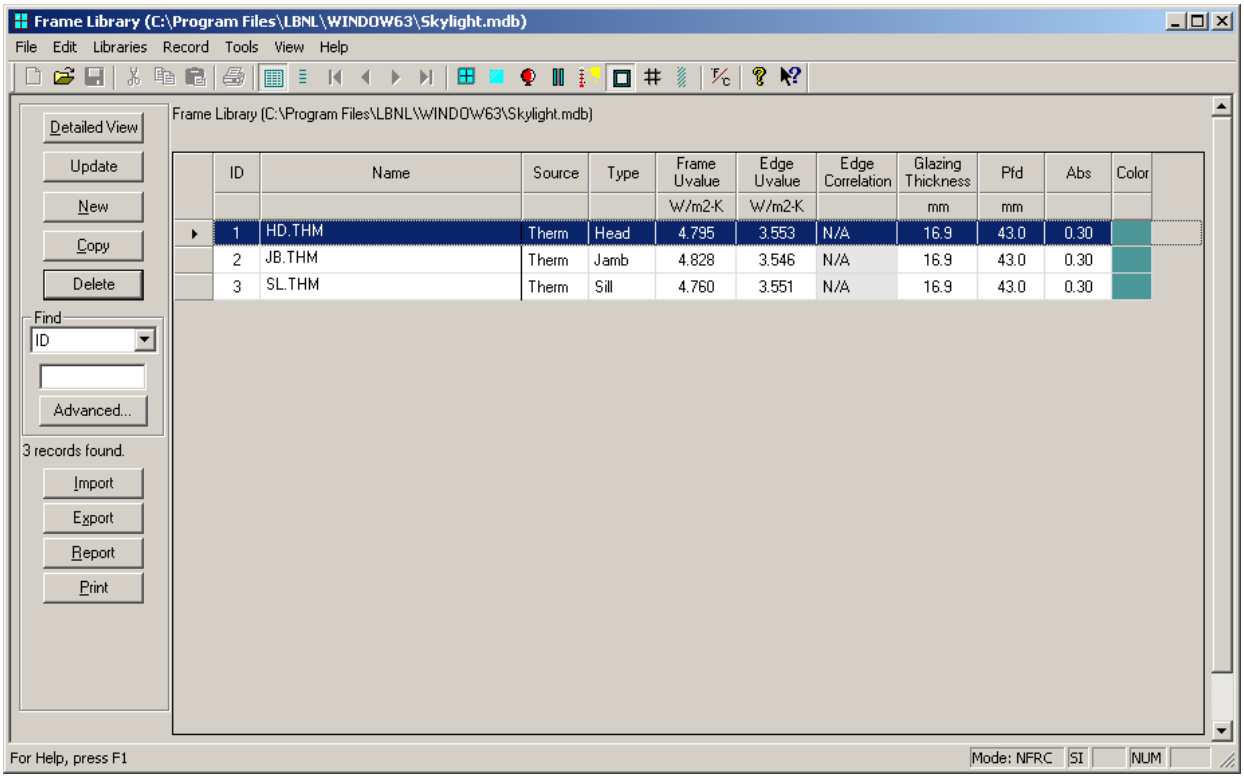


Figure 8-69 Import the skylight THERM files into the WINDOW Frame Library.

2. Construct the whole skylight in the WINDOW **Window Library** by using the THERM files for the frame components and the glazing system for the center of glass. Make sure that Type = Skylight and Tilt = 20.

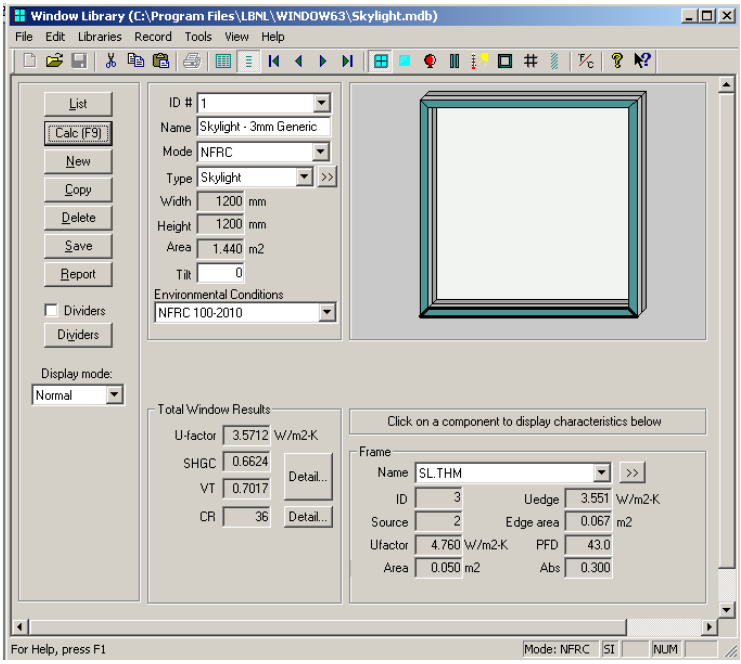


Figure 8-70. Create the whole skylight in the Window Library.

8.5.4. Domed Skylights / Glass Block

The following describes the steps for simulating a domed skylight or glass block product to obtain the total product U-factor.

1) Determine the glazing components conductance, Cs, per ASTM C1363.
2) Calculate the effective conductivity (to 3 significant figures) in Btu/h/ft/°F by the following formula:

   Keffglass = Cs * t / 12,

   Where:

   Cs = Conductance of glass as determined per ASTM C1363 test
   T = thickness of sample in inches
   12 = conversion factor from conductance to conductivity (Btu-in/hr/ft2/°F to Btu/h/ft/°F)

3) Make a new a glass layer in the Glass Library, and set the conductance to the calculated Keffglass value.
   a. Enter the thickness of the sample
   b. If the sample is glass, enter 0.84 for the emissivity of the front and back surfaces
   c. If the sample is not glass, then the emissivity of the material shall be determined per the applicable ASTM standard.
   d. The solar, visible, and Tir spectral data values shall not be used and therefore the default values shown do not need to be modified.
4) Build the glazing system to be used in the THERM model in the Glazing System Library
5) Import the glazing system into the applicable THERM model.

Glass Block Example

1) The Cs value from the ASTM C1363 test = 0.635 Btu/hr-ft2-°F. The glass = 1.008" thick.
2) Keffglass = 0.635 * 1.008 / 12 = 0.0533 Btu/hr-ft-°F = 0.092 W/m-K
3) In the Glass Library, make a new record, and set the Conducivity to 0.092 W/m-K. Set the front and back emissivity to 0.84.

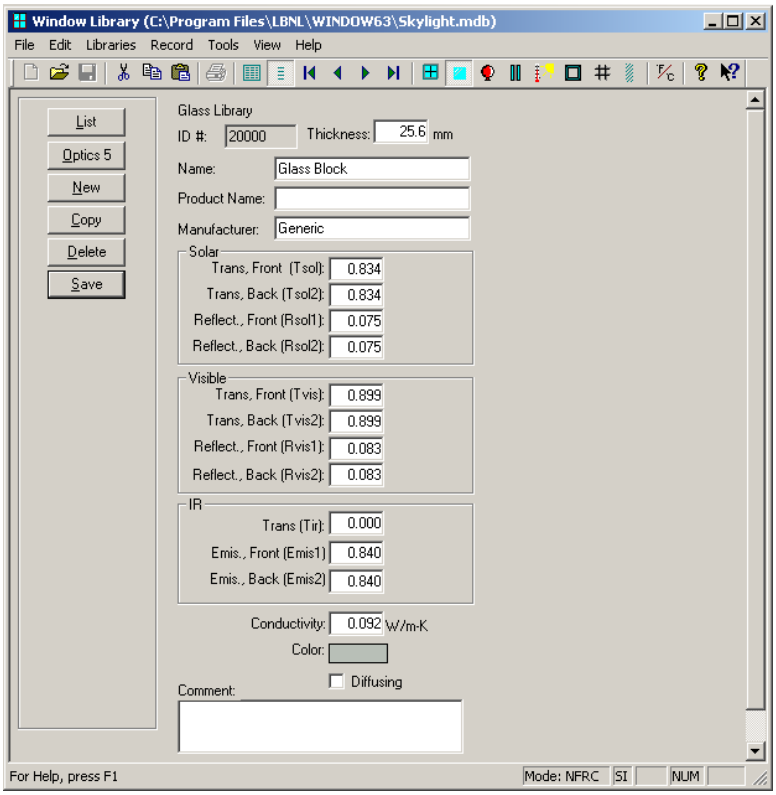


Figure 8-71. Create a new record in the Glass Library for the Glass Block tested value.

4) In the Glazing System library, create a record for, in this example, a glass block glazing system using the new glass layer created in the Glass Library, and calculate the properties.

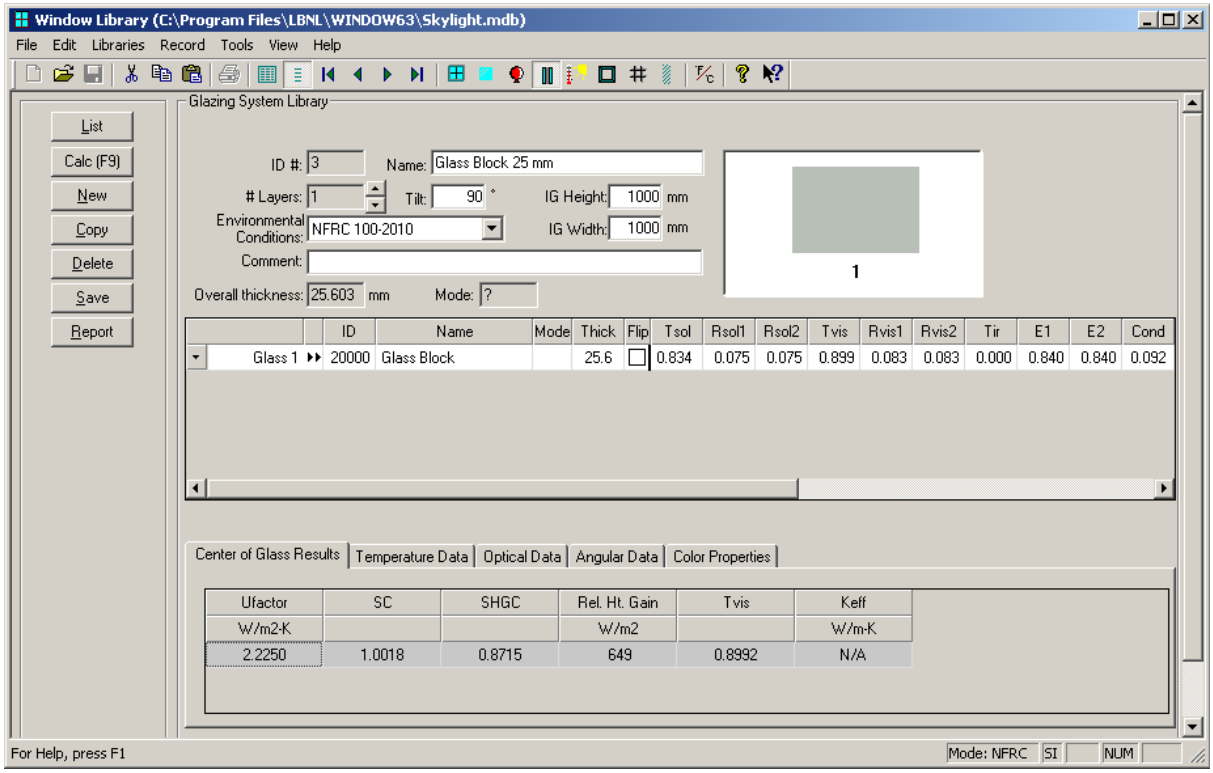


Figure 8-72. Create a new record in the Glazing System Library using the Glass Block layer.

5) Import the glazing system into the applicable THERM model and simulate the product.
6) Calculate the total product U-factor using a spreadsheet, rather than in WINDOW.

8.5.5. Sloped Glazing Systems with Large Gaps:

WINDOW6 cannot calculate the Center-of-Glass values for gap widths equal to or greater than 30 mm (1.17") on a 20° slope.

In order to model this situation, follow these steps:

In WINDOW:

- In the Glazing System Library, make the IG unit to be modeled except define the gap width as 29.5 mm (or some other value less than 30 mm) with a 20° slope.
- Obtain the effective conductivity (keff) of the gap from the "Keff" field in the "Center of Glass Results" tab in the Glazing System Library
- Multiply by the ratio of the actual gap width divided by the gap width used in the Glazing System model. This result is a new keff that will be used in the Therm model.

In THERM:

- Insert the glazing system and check "allow editing of IG polygons"
- Move one of the glass layers so that the gap width is the actual gap width of the product.
- Make a new material with a conductivity equal to the
- Assign this new material to the glazing system gap width.
- Simulate the file as usual.

8.6 Tubular Daylighting Devices

Tubular skylights are a group of products that can loosely be defined as non-standard skylight products. Their primary purpose is to provide daylighting, and not view to the outside. For this reason, there are some arguments whether these products can be considered fenestration at all. However, because they penetrate the building envelope and provide some of the essential functionality of a fenestration system (i.e., daylight) they are considered to be a fenestration product.

The NFRC Executive Committee has decided that the simulation method for determining a U-factor for TDD and HTDD products is effective until March 19, 2012. Effective March 20, 2012, TDD and HTDD product U-factors can only be achieved by physical testing per NFRC 102.

The assumptions and methodology for modeling these products differs considerably from typical fenestration products. The following is a list of standardized assumptions to be used when modeling tubular daylighting devices:

- D = Shaft Diameter = 350 mm (14 in.)
- L = Shaft Length = 750 mm (30 in.)
- Standard dome mounted on 350 mm (14 in.) shaft
- Exterior boundary conditions are applied on the exterior side of the dome
- Standard ASHRAE Attic boundary conditions are applied to the exposed surfaces of the shaft,
- Bottom of the shaft is mounted in a 250 mm (10 in.) thick surround panel (standard surround panel material, such as EPS),
- Bottom of tubular skylight is covered with light diffusing plate (manufacturer supplied).

The first step is to draw the geometry of the tubular daylighting device in THERM, per the manufacturers' drawings and using the assumptions above (see Figure 8-46). Material properties, other than frame cavities, should be assigned from the THERM material library.

Next calculate the effective conductivity of the shaft and dome cavity. The set of equations and assumptions required to calculate effective conductivity of this cavity is detailed in Curcija (2001). A custom spreadsheet is also designed to facilitate this calculation and is available on request from NFRC (tubes_keff.xls). The information necessary to calculate k_{eff} of this cavity are the average temperatures and emissivities of the inside surface of the diffuser plate at the bottom of the cavity, and inside surface of the dome at the top of the cavity. Initially these temperatures need to be estimated, a reasonable starting point being -2°C (28.4 °F) for the diffuser plate and –17°C (1.4 °F) for the dome (when the dome is single glazed). After the THERM simulation is calculated with the keff determined from these estimated temperatures, find the average temperatures for the diffuser plate and dome surfaces using the THERM tape measure tool. If the resulting average temperatures differ by more than 1° C (2 °F) from the estimated values, a new keff shall be calculated and the THERM simulation repeated with the new keff. This process should be repeated until the criterion of 1 ° C (2 °F) temperature difference is satisfied. In many cases, one iteration is enough, but the temperatures shall be checked to make sure that this has been met for the particular case. In the THERM file, fill the shaft/dome cavity with a solid material which has the conductivity equal to the calculated k_{eff}. Fill the other small frame cavities with the "Frame Cavity NFRC 100" frame cavity material, which will automatically calculate effective conductivity of them.

Next the boundary conditions need to be defined and assigned as shown in Figure 8-47. The exterior and adiabatic boundary conditions can be used from the THERM library, while the attic and indoor side of the diffuser plate must be defined in the THERM Boundary Condition Library. The following values should be used for the boundary conditions:

- Exterior: **NFRC 100-2010 Exterior**
  h_o = 30 W/m² ·K; T_o = -18 °C
  (h_o = 5.3 Btu/hr ·ft² ·°F; T_o = 0 °F)
- Adiabatic**: Adiabatic**
  q = 0 W/m²
  (q = 0 Btu/hr ·ft²)
- Attic: **User defined**
  h_a = 12.5 W/m² ·K; T_a = -18 °C
  (h_a = 2.2 Btu/hr ·ft² ·°F; T_a = 0 °F)
- Indoor Side of diffuser plate: **User defined**
  h_i = 9 W/m² ·K; T_i = 21 °C (1.582 Btu/hr ·ft² ·°F; T_i = 70 °F)

Note: The height of the shaft/dome cavity represents area weighted equivalent height, L_{eqv}, and is set to 1.041 m (41 in.) for domed top diffuser products and 750 mm (30 in.) for flat top diffuser products.

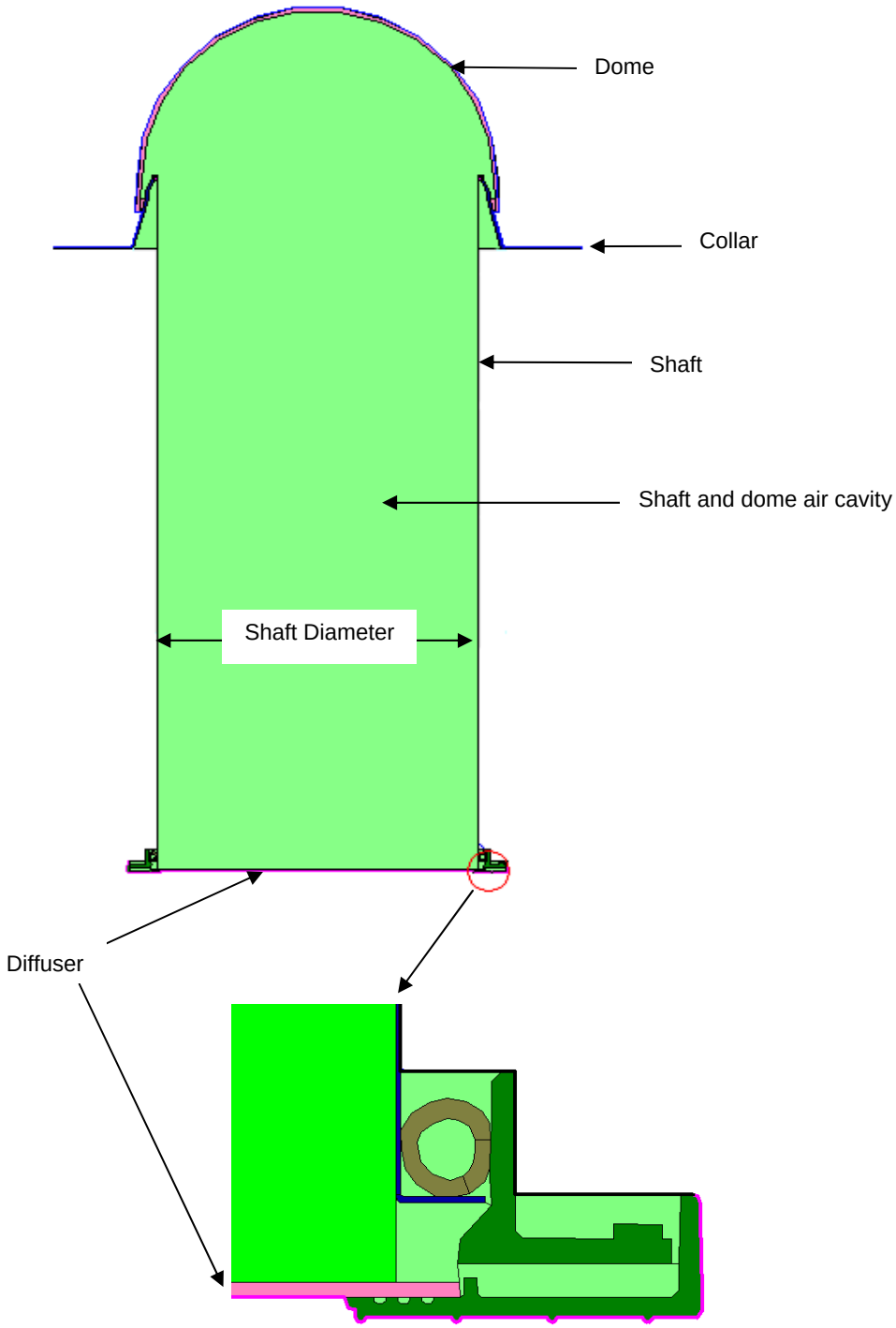


Figure 8-73 Tubular Daylighting Device Geometry drawn in THERM.

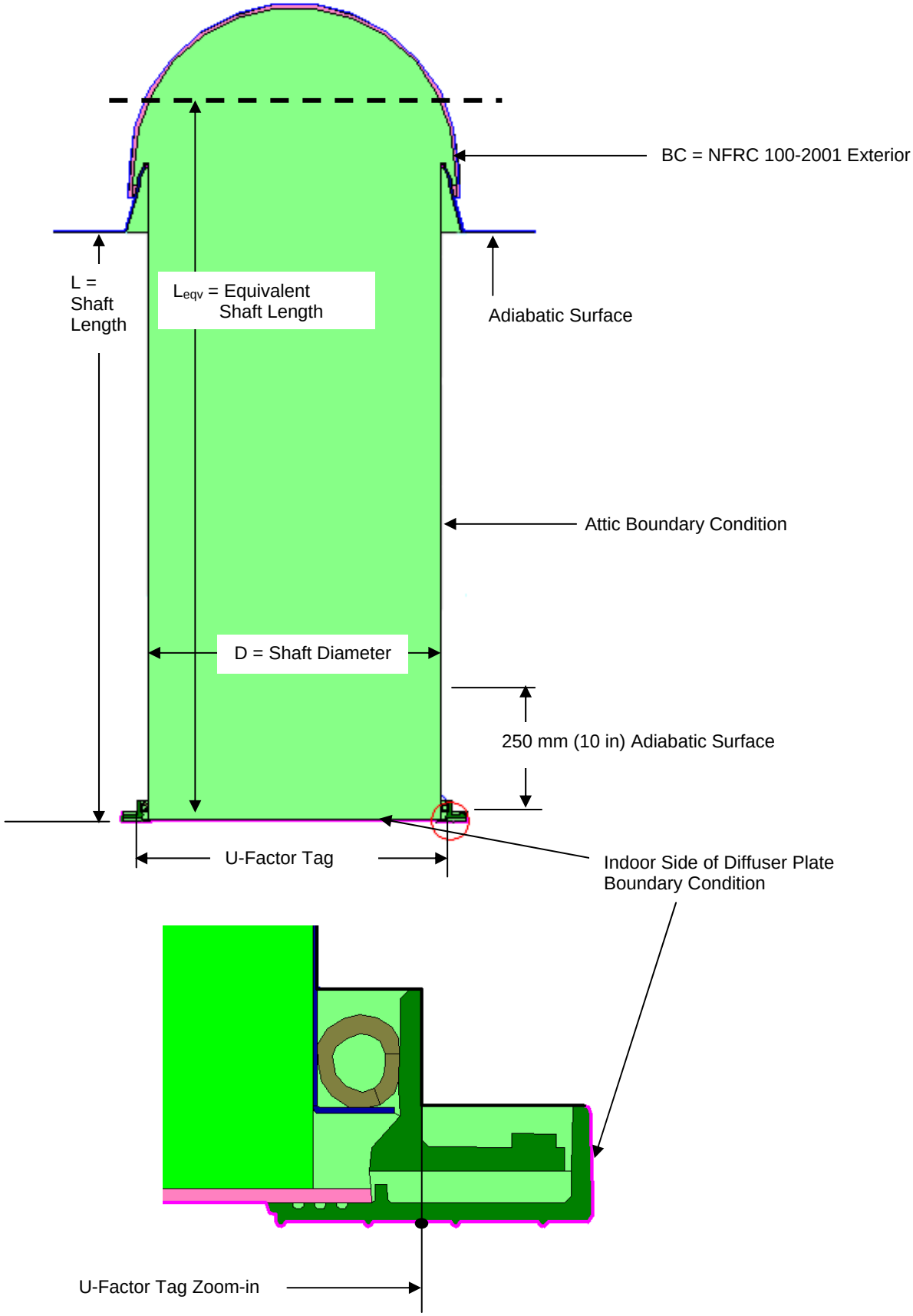


Figure 8-74 Boundary Conditions and location of U-factor tag for Tubular Daylighting Device.

The last step before simulating the problem is to define the U-factor tag. This tag is defined as shown in Figure 8-57. After the calculation is done, the U-factor obtained represents the total product performance.

8.6.6. Example Tubular Devices Problem

This example assumes that the bottom diffuser plate is made up of a single layer. For multiple layer plates, additional instructions are given at the end of this example. For single layer plates, it is not necessary to do calculations with WINDOW.

Begin by drawing geometry in THERM either by using DXF file underlay as shown below or by using a dimensioned drawing.

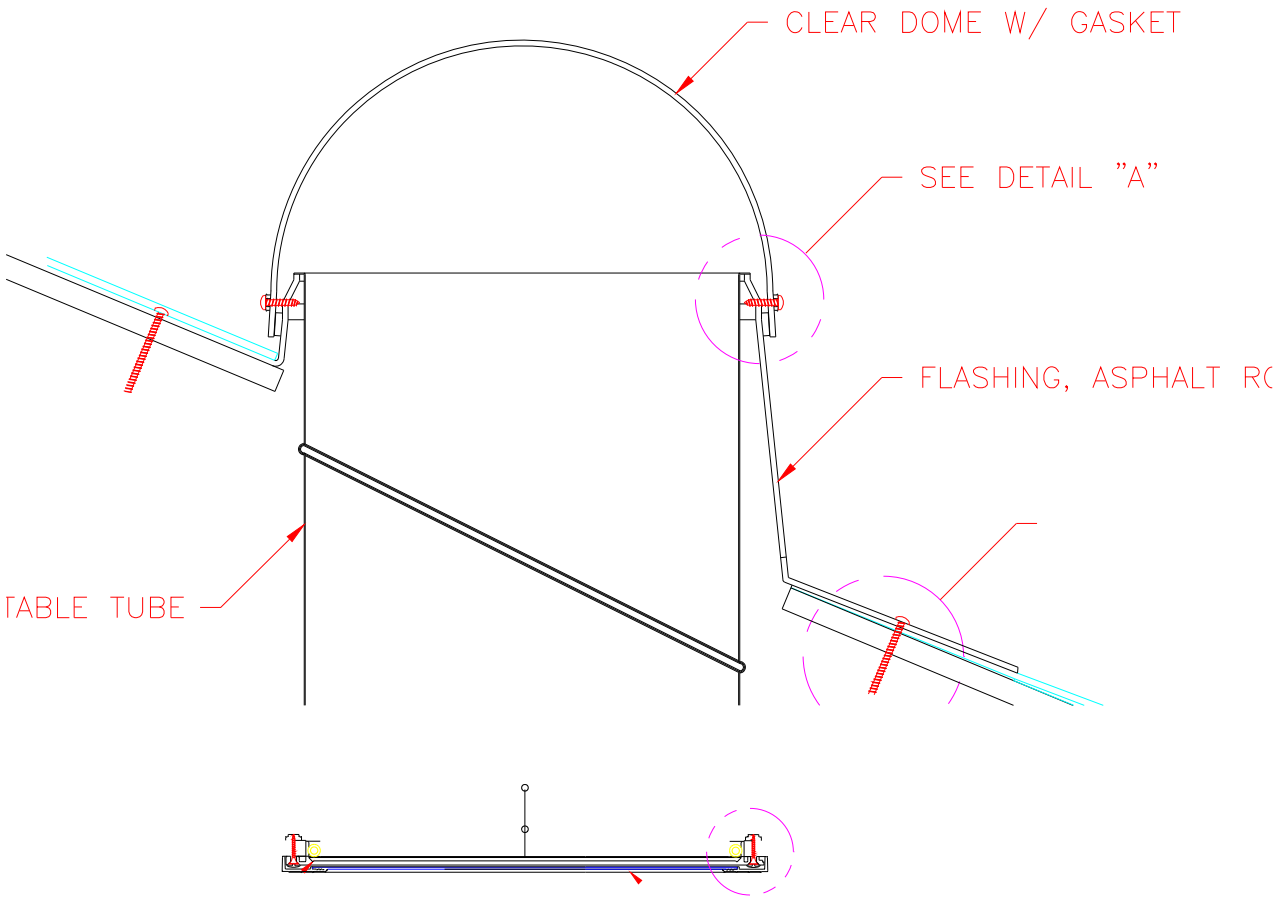


Figure 8-75 DXF File for Use as an Underlay in THERM.

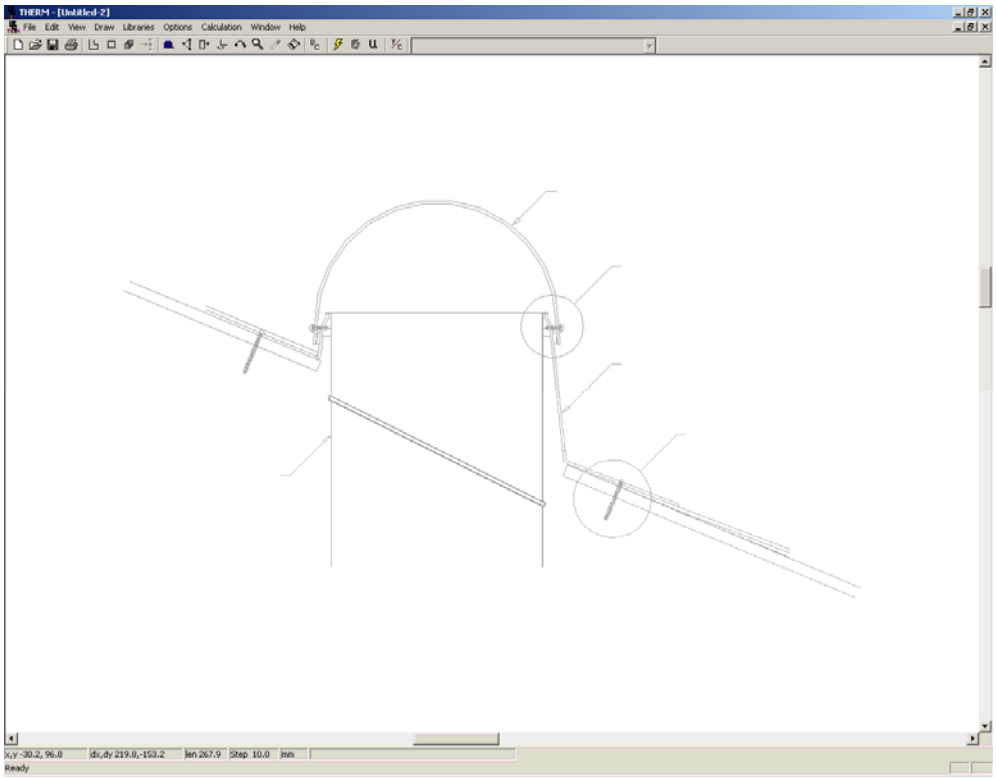


Figure 8-76 Underlay of the Top Part of the Tubular Daylighting Device.

Draw the geometry of all solid pieces of the tubular skylight, making sure that the shaft is 350 mm (14 in.) wide. The width of the dome should be adjusted to fit over such a shaft but thickness of the dome material shall not be changed. Include all of the details of sealing as per the manufacturers' drawings and specifications. The figure below shows the completed dome, collar, and one side of the shaft wall, along with gaskets.

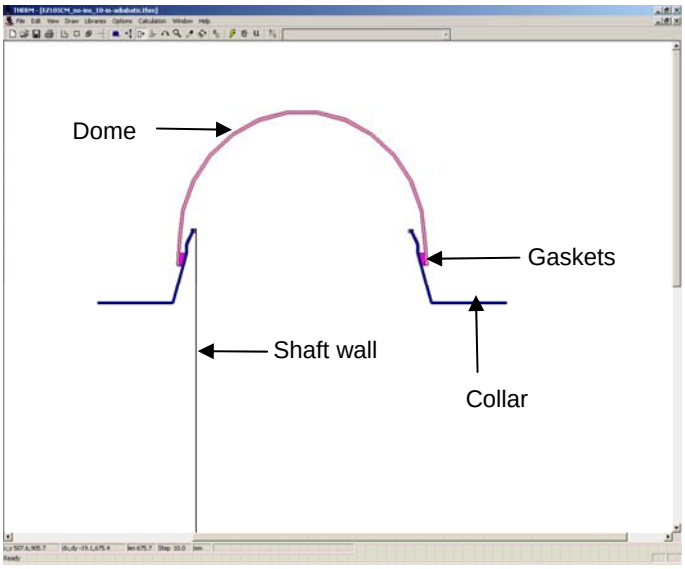


Figure 8-77 THERM drawing of the dome, collar, gaskets and one section of the shaft wall.

The figure below shows the completed solid sections without any frame cavity polygons defined.

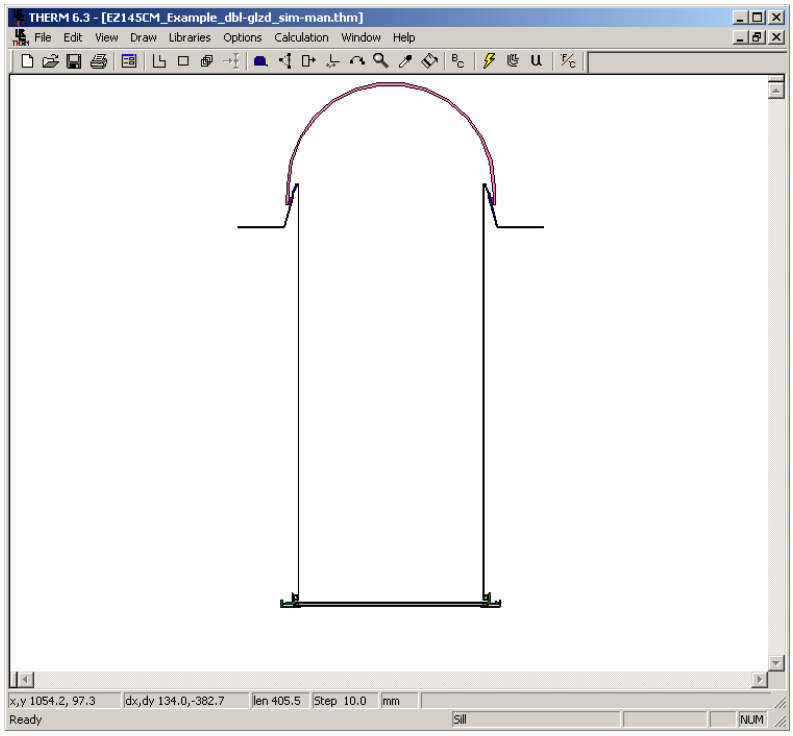


Figure 8-78 THERM drawing of all of solid sections.

Create polygons (using the **Fill** tool where possible) and assign the "Frame Cavity **NFRC 100**" material for all the frame cavities except the large central shaft/dome cavity, as shown in the figure below.

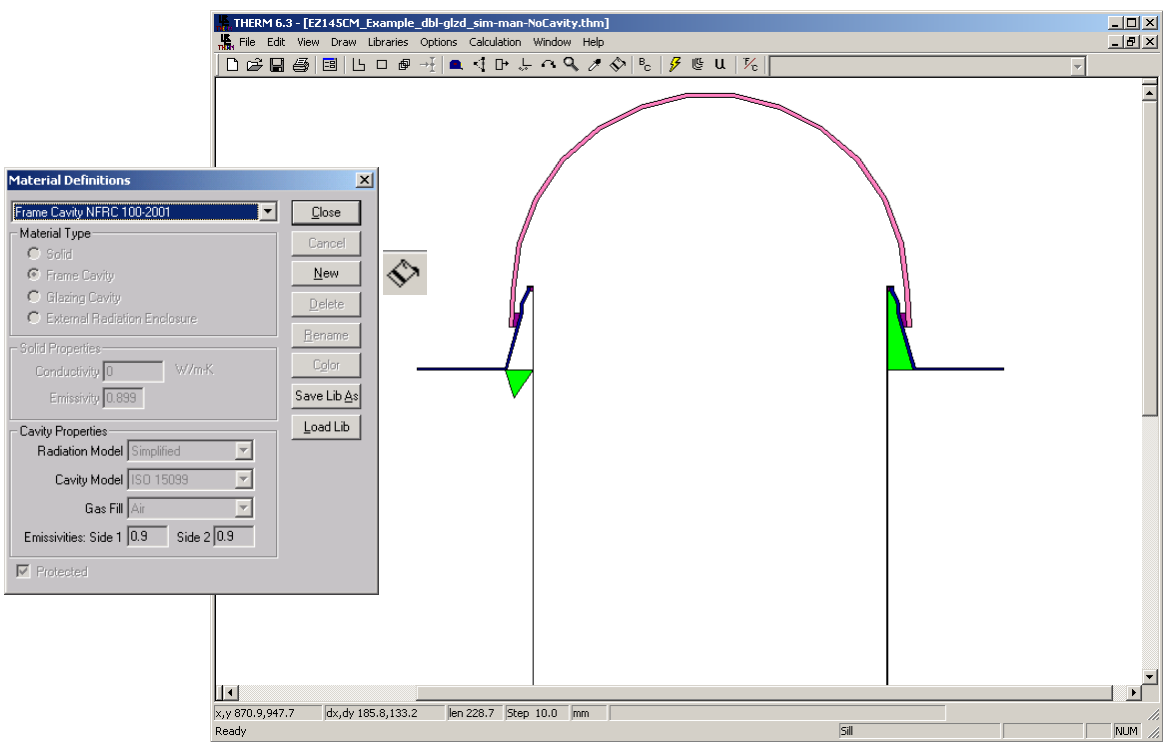


*Figure 8-79 Fill all cavities, except for shaft/dome, with the "Frame Cavity **NFRC 100**" material.*

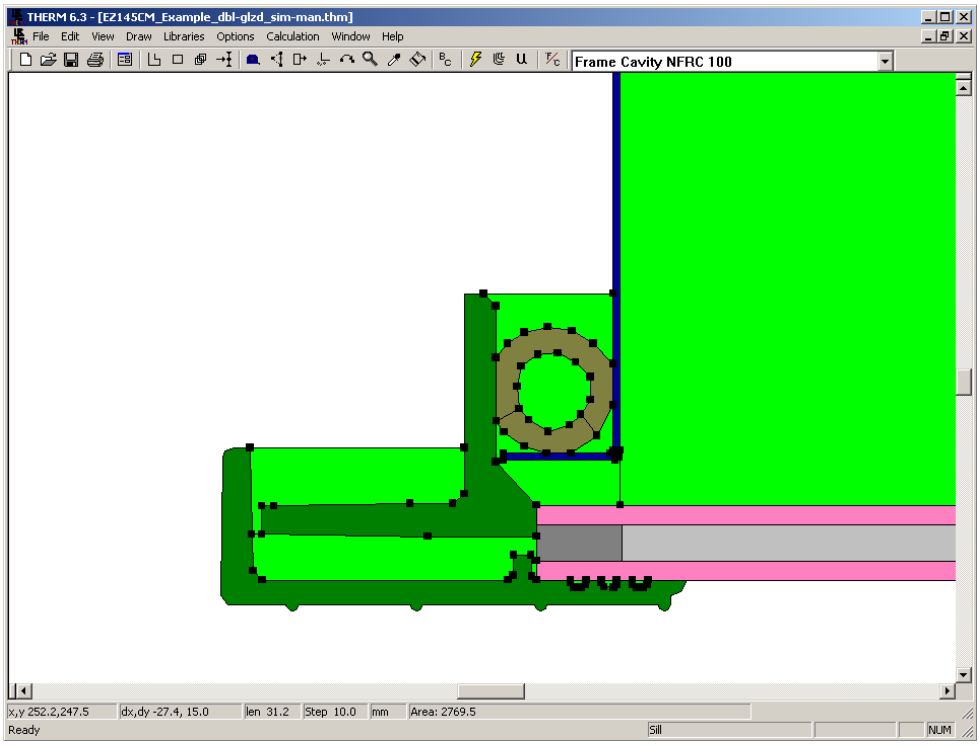


*Figure 8-80 Small Frame Cavities Around the Edges of the Diffuser set to "Frame Cavity **NFRC 100**" material.*

Before the large shaft/dome cavity can be filled, it is first necessary to calculate k_{eff} for this cavity. Open spreadsheet Tubes_keff.xls and input the four yellow highlighted fields that are available for inputting data as shown in the figure below:

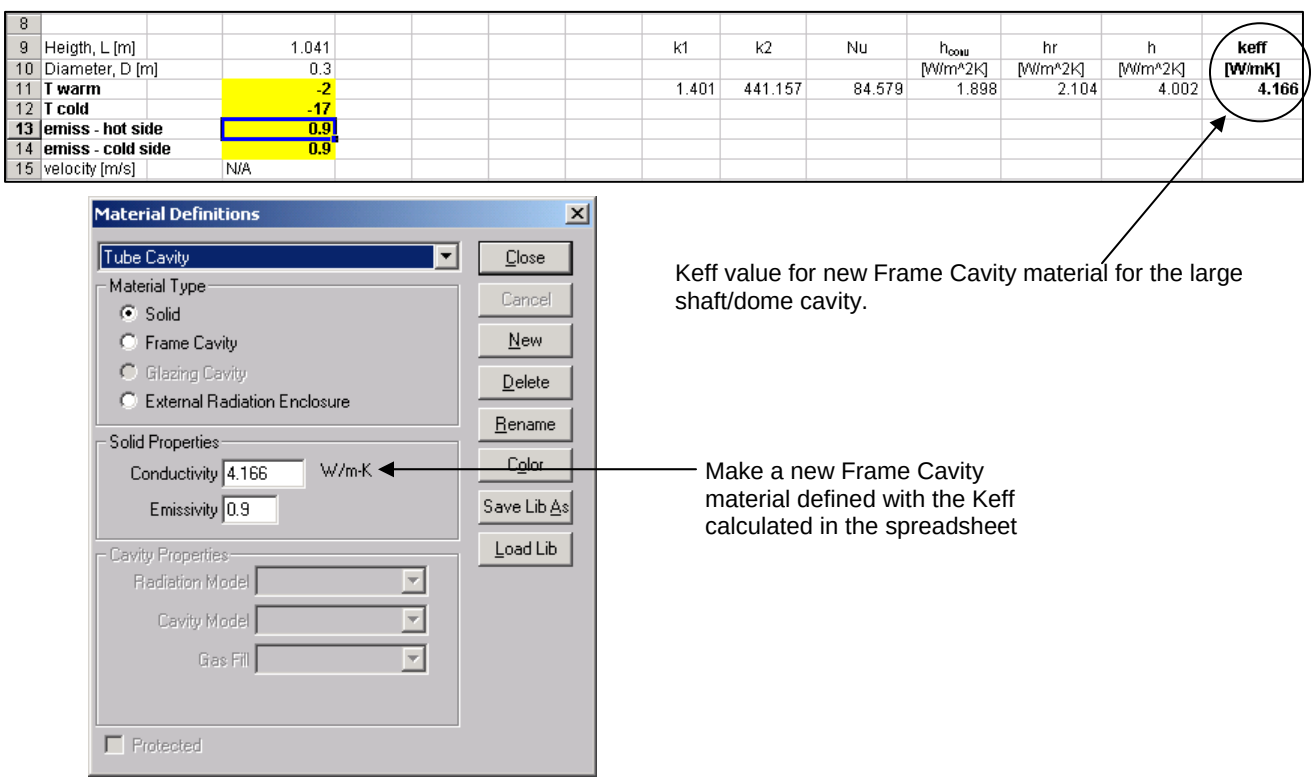


Figure 8-81 Tubes_keff.xls spreadsheet with input data highlighted in yellow

Temperatures of the inside surface of a bottom diffuser plate (T_{warm}) and top dome (T_{cold}) shall be estimated by finding respective average temperatures.

For the bottom diffuser plate, the average temperature can be estimated simply by stretching tape measure across the inside surface of the bottom diffuser plate from the left side of the shaft/dome cavity to the right side, as shown in the figure below.

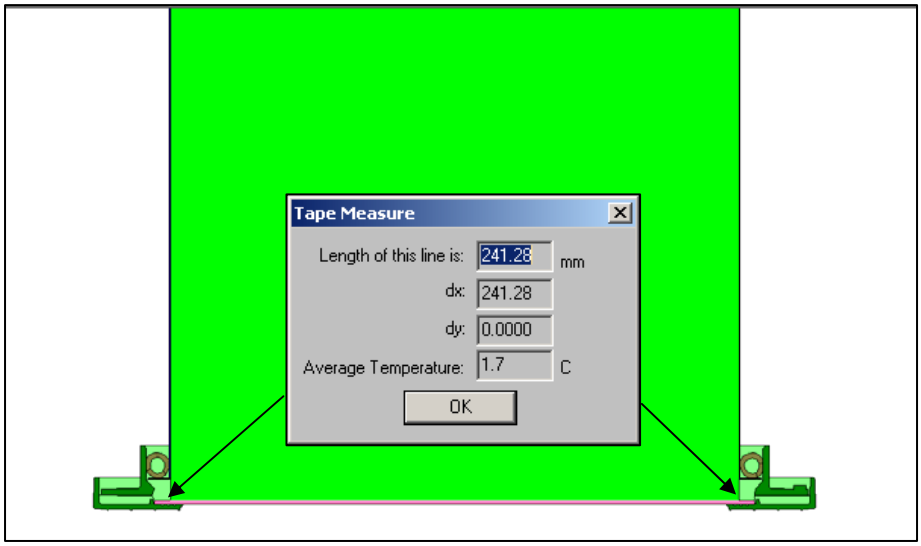


Figure 8-82. Estimate of the average temperature of the inside surface of a bottom diffuser plate

For the dome, the average temperature should be calculated in increments, because the surface consists of several straight line increments. Because the lines are of approximately the same length, the average can be estimated by summing the temperatures for all the segments and dividing by the number of segments, as shown in the figure below. As discussed at the beginning of this section, this is an iterative process, and once the model has been simulated, find the average temperatures for the diffuser plate and dome surfaces using the tape measuring tool, and if the resulting average temperatures differ by more than 1° C (2 °F) from the estimated values, the new Keff shall be calculated and the simulation repeated until the criterion of 1° C (2 °F) is met. Emissivities are input from the surface emissivities of the inside surface of the bottom diffuser plate (emiss – hot) and inside surface of the top dome (emiss – cold). The resulting k_{eff} value is calculated using the spreadsheet, and a new material shall be made with that conductivity and assigned to the shaft/dome cavity.

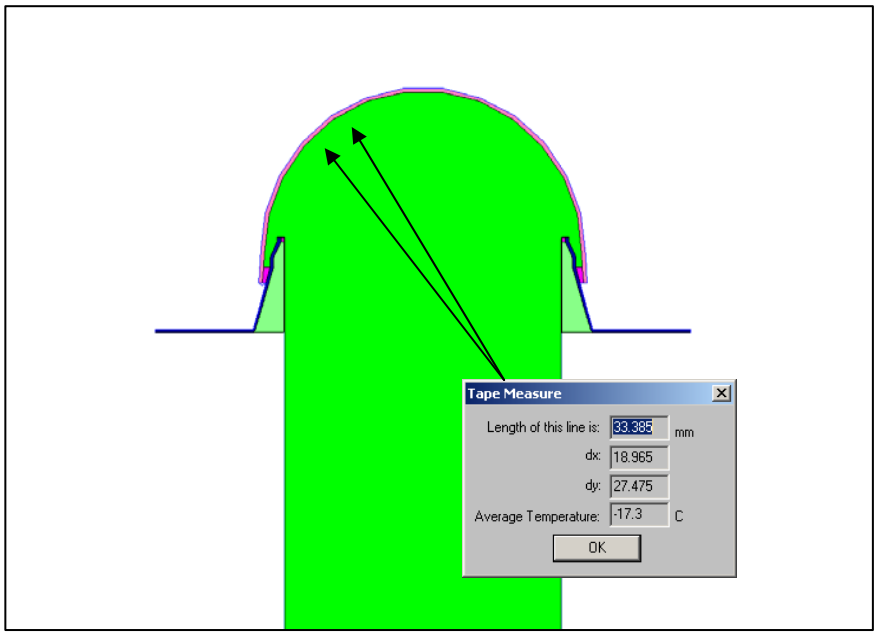


Figure 8-83. Estimate of the average temperature of the inside surface of a bottom diffuser plate temperatures of segments (usually at 15° increments)

The next step is to define the boundary conditions. The outside surface of the dome and collar should be assigned the standard "**NFRC 100-2010** Exterior" boundary condition. The bottom of the collar shall have standard "Adiabatic" boundary condition, as shown in the figure below.

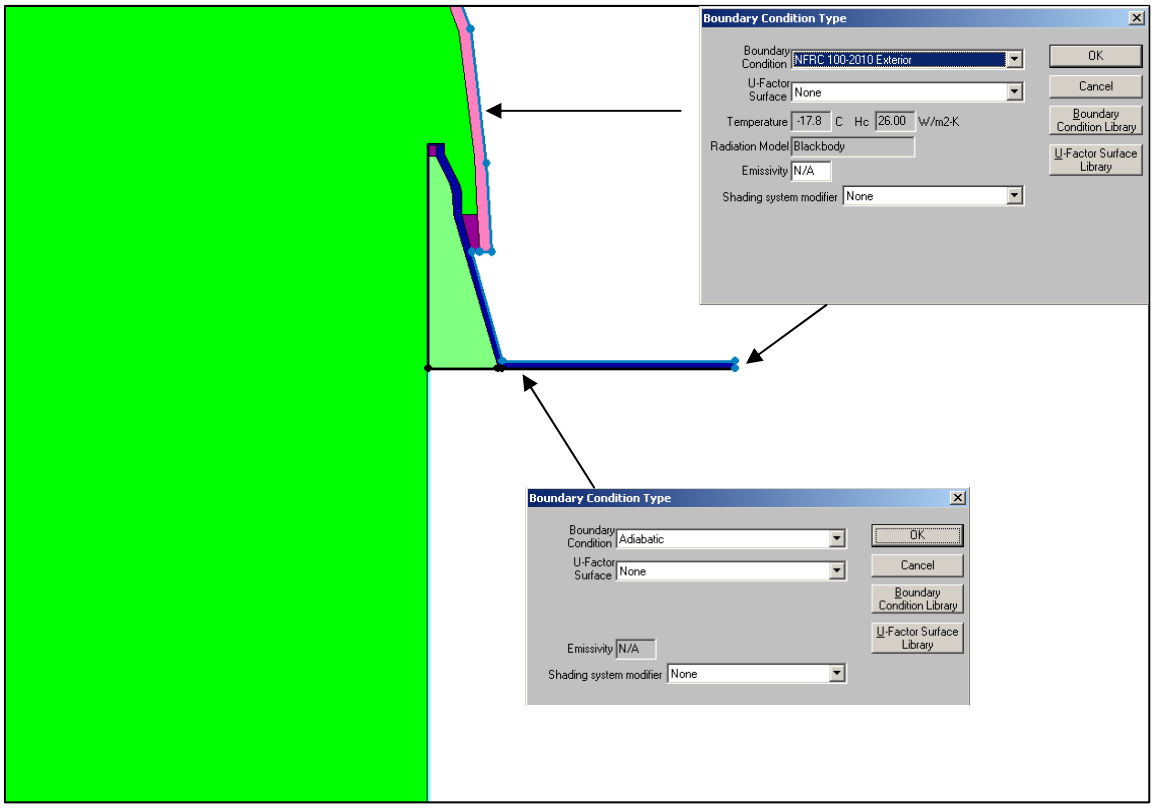


Figure 8-84. Exterior and adiabatic boundary conditions near the top dome

The outside surfaces of the shaft walls, except for the bottom 250 mm (10 inches) should be assigned a user defined "Attic boundary condition" (see description of all boundary conditions at the beginning of this section). The bottom 250 mm (10 in.) of the shaft walls and portion of the diffuser plate edge assembly shall have an "Adiabatic" boundary condition as shown in the figure below.

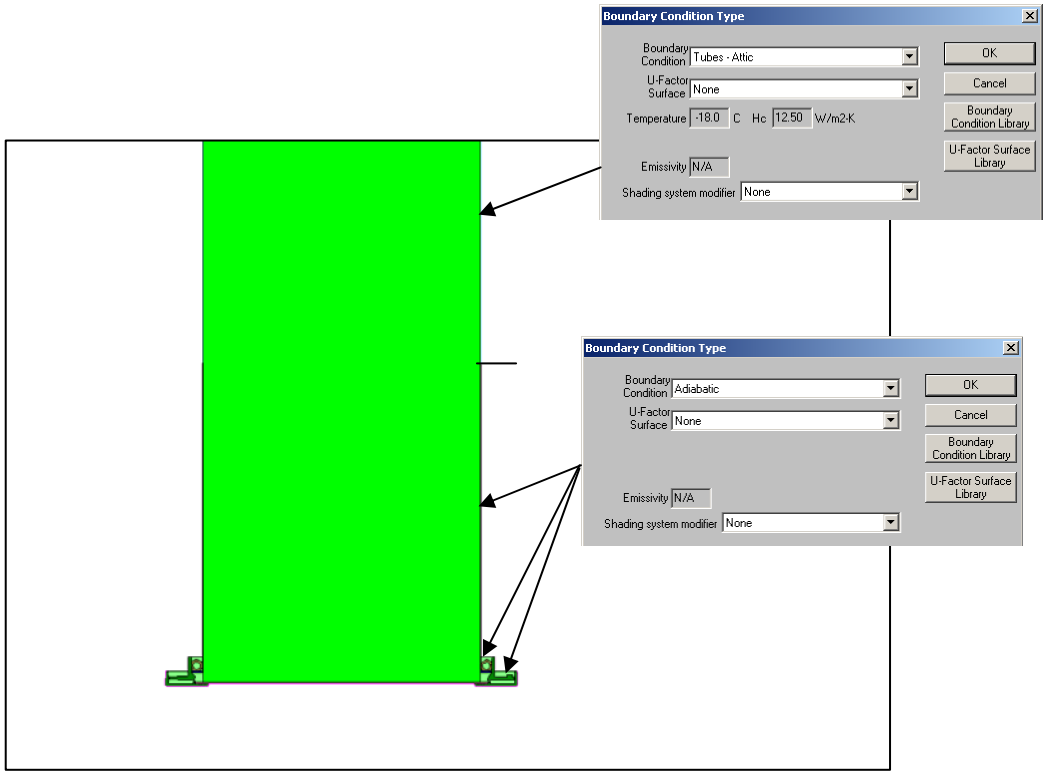


Figure 8-85. Attic and adiabatic boundary conditions on the shaft wall and near the bottom diffuser

The remaining boundary condition, "Indoor Side of Diffuser Plate" shall be applied to the exposed surfaces of the bottom diffuser plate and edge assemblies up to the point where adiabatic boundary condition ends, as shown in the figure below.

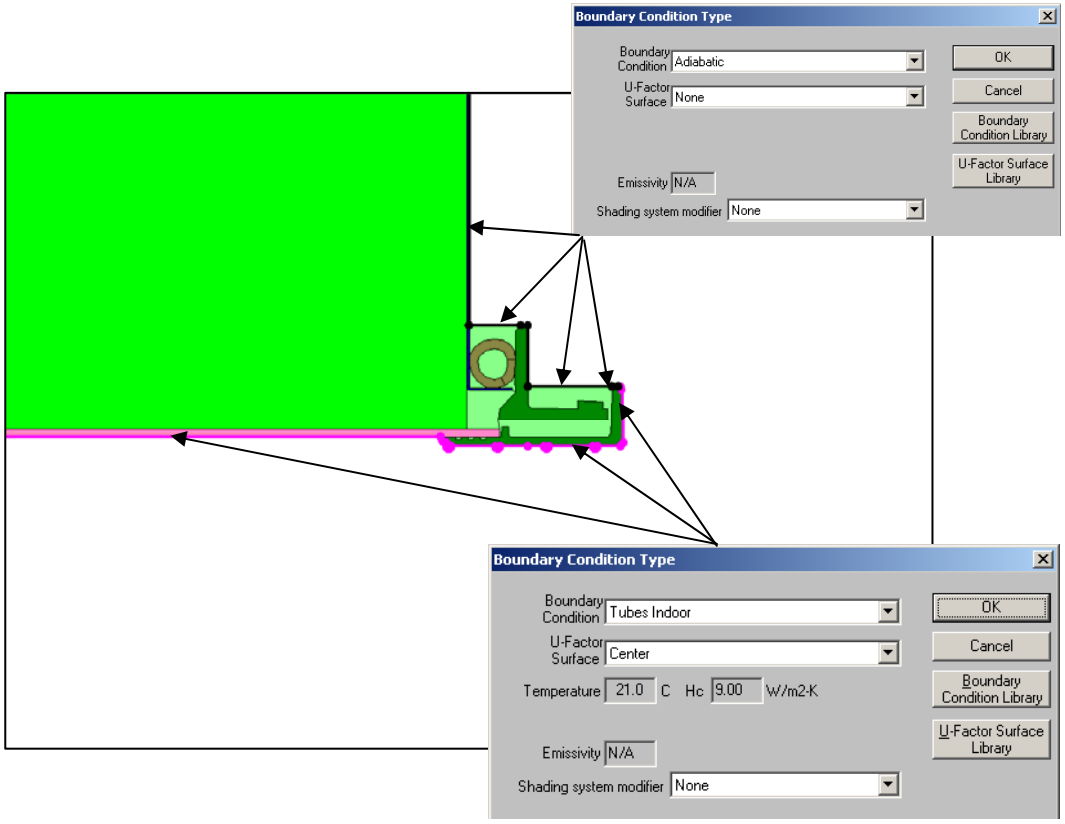


Figure 8-86. Indoor boundary condition on the exposed surfaces of the diffuser plate

After all boundary conditions are defined, the remaining task left is to define the U-factor tag. The U-factor shall be calculated for the area corresponding to the rough opening in the ceiling, which is defined on Figure 8-50. Select bottom diffuser plate and insert points on both sides of the model and define U-factor tag "Center" (or some other name if desired) for the surface between those two points.

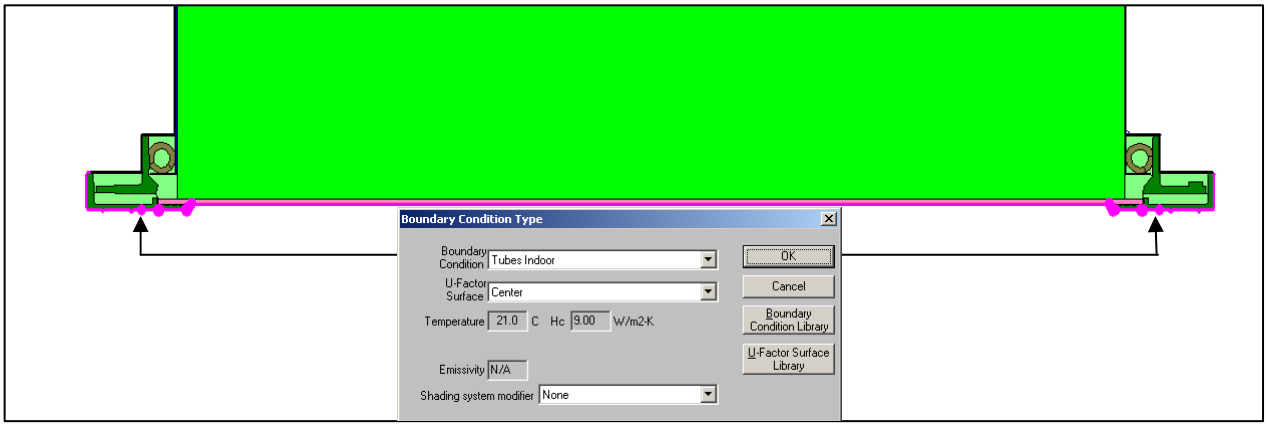


Figure 8-87. Definition of U-factor tag

This completes the definition of the model. The final step is to simulate the problem. As discussed at the beginning of this section, it is an iterative process to obtain the Keff value for the material defined for the

shaft/dome cavity. Once the model has been simulated, find the average temperatures for the diffuser plate and dome surfaces using the tape measuring tool, and if the resulting average temperatures differ by more than 1° C from the estimated values, the new Keff shall be calculated and the simulation repeated until the criterion of 1° C is met. The resulting U-factor is the overall product U-factor.

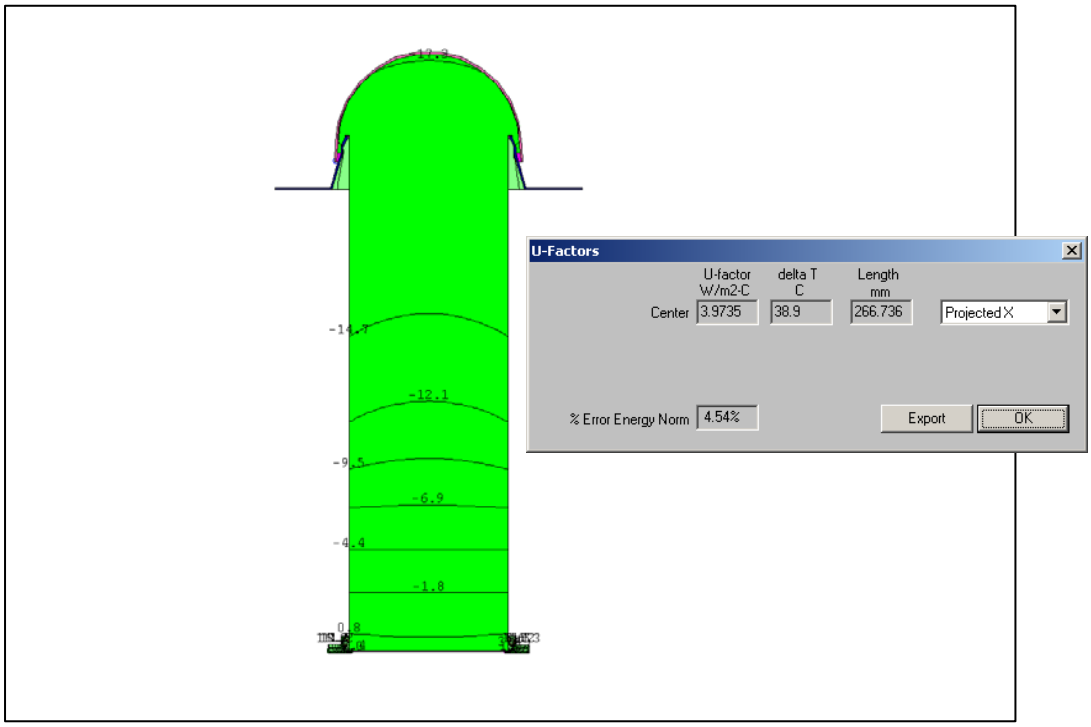


Figure 8-88. Temperature Contour plot and U-factor results

8.6.7. Example: Tubular Device Problem With the Double-Glazed Diffuser Plate

Using a double glazed diffuser plate is a variation to the design presented in the first example. This case can be modeled by first using WINDOW to calculate the effective conductivity of the gap space in a diffuser and then specifying this conductivity in the THERM model.

In WINDOW create a special boundary conditions for this case (i.e., tubes diffuser) by copying the **NFRC 100-2010** record in the Environmental Conditions Library to a new record, and set outdoor wind speed to 0 (this is the closest approximation to convection and radiation heat transfer inside shaft/dome cavity that borders cold side of this double layer diffuser). Name the new environmental condition something that makes it clear how it is to be used, such as "NFRC Tubular Skylight", as shown in the figure below.

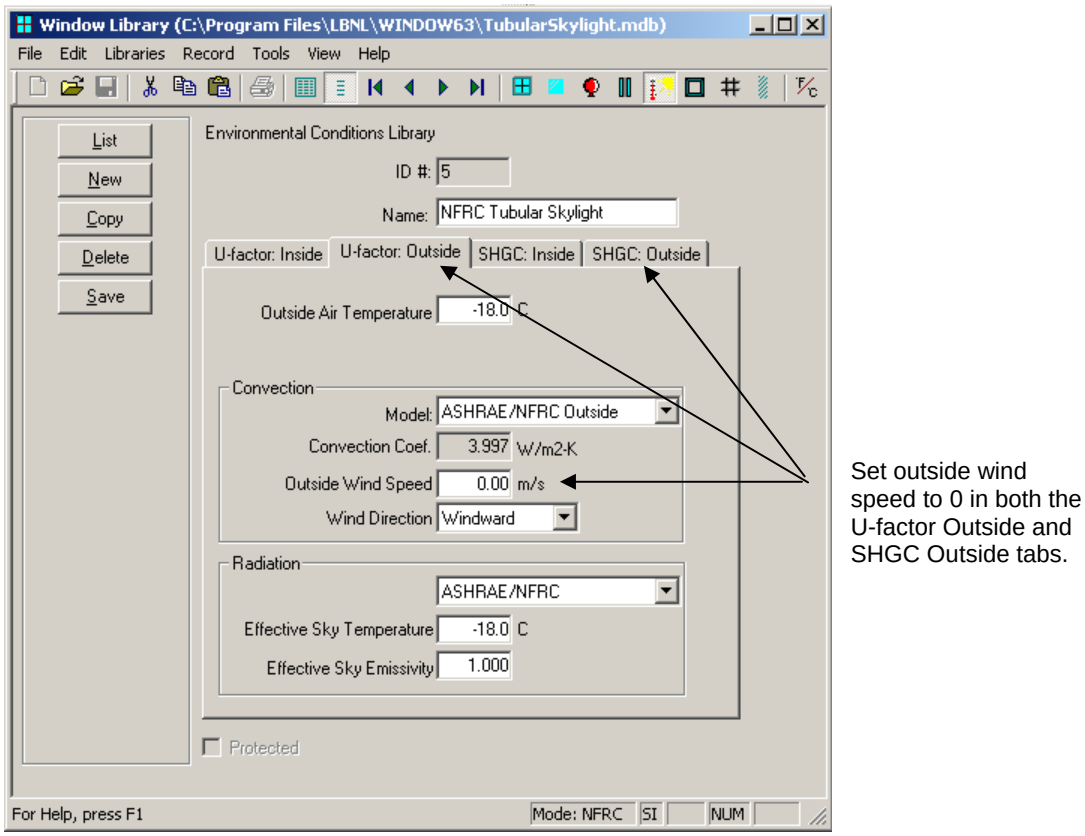


Figure 8-89. New environmental conditions for calculating center of glass performance of the diffuser plate.

In the glass library, create the new glazing layer, naming it appropriately to the material used (called Lexan in this example) and specify the thickness per the manufacturer drawings. Set the conductivity and emissivity by copying the values from the library of material thermo-physical properties or value derived from NFRC 101.

In the Glazing System Library, create a new double glazed system using the newly defined entries in the Glass Library, and reference the new environmental condition, "NFRC Tubular Skylight". Set the tilt to **0** degrees, and set the gap thickness and gap gas according to the manufacturer's specifications. After the calculation is done, make note of the effective conductivity (**Keff** value under the **Center of Glass Results** tab) for later use in THERM.

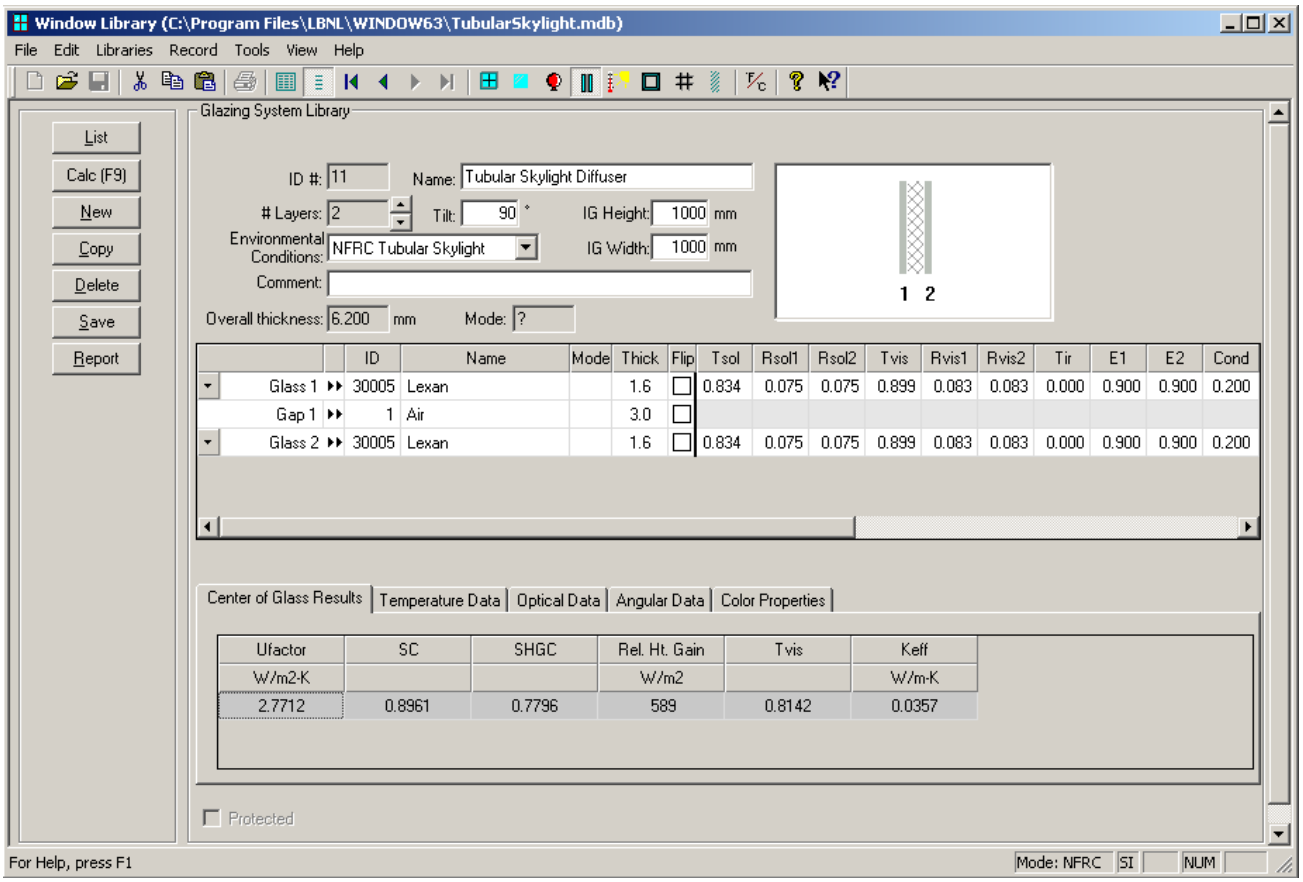


Figure 8-90. Glazing system for the double-layer diffuser plate

These calculations are only for U-factor; the SHGC results will not be valid because the layers were created without spectral data. When performing a calculation on this glazing system, the following message will appear, indicating that there is not spectral data associated with the glazing layers.

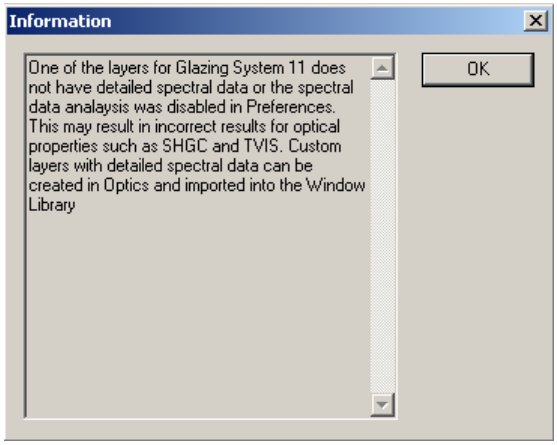


Figure 8-91. Message at calculation time, indicating that there is not spectral data for the glazing layers. Therefore, the SHGC value will not be accurate.

In THERM draw the geometry of the double-layer diffuser plate, including the detail of spacer and draw the rest of the geometry as per original example.

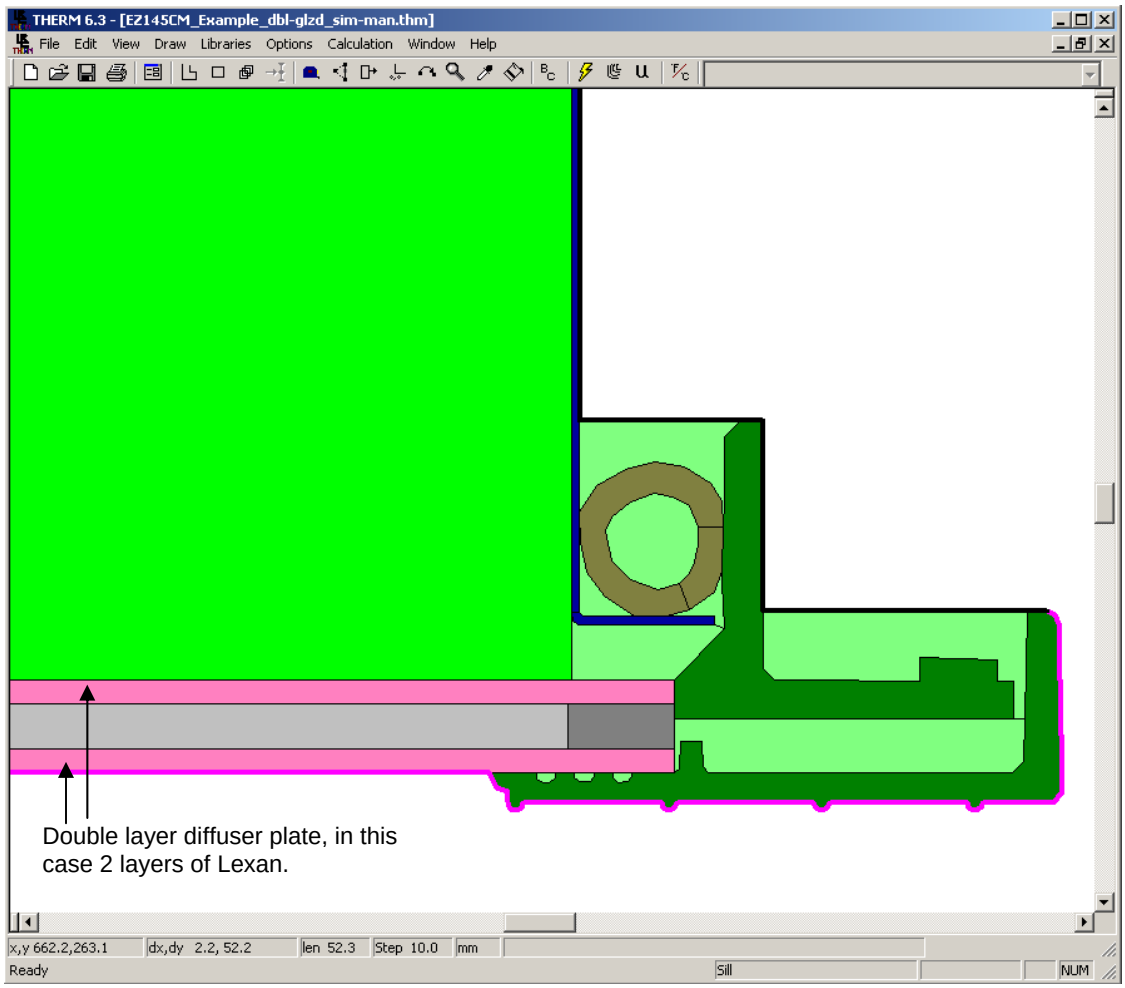


Figure 8-92. THERM model of double-layer diffuser plate

Define a new material with the conductivity equal to the effective conductivity (Keff) calculated in WINDOW and fill the cavity with that material. As discussed at the beginning of this section, it is an iterative process to obtain the Keff value for the material defined for the shaft/dome cavity. Once the model has been simulated, find the average temperatures for the diffuser plate and dome surfaces using the tape measuring tool, and if the resulting average temperatures differ by more than 1° C (2 °F) from the estimated values, the new Keff shall be calculated and the simulation repeated until the criterion of 1° C (2 °F) difference is met.

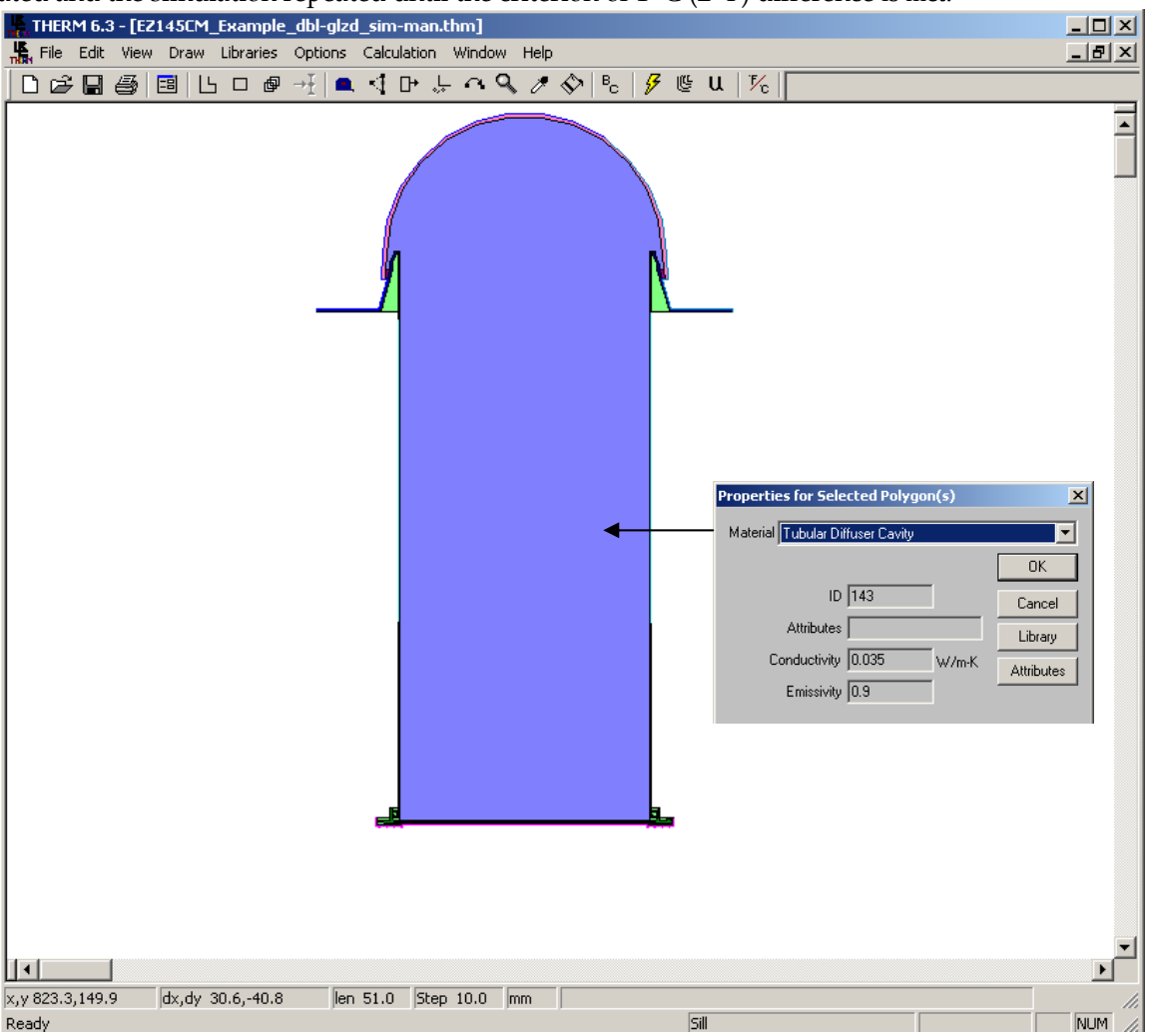


Figure 8-93. THERM model of double-layer diffuser plate

Define the same set of boundary conditions as in previous example and perform calculation. The following are results for an example where the two layers of Polycarbonate diffuser plates, separated by 3 mm (0.1181 inches) of air space and butyl spacer, are used.

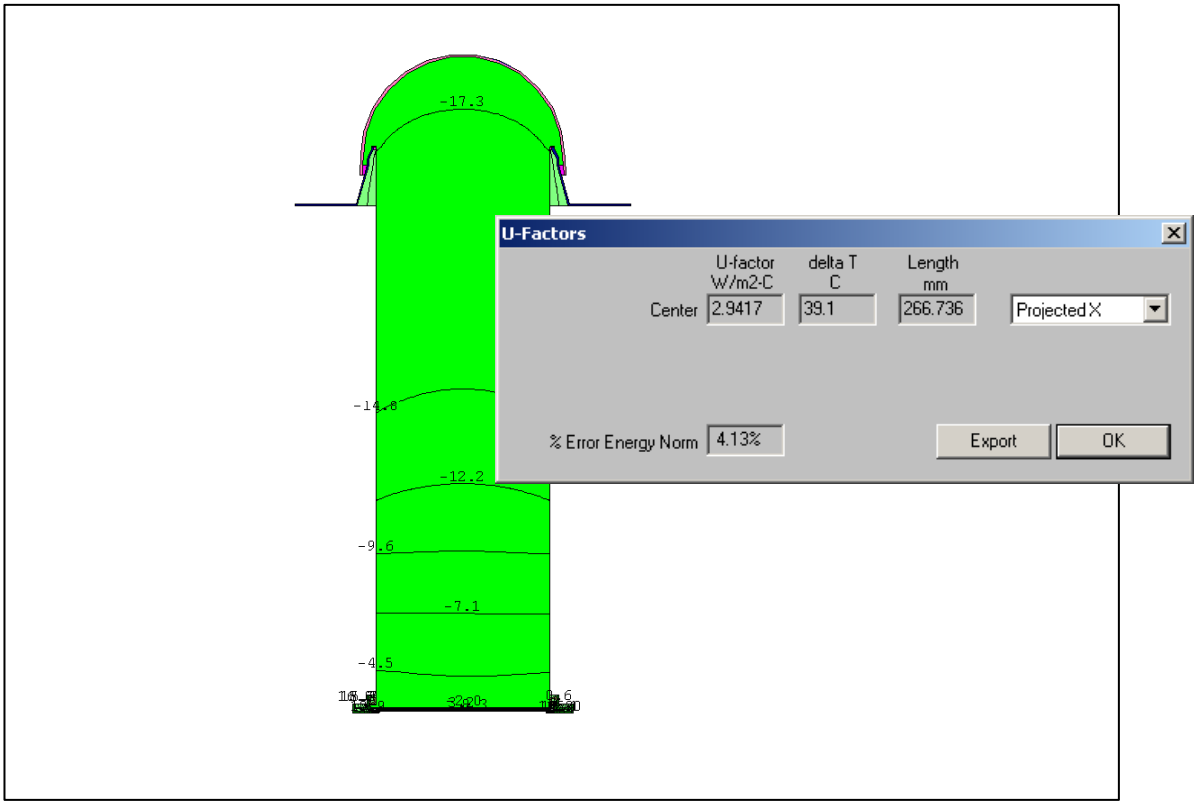


Figure 8-94. Heat Transfer Results for the Tubular Daylighting Device, Incorporating Double-Layer Diffuser Plate

Note that the overall U-factor has been reduced from 3.97 W/m²-°C (0.699 Btu/h-ft²-°F) to 2.94 W/m²-°C (0.518 Btu/h-ft²-°F), by using double-layer configuration for the diffuser plate instead of the original single layer. This analysis does not include solar optical properties or Solar Heat Gain Coefficient calculation, which will also be affected by the introduction of double-glazed diffuser plate. It is likely that the daylighting performance would be negatively affected due to the presence of an additional diffuser plate, which will reduce overall visible transmittance (VT).

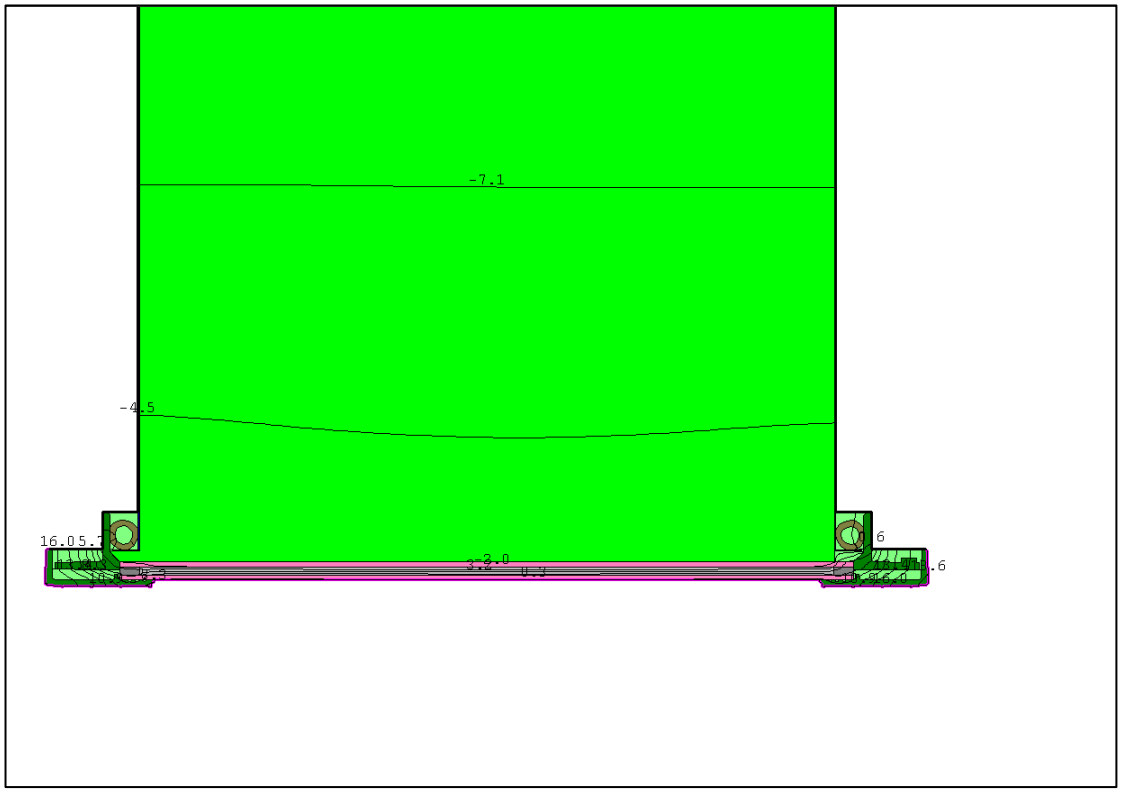


Figure 8-95. Zoomed-in Region Near the Diffuser Plate

References:

Curcija, D.C. 2001. "Proposed Methodology for Modeling Tubular Skylights For NFRC Rating Purposes." CEERE Technical Report. June, 2001.

8.7 Doors

Swinging entry doors are modeled differently than window products because there are more opaque sections to be modeled in THERM. The procedures for modeling doors are included in *NFRC 100* and that document should be reviewed in detail before modeling any entry door systems.

NFRC has defined nine regions within a door that need to be modeled. These regions include:

- Frame Area
- Lite Frame Area
- Divider area
- Edge-of-divider area
- Edge-of-Lite Area
- Center-of-lite area
- Door Core Area
- Panel Area
- Edge-of-Panel Area

NFRC 100 contains several figures which illustrate the location of the door sections to be modeled in THERM.

When modeling glazing options with caming, the NFRC default caming can be used. See the section on Dividers in this chapter for information about modeling caming inside an IG.

A spreadsheet must be used to do the door area-weighting from the THERM files, because the current version of WINDOW does not area-weight doors. In THERM, the U-factor Surface Tags can have any name and as many U-factor Surface Tags can be defined as are needed to accurately describe the model. (See Section 6.2.4, "Define U-factor Surface Tags in the *THERM User's Manual*), so define as many U-factor Surface Tags as needed and name them descriptively.

SHGC CalculationWhen calculating the SHGC for the opaque components of a door, using the ISO 15099 equation for frames (see formula for $SHGC_f$ below), using an h_{out} value of 30 W/m^2-^{o}C.

$$SHGC_f = \alpha_f \cdot \frac{U_f}{\frac{A_{surf}}{A_f} h_{out}}$$

Boundary Conditions for Steel Skin Doors

The following boundary conditions (BC) shall be applied when modeling doors containing a steel skin with either a non-metal or wood edge or steel edge. The appropriate BC shall be applied to applicable individual sections.

Door section material	Boundary Condition
Non-metal / wood edge	Wood / Vinyl
Steel edge	Thermally-Improved

Chapter 9 contains a door example, which describes in detail the THERM modeling steps.

8.8 Spacers

8.8.1. Overview

THERM has the capability to model spacers in great detail, so that modeling of spacer effective conductivity is no longer needed. Spacer models can be easily reshaped in THERM, and the program's cut and paste feature allows spacers to be copied into each cross section as needed. A library of spacer models can be produced for each spacer type. See the *THERM User's Manual*, Section 3.5, "Adding a Custom Spacer". A sample spacer, spacer.thm, is included on the THERM installation CD.

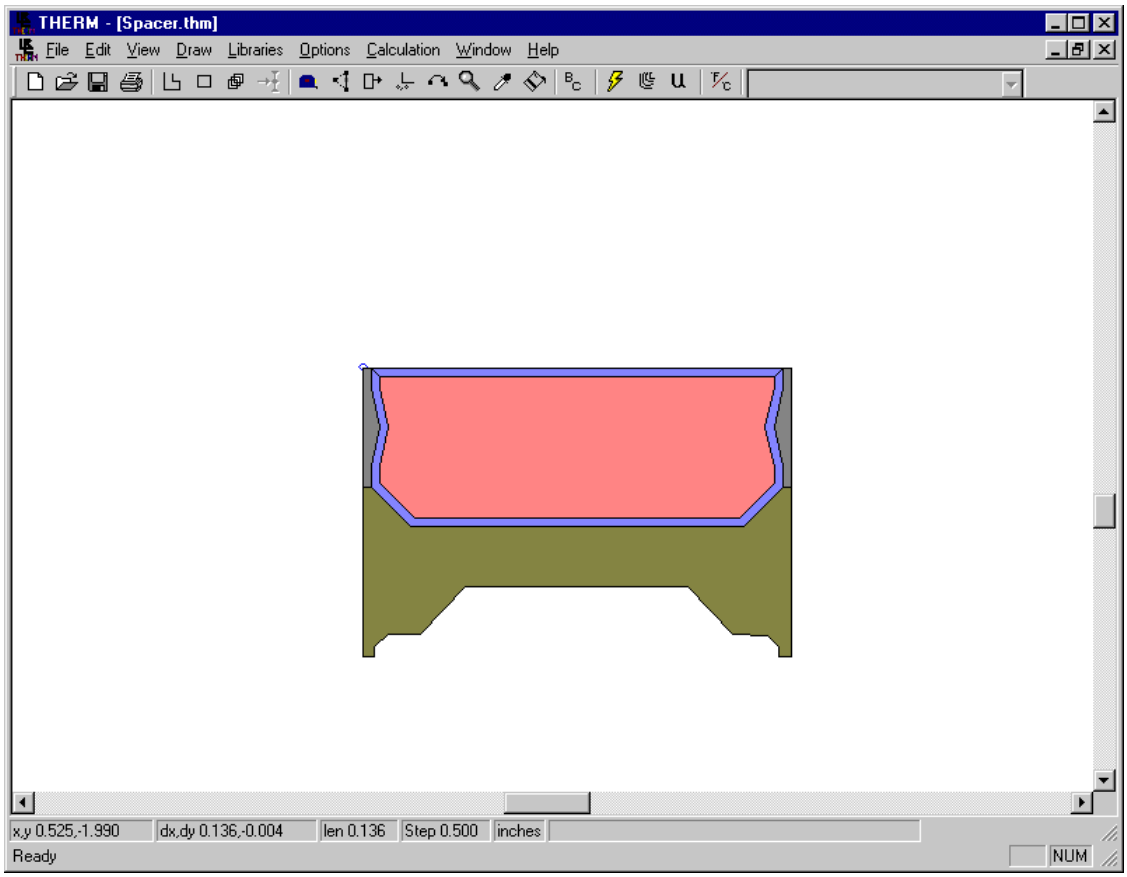


Figure 8-96. spacer.thm sample file.

8.8.2. Linking Glazing Cavity properties (imported from WINDOW) for Open Spacers

The properties of a glazing cavity can be linked to another polygon in order to properly model spacers that are open to the glazing system cavity. Section 5.11.5, "Linking Materials Properties of Polygons" in the *THERM User Manual* explains this methodology in detail.

To Link the properties of two materials, follow these steps:

- Select the polygon that is to linked to another polygon
- Select the Libraries/Create Link menu choice.
- The cursor will become an Eye Dropper. Click the Eye Dropper cursor in the polygon to be linked to. The material properties of the first polygon are not linked to the material properties of the second polygon.

When using the multiple glazing calculation option, THERM will automatically use the glazing system cavity properties for each glazing option for the linked polygon.

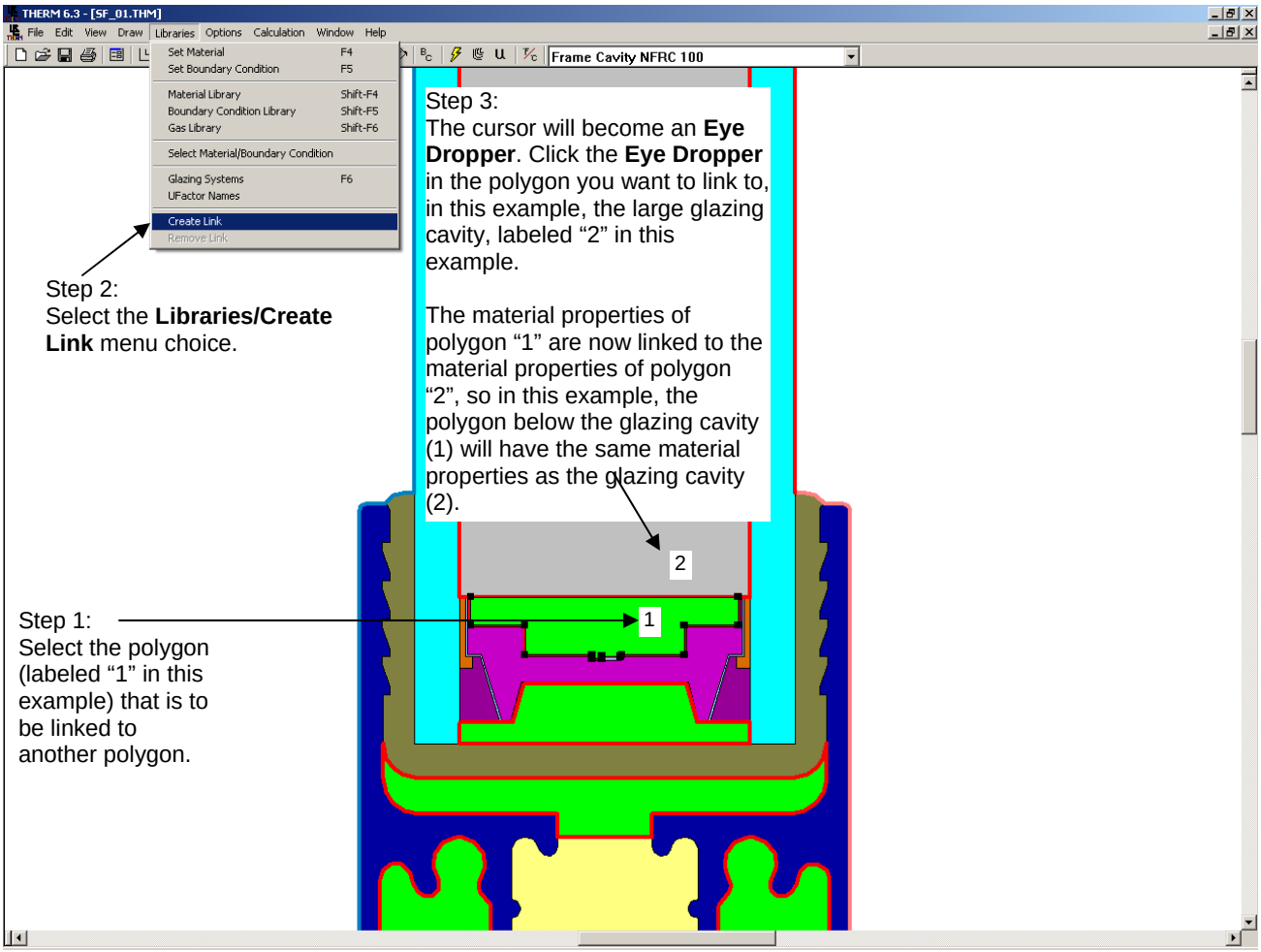


Figure 8-97. Link the open spacer cavity to the glazing system cavity using the Library/Create Link feature .

8.9 Non Continuous Thermal Bridge Elements

Bolts skip and debridge thermal break, including partially de-bridged thermal break material, and thermally slotted cross section shall be included in the model using the concept of *isothermal planes*. The isothermal planes methodology calculates an effective conductivity of the bridging material based on area weighting the sections of the product with and without thermal bridging material based on the bridging material spacing dimensions. This method is also valid for other regularly spaced thermal bridges such as skip-and-debridged systems.

The effect on the performance of a curtain wall system due to bolts is explained in detail in an ASHRAE paper published in 1998 entitled *"The Significance of Bolts in the Thermal Performance of Curtain-Wall Frames for Glazed Facades", by Brent Griffith, Elizabeth Finlayson, Mehrangiz Yazdanian and Dariush Arasteh.*

The THERM model to be simulated for the final result is one in which the actual materials of the thermal bridging elements are replaced with a user-defined material having an effective conductivity which represents the area-weighted value that combines the bridging and non-bridging elements.

Figure 8-98 below illustrates an example of a curtain wall system which would require that the thermal bridging elements, in this case the bolts, be modeled using the isothermal planes method.

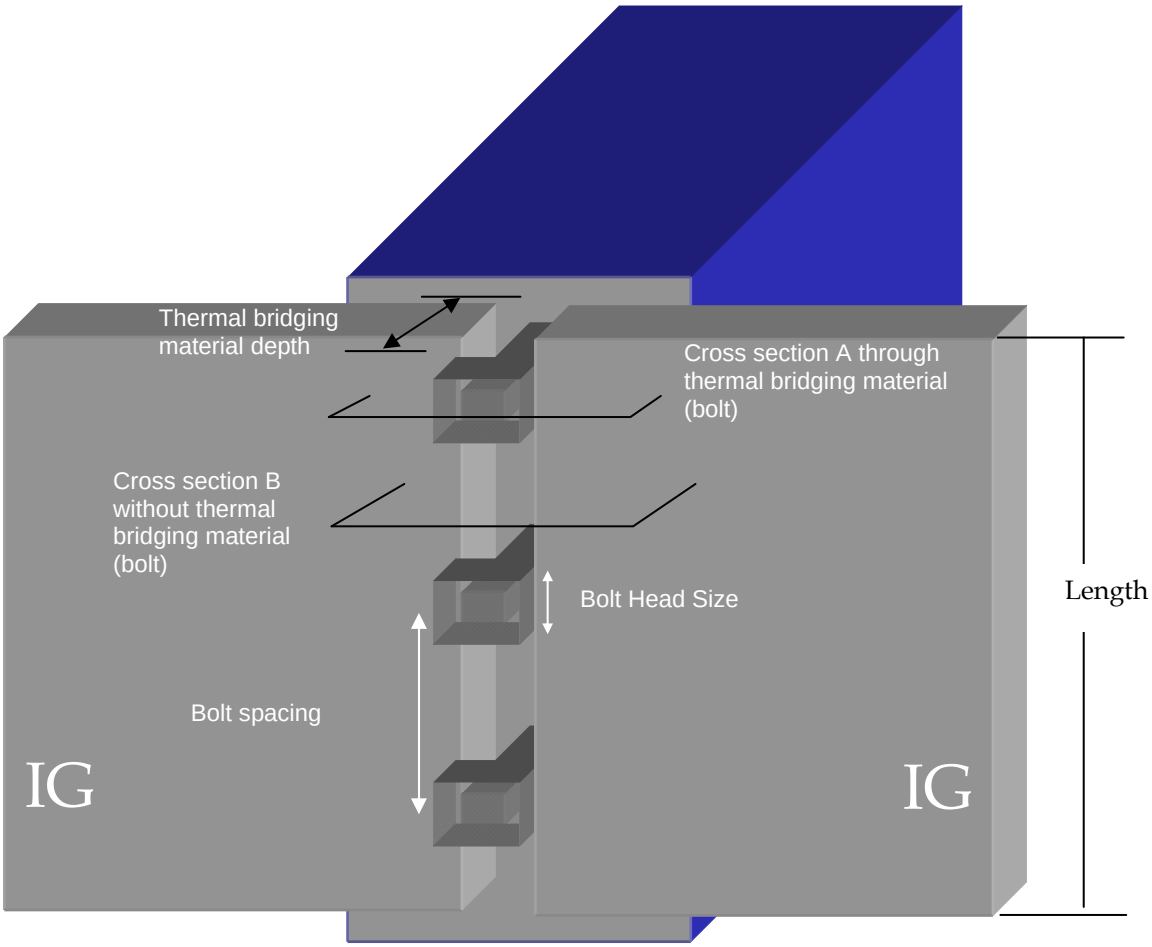


Figure 8-98. Example of a curtain wall system with regularly spaced bolts which act as thermal bridges.

8.9.3. Modeling Steps

The steps for constructing the final THERM model to be simulated are the following:

1. Draw the THERM model without the thermal bridging material.
2. Determine the conductivities of the materials that the thermal bridging material replaces.
   - Conductivities of *materials* can be obtained from the THERM Material Library
   - Conductivities of *air-filled* cavities (such as frame cavities) are assumed to be 0.024 W/m-K (or 0.014 Btu/hr-ft-^{o}F).
3. Using a cross-section that contains the non-thermal bridging material, measure the depths of each element of the non-thermal bridging material that will have a different thermal conductivity in the non-bridging cross section.
4. Use the conductivities of the non-thermal bridging materials and depths of the non-thermal bridging materials in Equation 2 below to determine the Resistance (R) for each non-thermal bridging element.
5. Sum the resistances (Rt) and divide by the total depth of the non-thermal bridging elements to obtain Kn, as shown in Equation 3, to calculate the conductivity of the non-thermal bridging elements
6. Calculate the fraction of thermal and non-thermal bridging material along the length of the façade using Equations 4 and 5.
7. Calculate the final effective conductivity value for the thermal bridging elements using Equation 1.
8. In THERM, define a new material with the Keff value derived in Step 7, and assign it to the cross section polygons that represent the thermal bridging elements.
9. Simulate the model.

8.9.4. Equations

Calculate the effective conductivity of thermal bridging elements (e.g., bolts, screws, etc.)

Keff= Fb*Kb + Fn*Kn *Equation 1*

where

Fb = Fraction of the Length which contains the thermal bridging elements (see equation 4 below)

Fn = the fraction of the Length which contains non-thermal bridging elements(see equation 5 below)

Kb = conductivity of the thermal bridging elements

Kn = conductivity of the non-thermal-bridging elements
(from the sum of the resistances, Rt, of individual elements from Equation 2 below)
Assume a default value of 0.024 W/m-K for air cavities.

This methodology should be applied with the following caveats:

- If less than 1% (to obtain percentage, multiply fraction by a 100) of the Length is made of thermal bridging elements (such as stainless steel), i.e., Fb < 0.01, do not model the thermal bridging elements.
- If between 1% and 5% of the Length is made of thermal bridging elements (0.01 <= Fb <= 0.05) and if the conductivity of the thermal bridging elements is more than 10 times the conductivity of the thermal break, model the thermal bridging elements using the keff calculated in Equation 1.
- If more than 5% of the length is made of thermal bridging elements (Fb > 0.05), model the thermal bridging elements using the keff calculated in Equation 1.

Calculate the total resistance of the non-thermal bridging elements, Rt, by summing individual resistances (non-thermal bridging element conductivity) for each non-thermal bridging element using the formula:

$Rt = \Sigma(D / k)$ *Equation 2*

Where:

Rt = Sum of the thermal resistances of the individual non-thermal bridging material. Units: $m^2 \cdot K/W$ (SI), or $hr \cdot ft^2 \cdot °F/Btu$ (IP)

D = Depth of the individual non-thermal bridging elements that will be substituted by the calculated effective conductivity. Units: m (SI), or ft (IP), or (in) (alternate IP)k = conductivity of the individual non-thermal bridging elements that will be substituted. Units: $W/m \cdot K$ (SI), or $Btu/hr \cdot in \cdot °F$ (IP), or $Btu \cdot in/hr \cdot ft^2 \cdot °F$ (alternate IP)

Therefore:

Kn=Dt/Rt *Equation 3*

Where:

Dt = Total depth, which is the sum of the depths of the individual non-thermal bridging elements

Calculate the fraction of thermal bridging material to non thermal bridging material as follows:

Fb=Wb / Sb (%Fb=Fb·100) *Equation 4*

Fn=1-Fb *Equation 5*

Where:

Wb = Bridging material width

Sb = Bridging material spacing

8.9.5. Example 1: Bolts in Curtain Wall

Note: This example is only presented in SI units and is not translated into IP units.

The following figures show two cross sections of the curtain wall in Figure 8-96. Figure 8-97 represents the cross section of the curtain wall where the bolt occurs (screw threads should be averaged and not drawn explicitly), and Figure 8-98 represents the cross section of the curtain wall where the bolt does not occur. The geometry of the cross-section in Figure 8-97 would be used for the final THERM run, and the conductivity of the materials used to define the bolt would be changed to the value derived from the methodology explained in this section. The geometry in Figure 8-98 is drawn only to obtain the conductivity values for calculating the conductivity of this "averaged" material.

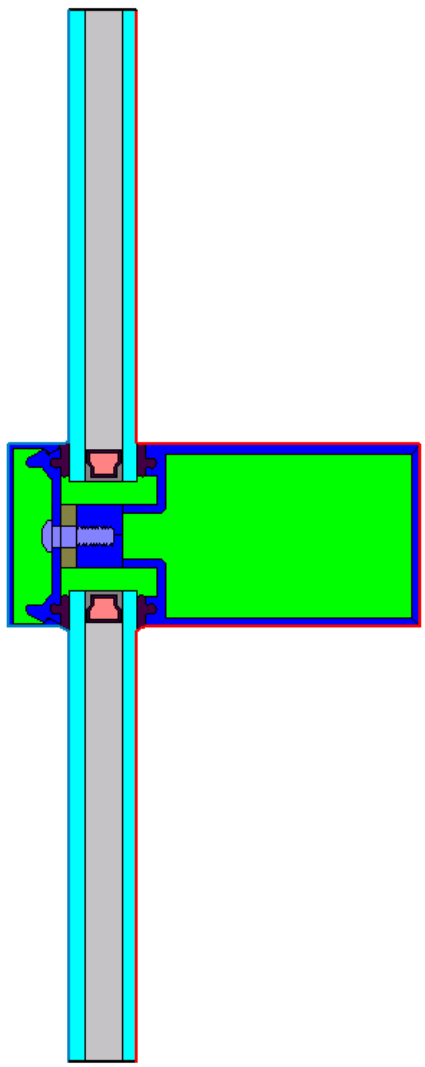


Figure 8-99. THERM cross section where the bolt occurs (curtain wall bolt.thm).

Figure 8-98 shows the conductivity values for the four materials that must be obtained for the calculation. Material 1 and 4 are air cavities, and the conductivity is assumed to be 0.024 W/m-K.

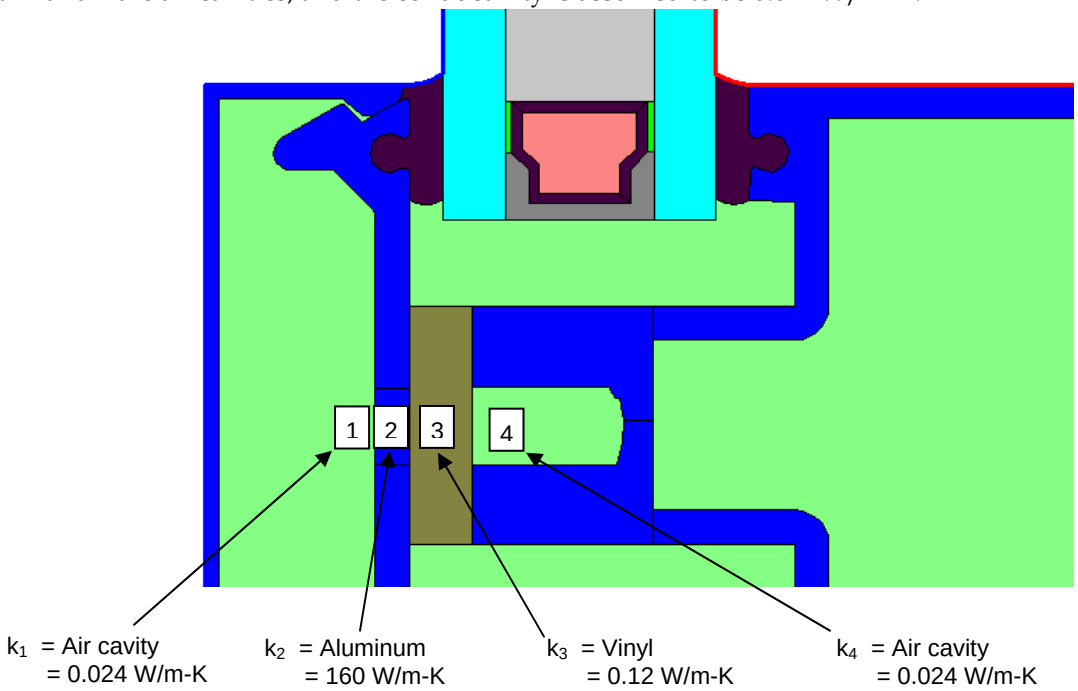


Figure 8-100. Materials in the non-bridging material cross section for which conductivities must be obtained.

Figure 8-99 shows the depths of each of the thermal bridging elements that are used in the Keff calculation.

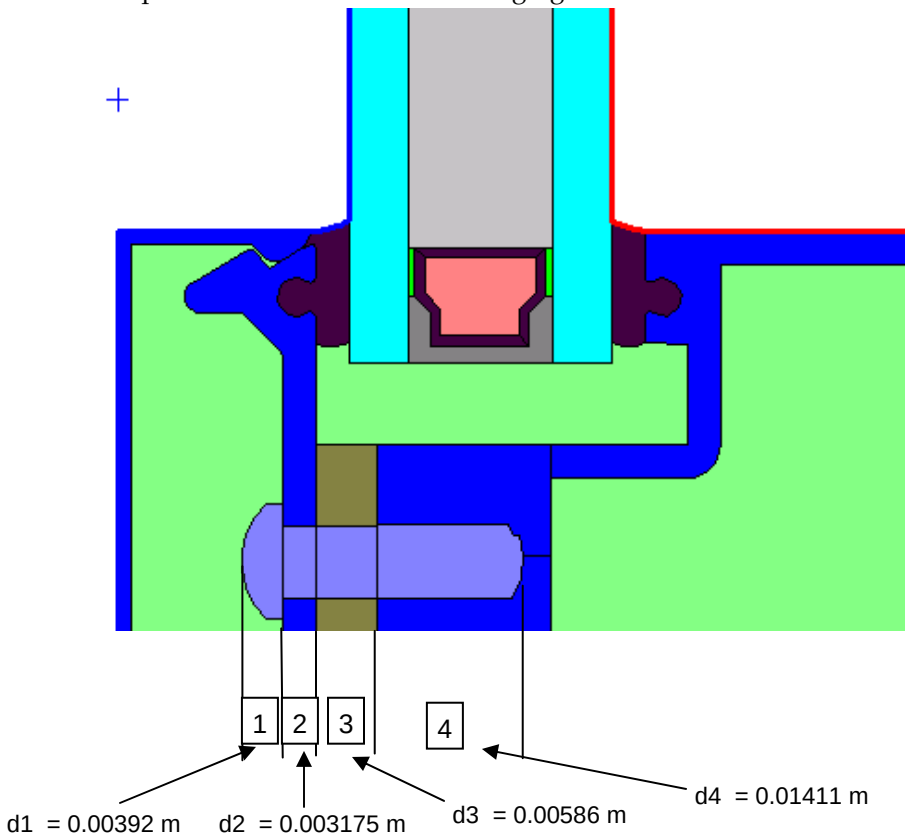


Figure 8-101. Material depths for the thermal bridging materials.

Table 8-1 shows the conductivity and depth values used to calculate the R for each non-thermal bridging element using Equation 2.

Table 8-1

Cross Section Element	Material	**Conductivity [W/mK]**	**Depth (m)**	**R [m2K/W]**
1	Air cavity (default value)	0.024	0.00392	0.16333
2	Aluminum (conductivity from THERM Material Library)	160	0.003175	0.0000198
3	Vinyl (conductivity from THERM Material Library)	0.12	0.00586	0.049
4	Air cavity (default value)	0.024	0.01411	0.587917
	Total		**0.02706**	**0.800103**

Calculate Rt as follows:

$R_t = \Sigma(d/k)$

$= (d_1/k_1) + (d_2/k_2) + (d_3/k_3) + (d_4/k_4)$

$= (0.00392 / 0.024) + (0.003175 / 160) + (0.00586 / 0.12) + (0.01411 / 0.024)$

$= 0.800103\ m^2K/W$

$D_t = 0.00392\ m + 0.003175\ m + 0.00586\ m + 0.01411\ m$

$= 0.02706\ m$

Calculate the conductivities as follows:

$Kn = D_t/R_t$

$= 0.02706 / 0.800103$

$= 0.033821\ W/m \cdot K$

Kb = 14.3 W/m·K (stainless steel)

Calculate the fraction of bolt to no bolt as follows:

Wb = Bolt head width

= 11.1 mm

Sb = Bolt spacing 12′′

= 304.8 mm

Fb = Wb / Sb

= 11.1 mm / 304.8 mm

= 0.036 (%Fb=0.036·100 = 3.6%)

Fn = 1-Fb

= 1- 0.036

= 0.964

Calculate the new Keff, which will be used in THERM as follows:

Keff = Fb*Kb + Fn*Kn

Keff = (0.036 * 14.3)+(0.964 * 0.033827)

= 0.55 W/m·K

In THERM, create a new material in the Material Library with this Keff. In the THERM cross section, the bolt material should be changed from Stainless Steel to this new material. The resulting cross section is a 2-D thermal equivalent of the cross section with and without the thermal bridging material.

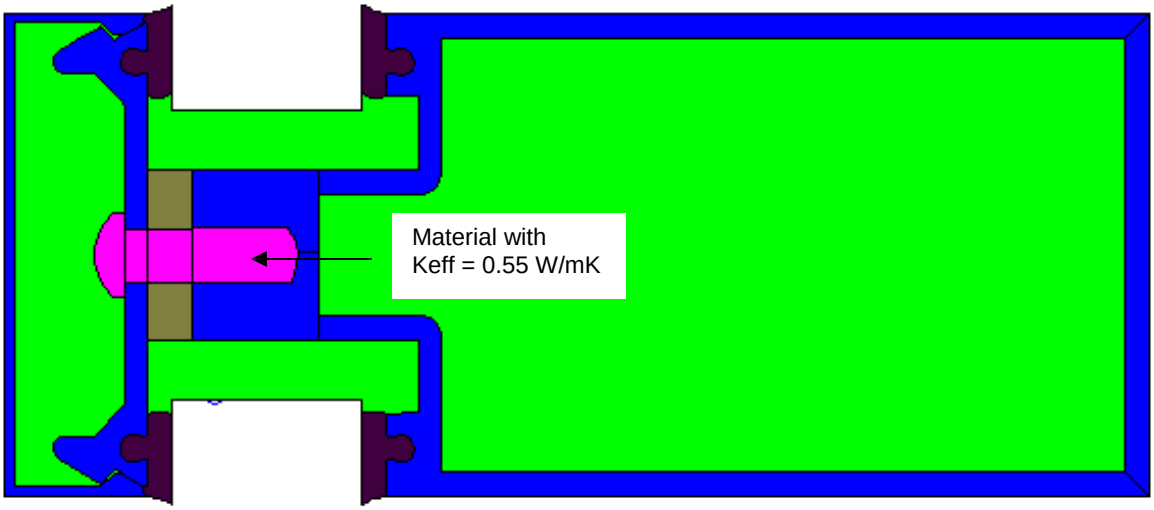


Figure 8-102. Final THERM model with boundary conditions defined.

8.9.6. Example 2: Thermally slotted cross-section

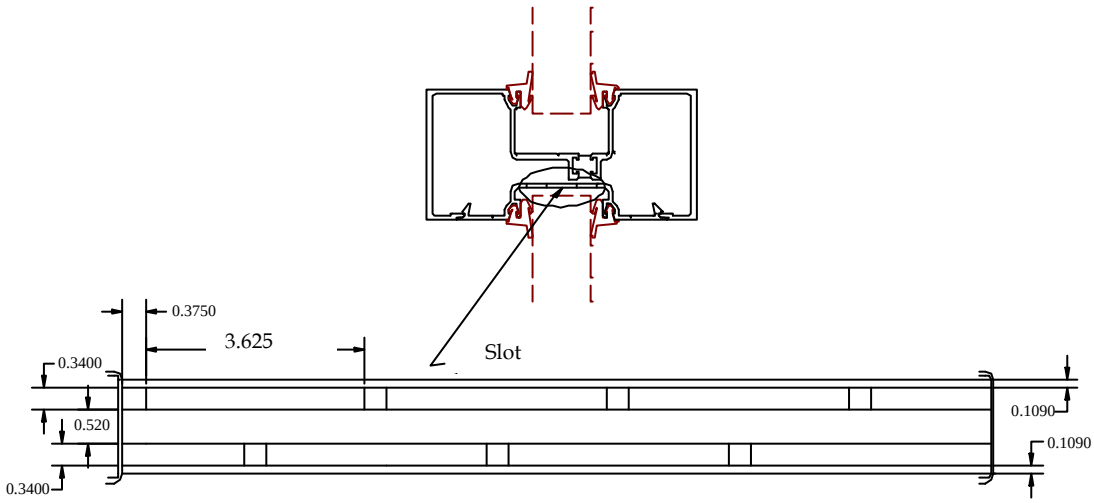


Figure 8-103. DXF for thermally slotted cross section.

Step I

Skip = 0.009525 m (0.375 in)

Slot (Air) = 0.092075 m (3.625 in)

Interval = 0.092075 m (3.625 in) + 0.009525 m (0.375 in)

= 0.1016 m (4 in)

=)

Fb = 0.009525 m/ 0.1016 m

= 0.094 m (3.7 in)

Fn = 1-Fb

= 1- 0.094 m

= 0.906 m (35.67 in)

Percent of thermal bridge = (Fb)*100

= (0.094 m) * 100

= 9.4%

Because the thermal bridge is 9.4% of the length of the façade, the skip-and-debridge needs to be calculated using the isothermal plane procedure. Note: The rest of the example will be in SI units only, with no IP unit translation

Kb = 160 W/m-K (conductivity of skipped debridge, in this case Aluminum)

Rt = ∑ (Depth/ conductivity)

= D_d/k_d

= (0.0086 m/0.024W/m-K)

= 0.35833 m^2-K/W

where Depth is length of thermal bridge in a direction of heat flow, and the air is assumed to have the conductivity of 0.024 W/m-K

Kn = total depth/Rt

= 0.0086m/ 0.35833 W/m-K

= 0.024W/m-K

Keff = Fb*Kb +Fn*Kn

= 0.094*160 W/m-K + 0.906* 0.024W/m-K

= 15.062 W/m-K

To convert to IP:

Keff = 15.062 W/m-K * 0.57782

= 8.703 Btu/hr-ft-^{o}F

or in alternative IP units,

Keff = 15.062* 0.57782 * 12 in/ft

= 104.436 Btu-in/hr-ft^2-^{o}F

Step-2

Replace the strip of air-aluminum-air with new keff material of 15.078 W/m-K

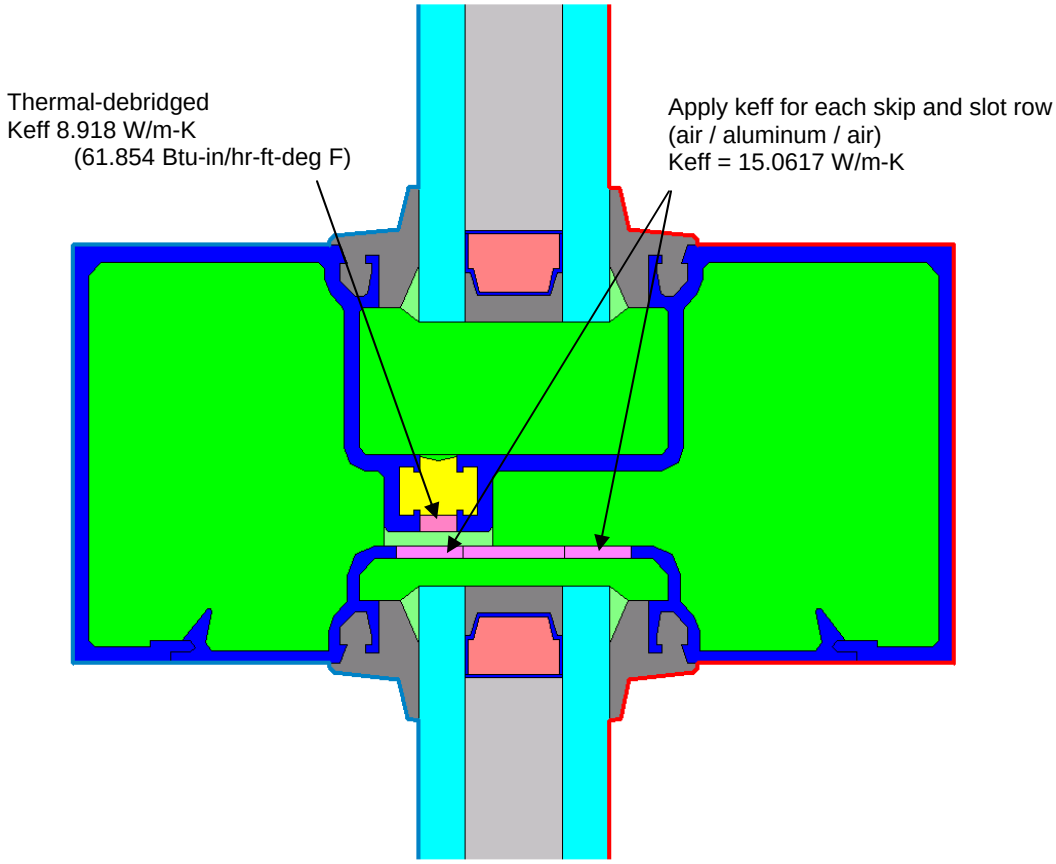
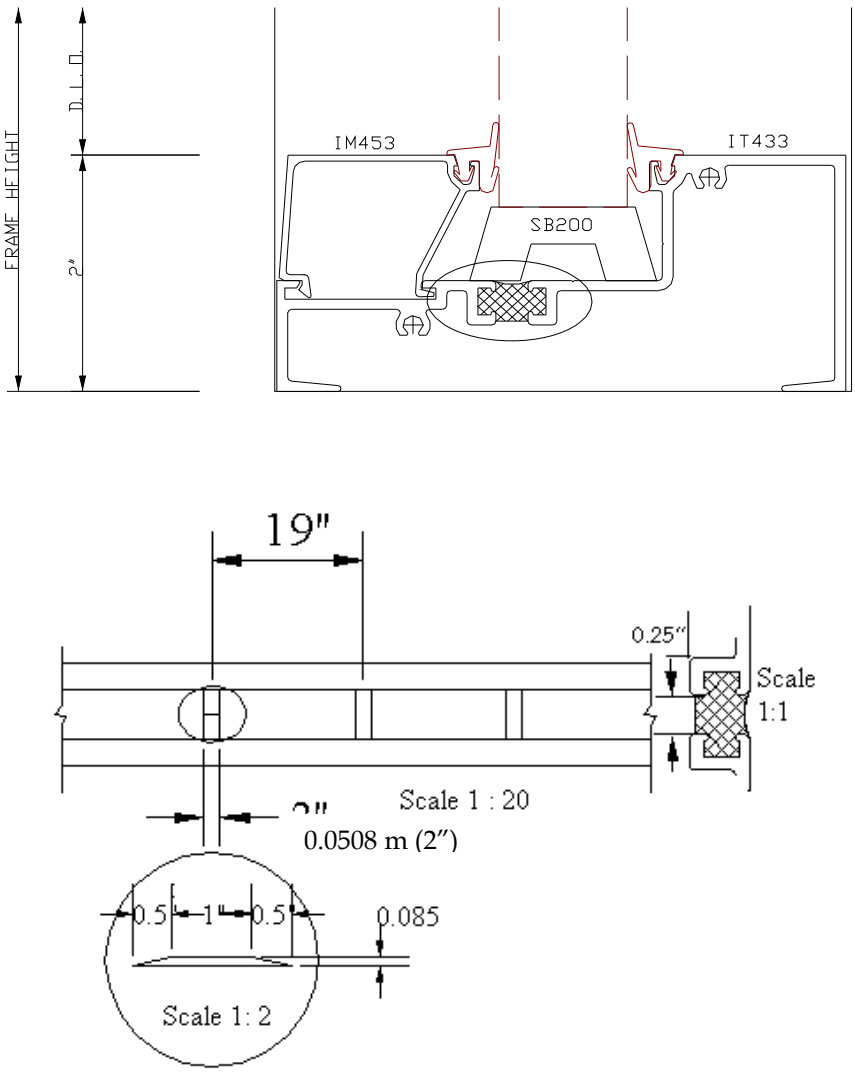


Figure 8-104. New Keff assigned to each skip and debridged row.

Step 3

Define the Boundary condition and run the model to calculate the U-factor for frame and edge-of-glass.

8.9.7. Example 3: Skip-and-debridge:



Note: the skip trapezoid shall be treated as a rectangle equal to the total length of the base of the trapezoid.

Figure 8-105. Drawings for Example 3 Skip and Debridge.

STEP 1

Skip = 0.0508 m (2 in)

Debridge (Air) = 0.4318 m (17 in)

Interval = 0.508 m (2 in) + 0.4318m (17 in) = 0.4826 m (19 in)

Note: The rest of the example will be in SI units only, with no IP unit translation

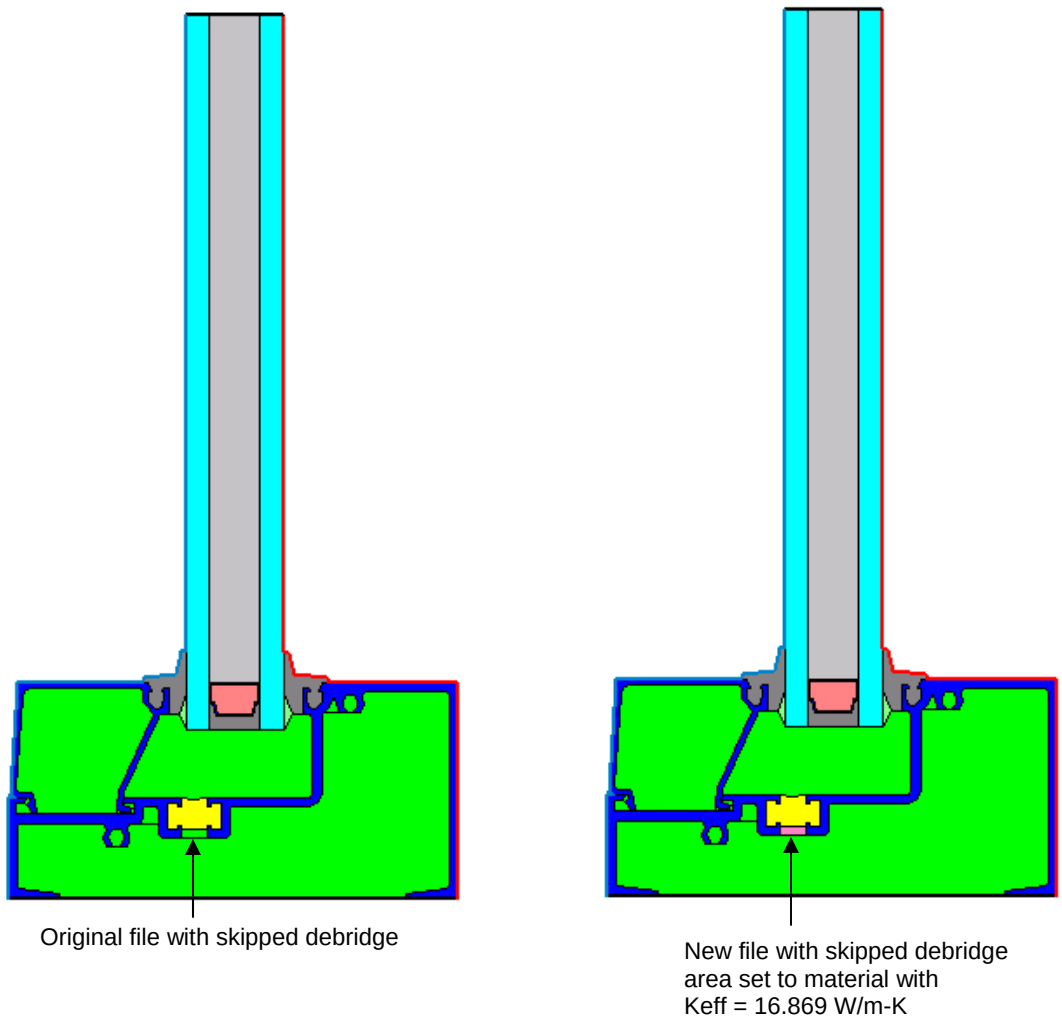


Figure 8-106. Original THERM model and new model with new Keff for skipped debridge area.

Fb = 0.0508 m/ 0.4826 m = 0.1053

Fn = 1-Fb
= 1- 0.1053 = 0.4947

%Fb = (Fb) ·100
= (0.1053) · 100
= 10.53% (Skip-and-debridge needs to be calculated using Isothermal plane procedure).

Kb = 160 W/m-K (conductivity of skipped debridge, in this case aluminum)

Rt = ∑ Length/ conductivity
= (0.00635 m/0.024 W/m-K)
= 0.2646 m^2-K/W

The length is the length of material in a direction of heat flow i.e. 0.25″ as shown in the figure. (The air effective conductivity calculated using THEM)

Kn = length/Rt
= 0.00635m/0.2646 m^2-K/W
= 0.024 W/m-K

Keff = Fb*Kb +Fn*Kn
= 0.1053*160 W/m-K + 0.8947*0.024 W/m-K
= 16.869 W/m-K

To convert to IP:

Keff = 16.869 * 0.57782 = 9.747 Btu/hr-ft-F (or in alternative IP Units: 116.97 Btu-in/hr-ft^2-F)

8.10 Site Built fenestration products (Curtain Walls, Window Walls and Sloped Glazing)

A few things to be aware of:

- Review the drawings carefully for non-continuous elements. These systems tend to have many such elements including shear blocks, installation clips and spacers at the bolts.
- Site built modeling is partially dependent on the installation of the product. Make sure that the drawings you have show the installation.
- Site built products are typically multiple lite systems where the intermediate vertical and horizontal frame members repeat in some pattern.
- Curtain Walls, per NFRC 100 Table 4-3, shall be simulated and tested with the intermediate verticals as jambs and intermediate horizontals as the head and sill members.
- Window Walls, or also known as strip windows, per NFRC 100 Table 4-3, shall be tested and simulated with intermediate verticals as jambs and standard head and sill members.
- Sloped Glazing may also be rated based on the centerline dimensions if utilized like a curtain wall or window wall, except for solariums and sunrooms. Sloped glazing of solariums and sunrooms shall be simulated and tested with standard jamb, head, and sill members.

Modeling of the representative products above used to compare to the physical validation test is as follows:

1. Simulate the full vertical intermediate member twice (for the left and right jambs):
    a. Once with the left glass replaced with wood, which is the same thickness as the IG unit
    b. Once with the right glass replaced with wood, which is the same thickness as the IG unit. The wood shall extend to the original site line.
2. Simulate the horizontal members.
    a. If this is for a curtain wall, then once with the top glass replaced with wood, which is the same thickness as the IG unit and then a second time with the bottom glass replaced with wood, which is the same thickness as the IG unit. The wood shall extend to the original site line.
    b. If this is for a window wall or sloped glazing, then the standard sill and head members are modeled.
3. A physical thermal testing laboratory shall test a sample with the same cross sections as simulated in the steps listed above per NFRC 102.
4. Validation is checked by comparing the values obtained by simulating the product using steps 1 and 2 above, and the physical test results.

8.10.1. Curtain Walls, Window Walls, and Sloped Glazing

NFRC defines a curtain wall and window wall as any building wall carrying no super imposed vertical load. A *curtain/window wall system* will typically be exterior to the building framework and will typically bypass the building floors.

NFRC 100 Table 4.3 states that curtain walls, window walls, and sloped glazed wall systemsare simulated as two lites with one vertical mullion. See the introduction to this section for the specific members of curtain walls, window walls, and sloped glazed wall systems that are to be modeled. If the intermediate vertical and horizontal members were simulated full width or height for the jambs, head and sill, then the total area of the frame as simulated would be significantly larger than actual frames, so for rating purposes, some members (depending on

whether it is a curtain wall, window wall or sloped glazing) are simulated as ½ the full height (for head and sill) or width (for jambs). The vertical mullion is always simulated full width.

Modeling Procedures:

- **Curtain Walls:** See the modeling steps in the following section.

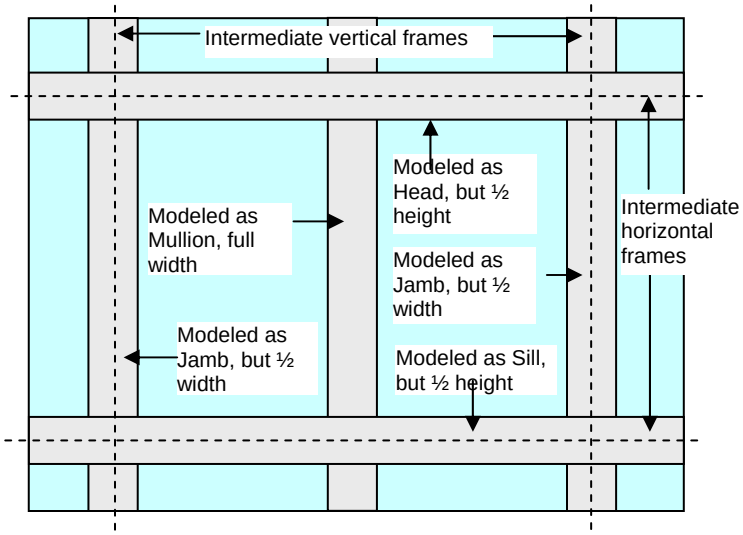


Figure 8-107. Curtain Wall Modeling Method

- **Window Walls:** For window walls, the standard head and sill members are modeled, and therefore the steps for simulation are identical to that of a normal window cross-section.

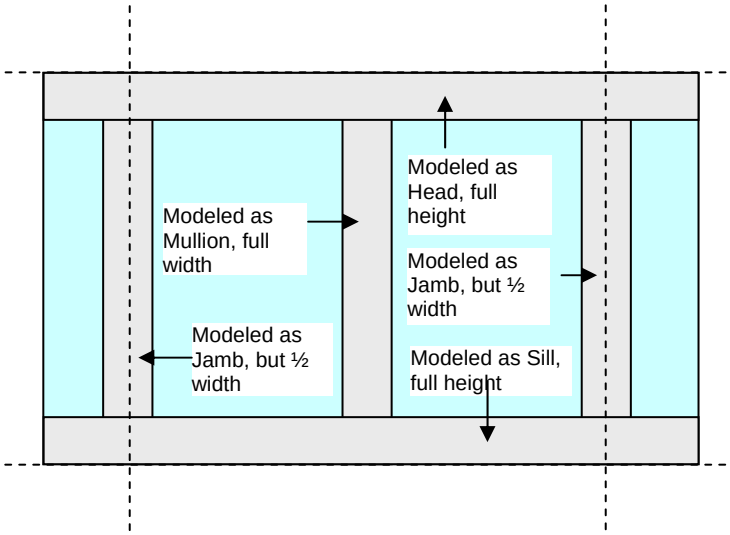


Figure 8-108. Window Wall Modeling Method

- **Sloped Glazed Wall System:** If the product to be simulated is a sloped glazed wall system, then the modeling steps are identical to a curtain wall or window wall, except that the cross-section is to be sloped 20 degrees (see skylight section for instruction on sloping products).

8.10.2. Curtain Wall Modeling Procedure

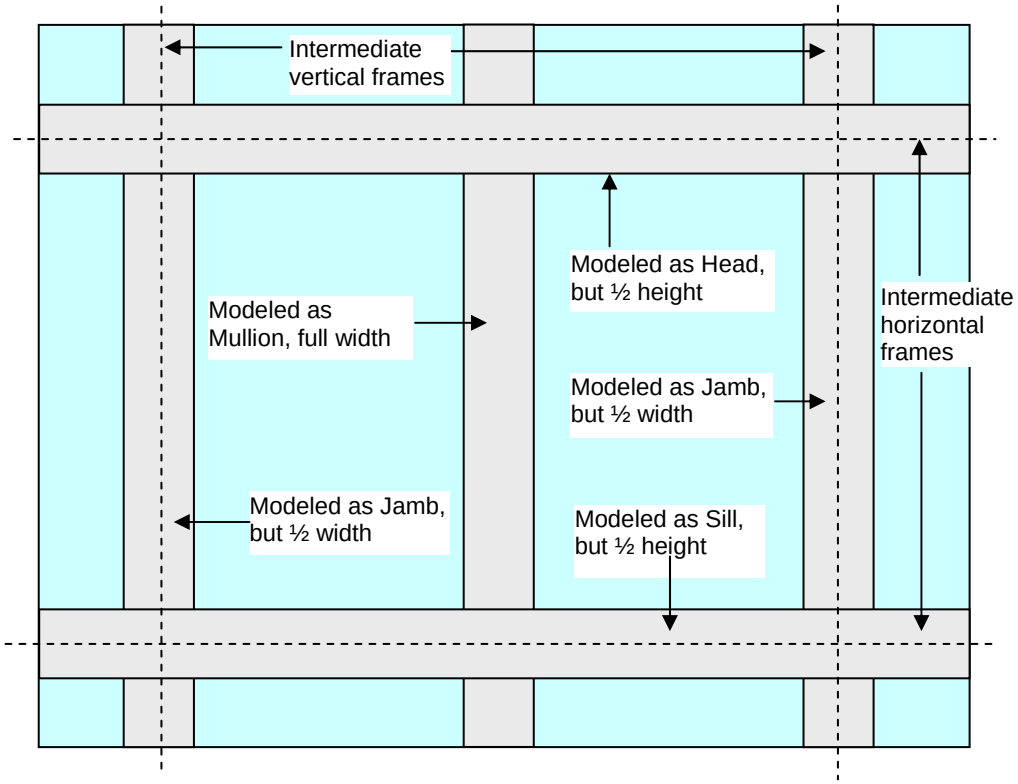


Figure 8-109. Curtain wall simulation model (represented by dotted lines) for rating, where the framing members are modeled at half their width.

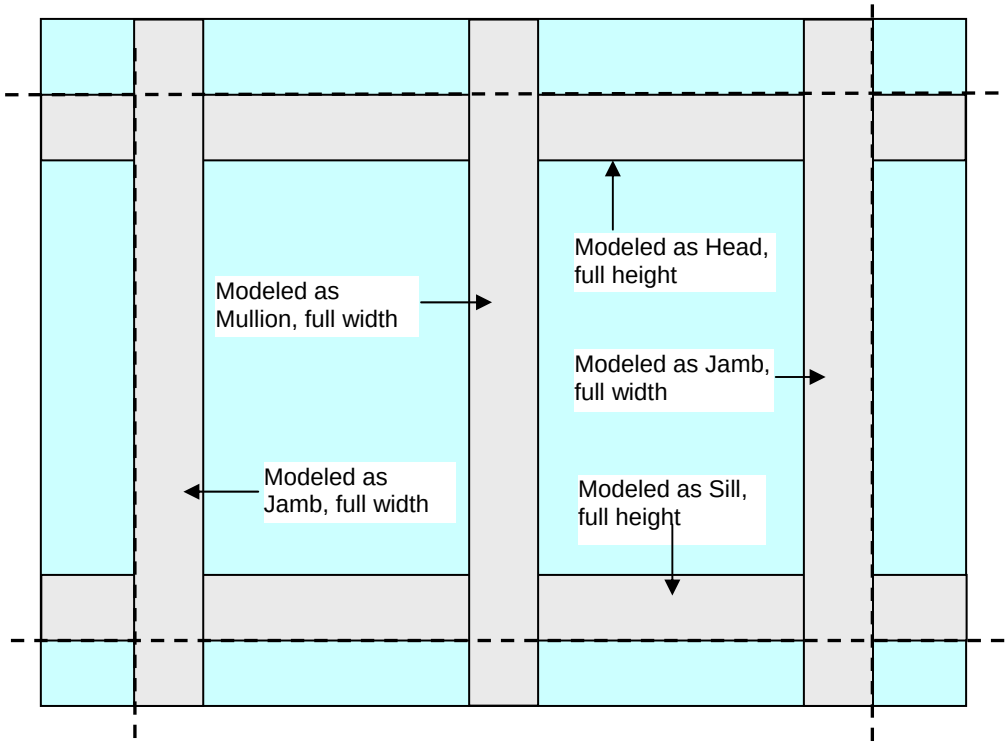


*Figure 8-110. Curtain wall simulation model (represented by dotted lines) to match **testing**.*

Steps in Modeling Curtain Walls for Rating Simulation

In WINDOW:

- Create glazing systems in WINDOW as usual, with Tilt set to “90".

In THERM:

- Draw the cross sections for curtain walls in the same manner as any other model in THERM – it will be a model similar to a meeting rail.

The following discussion lists the steps for making cross sections for intermediate horizontal and vertical frames. In the example, the horizontal frame and vertical frame are the same so only one drawing will be needed.

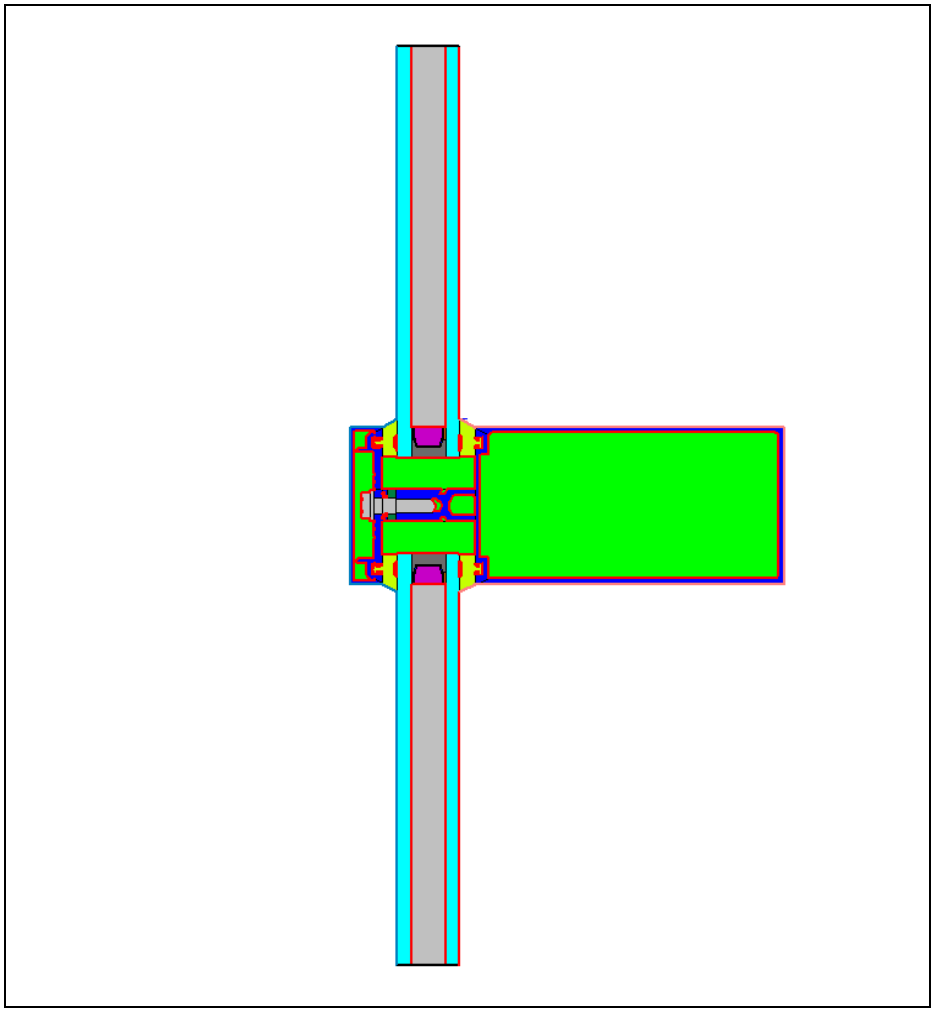


Figure 8-111. Curtain Wall Mullion Cross Section (mull.thm)

Modeling the Intermediate Vertical Mullion:

Using the dimensioned drawings or a DXF file, create the cross section for the frame portion of the vertical mullion. The figure below shows a THERM cross section of the frame portion of the vertical mullion.

Make sure that the section is oriented correctly with the glazing oriented up and down.

- If bolts are present make sure to model them as non-continuous thermal bridging elements if needed. (see Section 8.9).
- Pay particular attention to the aluminum finish in order to assign the correct materials to the drawing. (In the figure below, where the arrows point to Aluminum)

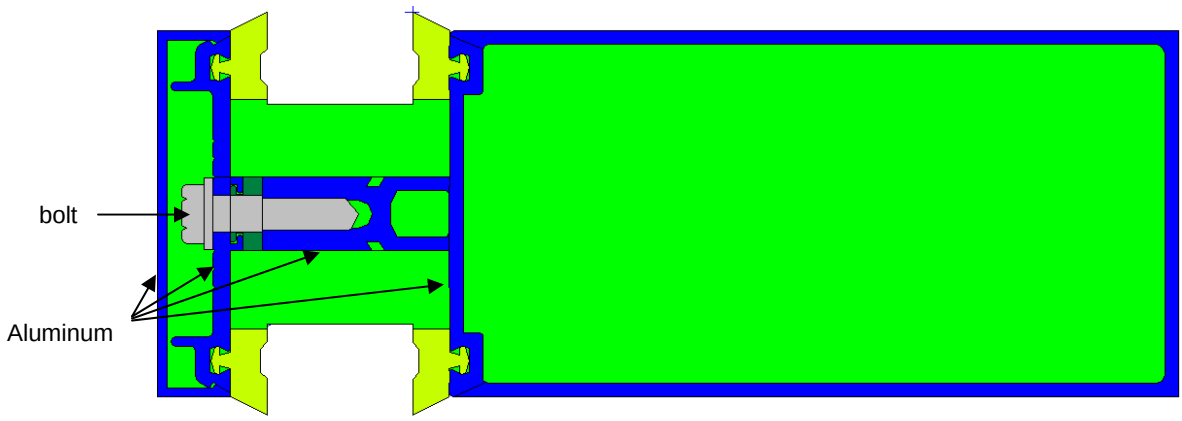


Figure 8-112. Mullion frame cross section without glass (Mull_noglass.thm)

This vertical cross section will be used for the vertical intermediate (mullion) and for the jambs. The jamb model it is necessary to determine and mark the ½ width point between the sight lines. The easiest way to do this is to make temporary reference rectangles as follows:

Determine Frame Midpoints

In order to model the "half-width" frame dimensions for the rating simulation, it is necessary to determine the mid-point of the frame, which is most easily done before the glazing systems are inserted.

- Draw a rectangle from the sight line (highest interior point) for both glazing systems, going horizontally in both directions, so that each rectangle is larger than the horizontal dimension of the frame.
- On both the right and left side of the frame draw a rectangle between the other two reference rectangles and make sure it contacts the frame.
- Measure the exterior rectangle just created in the vertical dimension. The midpoint of the frame is half of this dimension.
- For both the right and left sides of the frame cross section, select the vertical frame component and insert a point on the frame at the midpoint dimension.

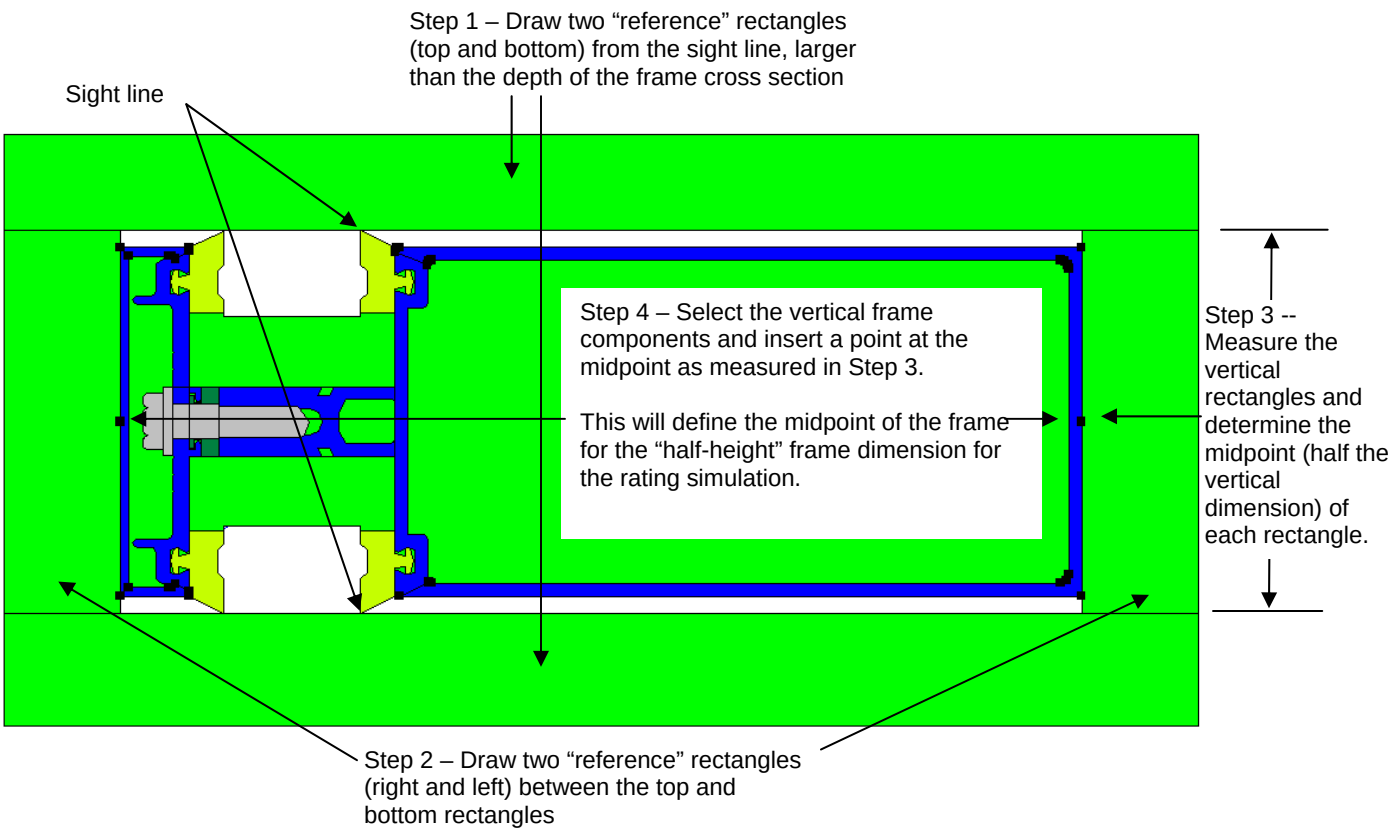


Figure 8-113. Determine the frame mid-points (mull_midpoint.thm)

Finish the cross section

- Delete the four "reference" rectangles.
- Insert the glazing and spacers as usual.
- In **Therm File Properties** (File/Properties), set the **Cross Section Type** to "Vertical Meeting Rail".
- Assign the **Boundary Conditions** as follows:
  - **Interior Frame:** For the mullion cross section, the entire frame width (not just half) is modeled, so all the interior frame boundary condition elements are assigned a **Boundary Condition** of "<frame type> Interior (Convection Only), and a **U-factor Surface** tag of "Frame".

- **Interior Glazing:** Set the **Boundary Conditions** for each glazing system to "<glazing system> U-factor Inside Film" and the **U-factor Surface** tag to "Edge" for the first 63.5 mm (2.5 inches) from the sight line, and "None" for the remainder of the glazing system.
- **Exterior Frame:** Set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "SHGC Exterior" for the exterior frame
- **Exterior Glazing:** Set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "None" for both exterior glazing systems.

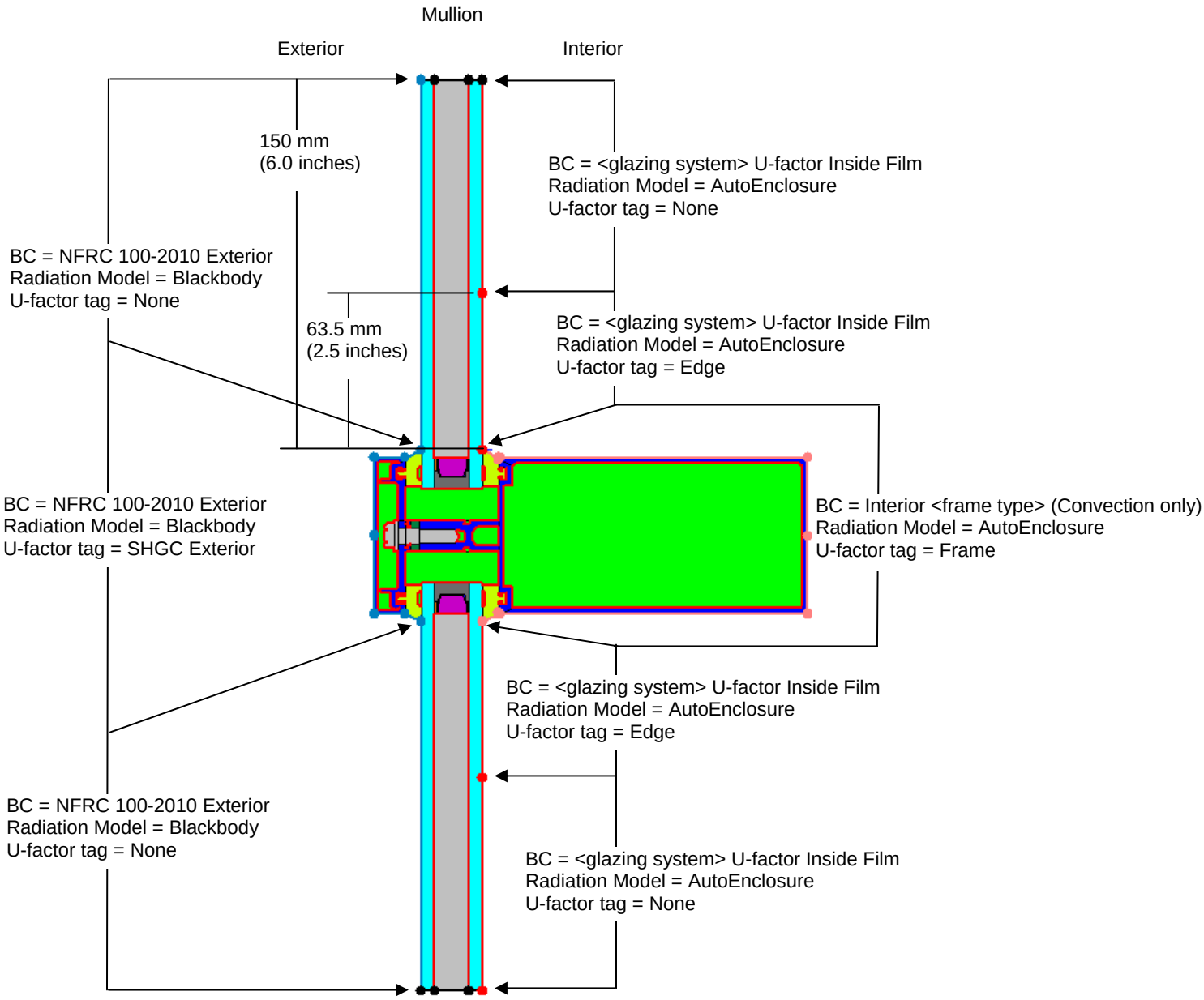


Figure 8-114. Curtain Wall Mullion Boundary Conditions (mull_boundary.thm)

Modeling Curtain Wall Jambs:

In this example, the curtain wall jambs are modeled using the same drawing as the mullion. The boundary conditions are adjusted to capture the heat flow of only half the width. Since the sections may be asymmetrical, both the left and right portions of the mullion are required to be simulated as left and right jambs.

For the Right Jamb:

- Copy the vertical mullion drawing with boundary conditions assigned .
- In **Therm File Properties** (File/Properties), set the **Cross Section Type** to "Vertical Meeting Rail".
- Do not change the **Boundary Conditions** but assign new **U-factor Surface** tags as follows:
  - **Interior Frame:**
    - from the midpoint to the top sight line set the **U-factor Surface** tag to "Frame"
    - from midpoint to the bottom sight line and the entire bottom glass assign the **U-factor Surface** tag to "None".
    - **Interior Glazing System:** for the first 63.5 mm of the top glazing system set the **U-factor Surface** tag to "Edge", and the remainder of the glazing system to "None". For the entire bottom glass assign the **U-factor Surface** tag to "None".
  - **Exterior Frame:**
    - from the midpoint to the top sight line assign the **U-factor Surface** tag to "SHGC Exterior"
    - from midpoint to the bottom sight line assign the **U-factor Surface** tag to "None".
  - **Exterior Glazing System:** set the **U-factor Surface** to "None".

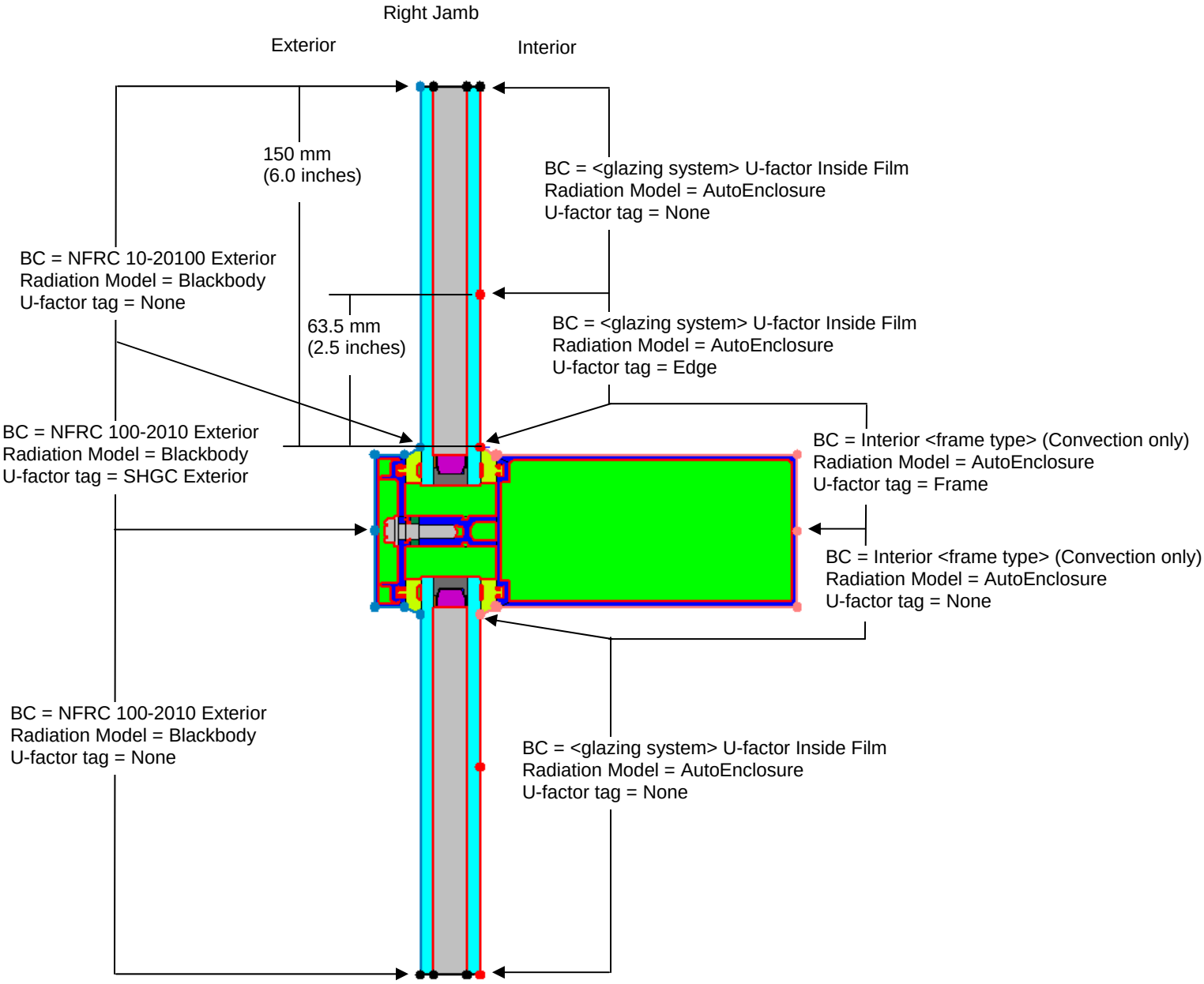


Figure 8-115. Right Jamb Boundary conditions (rightjamb_boundary.thm).

For the Left Jamb:

- The process is the same as the right jamb except that the Frame, edge and SHGC Exterior tags are assigned to the bottom half of the drawing and the top half is assigned the tag of "none"

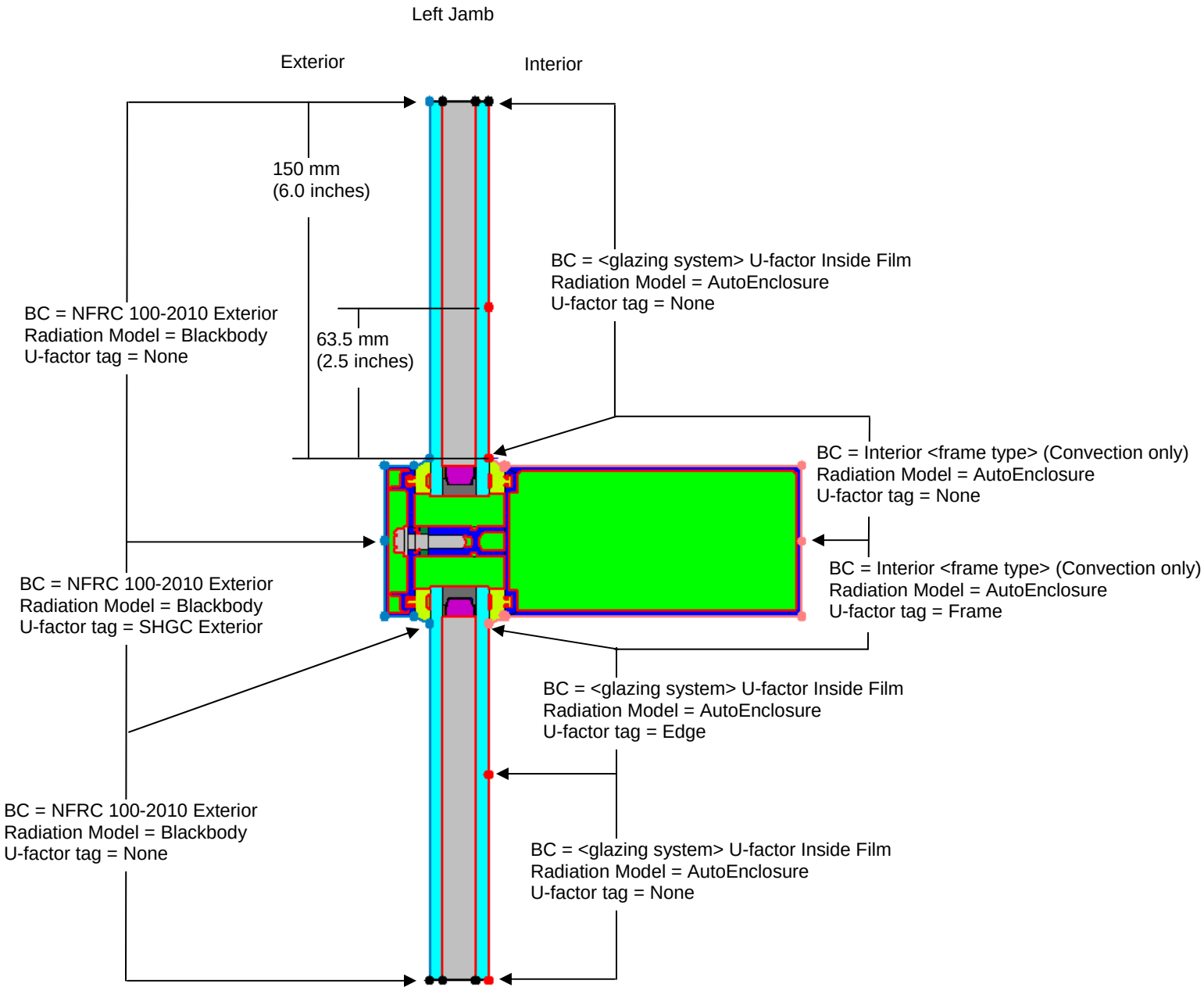


Figure 8-116. Left Jamb Boundary Conditions (leftjamb_boundary.thm)

NOTE: the Therm File option " Use CR Model for Window Glazing System" may be left checked since Therm will not calculate Condensation resistance for a cross section Type tagged Vertical Meeting Rail or Jamb.

Modeling the Intermediate Horizontal (as Head and Sill):

The horizontal frame cross section is drawn in exactly the same way as the intermediate vertical frame cross section, including inserting the midpoint. For this example the horizontal and vertical frames are identical so the same drawing is used. Assign boundary conditions in the usual way and then assign new boundary condition U-Factor Surface tags as follows for the head and sill.

For the Head:

- Use the drawing for the intermediate horizontal.
- In **Therm File Properties** (File/Properties), set the **Cross Section Type** to "Head".
- Assign the Boundary Conditions as follows:
  - **Interior Frame:**
    - For the interior frame from the midpoint to the *bottom* sight line, set the **Boundary Condition** to "<frame type> Interior (Convection Only), and the **U-factor Surface** tag to "Frame".
    - For the interior frame from midpoint to the *top* sight line, set the **Boundary Condition** to "<frame type> Interior (Convection Only), and the **U-factor Surface** tag to "None".
  - **Interior Glazing:** Set the **Boundary Conditions** for each glazing system of the bottom of the glass to "<glazing system> U-factor Inside Film" and the **U-factor Surface** tag to "Edge" for the first 63.5 mm (2.5 inches) from the sight line, and "None" for the remainder of the glazing system.
  - **Exterior Frame:**
    - For the exterior frame from the midpoint to the *bottom* sight line, set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "SHGC Exterior".
    - For the exterior frame from the midpoint to the *top* sight line, set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "None".
  - **Exterior Glazing:** Set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "None" for both exterior glazing systems.

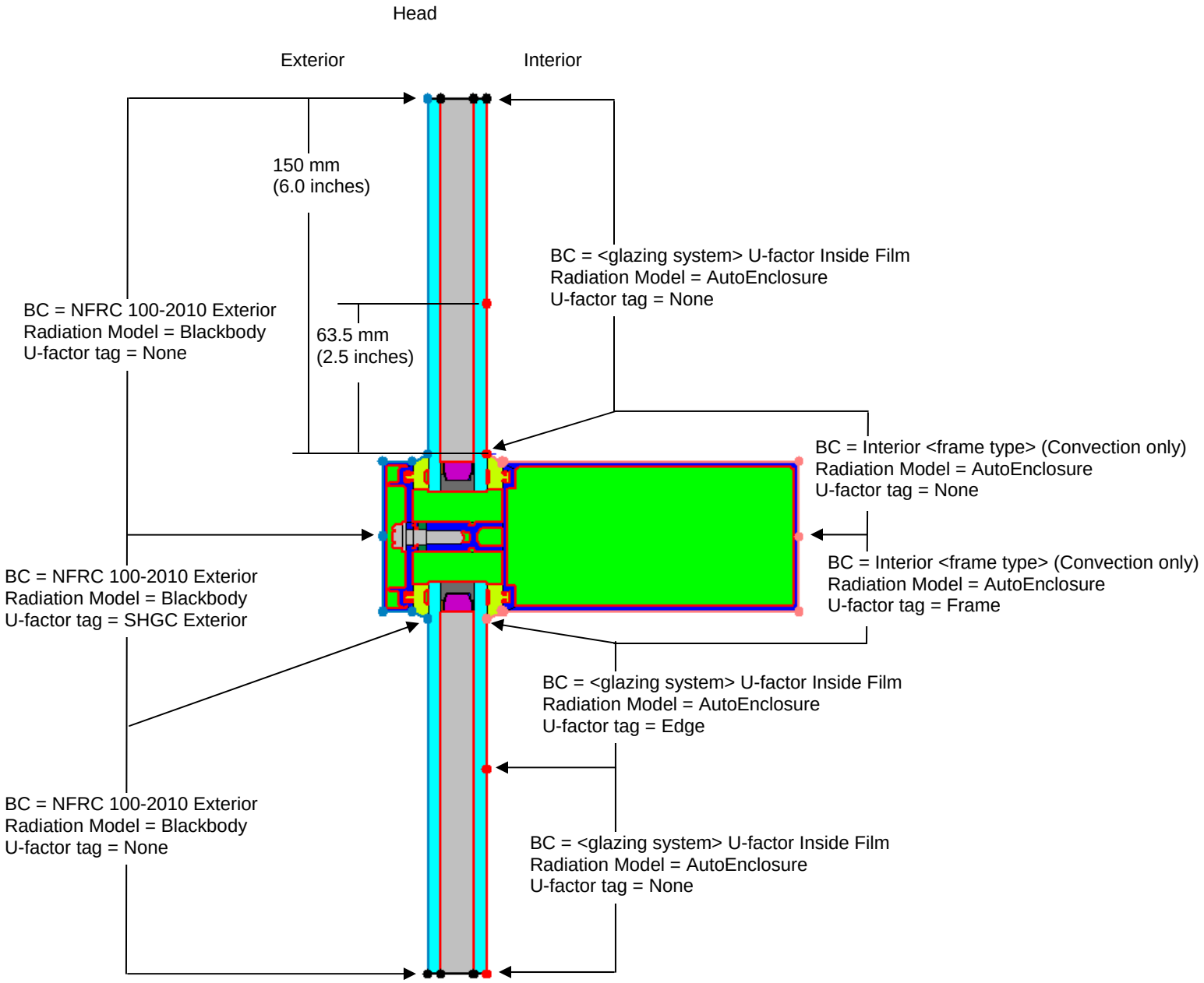


Figure 8-117. Head Boundary Conditions (head_boundary.thm)

For the Sill:

- Use the drawing for the intermediate horizontal.
- In **Therm File Properties** (File/Properties), set the **Cross Section Type** to "Sill".
- Assign the Boundary Conditions as follows:
  - **Interior Frame:**
    - For the interior frame from the midpoint to the *top* sight line, set the **Boundary Condition** to "<frame type> Interior (Convection Only), and the **U-factor Surface** tag to "Frame".
    - For the interior frame from midpoint to the *bottom* sight line, set the **Boundary Condition** to "<frame type> Interior (Convection Only), and the **U-factor Surface** tag to "None".
  - **Interior Glazing:** Set the **Boundary Conditions** for each glazing system of the *top* of the glass to "<glazing system> U-factor Inside Film" and the **U-factor Surface** tag to "Edge" for the first 63.5 mm (2.5 inches) from the sight line, and "None" for the remainder of the glazing system.
  - **Exterior Frame:**
    - For the exterior frame from the midpoint to the *top* sight line, set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "SHGC Exterior".
    - For the exterior frame from the midpoint to the *bottom* sight line, set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "None".
  - **Exterior Glazing:** Set the **BoundaryCondition** to "NFRC 100-2010 Exterior" and the **U-factor Surface** tag to "None" for both exterior glazing systems.

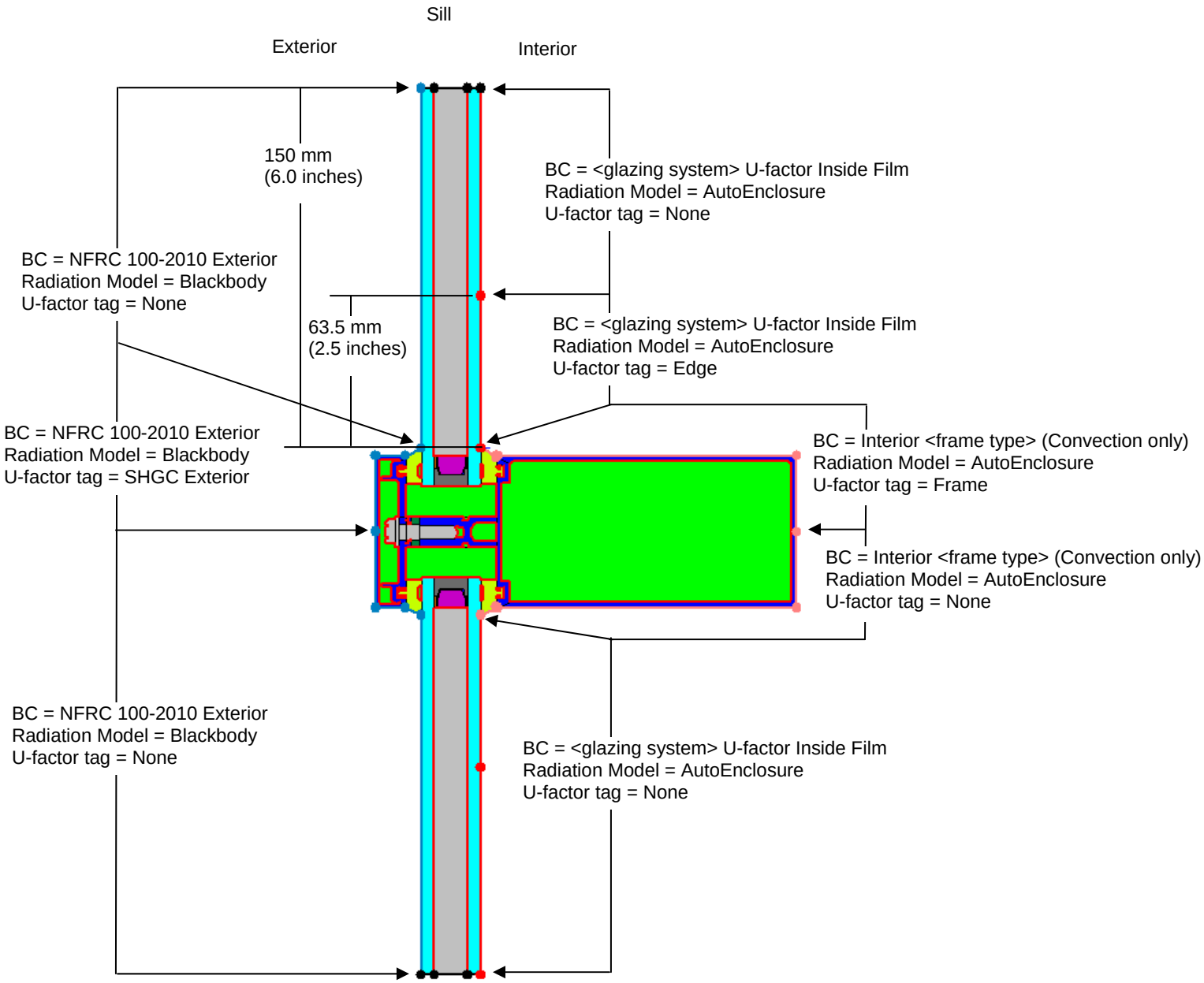


Figure 8-118. Sill Boundary conditions (sill_boundary.thm)

It is a good idea at this point to verify the orientation and the direction of the gravity arrows of these sections.

In WINDOW:

Calculate these files and import into WINDOW. Use the files to create the whole product in the Window Library as applicable.

8.11. Retractable Venetian Blinds in Fully Open Position

Integral venetian blinds (venetian blinds between two glazing layers in a glazing system) fall into the category of a dynamic glazing product. The rules for rating dynamic glazing products, according to NFRC 100 and 200, state that they must be rated in both their fully open and fully closed positions. In the case of modeling retractable integral venetian blinds as part of a dynamic glazing product, the fully open position is when the venetian blind is completely retracted. However, even when completely retracted, the stacked venetian blind slats become a "block" of material that must be modeled.

The following illustrates how to model a fully retracted venetian blind that has a stack of blind slats at the top of the glazing system.

In this discussion, only the Head section will be discussed. For Vertical Sliding windows where the lower sash contains an integral venetian blind, the lower sash portion of the Meeting Rail section will be modeled with the same venetian blind considerations as the Head section. The other cross sections (Jambs, Sills and Meeting Stiles) are modeled normally, without any venetian blind considerations. Two examples will be illustrated:

- The venetian blind fully retracted inside a double glazed system.
- The venetian blind fully retracted between a double glazed system and a third glazing layer (such as, but not limited to, an add-on panel).

8.11.3. Venetian Blind Fully Retracted Inside a Double-Glazed System

The following figure shows the Head cross section for a venetian blind in the fully-retracted position inside a double-glazed system.

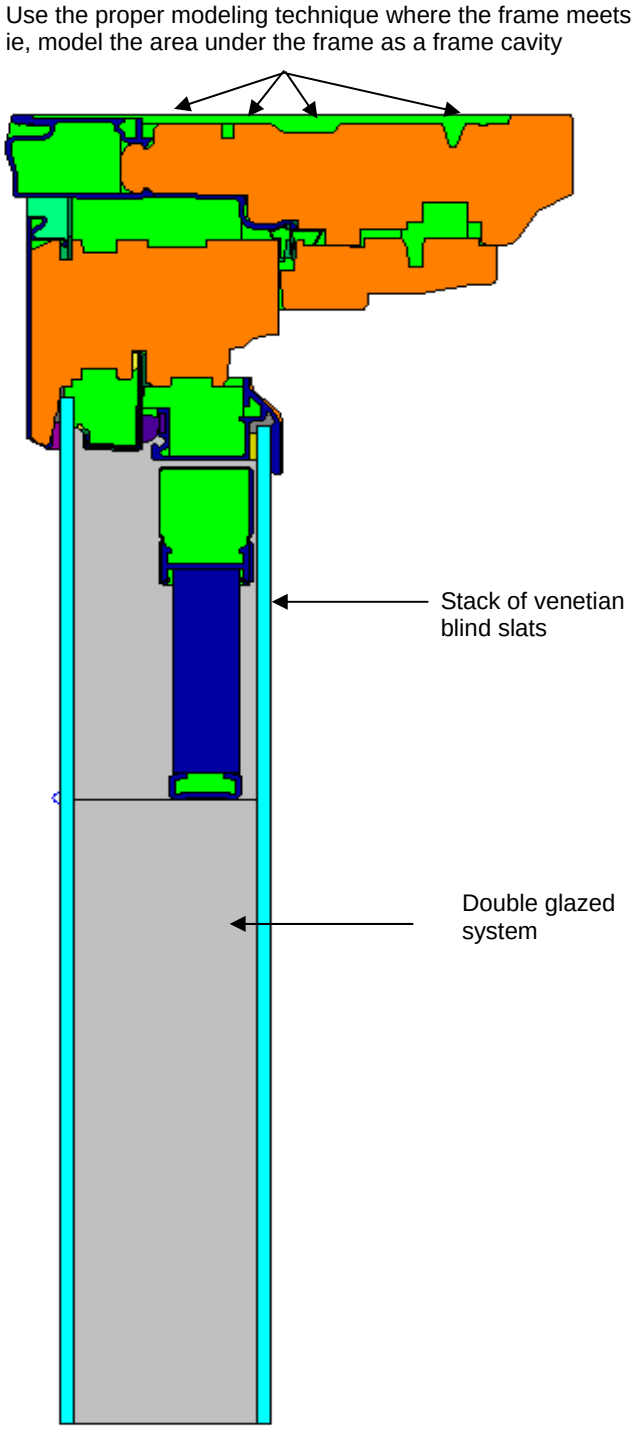


Figure 8-107. Head cross section with fully retracted venetian blind inside a double-glazed system.

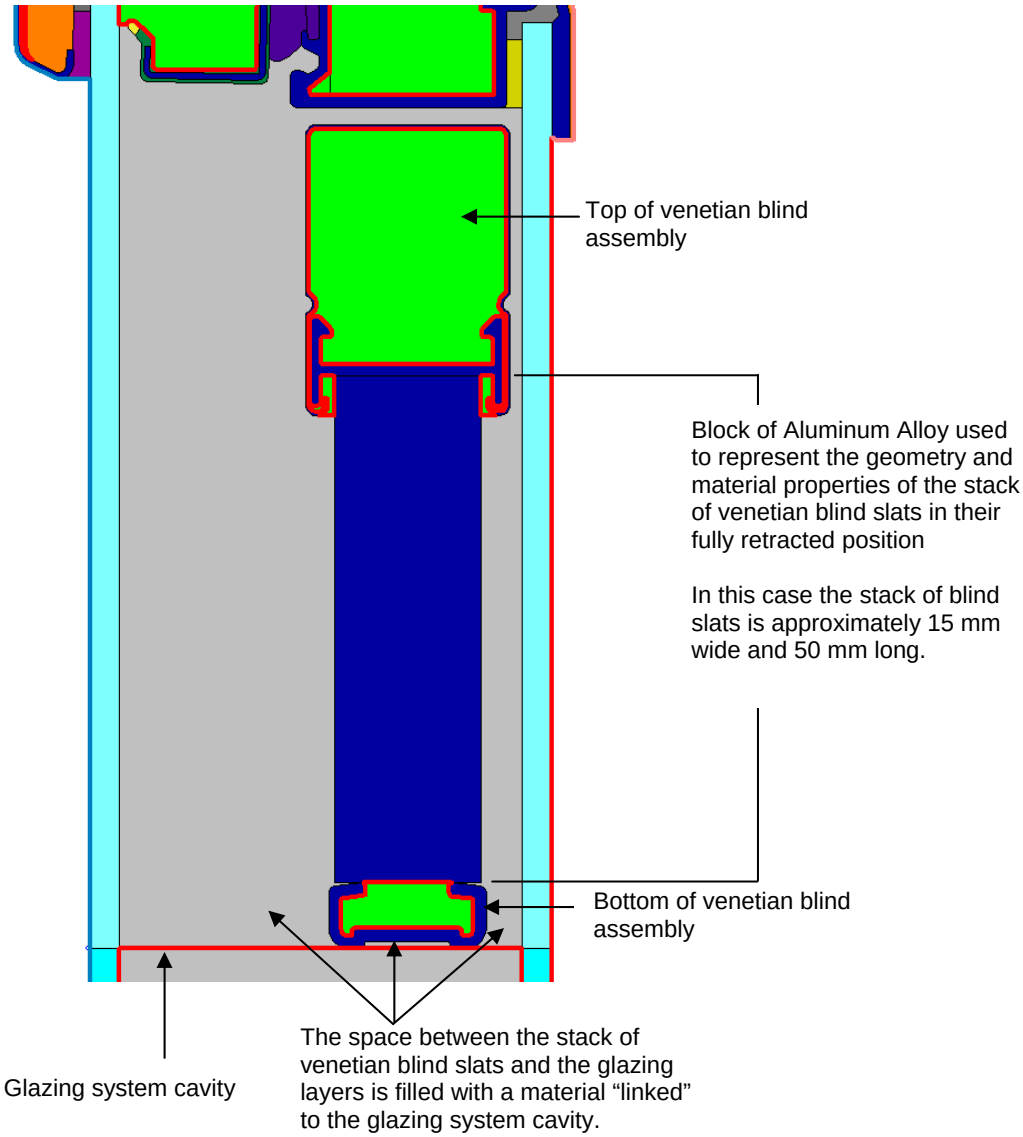


Figure 8-108. The Head cross section with the retracted venetian blind, including the stacked slats, and the top and bottom assemblies for the blind that are continuous across the section.

Follow these steps to model a fully retracted venetian blind:
(Note: This example was done for Aluminum slat blinds. If the material of the blinds is not Aluminum, use the appropriate material properties from NFRC 101 "Procedure for Determining Thermo-Physical Properties of Materials for Use in NFRC-Approved Software Programs" for the stack of retracted venetian blind slats.)

1. Draw the Head cross section of the product frame.
2. Draw the geometry of the retracted venetian blind, including the length and width of the stacked venetian blind slats and any continuous hardware that holds the blind in place (top and bottom). (*Note: In this case, the system seems to be "floating" because non-continuous hardware is used to attach the blind to the fenestration system.*)

3. Insert the glazing system.
   The example shown below has glazing layers that intersect the frame at two different heights. There are numerous methods for modeling this. The method shown is to "stretch" the glazing layers to meet the frame at the appropriate place, and this method also necessitates inserting points on the glazing system for the correct boundary conditions segments. Another method would be to insert "float glass" polygons for the glazing layer extensions – this method eliminates the need to insert the points in the glazing system for the boundary condition segments.

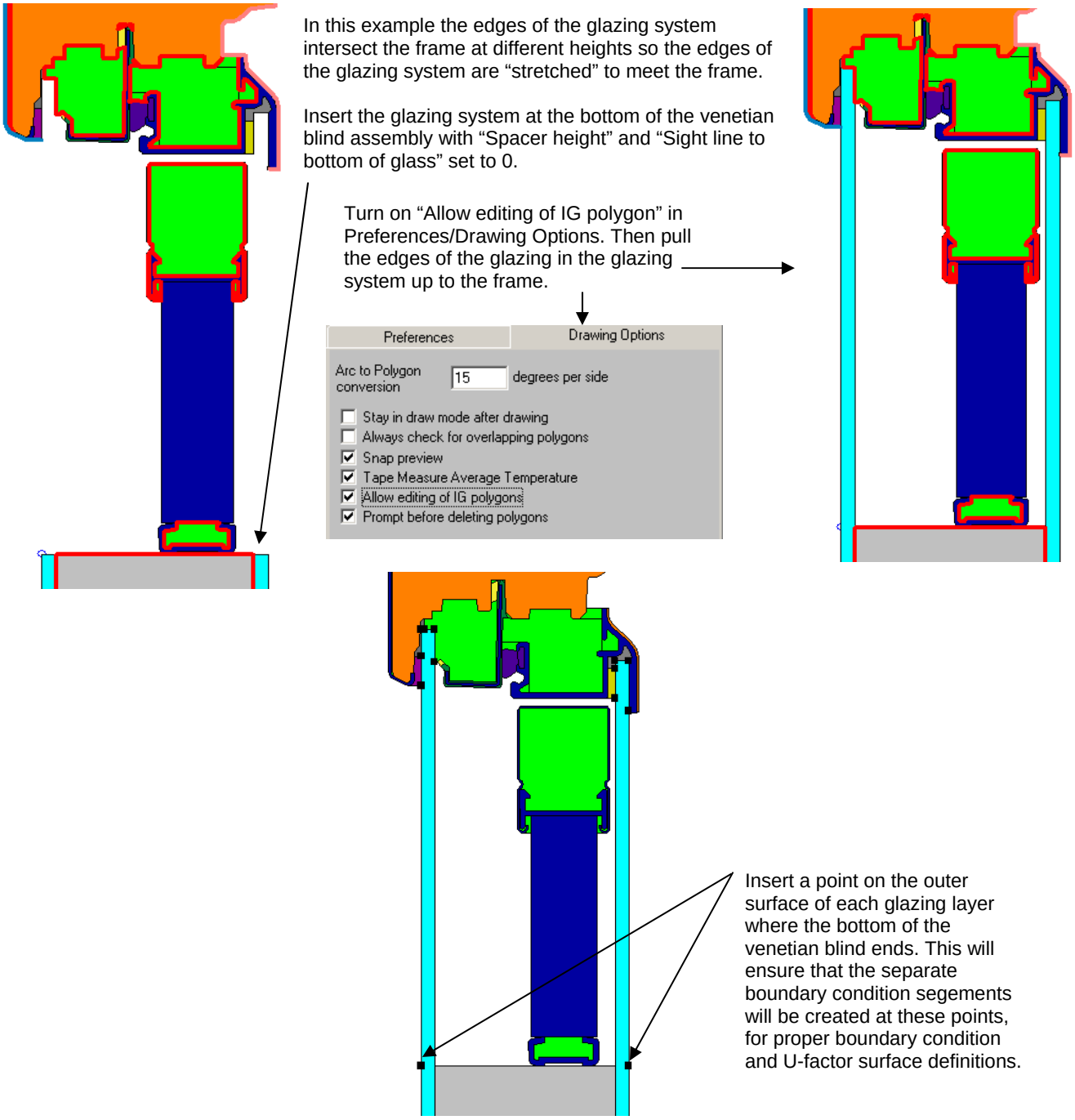


Figure 8-109. Insert the glazing system.

4. Fill the cavities around the venetian blind with a material, and then link that material to the cavity of the main glazing system. There may be several cavities to be linked, as shown in the figure below.

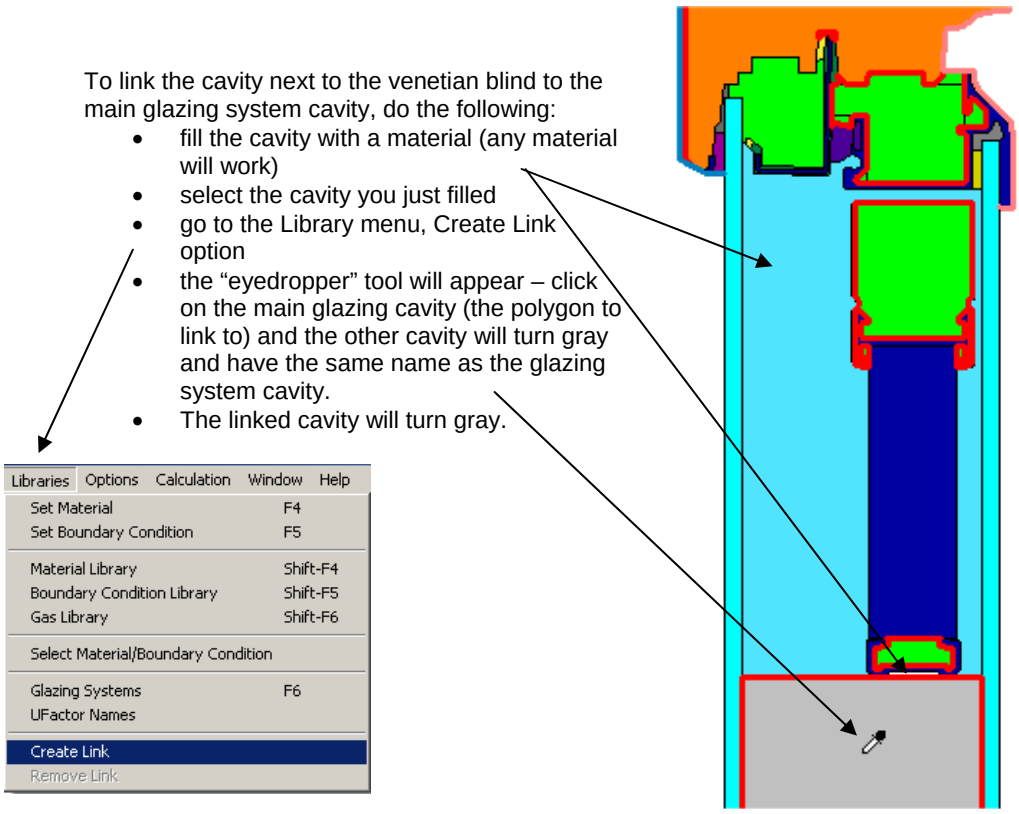


Figure 8-110. Fill the cavity next to the venetian blind by linking it to the main glazing cavity.

5. Generate the Boundary Conditions. The section of the warm side of the glazing system adjacent to the retracted venetian blind should be defined with a U-factor Surface tag of "Frame".

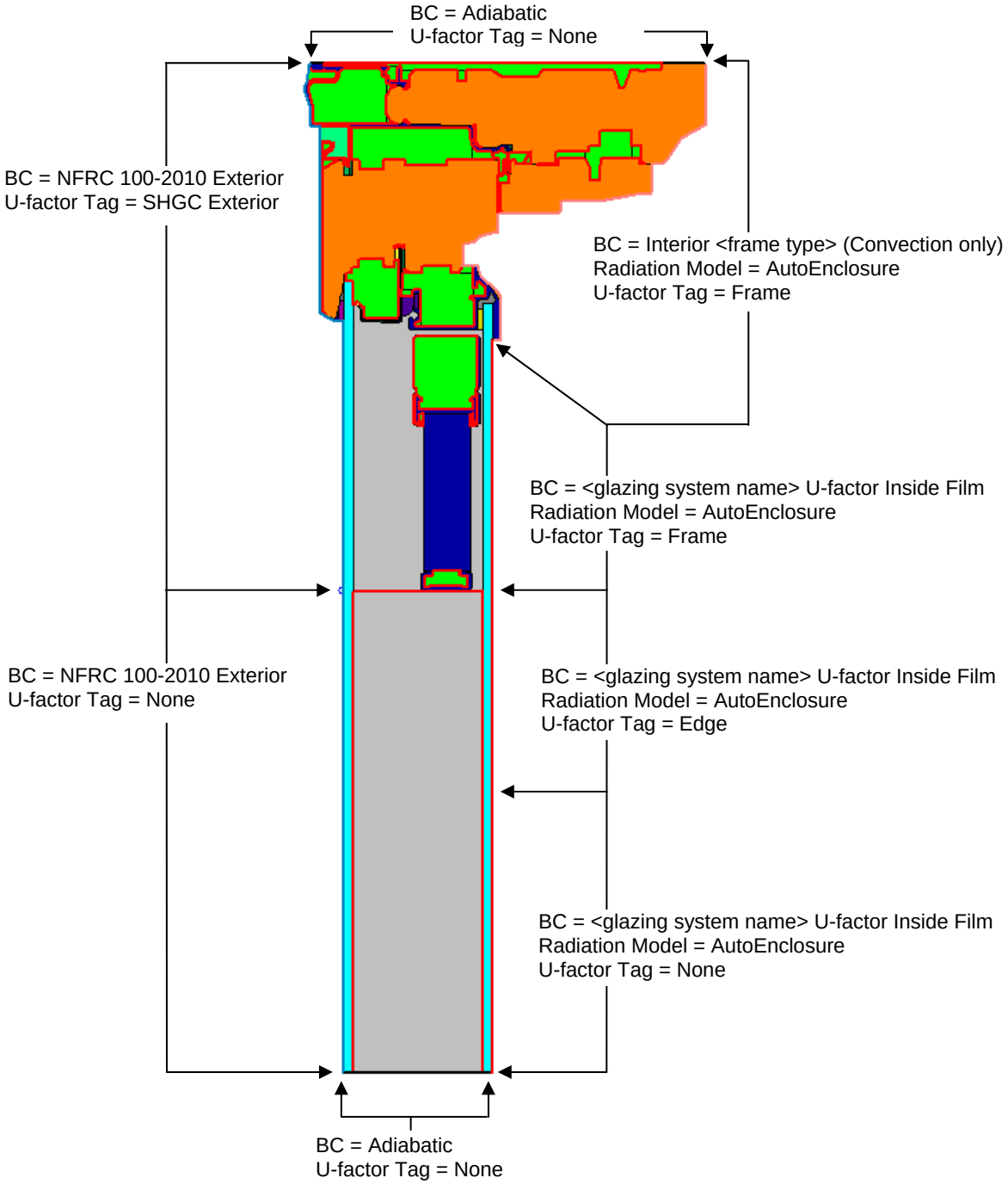


Figure 8-111 Define the boundary conditions for the cross section

6. Calculate the results for this cross section.
7. Complete the calculations for the other product cross sections (Sill, Jambs and Meeting Rails / Stiles as appropriate).
8. Import all the cross sections into the WINDOW Frame Library and calculate the total product U-value, SHGC and VT.

8.11.4. Venetian Blind Fully Retracted Between a Double-Glazed System and a Third Glazing Layer

The following figure shows the Head cross section for a venetian blind in the fully-retracted position between a double-glazed system with a third glazing layer, such as, but not limited to, an add-on panel.

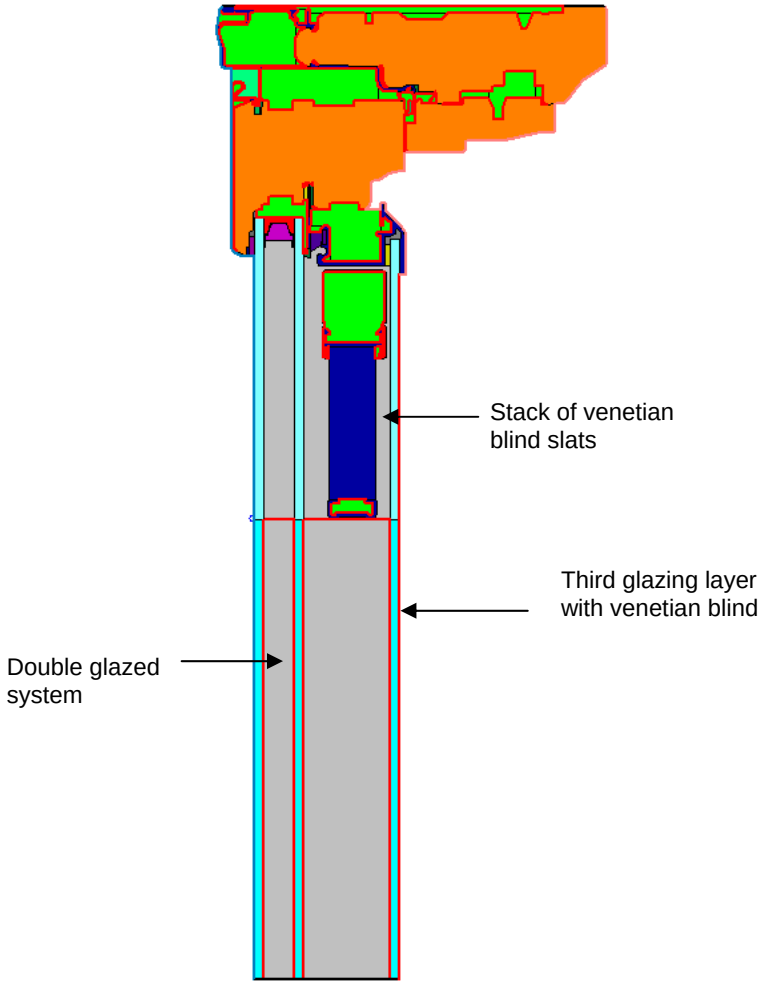


Figure 8-112. Head cross section with fully retracted venetian blind between a double-glazed system and a third glazing layer.

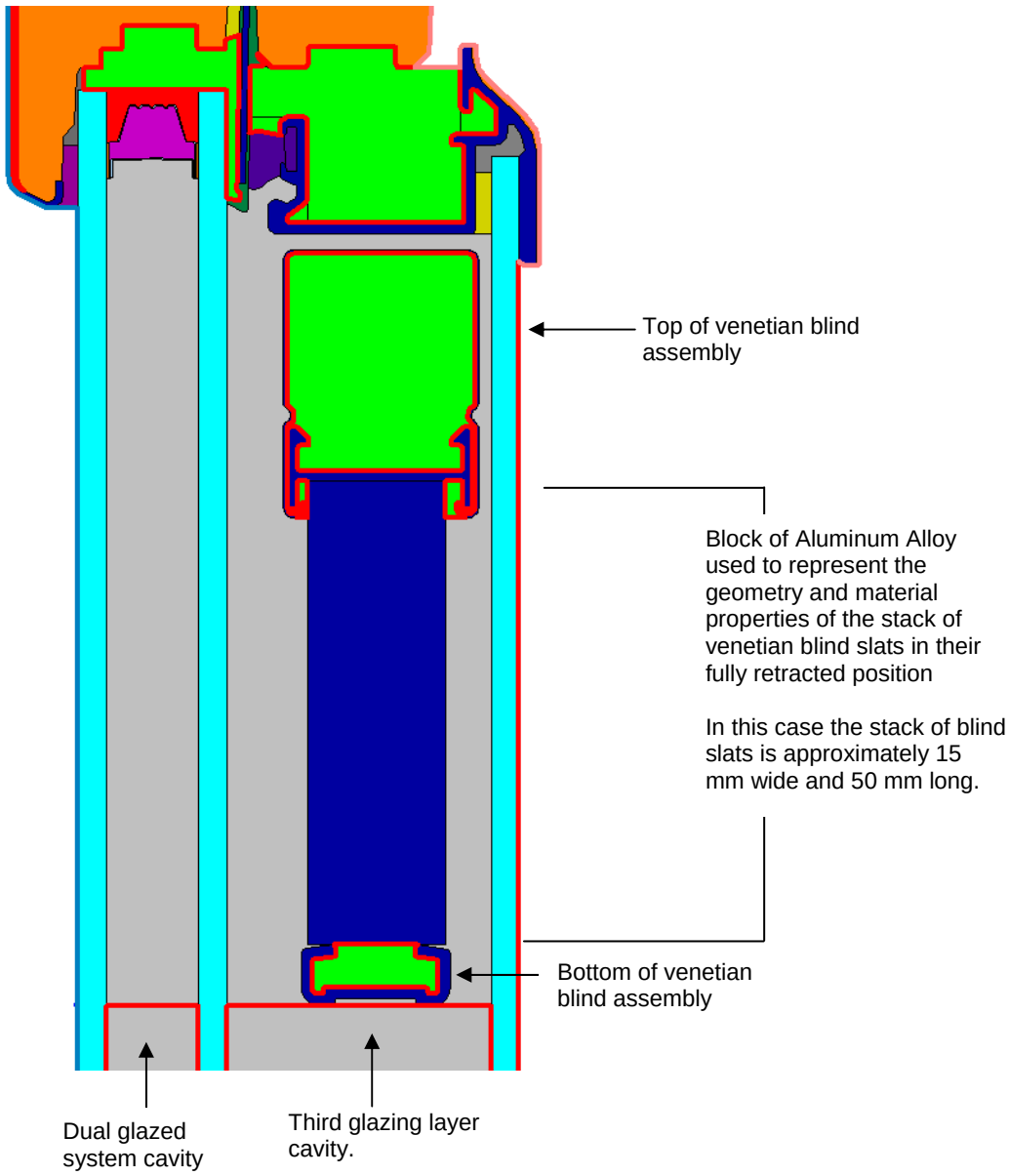


Figure 8-113. The Head cross section with the retracted venetian blind, including the stacked slats, and the top and bottom assemblies for the blind that are continuous across the section.

Follow these steps to model a fully retracted venetian blind between a double glazed system and a third glazing layer:
(Note: This example was done for Aluminum slat blinds. If the material of the blinds is not Aluminum, use the appropriate material properties from NFRC 101 "Procedure for Determining Thermo-Physical Properties of Materials for Use in NFRC-Approved Software Programs" for the stack of retracted venetian blind slats.)

1. Draw the Head cross section of the product frame.
2. Draw the geometry of the retracted venetian blind, including the length and width of the stacked venetian blind slats and any continuous hardware that holds the blind in place (top and bottom).
3. In WINDOW, make the appropriate glazing system (in this case a triple glazed system that represents the double glazed system and a third glazing layer (such as an add-on panel)).

4. Insert the glazing system.
   The example shown below has glazing layers that intersect the frame at two different heights. There are numerous methods for modeling this. The method shown is to "stretch" the glazing layers to meet the frame at the appropriate place, and this method also necessitates inserting points on the glazing system for the correct boundary conditions segments. Another method would be to insert "float glass" polygons for the glazing layer extensions – this method eliminates the need to insert the points in the glazing system for the boundary condition segments.

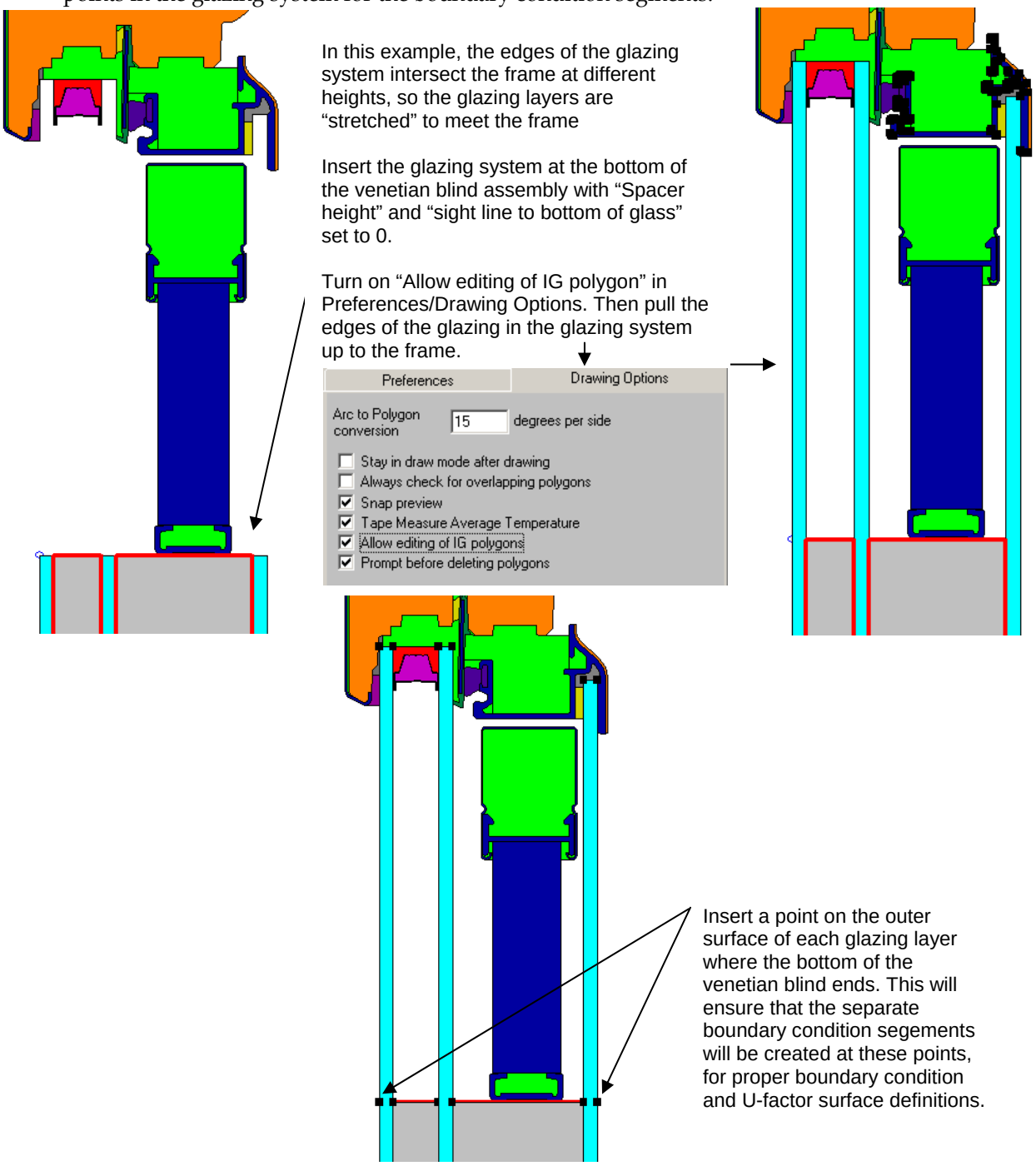


Figure 8-114. Insert the glazing system and edit it if necessary to bring the glazing layers to the frame.

5. Fill the cavities in the double glazing system and around the venetian blind in the third glazing layer with a material (any material), and then link that material to the appropriate cavity – the double glazing system cavity to the double glazing system and the third glazing layer cavity to the third glazing layer. There may be more than one area that is linked to a cavity, so make sure to link them all.

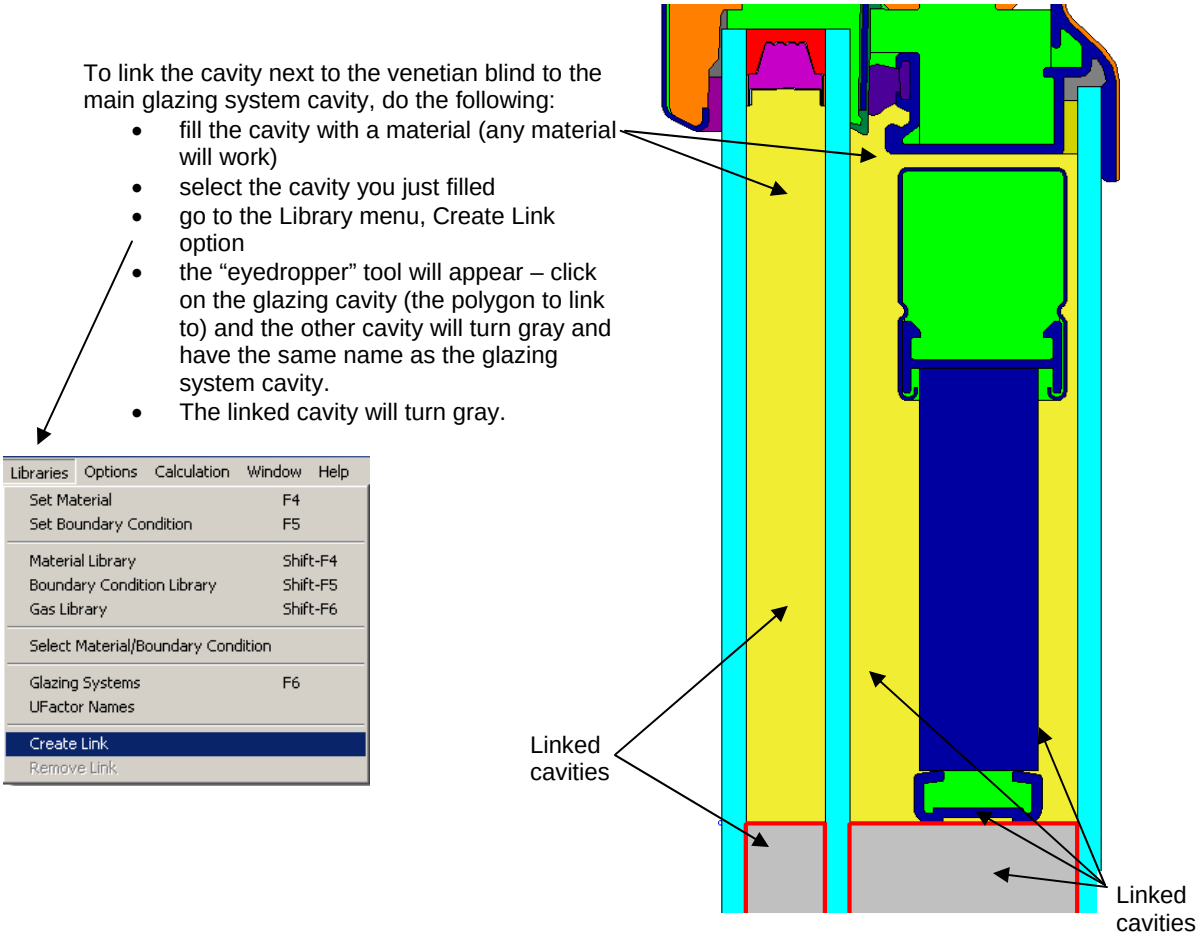


Figure 8-115. Fill the cavity next to the venetian blind by linking it to the main glazing cavity.

6. Generate the Boundary Conditions. The section of the warm side of the glazing system adjacent to the retracted venetian blind should be defined with a U-factor Surface tag of "Frame".

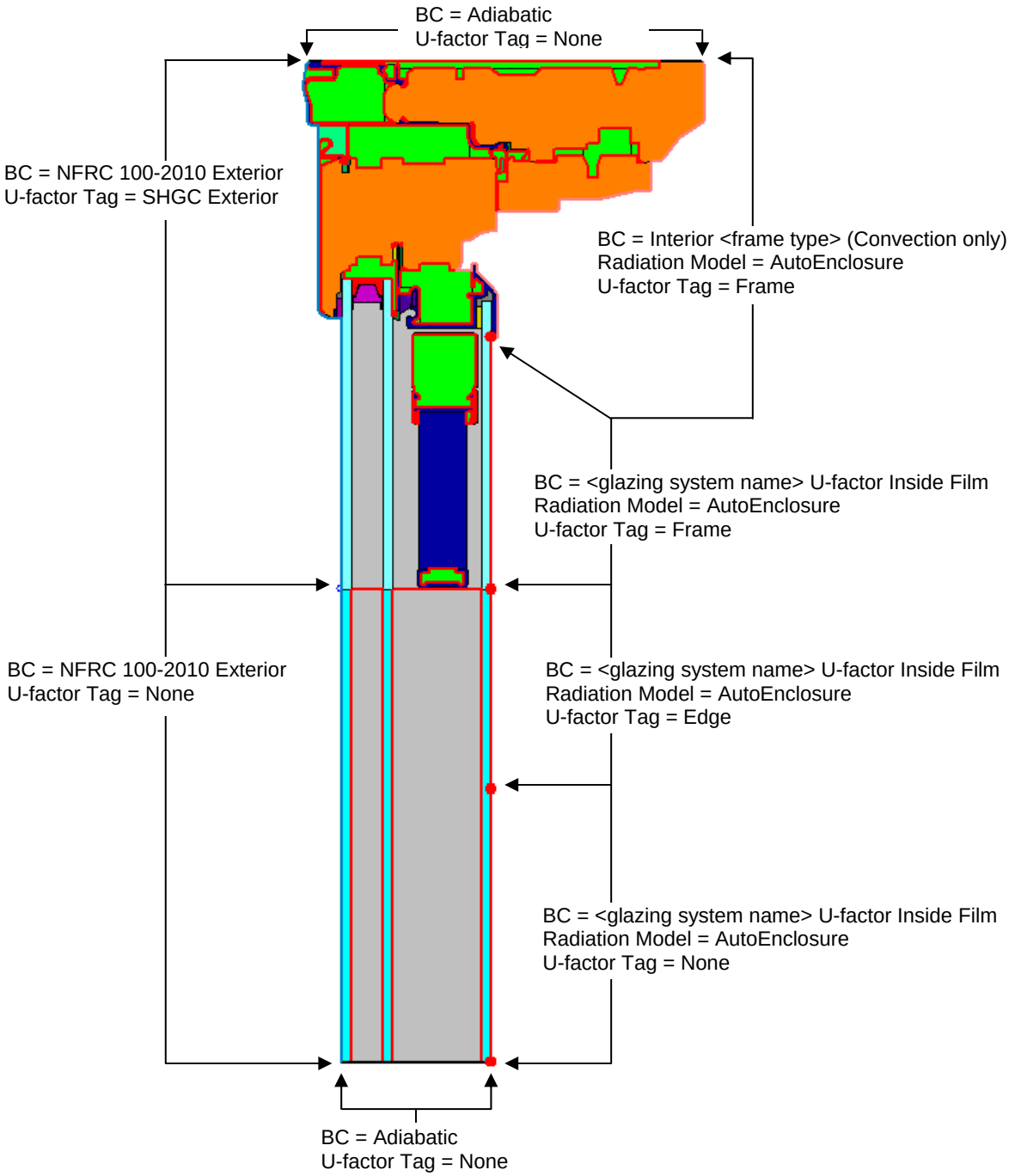


Figure 8-116 Define the boundary conditions for the cross section

7. Calculate the results for this cross section.
8. Complete the calculations for the other product cross sections (Sill, Jambs and Meeting Rails / Stiles as appropriate).
9. Import all the cross sections into the WINDOW Frame Library and calculate the total product U-value, SHGC and VT

8.12 Garage / Rolling Doors

Garage doors and rolling doors are modeled differently than window products because there are more opaque sections to be modeled in THERM. The procedures for modeling doors are included in *NFRC 100:* and that document should be reviewed in detail before modeling any entry door systems.

As with all other product modeling, all relevant cross sections must be modeled in THERM. Detailed illustrations of sections, elevations and model details, as well as the area-weighting methodology for calculating the whole product properties (based on THERM results from of each cross section) are defined in NFRC 100-2004. The information in this manual covers the specific modeling prcedures for the THERM cross-sections.

NFRC has defined nine regions within a door that need to be modeled. These regions include:

- Frame Area
- Lite Frame Area
- Divider area
- Edge-of-divider area
- Edge-of-Lite Area
- Center-of-lite area
- Door Core Area
- Panel Area
- Edge-of-Panel Area

NFRC 100 contains several figures which illustrate the location of the door sections to be modeled in THERM.

When modeling glazing options with caming, the NFRC default caming can be used.

A spreadsheet must be used to do the door area-weighting from the THERM files, because the current version of WINDOW does not area-weight doors. In THERM, the U-factor Surface Tags can have any name and as many U-factor Surface Tags can be defined as are needed to accurately describe the model. (See Section 6.2.4, "Define U-factor Surface Tags in the *THERM User's Manual*), so define as many U-factor Surface Tags as needed and name them descriptively.

8.12.1. Sectional Garage Door (Insulated and Non-Insulated)

The overall product U-factor is calculated based on the area weighted average of the U-factor of each component of the door. The components used for area weighting a sectional garage door are:

- Top Rail
- Bottom Rail
- End Stile
- Meeting Rail
- Door Panel Core
- Edge-of-Lite
- Center-of-Lite

The U-factor of each component is calculated using two dimensional heat transfer software THERM. The sectional garage doors with embossed or raised panels are not covered in this section. However, refer to the

entry door section for the principles of modeling embossed or raised panels which can then be applied to sectional doors.

The boundary condition details and other modeling assumptions used on the simulation models for door components are discussed in the following sections.

8.12.1.1. Top Rail Model

A nominal 2x4 wood block is used in the Top Rail Model as shown in the figure below. The torsion spring assembly, and any non-continuous hardware, shall not be included in this model. The boundary condition (BC) type and U-factor tags used in the model are illustrated in the figure below.

THERM File Properties:

- **Cross Section Type:** Head
- **Gravity Arrow:** Down

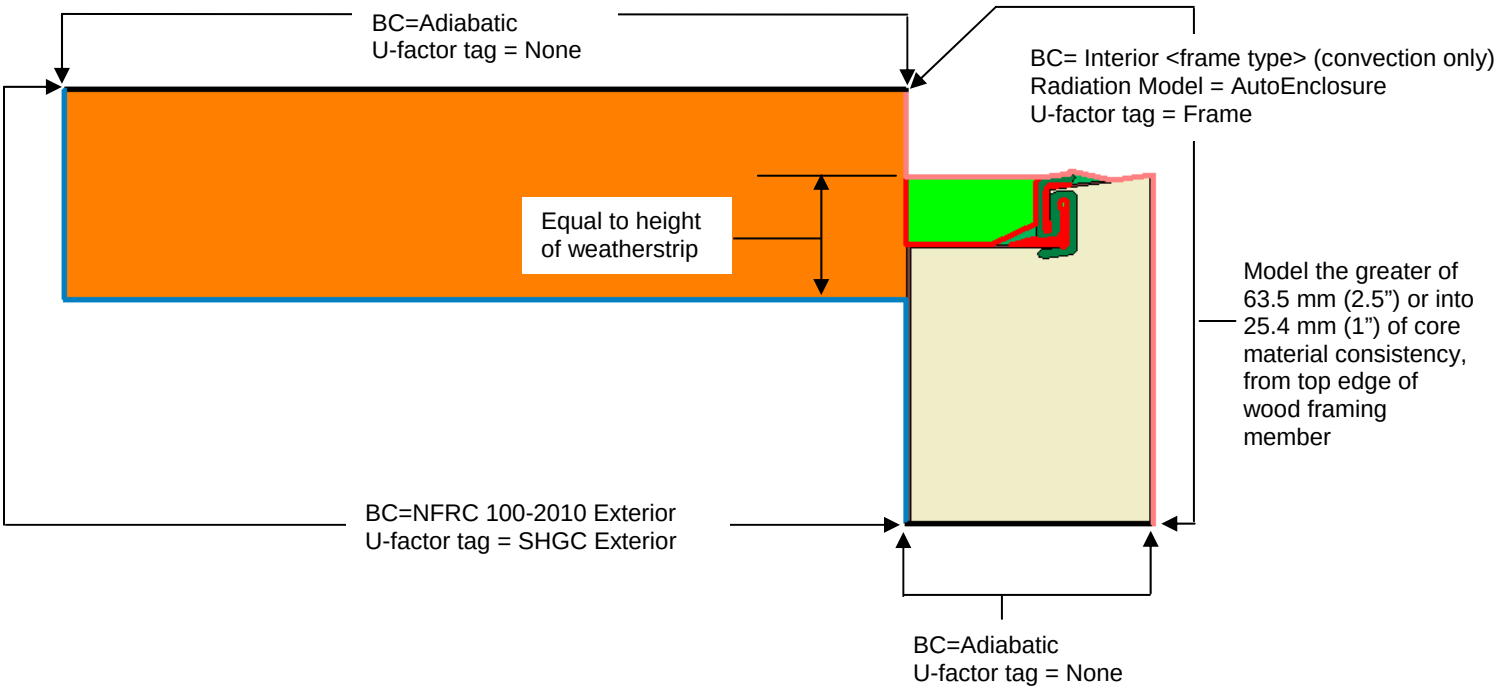


Figure 8-117 Top Rail Model.

8.12.1.2. Bottom Rail Model

A nominal 2 x 6 wood block is used in the bottom rail model of the garage door. Refer to the figure below for the boundary conditions and U-factor tag tags.

THERM File Properties:

- **Cross-section Type:** Sill
- **Gravity Arrow:** Down

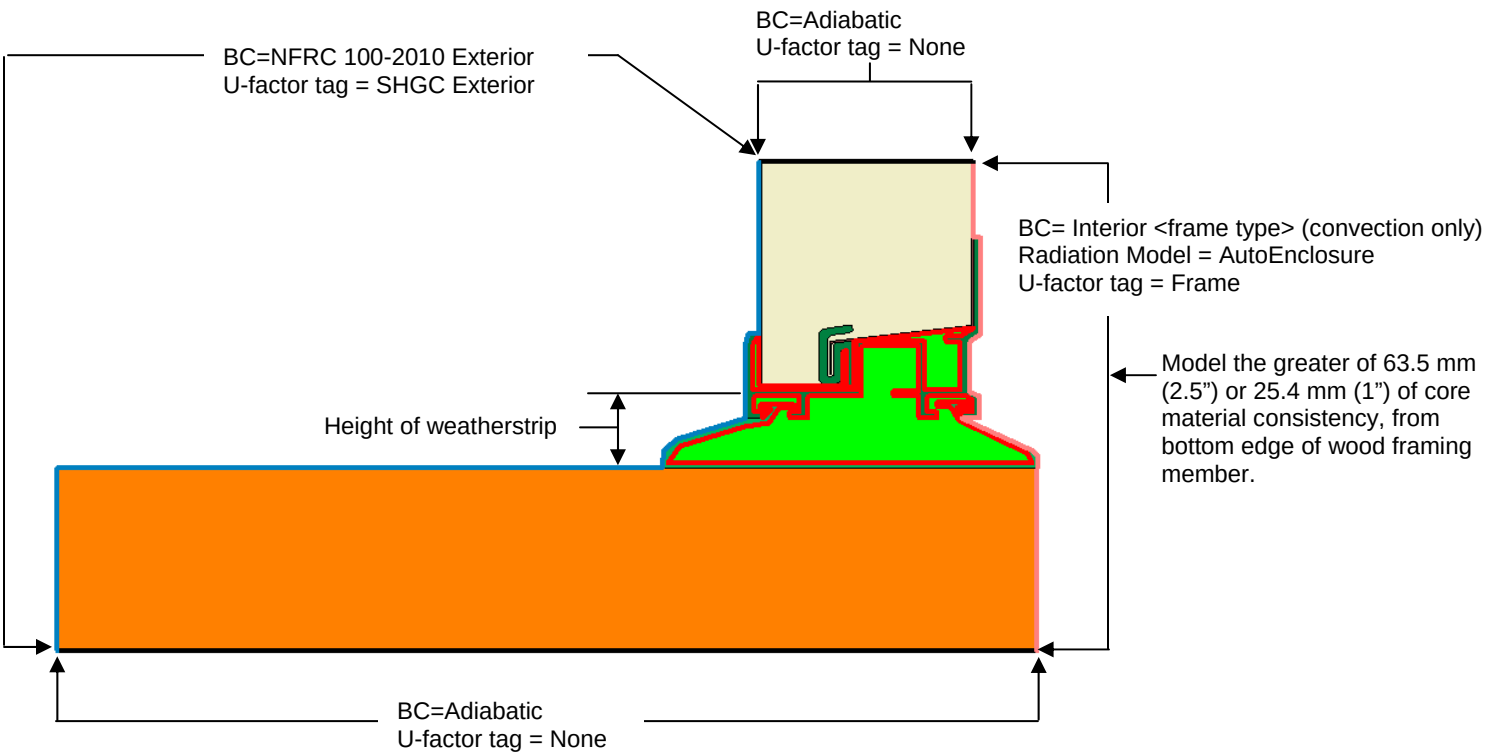


Figure 8-118 Bottom Rail Model.

8.12.1.3. End Stile Model

A nominal 2x4 wood block is used in the End Stile Model. The projected frame dimension shall incorporate a 1″ uniform section of the garage door panel. Any non-continuous hardware, such as rollers, shall not be included in the model. The boundary condition type and the U-factor tag used on the End Stile model are shown in the figure below.

THERM File Properties:

- **Cross-section Type:** Jamb
- **Gravity Arrow:** Into the Screen

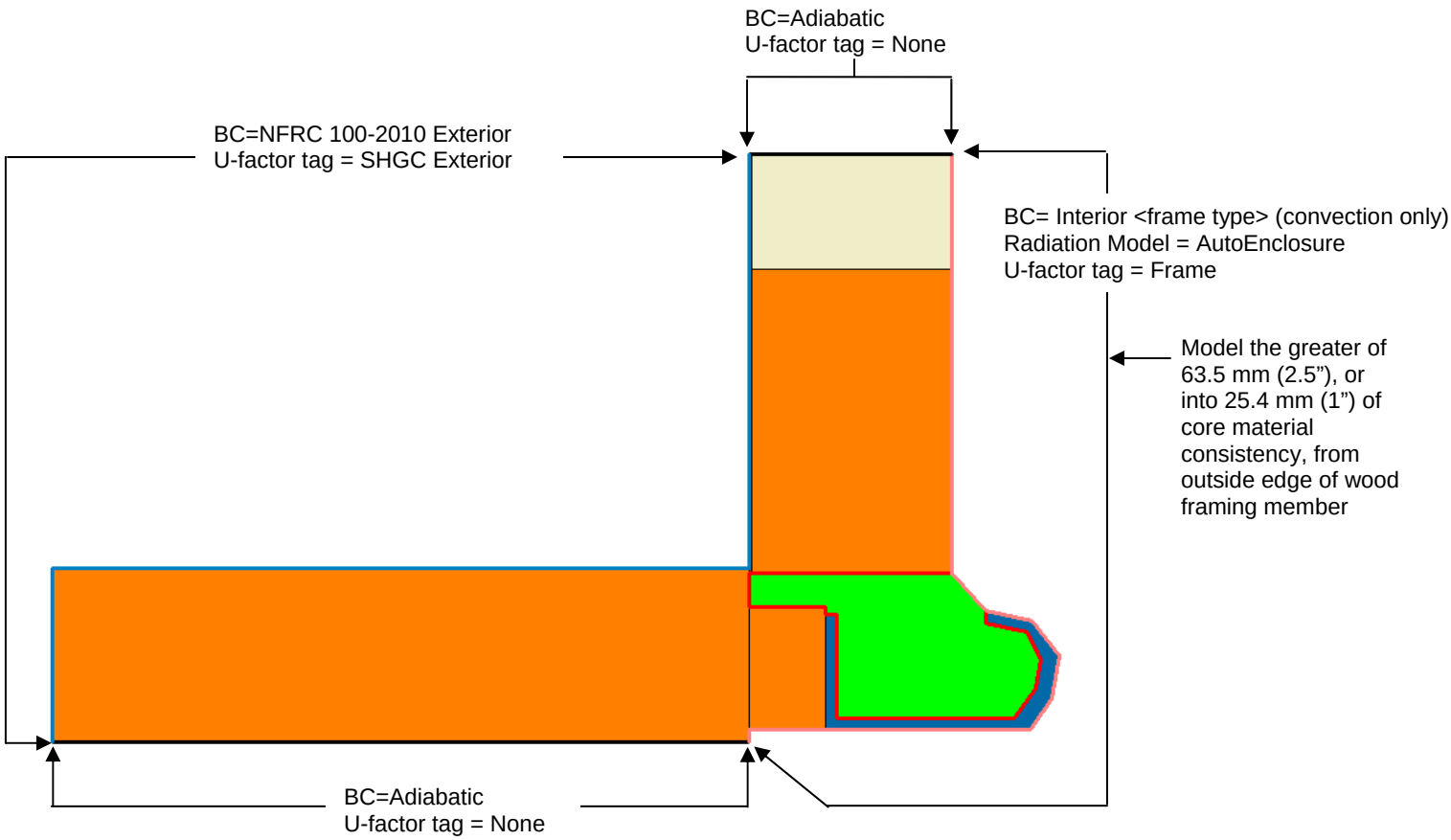


Figure 8-119 End Stile Model.

8.12.1.4. Meeting Rail / Door Panel Core Model

The Meeting Rail Model is combined with the Door Panel Core Model, as shown in the figure on the following page. The meeting rail model shall include 63.5 mm (2.5″) section of the each joining panel. The projected dimension of the panel core section shall be equal to:

([Height of the Panel]-5″) / 2

THERM File Properties:

- **Cross-section Type:** Horizontal Meeting Rail
- **Gravity Arrow:** Down

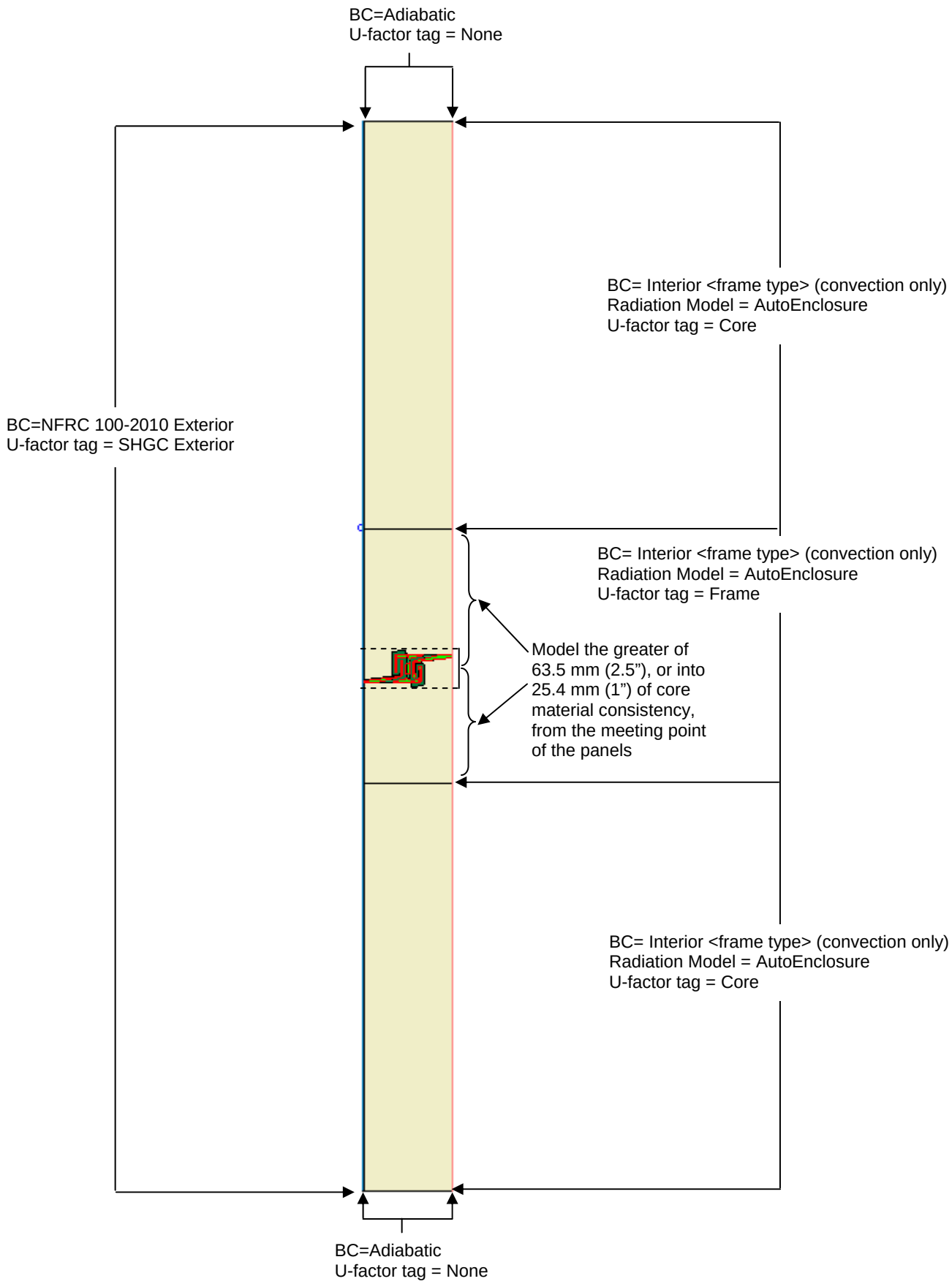


Figure 8-120 Meeting Rail and Door Panel Core Model.

8.12.1.5. Edge-of-Lite Model

The procedure for modeling edge-of-lite (edge-of-glazing) properties is the same procedure as for entry doors. See the entry door procedure in this manual for detailed instructions for modeling these cross-sections.

Below is a sample THERM cross section for the Door Lite Sill. See Section 9.5.4 for the complete example for Entry Doors.

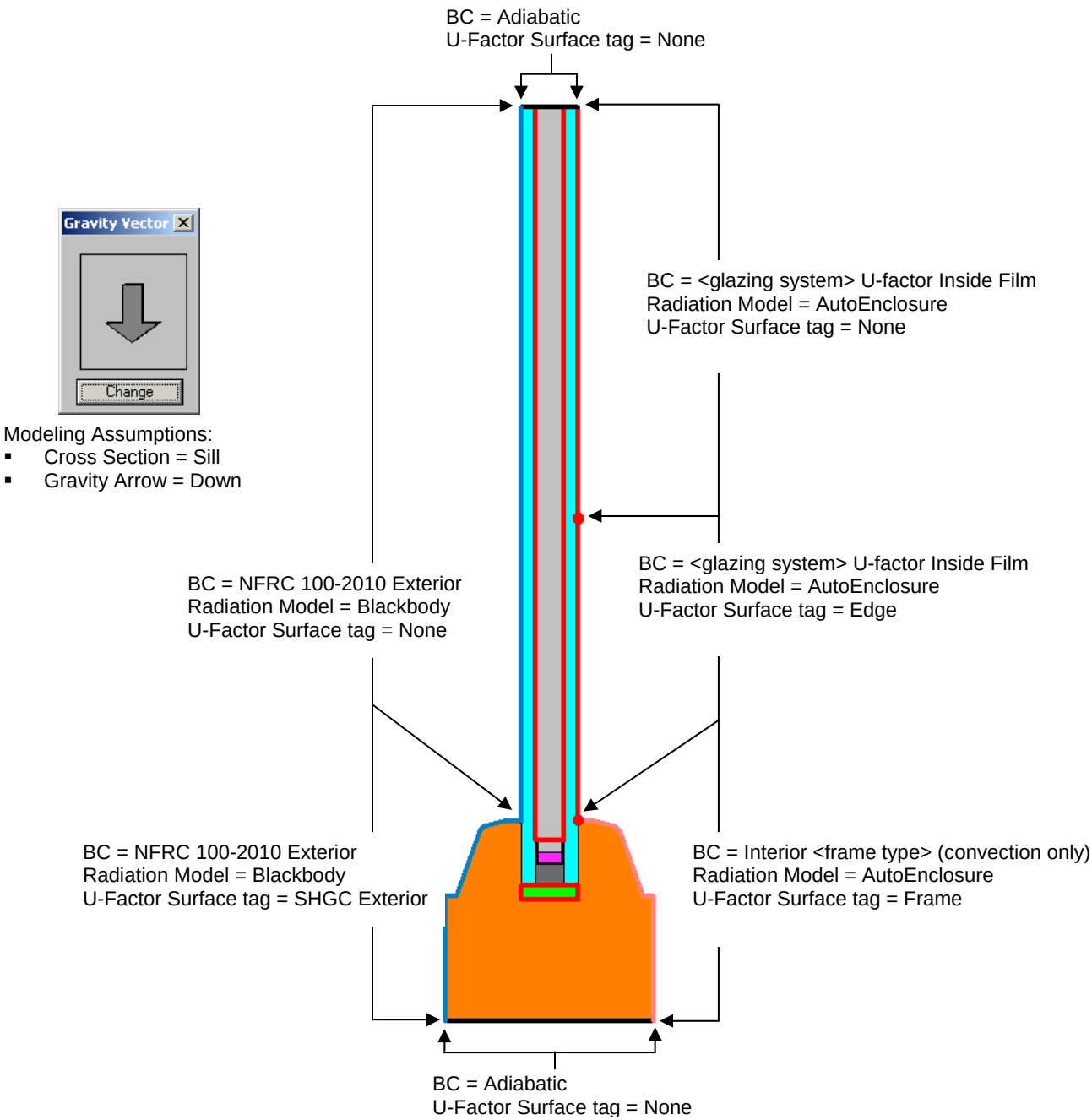


Figure 8-121 Edge-of-Lite model for the garage door lite.

8.12.2. Rolling Door

The overall product U-factor is calculated based on area weighted average of various component's U-factor. The components used for area weighting a rolling door are:

- Top Rail
- Bottom Rail
- End Stile
- Door Core

The U-factor of each component is calculated using two dimensional heat transfer software THERM.

The boundary condition details and other modeling assumptions used on the simulation models for door components are discussed in the following sections.

8.12.2.1. Top Rail Model

A nominal 2x4 wood block is used in the Top Rail Model as shown in the figure below. The torsion spring assembly, and any non-continuous hardware, shall not be included in this model. The boundary conditions (BC) and U-factor tags used in the model are described in the figure below.

THERM File Properties:

- **Cross-section Type:** Head
- **Gravity Arrow:** Down

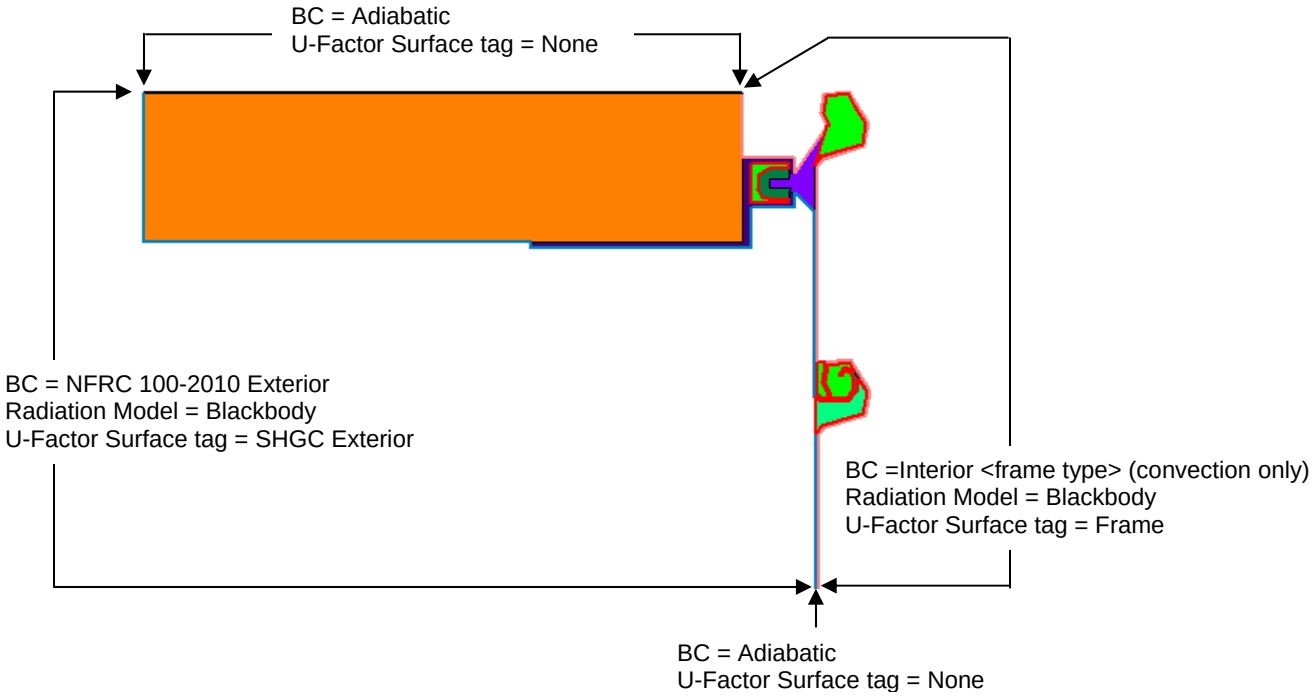


Figure 8-122 Top Rail Model for Rolling Door

8.12.2.2. Bottom Rail Model

A nominal 2 x 6 wood block is used in the bottom rail model of the rolling door. The figure below illustrates the boundary conditions and U-factor tags.

THERM File Properties:

- **Cross-section Type:** Sill
- **Gravity Arrow:** Down

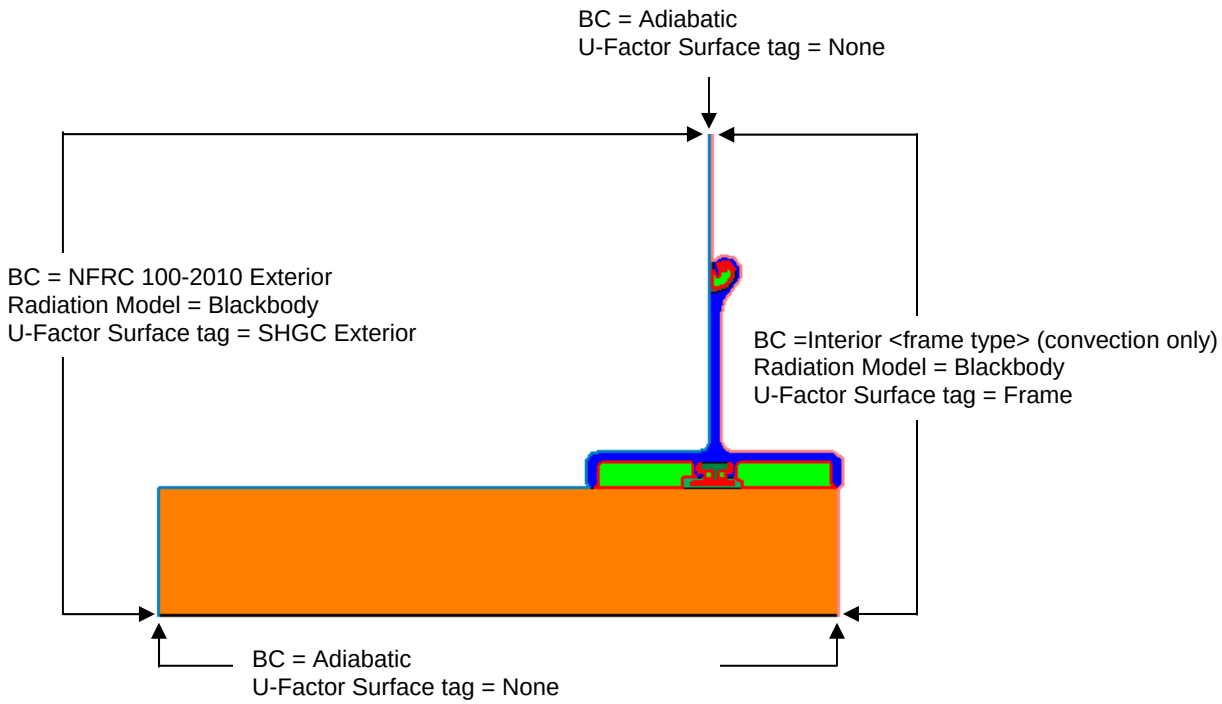


Figure 8-123 Bottom Rail Model for Rolling Door

8.12.2.3. End Stile Model

A nominal 2x4 wood block is used in the Stile Model. The boundary condition type and the U-factor tag used on Stile model are shown in the figure below

THERM File Properties:

- Cross-section Type: Jamb
- Gravity Arrow: Into the Screen

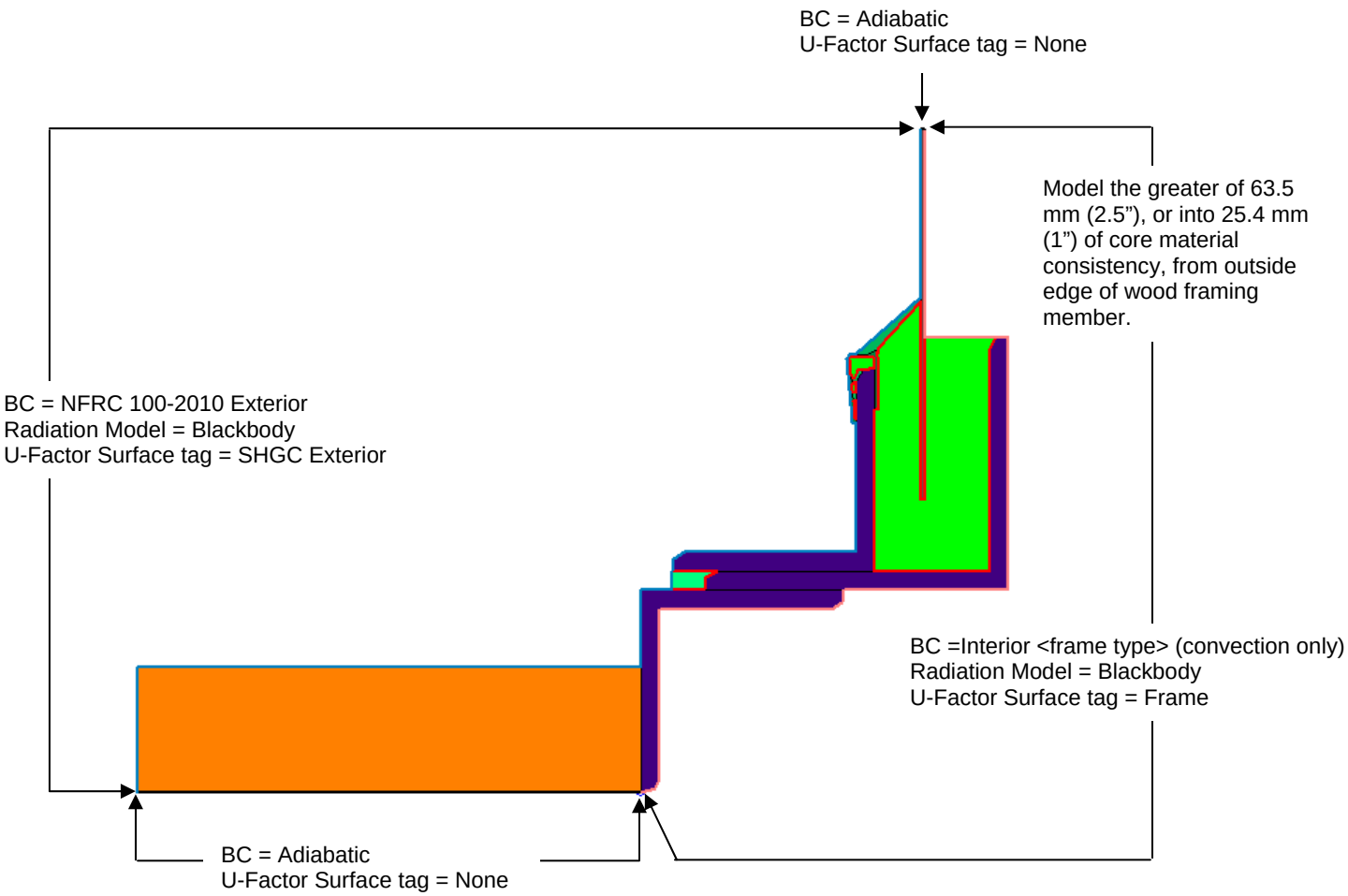


Figure 8-124 End Stile Model for Rolling Door

8.12.2.4. Door Core Model

The Door Core Model shall include two full slats and two half slats at each end. The details of the section where slats join shall be obtained from the manufacturer. The boundary conditions on door core model are specified in the figure below.

THERM File Properties:

- **Cross-section Type:** Horizontal Meeting Rail
- **Gravity Arrow:** Down

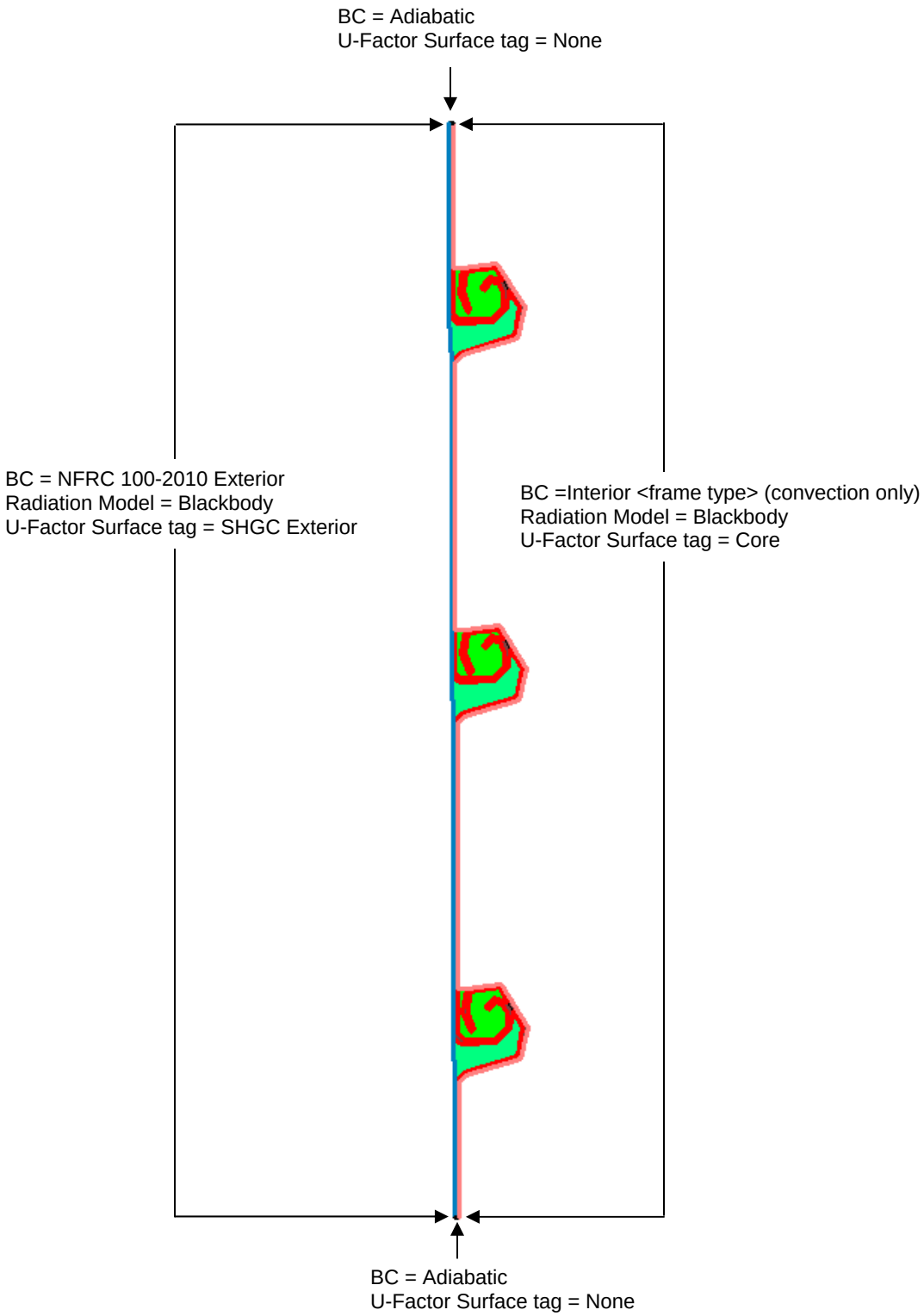


Figure 8-125 Door Core Model for Rolling Door

8.13. Creating a Laminate in Optics for NFRC

8.13.1. Overview

Optics5 can be used for the limited purpose of constructing laminates for NFRC certified simulations using the following criteria:

- Laminates *cannot* have embedded coatings, where embedded coatings are defined as a coating on a substrate that touches an interlayer
- Only NFRC glass layers with the NFRC approval indicator "#" can be used in these constructed laminates
- The glass layers can be tinted or coated as long as the coatings do not face the interlayer
- The interlayers in Optics5 do not have a "#" on them and therefore, only interlayers from the LBNL/NFRC "Approved Interlayer" list can be used (updated by LBNL with every IGDB release and available on the WINDOW Knowledge Base website), which means the data for those interlayers was submitted to the IGDB using the criteria specified in Section 1.2 of this document.

For NFRC verification of the laminate construction submitted by simulators:

- Laminates constructed by simulators in Optics5 will not have a # next to them. The simulator shall provide base properties for the complete laminate assembly, including solar transmittance (solar, T), visible transmittance (photopic, T), solar reflectance front (solar, Rf), solar reflectance back (solar, Rb), visible reflectance front (photopic, Rf), visible reflectance back (photopic, Rb), Emissivity front (EmitF), Emissivity back (EmitB). These values are reported on the Optics screen when the laminate is calculated, and also in the WINDOW Detailed Report from the Glazing System Library. This requirement is satisfied by submitting a WINDOW "mdb" database file which includes this laminate.
- An IA (or anyone else wanting to check the results) can recreate the laminate from the specified layers and verify the calculated values
- NFRC simulators shall assign numbers to the laminates starting with 30,000. The numbers do not have to be unique between simulation laboratories or even between projects in the same laboratory. These laminates are not stored in a central NFRC database.
- The naming convention for the laminate should describe the layers used to construct the laminate, using the IGDB Layer ID for glass layers and the interlayer name (from the Optics program) for the interlayer. If a glass layer is flipped, add the "F" designator to the end of the layer number. The total number of characters (not including extension, but including "/" separators in the name) cannot exceed 45.

  <glass layer ID><F if layer is flipped>/<interlayer name from Optics5>/<glass layer ID><F if layer is flipped>

  For example:

  102/030keepsafe/2026F

8.13.2. Laminate Interlayer Data

Optics can accurately calculate the optical properties of laminates as long as the component layers with the following characteristics (and only interlayers submitted with these characteristics will be included in the "Approved Interlayer List" for NFRC certification):

- Interlayers are measured with transparent glass with a solar transmittance Tsol > 0.820 and Tvis > 0.890. This ensures that a "constructed" laminate in Optics5 will always have a similar or lower transmittance than the reference laminate which determines the interlayer properties
- No glass layers have coatings next to interlayers (embedded coatings).
- Substrate layers (the base glass to which the interlayers are applied) are measured separately from the interlayers. This is the responsibility of the manufacturer submitting data to the IGDB, as discussed below.

As discussed in the LBNL document which contains guidelines for submitting data to the IGDB (*International Glazing Database: Data File Format, Version 1.4*, April 2003), "an interlayer is an adhesive layer used to join components in a laminate. The optical properties of laminate layers cannot be measured directly. Instead they are calculated from the spectral properties of a 'reference laminate' which consists of the interlayer laminated between two glass layers of known optical properties. To submit data for an interlayer, both the spectral optical properties of the reference laminate, and the glass layers used in the reference laminate should be submitted."

This means that in order for an interlayer to be added to the Optics5 "Interlayer" type, and therefore used in making laminate constructions in Optics5, the spectral data for a "reference" laminate which contains that interlayer is submitted to the IGDB as follows:

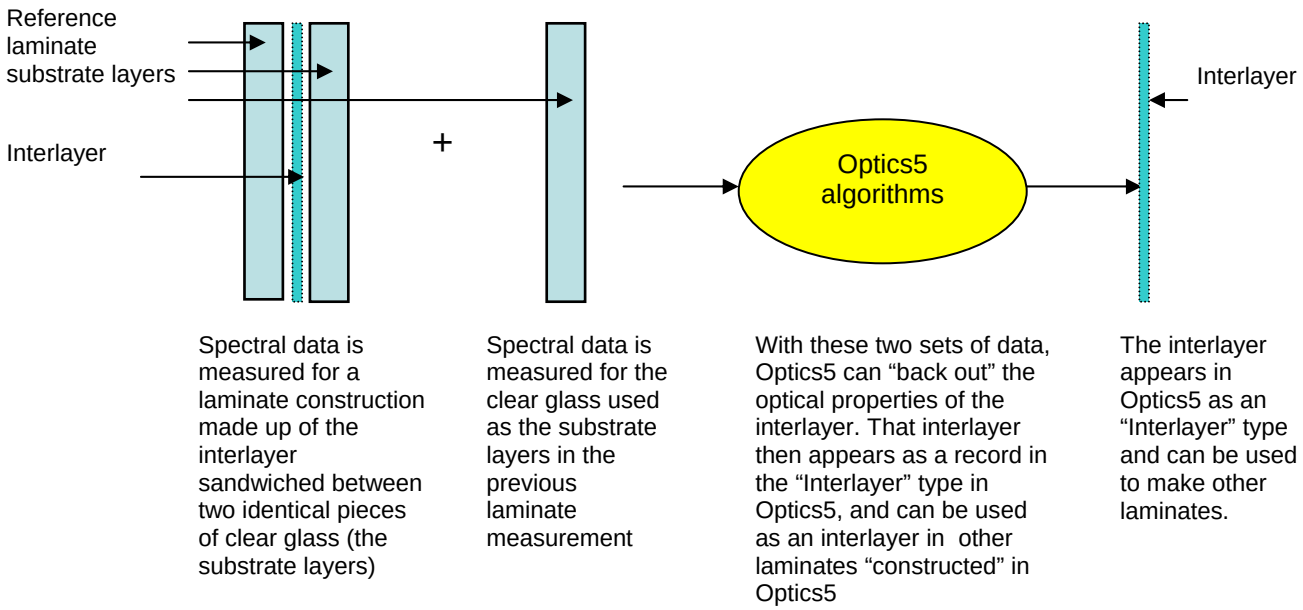


Figure 8-126. How Optics "deconstructs" measured data to obtain interlayer information.

Optics5 can do an accurate calculation for the interlayer properties from the reference laminate as long as the substrate glass layers have a high solar and visible transmittance, hence the requirement of Tsol > 0.820 and Tvis > 0.890. This ensures that laminates that are later created in Optics5 with this interlayer will almost always have a lower solar and visible transmittance then the reference laminate.

8.13.3. Constructing a Laminate in Optics5

8.13.3.1. Building a New Laminate

When Optics5 starts, you can start building a laminate immediately by switching to the 'Laminate' tab and adding layers (see "8.13.3.3. Add Layers to a Laminate").

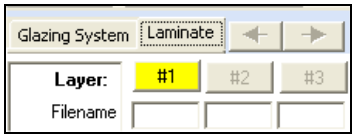


Figure 8-127. Click on the Laminate tab to start constructing a laminate.

If you have created a laminate already, but want to start over with an empty laminate:

- Make sure the 'Laminate' tab is selected
- Choose menu option **File|New Laminate**
- You will be prompted to save the current laminate if one already exists

Note: if you created new layers and did not save the layers or did not save the laminate (which would save any new layers), the new layers will be lost when you start a new laminate

8.13.3.2. Wavelength Sets

Use the NFRC default wavelength set, which is called "Optics5". This setting is shown on startup of the program, and also can be viewed (and changed if necessary) from the menu option **Tools|Select Wavelength Set**.

8.13.3.3. Add Layers to a Laminate

You can add monolithic, coated, and interlayer type layers to a laminate. There are a number of 'rules' for building laminates:

1. The first and last layer in a laminate must be a non-interlayer type (e.g. monolithic or coated)
2. You can place as many interlayers as you like adjacent to each other, but you must separate rigid non-interlayers with at least one interlayer.
3. For NFRC certified simulations, you can NOT place a coating next to an interlayer.

If you break rule 1 or 2, the operation will be cancelled.

Use the 'Add Interlayer' tab above the database to add interlayers. To add other layers, use the 'Add Glazing' tab. Only those database records with enough data to be loaded into a laminate will be shown in these views – if you want to see all records in the database, including those which cannot be used in laminates, use the 'View All' tab. If you try to load an invalid layer into a laminate from the 'View All' view of the database, an error message will be displayed.

8.13.3.4. Add Glazings to a Laminate

You can add monolithic, coated, and interlayer type layers to a laminate as long as you follow the laminate-building 'rules' (see "8.13.3.3. Add Layers to a Laminate" above).

To add layers from the current database to a laminate:

- Select the first available (unoccupied) layer in the laminate by clicking on its layer button – if you select an occupied layer, it will be replaced (see "8.13.3.8. Replace a Layer in a Laminate")

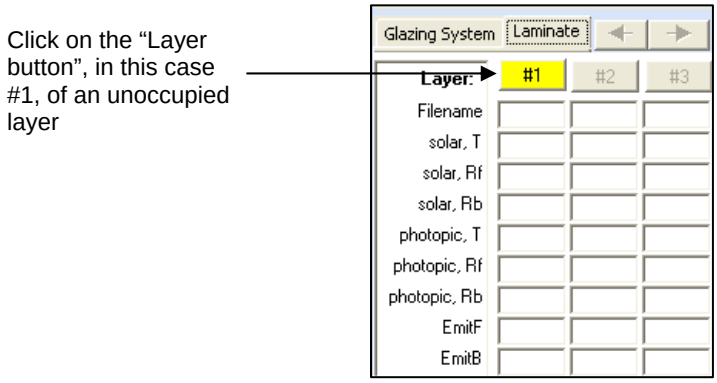


Figure 8-128. Click on the #1 layer button to add the first glass layer.

- Select the 'Add glazing' tab in the database

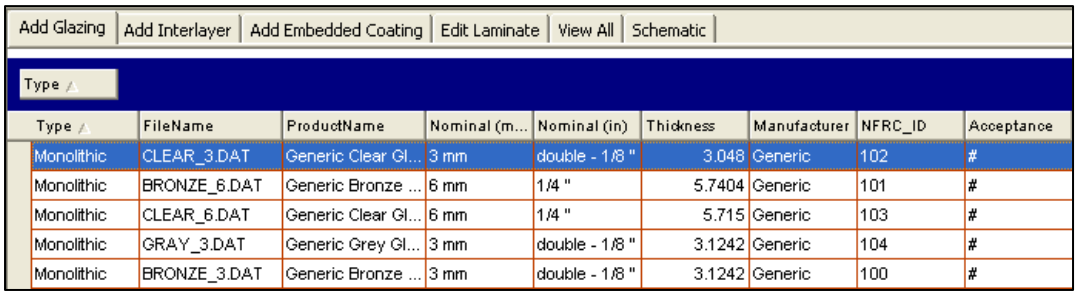


Figure 8-129. Select the glass layer from the Add Glazing tab.

- Double-click on the layer in the database
  or
- Using the mouse, drag the layer from the database over the layer button where you want to add the layer and release the mouse button
  or
- Select the layer in the database, then choose the menu option **Database|Add/Replace Layer**
  or
- Select the layer in the database, then right-click to display the pop-up menu then choose **Add/Replace Layer**

If you are replacing a layer, a dialog box will appear to confirm that you want to replace the existing layer.

Note: Select a layer in the database by clicking on it with the mouse, or by browsing to it by pressing the up and down arrow.

8.13.3.5. Add Interlayers

To add an interlayer to a laminate:

- Select the first available (unoccupied) layer by clicking on a layer button
- Select the 'Add Interlayer' tab
- Select the interlayer you want to add, and load it into the laminate (see "8.13.3.3. Add Layers to a Laminate")

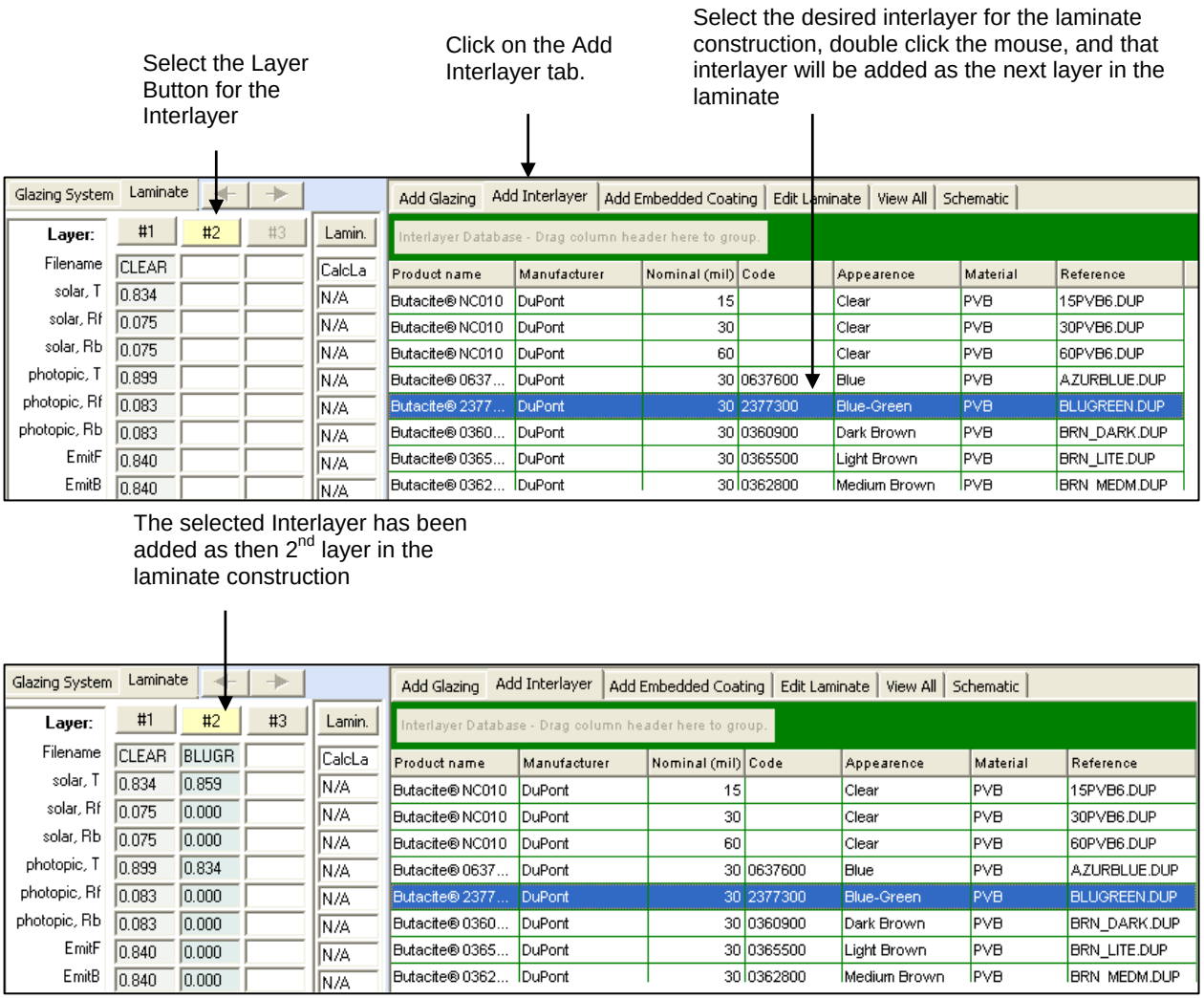


Figure 8-130. Select the desired interlayer from the Add Interlayer tab for layer #2.

8.13.3.6. Flip Layers in a Laminate

To flip layers in a laminate:

- Select the layer to flip by clicking a layer button
- Choose the menu option **Edit|Flip Layer**
  or
- Right-click on the layer button to display the pop-up menu and select **Flip Layer**

- If flipping the layer would place a coating adjacent to an interlayer, and this will break the laminate-building rules (see "8.13.3.3. Add Layers to a Laminate") and the laminate cannot be constructed for NFRC certification.

Note: Check the schematic view and the layer spectral averages if you are not sure which way a layer is oriented.

If any glass layers are flipped, make sure to add an "F" to the NFRC ID in the name of the final laminate.

8.13.3.7. View the Properties of a Laminate

To view the calculated spectral data, spectral averages and other properties of a laminate:

- Select the laminate by clicking on the 'Lamin.' layer button
- The laminate is now the current layer, so its spectral data and spectral averages are displayed in the lower part of the screen

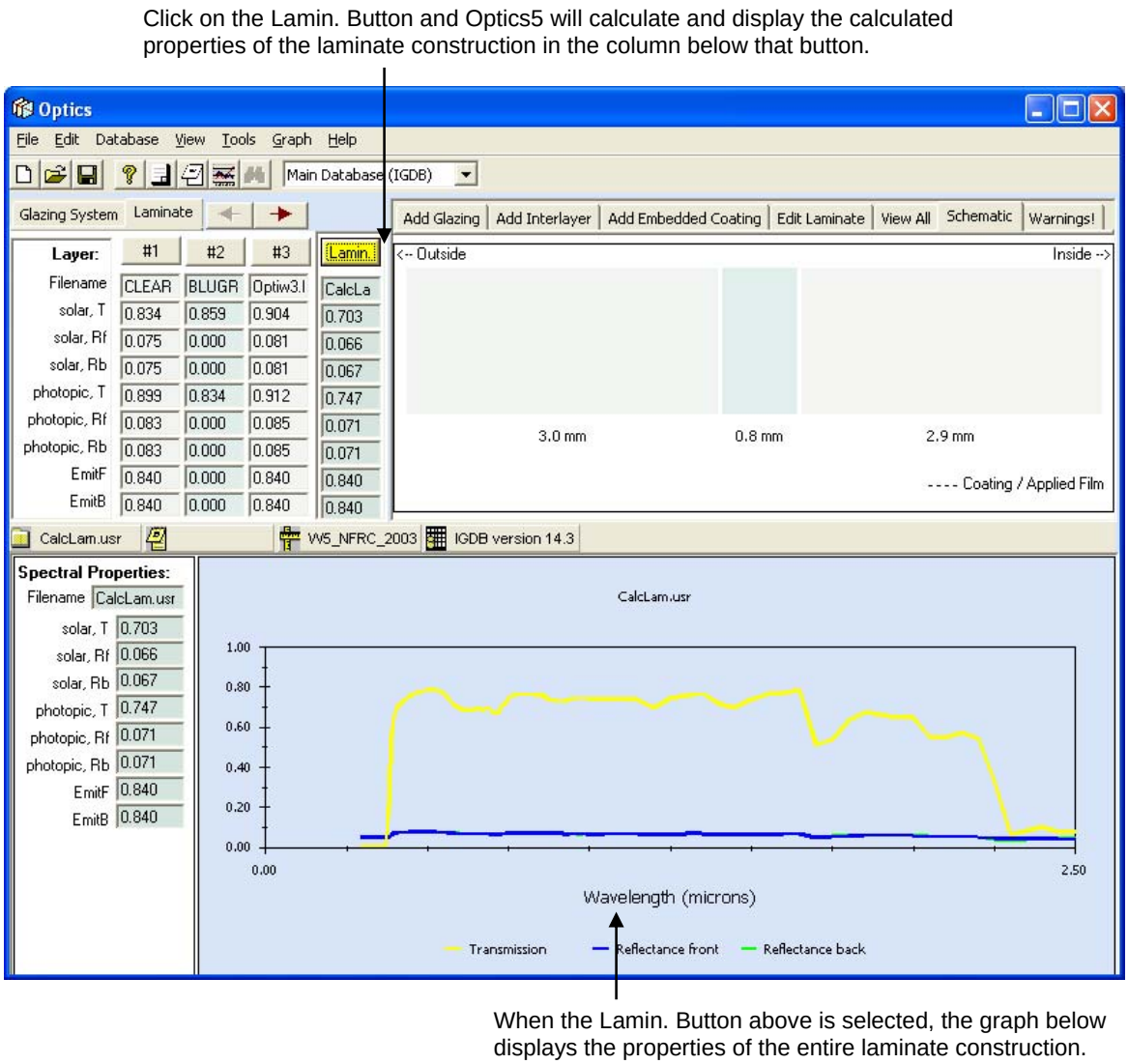


Figure 8-131. Click on the Lamin button to view the optical properties of the entire laminate structure.

- To view a schematic diagram of the laminate, select the 'Schematic' tab in the upper right part of the screen

- To view the spectral data in a table, choose menu option **View|Spectral Data Grid**.
- To view calculation warnings for the laminate data, select the 'Warnings' tab in the upper right part of the screen
- To see more information about the laminate, choose menu option **View|View Details**

8.13.3.8. Replace a Layer in a Laminate

Replace a layer in a laminate in the same way as you would replace a layer in a glazing system – you must respect the laminate-building rules (see "8.13.3.3. Add Layers to a Laminate").

You cannot insert layers into a laminate – you must delete and add layers from the interior side of the laminate to modify the structure.

8.13.3.9. Delete a Layer in a Laminate

You can only delete the last (interior side) layer in a laminate. To delete the last layer:

- Select the last layer by clicking the layer button
- Choose the menu option **Edit|Delete Layer**
  or
- Right-click on the layer button to display the pop-up menu and select **Delete Layer**

8.13.3.10. Save a Laminate

To save a laminate to the user database:

- Select the laminate by clicking on the 'Lamin.' layer button
- Click the 'Save' button on the toolbar:
  or
- Choose the menu option **File|Save *filename***
  or
- Right-click the layer button to display the pop-up menu and select **Save *filename***

Note: To save the laminate under a different name, choose the menu item **Save As…**

8.13.3.11. Edit a Laminate

To edit a laminate saved in the user database:

- Make sure the 'Laminate' tab is selected above the layer buttons
- Select the 'Edit Laminate' tab in the upper right part of the screen
  or
- Choose the menu option **File|Edit Laminate**
- Load the laminate you wish to edit like you would add a layer into any layer position – the current laminate will be cleared, and the saved laminate loaded.

Note: You cannot edit laminates in 'Glazing' mode, you must switch to 'Laminate' mode first. In order to use the edited laminate in a glazing system, save the laminate to the user database, switch to 'Glazing' mode and re-load the laminate layer into the glazing system from the user database.

Note: You cannot use a laminate as a component of another laminate

8.13.3.12. Calculation Warnings for Laminates

The optical properties of most laminates without coatings can be calculated without generating warnings, except that it is likely that some components will not have spectral data across the whole range of the selected wavelength set (see "8.13.3.2. Wavelength Sets"), so the wavelength set will be truncated.

8.13.3.13. Viewing Calculation Warnings for Laminates

To view calculation warnings for a laminate:

- Select the laminate by clicking on the 'Lamin.' layer button
- Select the 'Warnings' tab

The example below shows a warning message that says:

> Results could not be calculated at all wavelengths in the selected wavelength set. Wavelength set truncated to: 0.300 – 2.500 um

This message does not indicate a problem because the solar optical properties in WINDOW are calculated between 0.300 and 2.500 um.

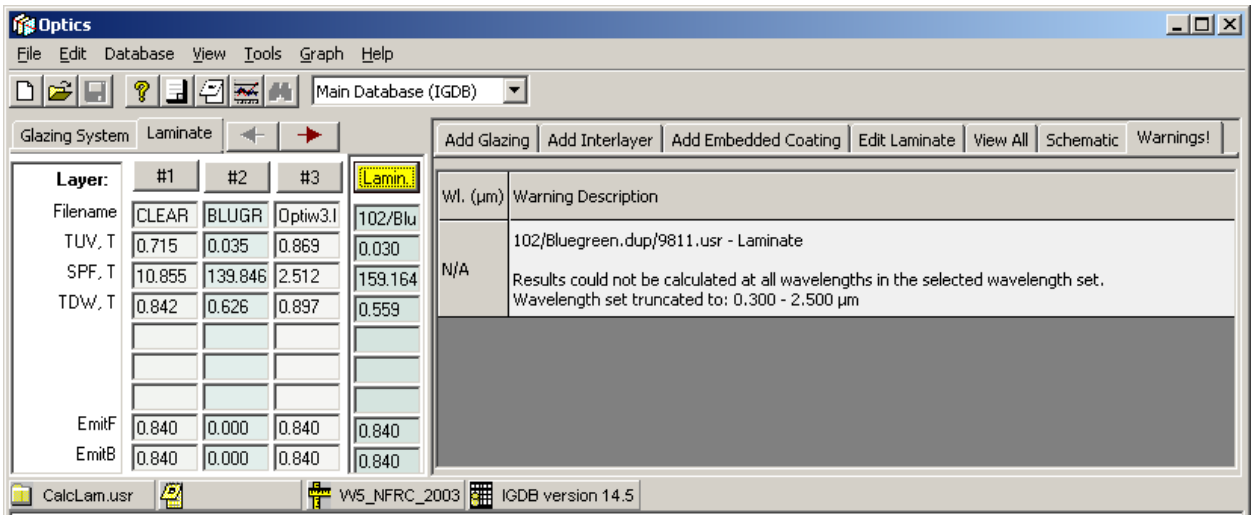


Figure 8-132. An example of a warning that is not relevant for the calculations WINDOW will be doing with the laminate.

8.13.3.14. Save the Laminate to a User Database to Import into WINDOW5

User databases have the same format as the IGDB, but they are used to store data that the user has imported, or generated with Optics5. It is not possible to add layers to the IGDB, so all new layers are saved to the user database.

The default user database is '`UserGlazing.mdb`' in the `'\LBNL Shared'` directory of your program installation. You can specify the location of the user database – this allows you to use as many user databases as you like (one at a time) with Optics5.

To create a new (empty) user database:

- Click on the Database menu, and select the choice "Create new user database".

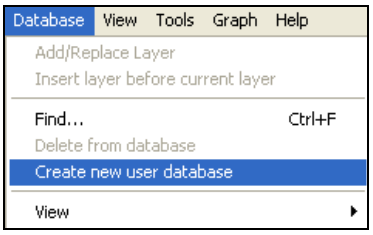


Figure 8-133.Use the Database/Create new user database option to create a blank user database.

- The program will ask you for a database name and location. Name the database as appropriate and put it in whatever directory is desired – the default directory for the default Optics User Database (called UserGlazing.mdb) is the "c:\Program Files\LBNL\LBNL Shared" directory, but any user database can be put in any directory, as long as the path is specified (Tools menu,

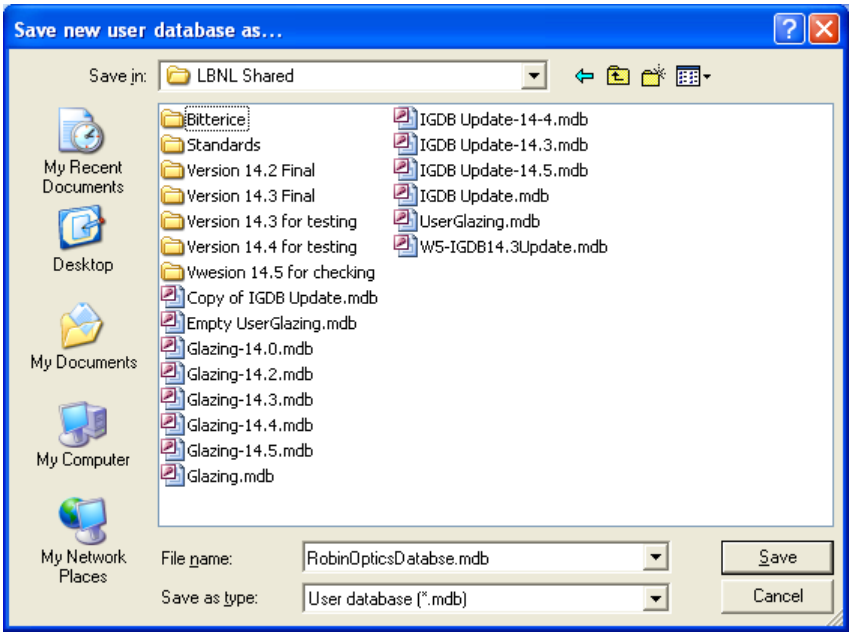


Figure 8-134.Specify the name of the new user database as well as the location where it will be stored.

- Set the default user database to the newly created database from Tool/Options

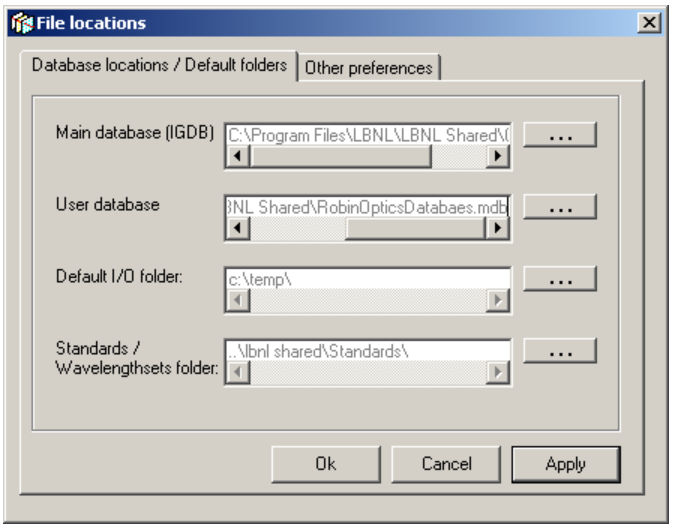


Figure 8-135.Define the location for the User Database from the Tool/Options menu, setting the "User database" field

You can save a layer to the user database if it has a different filename to any layer currently in the user database or in the IGDB. If you save a layer that has components (such as a coated layer that has a substrate, or a laminate which has component layers), the component layers will be saved to the user database at the same time (unless they already exist in the IGDB or user database). This allows you to load and edit those layers at a later time.

If you want to save an unmodified layer from the IGDB to the user database, you must change its filename first.

To save a layer to the user database:

- Select the layer or system to save by clicking on a layer button
- Click the 'Save' button on the toolbar:
  or
- Choose menu option **File|Save *filename***
  or
- Right-click to display the pop-up menu and select the option **Save *filename***
- If the layer or system you saved had components, or if the save operation fails, you will be asked 'Do you want to view the details of the save operation?'. If you answer yes, you can view information about components that were saved to the user database, and components that were not saved to the user database along with an explanation of why some components were not saved.

Note: to change the filename and save in one operation, choose menu option **Save As..** instead.

Note: You cannot save data for a layer with the same filename as another layer in the IGDB or your current user database. If a conflict is detected, Optics will ask you to rename the layer before saving it, or cancel the import. The most common reason a component is not saved is that its filename already exists in the IGDB or user database. In this case Optics assumes that the component layer information is already available and does not need to be saved again.

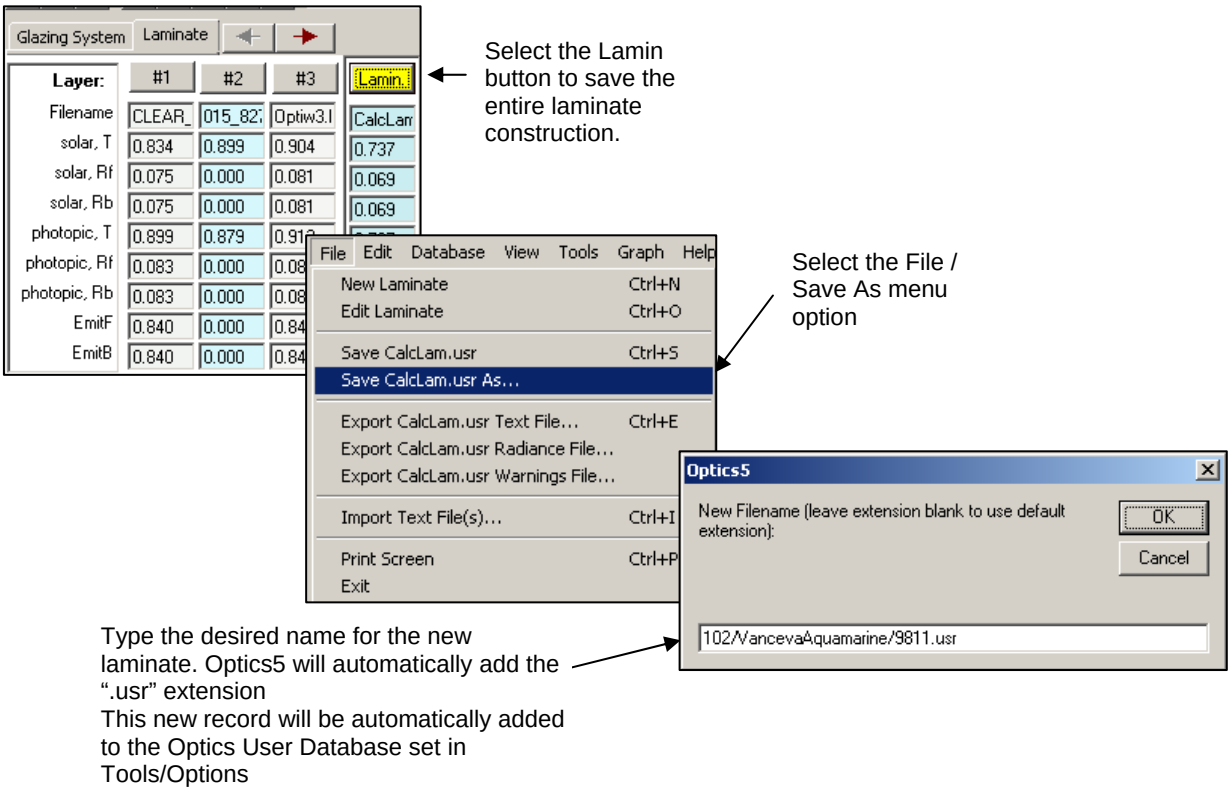
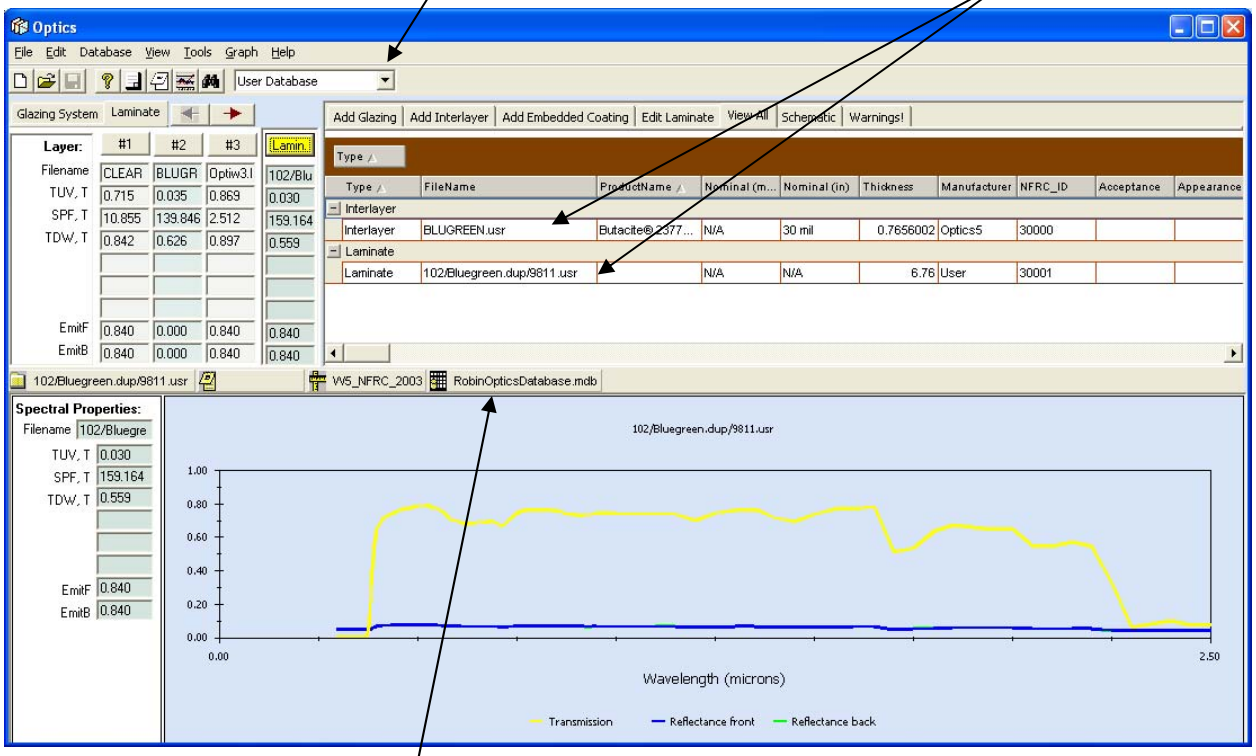


Figure 8-136. Save the final laminate using the naming convention of<glass layer ID>/<interlayer name/><glass layer ID>.

Select User Database from the pulldown list to see the records in the User Database.

The laminate construction (called in this case ClearLaminate.usr) as well as the Interlayer used in the laminate is saved in the User Database. The glass layers on either side of the Interlayer are not saved in the User Database because they are found in the IGDB



The name of the User Database is displayed on this button

Figure 8-137.Select the User Database to see the constructed laminates (and the associated interlayers)

8.13.3.15. Importing the Laminate into WINDOW from the Optics5 User Database

In WINDOW, in **File/Preferences**, go to the Optical Data tab, and set the second option, Optics5 User Database, to your Optics5 user database (which by default is called UserGlazing.mdb, but it can have any name with the "mdb" extension) -- you can browse to the file with the browse button (its default location is in Program Files\LBNL\LBNL Shared directory).

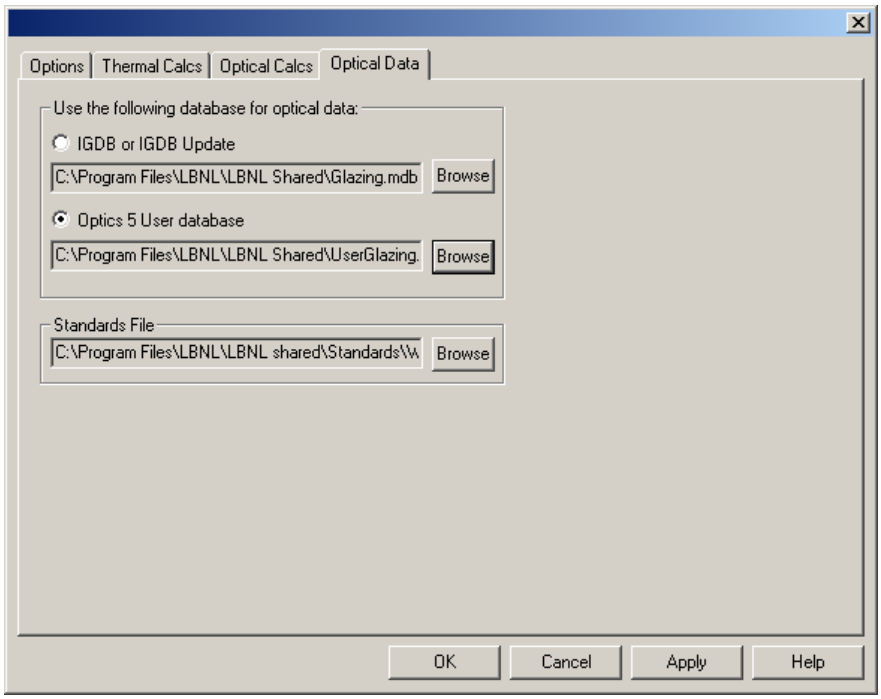


Figure 8-138. Using the File/Preferences menu, click on the radio button for the "Optics 5 User database" and use the Browse button to specify the file with the full directory path.

In WINDOW5, go to the **Glass Library List View**, click on the **Import** button, select "IGDB or Optics User Database" as the format, and click **OK**.

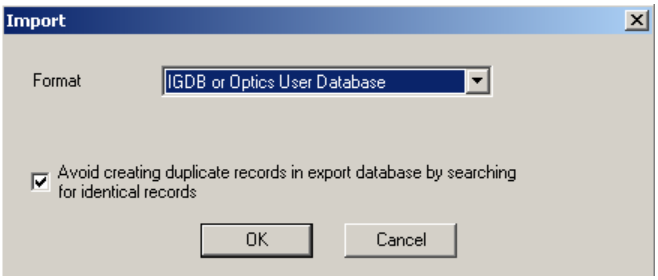


Figure 8-139. Import the data from the Optics User Database.

The program will open the user database set in the **File/Preferences** dialog box (the name will be displayed at the top of the dialog box) and you will see the glass layers that can be imported in to the existing library.

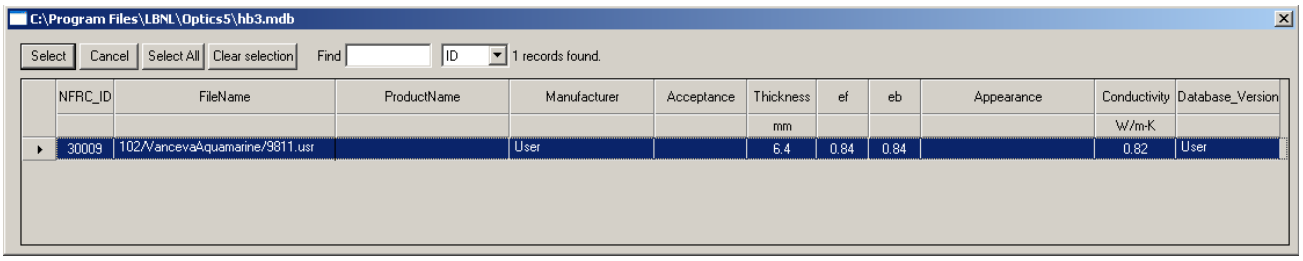
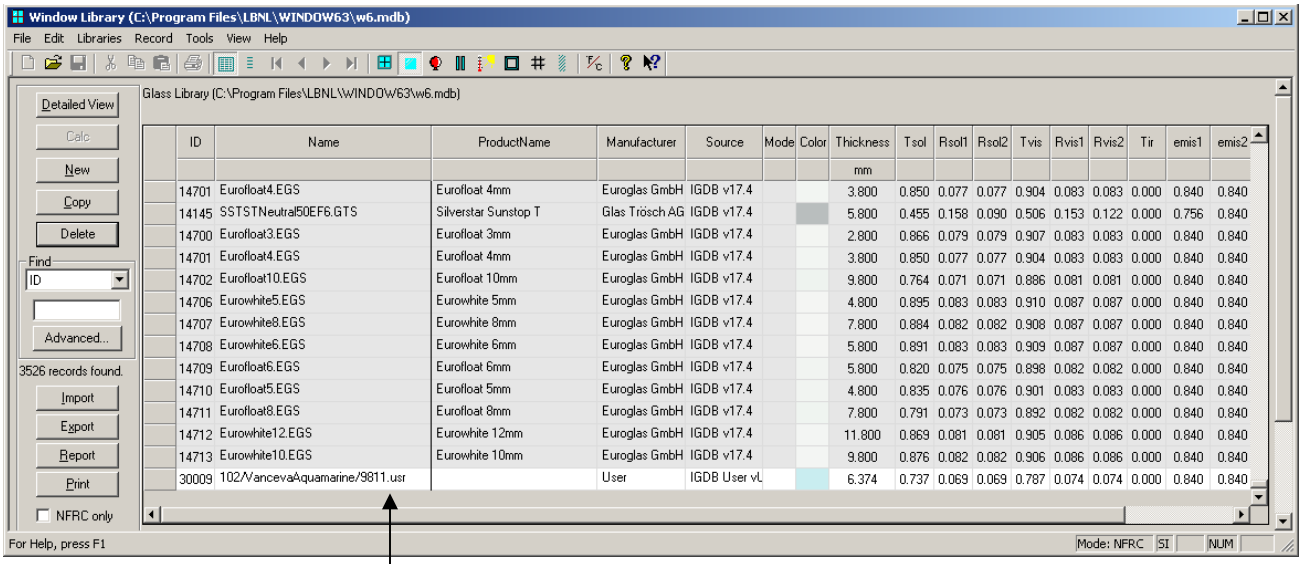


Figure 8-140. You will see all the entries in the specified user database.

You can select the records you want to import (use **Shift Click** to select contiguous records, **Ctl Click** to select multiple non-contiguous records, or **Select All** to select all records). Then click the **Select** button, which will import the selected records into the **Glass Library**.



The laminate has now been imported from the Optics5 user database to the WINDOW Glass Library. It can now be used in the Glazing System Library to create a glazing system.

Figure 8-141. The laminate has now been added to the WINDOW Glass Library.

8.14. Creating an Applied Film Layer in Optics for NFRC Certification

8.14.1. Overview

Glazing layers with applied films can be constructed using Optics5 for NFRC certified simulations using the following criteria:

- The substrate for the applied film *cannot* have embedded coatings, where embedded coatings are defined as a coating on a substrate that touches the applied film.
- Only NFRC glass layers with the NFRC approval indicator "#" can be used as the substrate for applied film layers
- The glass layers used as the substrate for the applied film can be tinted or coated as long as the coatings do not face the applied film
- Only the layers of the Type "**Applied Films**" in Optics5 that have a "#" on them and are also on the "Approved Applied Films List" (updated by LBNL with every IGDB release and available on the WINDOW Knowledge Base website) can be used. This means that the data for those applied films was submitted to the IGDB using the criteria specified in Section 1.2 of this document, and that the Applied Film manufacturers are participating in the NFRC rating program.

For NFRC verification of the laminate construction submitted by simulators:

- Glass Layers with an applied film constructed by simulators in Optics5 will not have a # next to them when imported into WINDOW 5. The simulator shall specify in simulation reports the NFRC ID's of the applied film and the substrate, which shall all meet the # criteria, such as:

  2802 / 5038
- The simulator shall provide the properties for the applied film layer, including solar transmittance (solar, T), visible transmittance (photopic, T), solar reflectance front (solar, Rf), solar reflectance back (solar, Rb), visible reflectance front (photopic, Rf), visible reflectance back (photopic, Rb), Emissivity front (EmitF), Emissivity back (EmitB). These values are reported on the Optics screen when the laminate is calculated, and also in the WINDOW5 Detailed Report from the Glazing System Library. This requirement can be met by submitting the Optics5 User Database containing the applied film glass layers with the certification documentation.
- An IA (or anyone else wanting to check the results) can open the Optics5 User Database to verify the film and substrates used, as well as recreate the applied film layer from the specified film and substrate to verify the calculated values

8.14.2. Film Data

There are two types of films in Optics 5; the difference between them is how they were measured for submittal to the International Glazing Database:

- **Films:** These films were measured without a substrate and may appear in and be inputs to Optics5 calculations. However, the IGDB submittal process no longer accepts this type of submittal, and **they cannot be used for the NFRC Applied Film procedure**. Data in this category can be resubmitted to the IGDB, measured as an applied film with a substrate, and thus be added to the Applied Film category.
- **Applied Films:** These films are measured with a substrate. For the purposes of the NFRC Applied Film procedure, the only films that can be used are those that were measured with a clear substrate, the substrate having the properties of Tsol > 0.820 and Tvis > 0.890

Optics5 can accurately calculate the optical properties of applied films on glass layers as long as the applied films were measured following the guidelines listed below (and only applied films submitted with these characteristics will be included in the "Approved Applied Films" list for use in NFRC certified product calculations):

8.14.2.1. IGDB Submittal for Applied Films

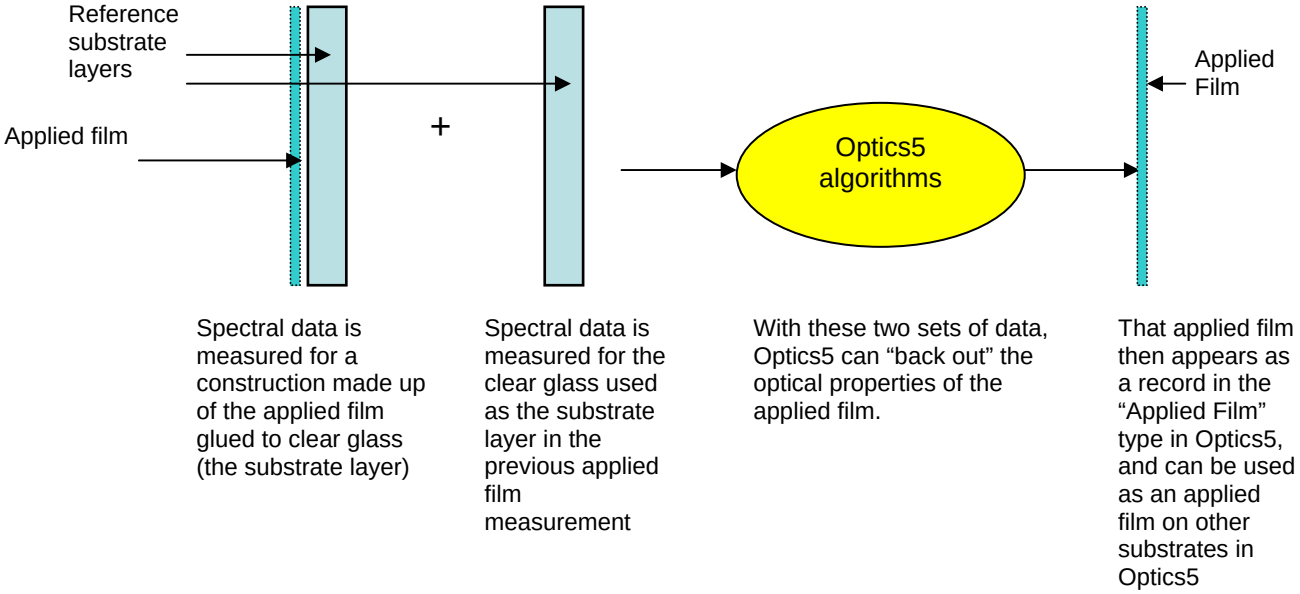
As discussed in the LBNL document which contains guidelines for submitting data to the IGDB (*International Glazing Database: Data File Format, Version 1.4*, April 2003), "an applied film glazing is an adhesive backed film applied to a Monolithic substrate." If the measured data submitted to the IGDB includes the substrate information, Optics5 can apply the film to another substrate.

This means that in order for an applied film to be added to the Optics5 "Applied Film" type, and therefore used in making applied film glass layers in Optics5, the spectral data for the "reference" substrate to which that applied film was attached, is submitted to the IGDB as follows:

- Applied films are measured with transparent glass with a solar transmittance greater than 0.820 (Tsol > 0.820) and a visible transmittance greater than 0.890 (Tvis > 0.890). Glass that meets this criteria includes 3mm clear glass, 3 mm low-iron glass, 6 mm low-iron glass. This ensures that an applied film layer in Optics5 will always have a similar or lower transmittance than the reference substrate which determines the applied film properties
- Substrate layers (the base glass to which the applied films are applied) are measured separately, without the applied films attached, and submitted to the IGDB. This is the responsibility of the manufacturer submitting data to the IGDB, as discussed below.

The applied film manufacturer can submit to the IGDB two spectral data files, single 3 mm clear with the applied film on a clear substrate and the clear substrate by itself. With this data in the IGDB, simulators, using this Applied Film Procedure, can then create the other two cases, the single 6 mm clear with the film, and the single 6 mm gray with the film, to do the SHGC and VT calculations.

This will allow a film manufacturer to submit to the IGDB several different films with the same clear substrate, if they are all measured on the same clear 3 mm substrate (from the same glass batch). For example, if a film manufacturer wanted to submit data for 20 different applied films, they would submit one spectral data file for the substrate of all 20 measurements (assuming the substrates for each film all came from the same glass batch), and 20 spectral data files, one for each film on the substrate, resulting in 21 files submitted.



Each of the 20 spectral data files for the films applied to the substrate would reference the substrate spectral data file.

Additionally, the glass manufacturer will not have to submit spectral data for the applied films attached to 6 mm clear or 6 mm gray cases, as they can be simulated in Optics5 from the applied film on the 3 mm clear substrate.

8.14.3. Using this Procedure for NFRC 200:

NFRC 200 specifies a procedure for calculating SHGC and VT for attachments, which applies to "Applied Films". This procedure specifies that reference glazing systems shall be calculated "with and without the film installed" from the following glass layers.

- Single 3 mm clear
- Single 6 mm clear
- Single 6 mm gray

The first case, "Single 3 mm clear" is what the applied film manufacturers submit to the IGDB and will be in that database. The other two cases, "Single 6 mm clear" and "Single 6 mm gray" can now be calculated with Optics5.

8.14.4. Creating a Layer with an Applied Film in Optics5

8.14.4.1. Adding an Applied Film to an Uncoated Layer

You can apply a film to a monolithic layer in Optics5 to create a new applied film layer.

To apply a film to a monolithic layer follow the steps below:

- Click on the **Glazing System** tab
- Add the desired layer to a layer column under the **Glazing System** tab
- Select the monolithic layer by clicking on the desired layer number button
- Add an Applied Film to the selected glazing layer in one of the following ways:
  - Choose the menu option **Edit|Change/Add Film**

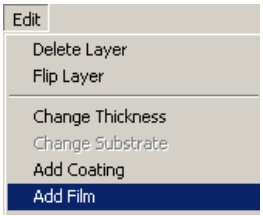


*Figure 8-142. Select a monolithic glass layer, click on the **Layer** button, and select the **Edit/Add Film** menu choice*

OR

  - Right click on the selected glazing layer button and select the choice "Add Film"
- **The Change Glazing** dialog box will appear. The film name box is highlighted in blue – click on it to select an applied film from the database (you must select an "Applied Film" layer , not a "Film" layer). You must choose a film that is on the "Approved Applied Films" list.
- The new film will be added to the side you select in the 'Apply Film to' section of the dialog box:
- You will be prompted to enter a new name for the glazing
- If you want to keep the new layer, save it to the user database (see "Saving Layers to the User Database").

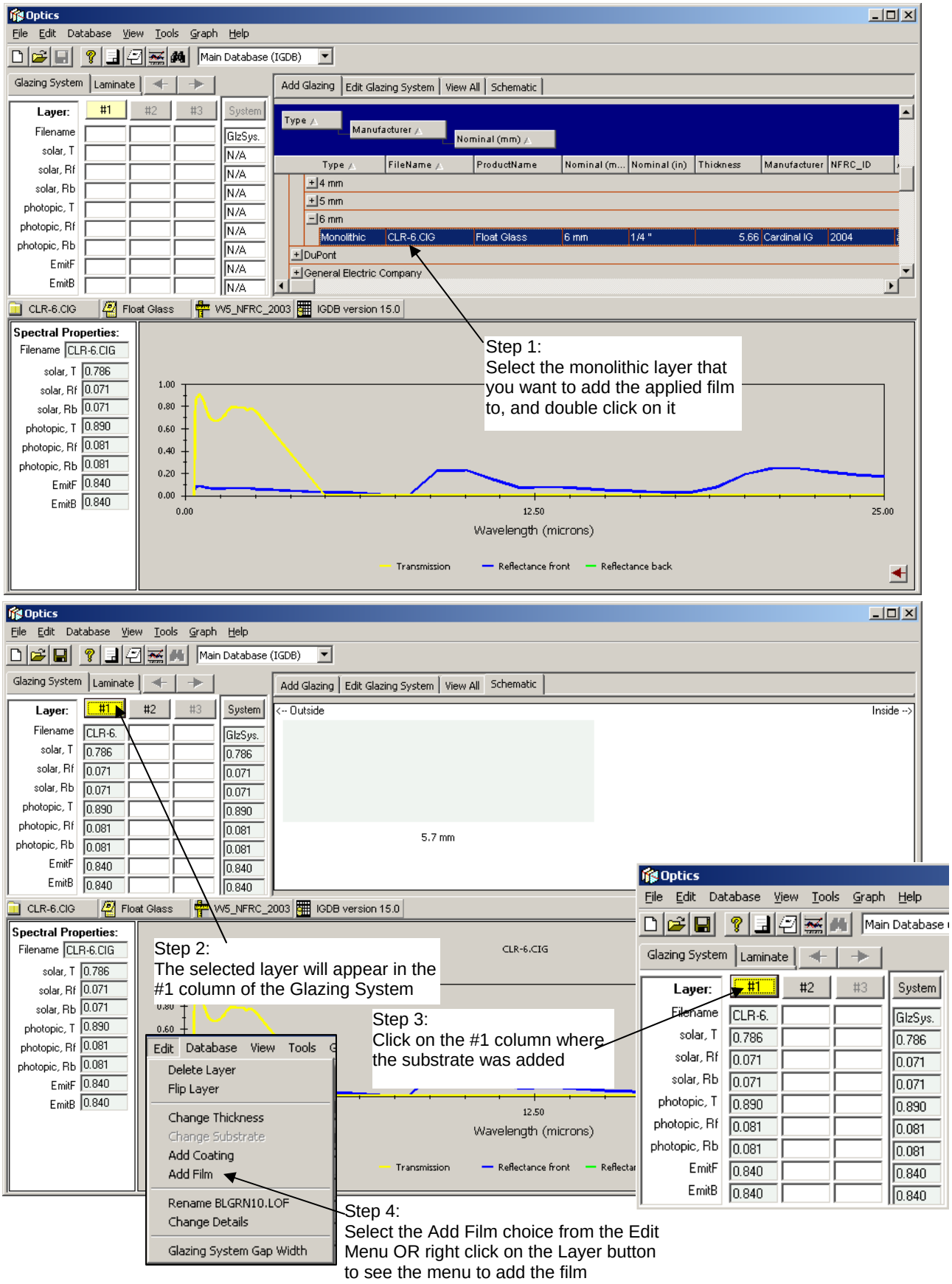


*Figure 8-143. Select a monolithic glass layer, click on the **Layer** button, and select the **Edit/Add Film** menu choice*

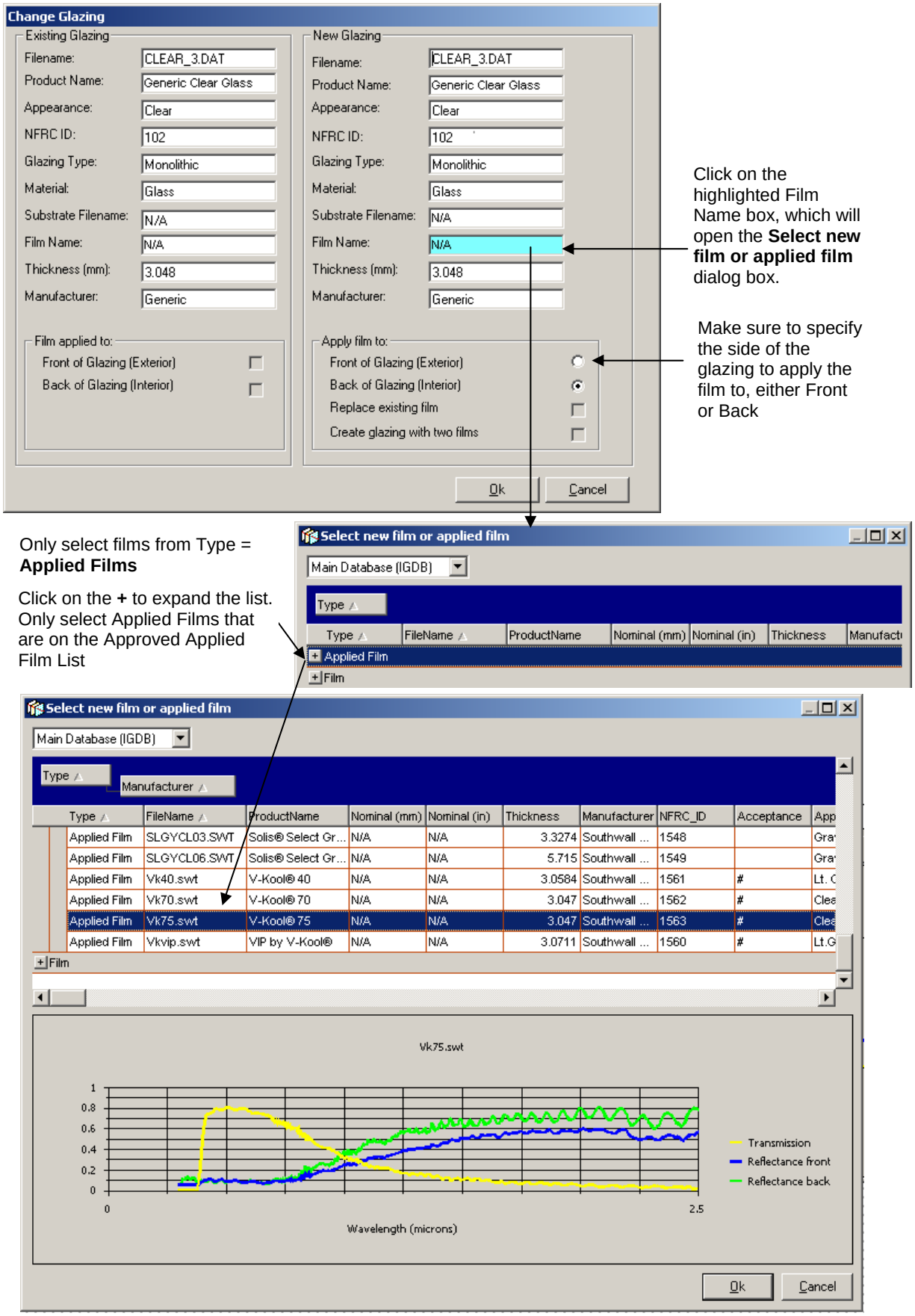


Figure 8-144. Choose the film to apply

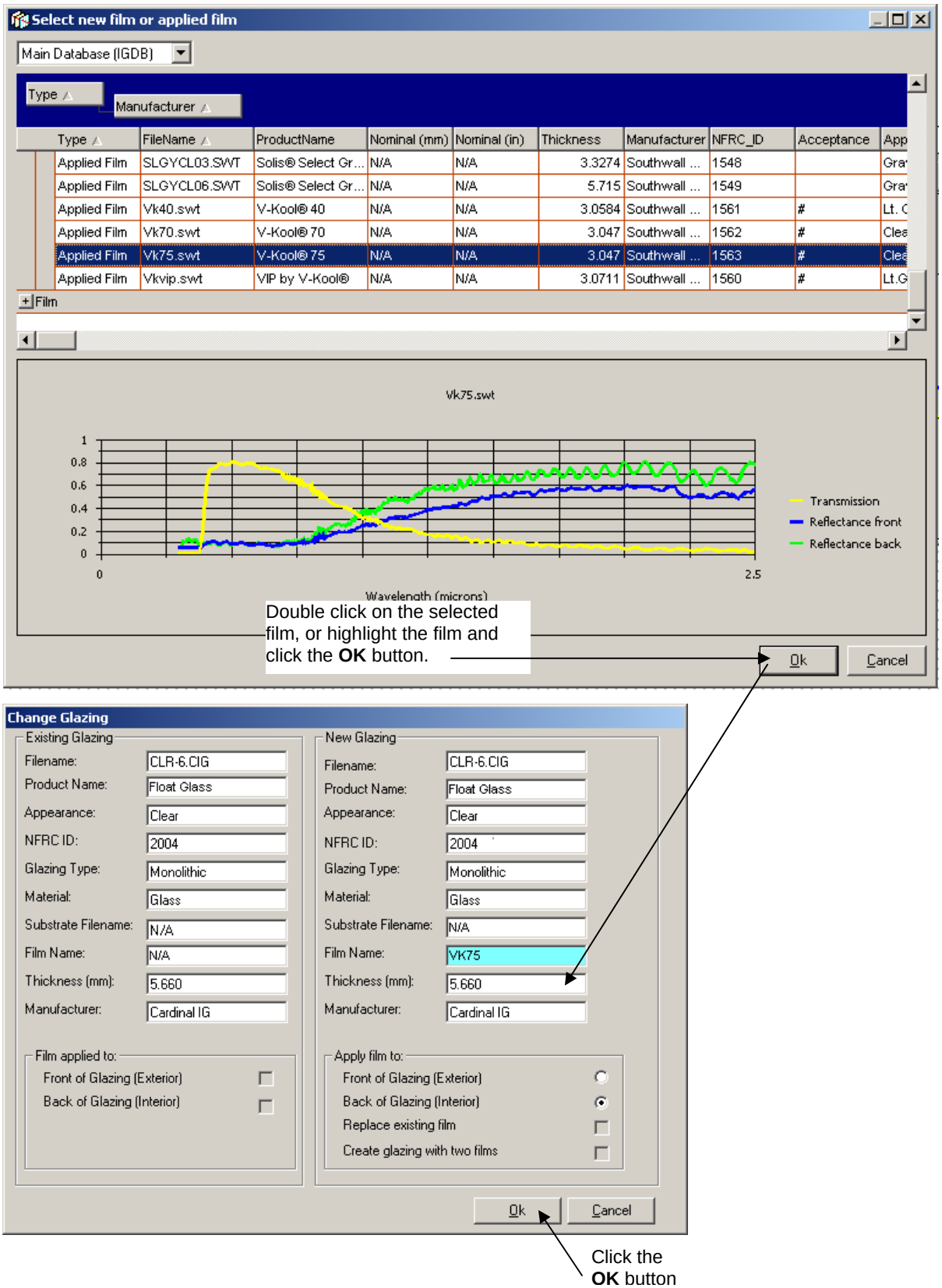
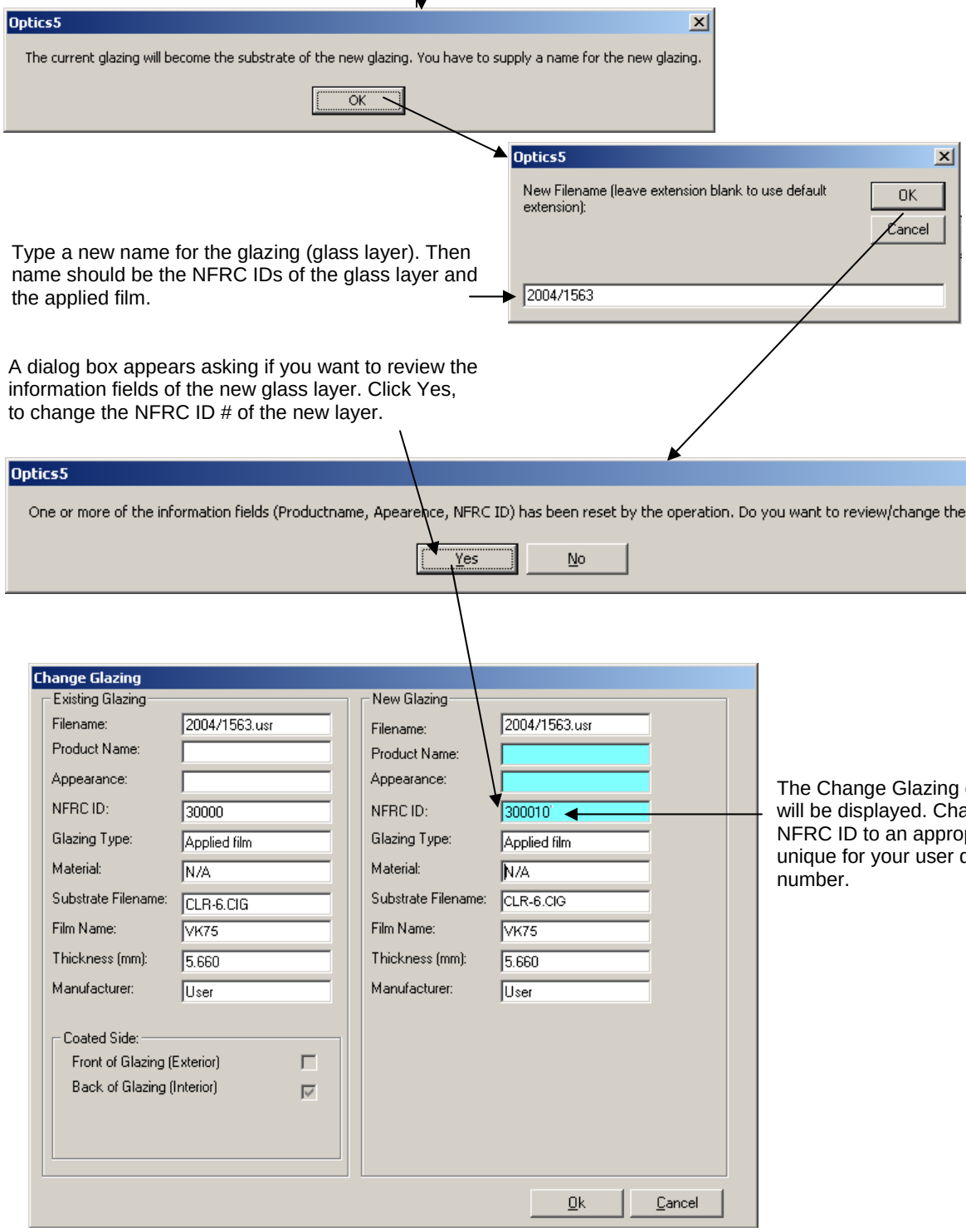


Figure 8-145. Apply the film to the substrate

The dialog appears saying a new name must be applied to the new glazing (glass layer)



Type a new name for the glazing (glass layer). Then name should be the NFRC IDs of the glass layer and the applied film.

A dialog box appears asking if you want to review the information fields of the new glass layer. Click Yes, to change the NFRC ID # of the new layer.

The Change Glazing dialog box will be displayed. Change the NFRC ID to an appropriate (and unique for your user database) number.

Figure 8-146. Give the new applied film layer a name and a new NFRC ID number if needed to ensure uniqueness.

8.14.4.2. Adding an Applied Film to a Coated Layer

You can apply a film to the uncoated side of a coated glazing, creating a double-coated layer with the coating on one side and the film on the other.

To apply a film to a coated layer:

- Click on the **Glazing System** tab
- Add the desired layer to a layer column under the **Glazing System** tab
- Select the coated layer by clicking on the desired layer number button
- Choose the menu option **Edit|Change/Add Film**
- OR
- Right click on the selected glazing layer button and select the choice "Add Film"
- The Change Glazing dialog box will appear. The film name box is highlighted in blue – click on it to select an applied film from the database (you must select an "Applied Film" layer , not a "Film" layer). You must choose a film that is on the "Approved Applied Films" list.
- The new film will be applied to the uncoated side of the glazing to create a double-coated layer with the film on one side and the coating on the other – this is indicated in the 'Apply Film to' section of the dialog box.
- You will be prompted to enter a new name for the glazing. Use the naming convention specified in the beginning of this document, i.e., NFRC IDs for both the glazing layer and the applied film.
- If you want to keep the new layer, save it to the user database (see "Saving Layers to the User Database").

8.14.4.3. Adding an Applied Film to a Laminate

In the same manner as adding an applied film to either a coated or an uncoated layer, a film can be applied to a laminate. This laminate can already exist in the IGDB or can be a laminate constructed using the NFRC Laminate Procedure. The laminate is treated as a glass layer in the Glazing System tab, and the applied film is then added to that layer.

8.14.4.4. Change a Film

To change the film applied to an applied film layer:

- Select the applied film layer by clicking on the appropriate layer button
- Choose the menu option **Edit|Change/Add Film**
- The Change Glazing dialog box will appear The film name box is highlighted in blue – click on it to select an applied film from the database (you must select an "Applied Film" layer , not a "Film" layer). You must choose a film that is on the "Approved Applied Films" list.
- The new film will replace the current film – this is indicated in the 'Apply Film to' section of the dialog box
- You will be prompted to enter a new name for the glazing. Use the naming convention specified in the beginning of this document, i.e., NFRC IDs for both the glazing layer and the applied film.
- If you want to keep the new layer, save it to the user database (see "Saving Layers to the User Database").

8.14.4.5. Saving Layers to the User Database

You can save a glazing layer with an applied film to the user database if it has a different filename from any layer currently in the user database or in the IGDB. If you save a layer that has components (such as a glazing layer that has an applied film), the component layers will be saved to the user database at the same time (unless they already exist in the IGDB or user database). This allows you to load and edit those layers at a later time.

To save a layer to the user database:

- Select the layer or system to save by clicking on a layer button
- Click the 'Save' button on the toolbar:
  or
  Choose menu option **File|Save** *filename*
  or
  Right-click to display the pop-up menu and select the option **Save** *filename*
- If the layer or system you saved had components, or if the save operation fails, you will be asked 'Do you want to view the details of the save operation?'. If you answer yes, you can view information about components that were saved to the user database, and components that were not saved to the user database along with an explanation of why some components were not saved.

Note: to change the filename and save in one operation, choose menu option **Save As..** instead.

Note: You cannot save data for a layer with the same filename as another layer in the IGDB or your current user database. If a conflict is detected, Optics will ask you to rename the layer before saving it, or cancel the import. The most common reason a component is not saved is that its filename already exists in the IGDB or user database. In this case Optics assumes that the component layer information is already available and does not need to be saved again.

8.14.4.6. Renaming a Layer

To rename a layer with an applied film:

- Select the layer you want to rename by clicking on a layer button.
- Choose menu option **Edit|Rename** *filename*
  or
  Right-click on the layer button to display the pop-up menu, and select item **Rename** *filename*
- Enter a new filename and click 'OK'

If you want to save the layer under the new name, save it to the user database (see "Saving Layers to the User Database"). You could also achieve the same result by using the File|Save As… menu option to rename and save the layer in one operation.

8.15. Framed Intermediate Pane

8.15.1. Overview

For a product that has an intermediate pane with it's own frame, the modeling steps are as follows:

In WINDOW:

- Create the glazing system, including the intermediate pane.

In THERM:

- Model the head, sill and jamb sections including the intermediate pane and frame, using the glazing system created in WINDOW. Model caming, if applicable, as shown in the Dividers section (8.3.4) of this manual

In WINDOW:

- Import the THERM cross sections into the Frame (and Divider if modeling caming) Libraries.
- Model the whole product using the Glazing System, Frame and Divider components.

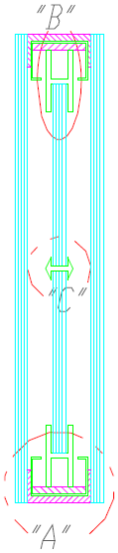


Figure 8-147. An example of a framed intermediate pane. Section A is modeled for the Sill/Jamb, Section B is modeled for the Head, and Section C is modeled as a Divider.

8.15.2. THERM Modeling Details

The THERM modeling is relatively straightforward, with a few details to be aware of shown below.

The head and sill are modeled normally, except that the extra frame for the intermediate pane is also modeled. The sightline will remain defined as the highest interior point on the window/door frame.

Example Sill

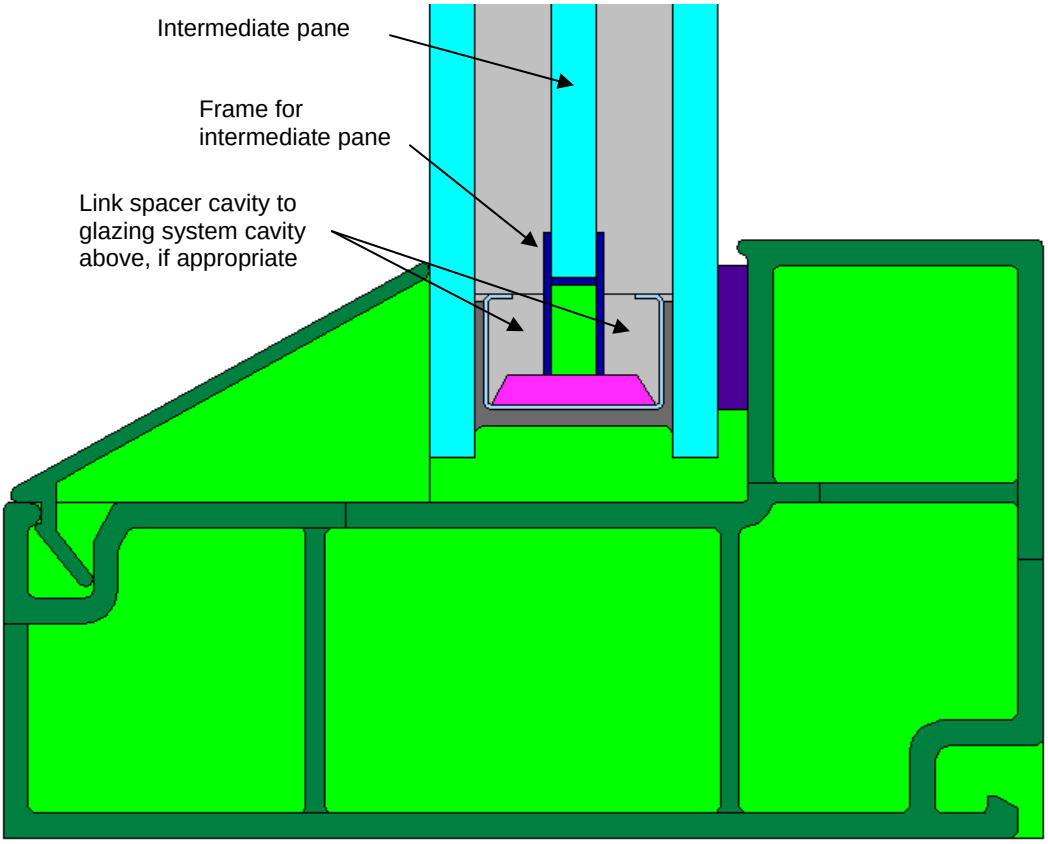


Figure 8-148. Example sill with framed intermediate pane

Example Head

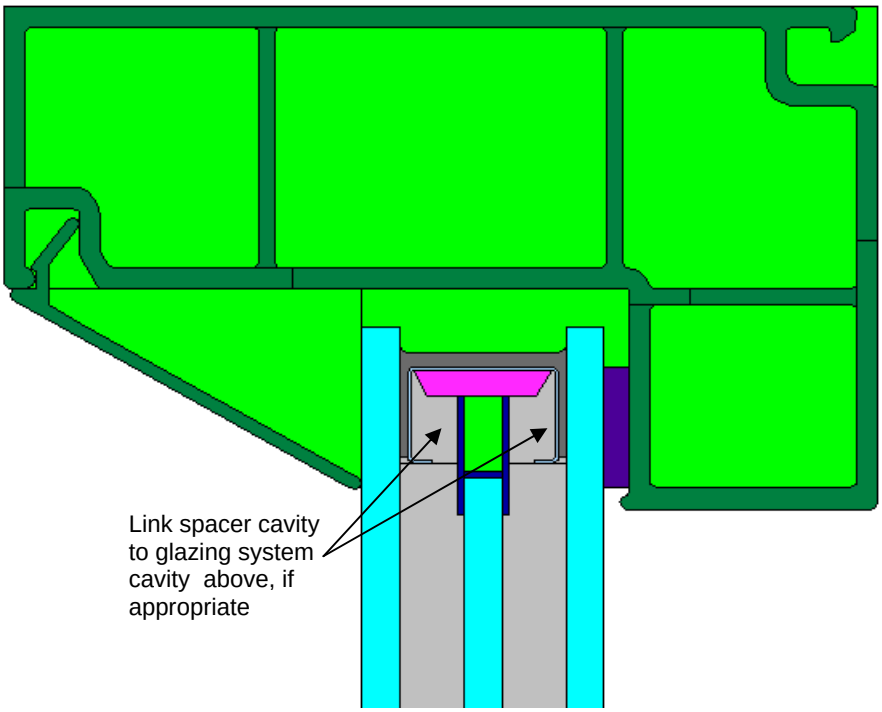


Figure 8-149. Example head with framed intermediate pane

Example Caming / Divider

Caming, if it exists, is modeled as a Divider.

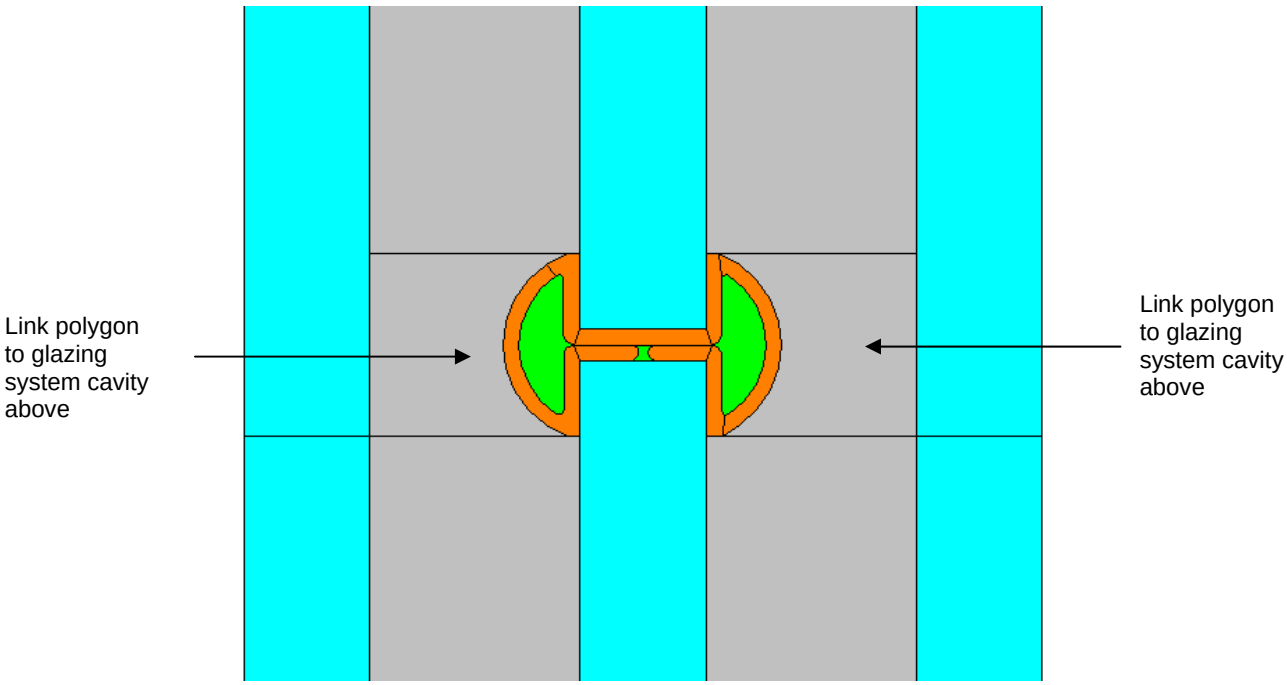


Figure 8-150. Example caming with framed intermediate pane

9. SAMPLE PROBLEMS

9.1. Overview

There are four sample problems:

- Problem 1: Vinyl Fixed Window page 9-2
- Problem 2: Aluminum Horizontal Sliding Window page 9-16
- Problem 3: Skylight page 9-50
- Problem 4: Door page 9-59

These sample problems may contain boundary conditions, frame cavity conditions and modeling techniques that do not conform to the NFRC modeling rules. If this is the case, the NFRC modeling rules always take precedence over what is shown in these example problems. Also, the results shown in these examples may not correspond exactly to results obtained with the WINDOW and THERM programs.

Please note that some of the drawings provided with these sample problems are proprietary. Therefore, they shall not be used by anyone for any purpose other than the enclosed sample problems without the prior written consent of NFRC.

9.2 Problem 1: Vinyl Fixed Window

For this fixed vinyl window, calculate the U-factor, SHGC, and VT values.

9.2.1. Description

Window Type	Fixed picture window.
Overall Size	Width = 1200 mm; Height = 1500 mm
Frame Material	PVC frame and stop, with a wall thickness of 3.175 mm (0.125″). The same geometry can be used for the head, jambs and sill.
Glazing System	Double glazing, 19.05 mm (0.750″) overall I.G. thickness. The outboard lite is double-strength clear glass, 3.277 mm (0.129″) thick. The inboard lite is double-strength clear glass with a PPG Sungate100 Low-E coating on surface three. The glazing cavity is air filled, 12.5 mm (0.492″) thick.
Spacer Type	Intercept spacer with PIB primary seal and hot-melt butyl secondary seal.
Glazing Method	Foam rubber tape, 3.175 mm (0.125″) thick.
Dividers	Aluminum grille pattern, painted white. The grille pattern for the window is three by four, and is between the glass.
Cross Sections	See Section 9.2.7 for drawings of this product.

9.2.2. Glazing Matrix

The window is offered by the manufacturer both with and without dividers. The drawings indicate that there is less than 3.0 mm (0.118″) between the glass and the divider, so the glazing matrix must include both a case with and without dividers.

9.2.3. Center-of-glazing Modeling (WINDOW)

Model the glazing system in WINDOW with double strength clear glass, a 12.5 mm (0.492") air space (air filled), and Sungate100 Low-E.

The figure below shows the WINDOW Glazing System Library for this glazing system.

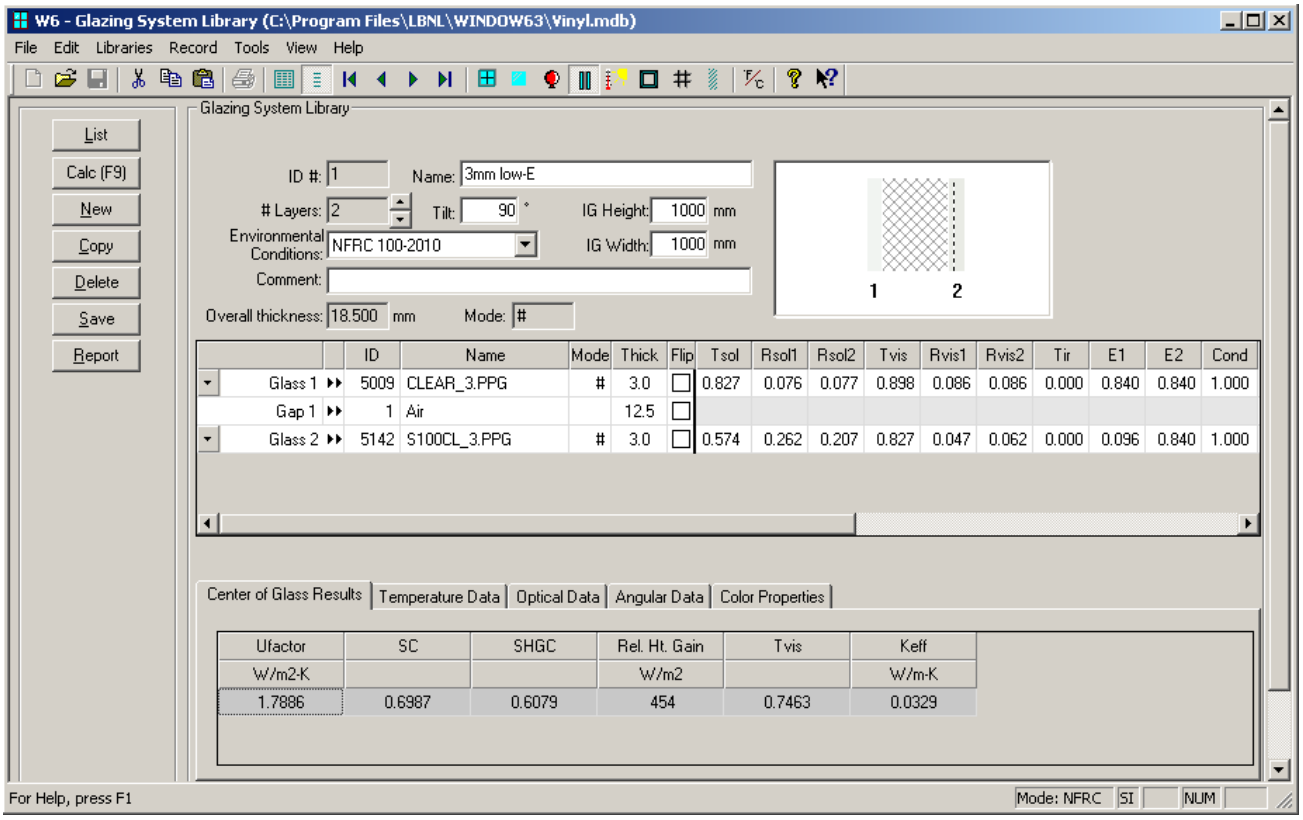


Figure 9-1. WINDOW Glazing System Library for the vinyl window.

The results for the center-of-glazing U-factor are shown in the following table:

Table 9-1. Center-of-glazing U-factor results from WINDOW.

		Center-of-Glazing U-Factor	
	Glazing Options 19.05 mm (0.75") overall thickness	**W/m^2-°C**	**(Btu/hr-ft^2-°F)**
1	Clear (3 mm), Air, Low-E (3 mm)	1.7886	0.3150

This glazing system will be used in THERM to calculate the edge-of-glazing and frame U-factors, and also in WINDOW to calculate the overall product U-factor.

9.2.4. Edge-of-glazing and Frame Modeling for U-Factor (THERM)

Because this is a fixed window where the head, sill and jambs have the same geometry, the frame and stop portions of the cross sections created in THERM will be the same. However, due to the ISO 15099 modeling assumptions for gravity vectors and Condensation Resistance modeling, it is necessary to create a unique cross section for each component type to reflect the proper orientation of the glazing system and gravity vector.

The table below shows the files that are associated with this example.

Table 9-2. Files associated with the vinyl window example.

Cross Section	DXF Filename	THERM Filename
Sill	Vinyl–Frame.dxf	Vinyl-Sill.thm
Head	Vinyl–Frame.dxf	Vinyl-Head.thm
Jamb	Vinyl–Frame.dxf	Vinyl-Jamb.thm
Divider		Vinyl-Div.thm

The table below shows the resulting U-factors for the vinyl frame and divider cross sections.

Table 9-3. THERM results for the vinyl window cross sections.

	Frame U-Factor		Edge U-Factor	
Cross Section	W/m^2-°C	$Btu/hr\text{-}ft^2$-°F	W/m^2-°C	$Btu/hr\text{-}ft^2$-°F
Sill	1.5988	0.2816	2.1163	0.3727
Head	1.6037	0.2824	2.1151	0.3725
Jamb	1.6498	0.3182	2.1176	0.3706
Divider	2.6050	0.4593	1.9986	0.3521

Figures 9-2 through 9-5 show the THERM cross sections and U-factor results for this window.

Sill

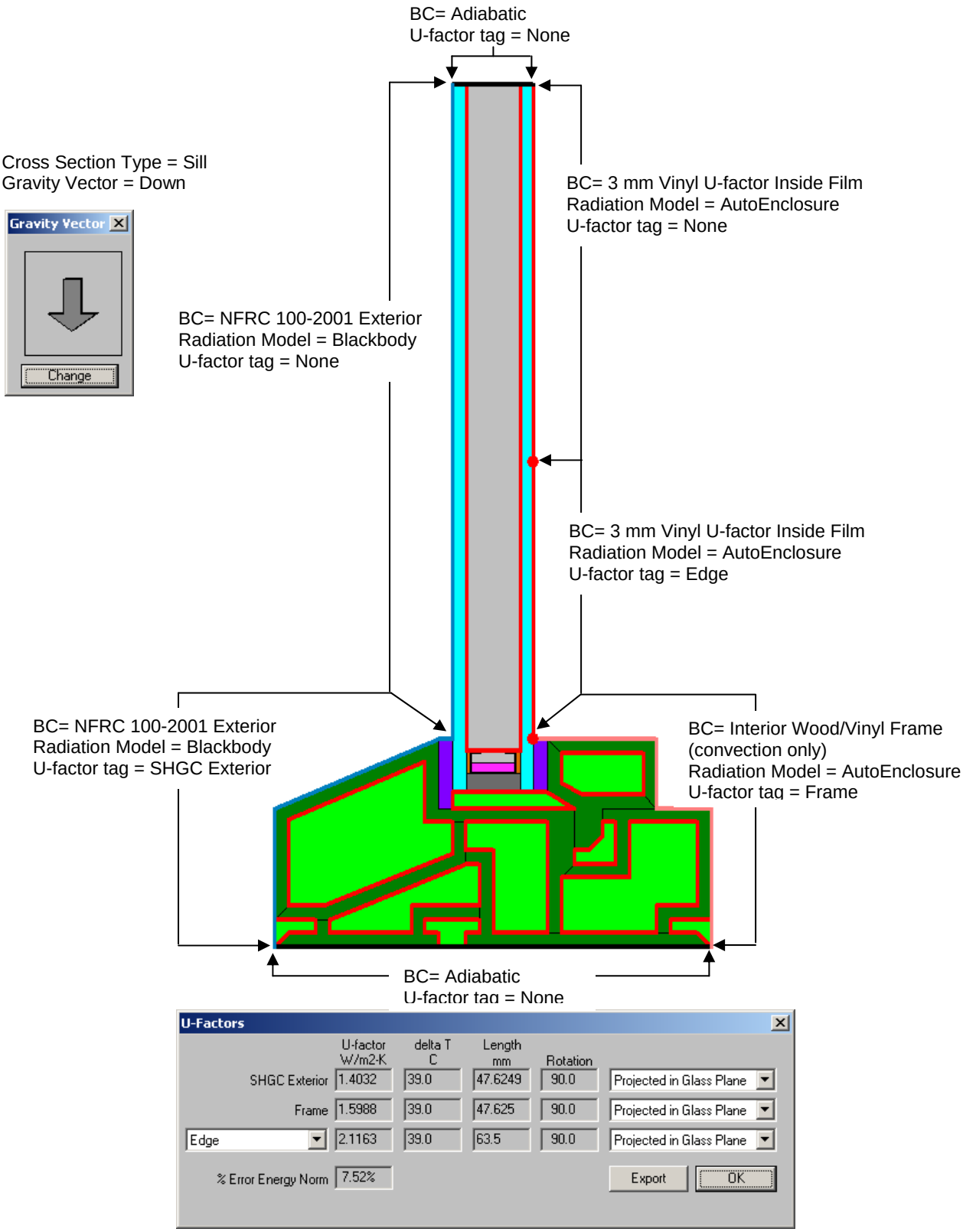


Figure 9-2. THERM cross section and U-factor results for the sill cross section.

Jamb

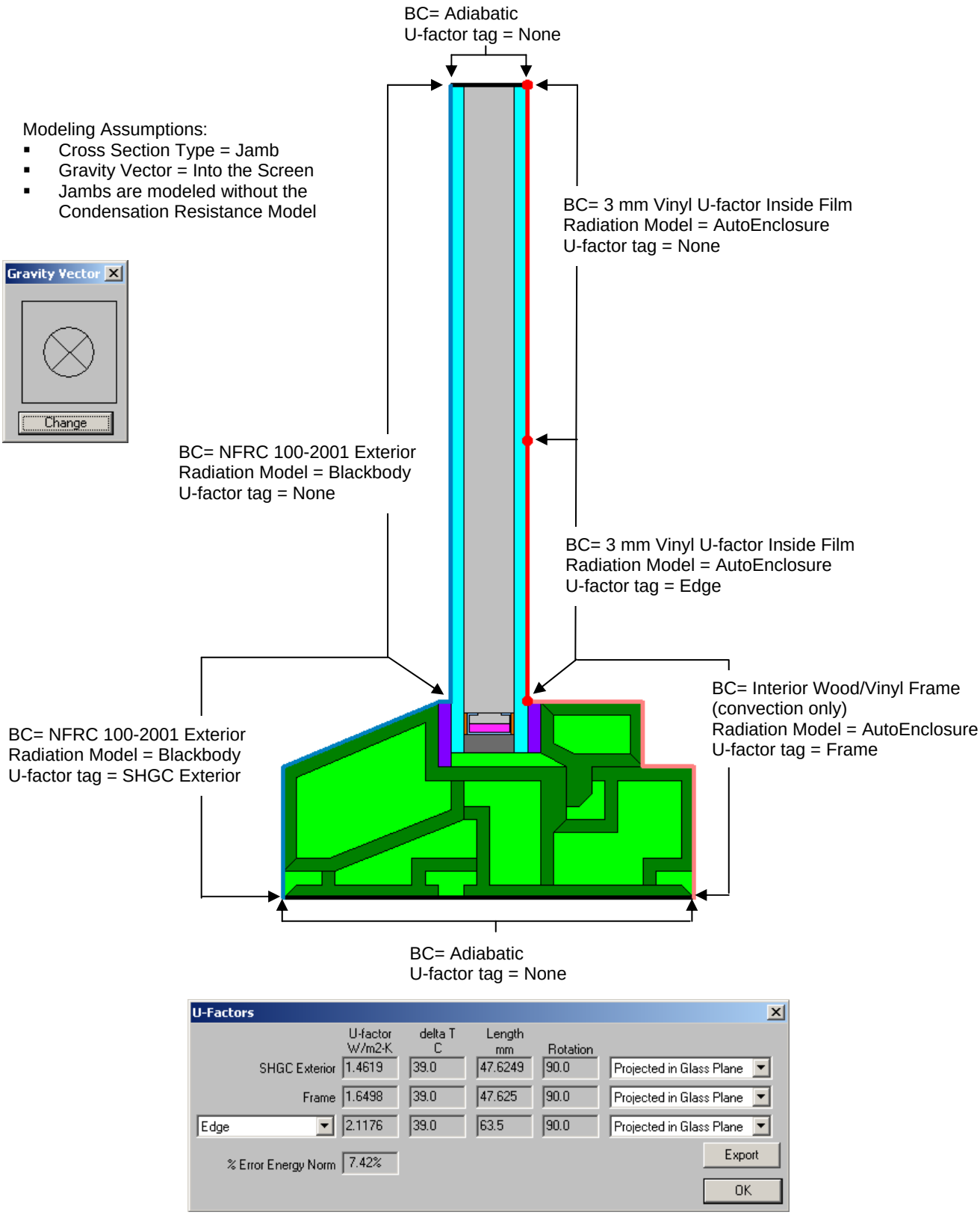


Figure 9-3. THERM cross section and U-factor results for the jamb cross section.

Head

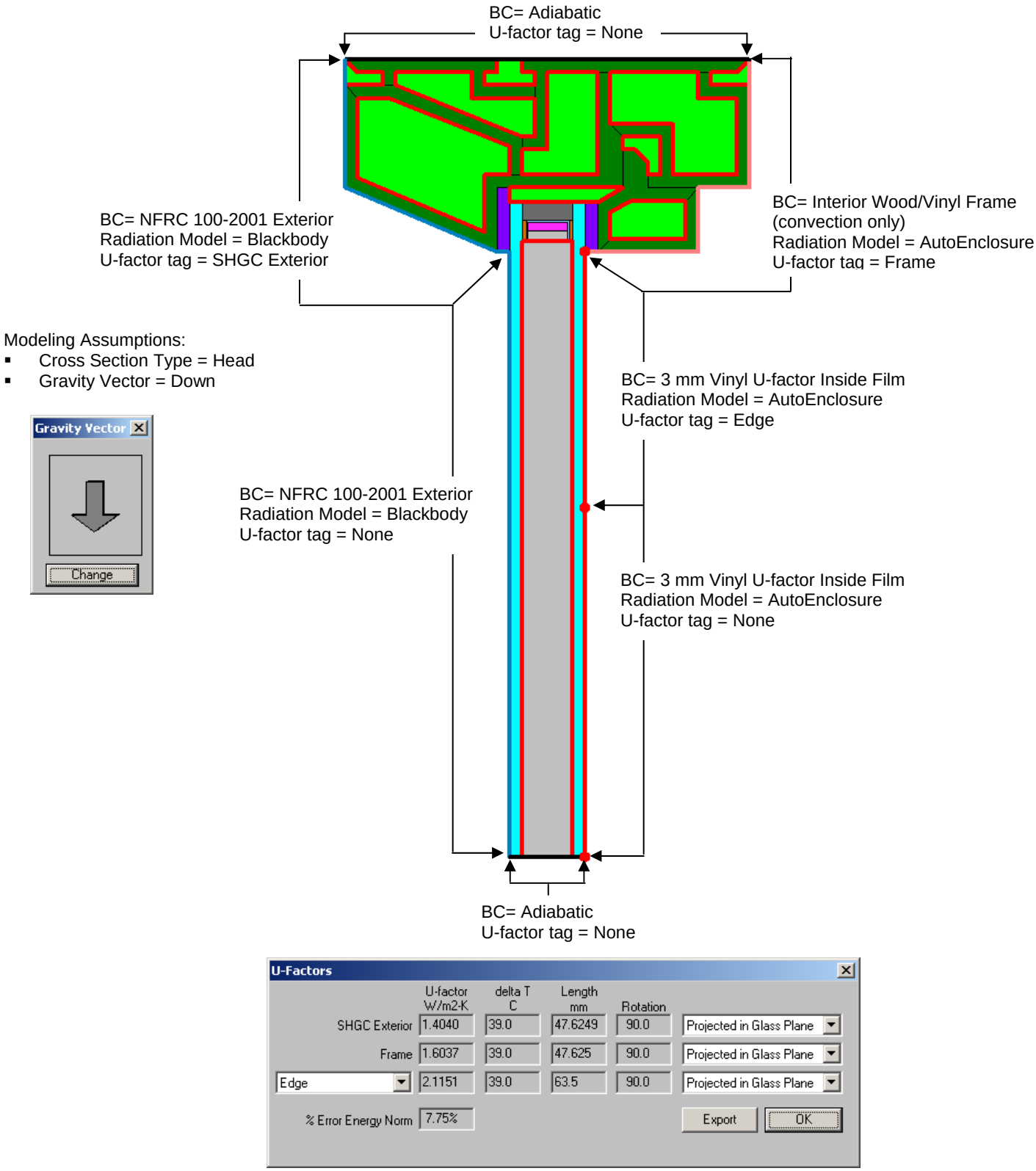


Figure 9-4. THERM cross section and U-factor results for the head cross section.

Divider

- Cross Section Type = Vertical Divider
- (model both vertical and horizontal dividers as Vertical)
- Do not use the CR model with a Vertical Divider cross section.
- Gravity Vector = Into the Screen
- It is not necessary to apply the SHGC Exterior U-factor tag in this case because the interior projected frame dimension and the exterior wetted length are the same (but it should be added for consistency).

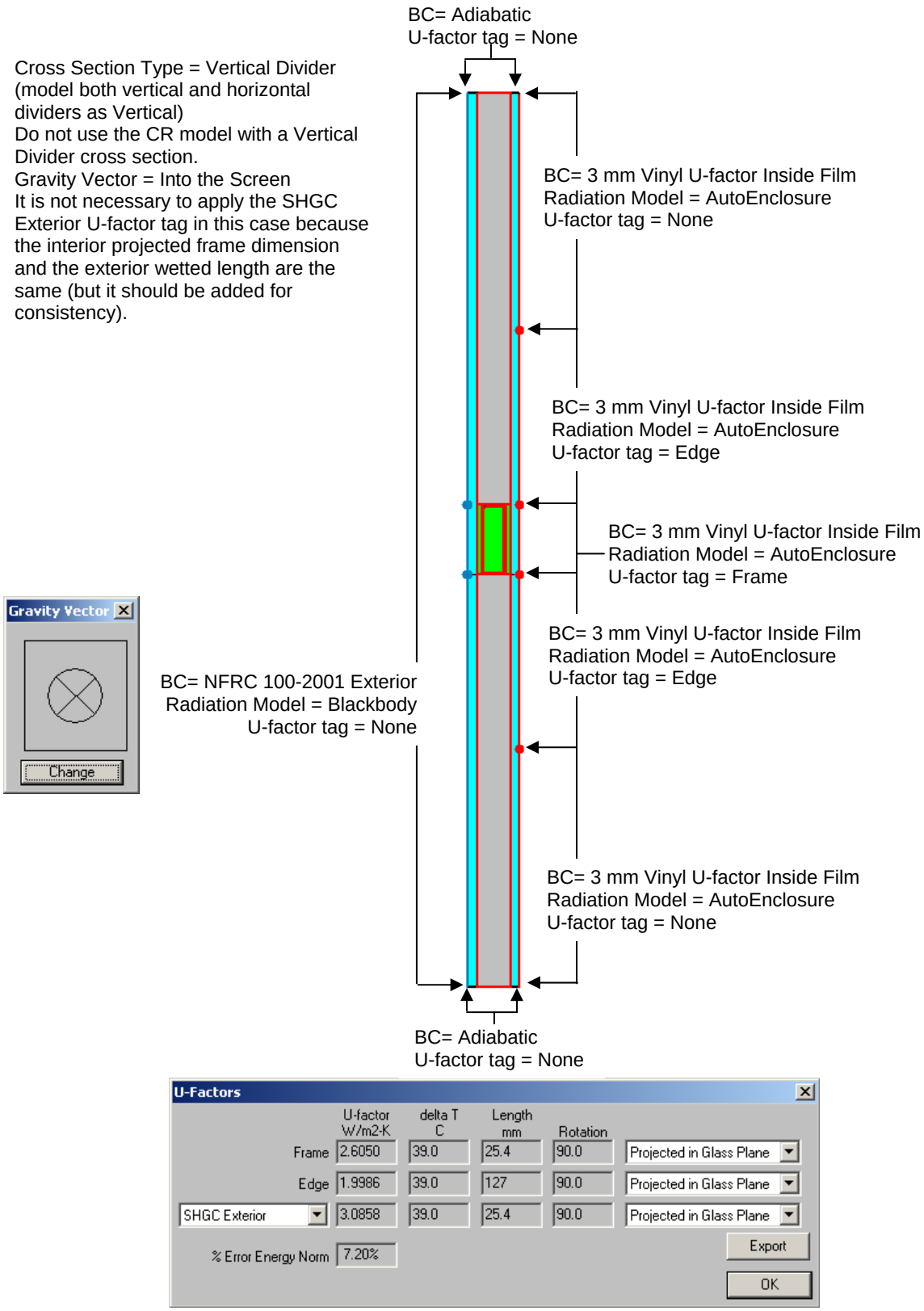
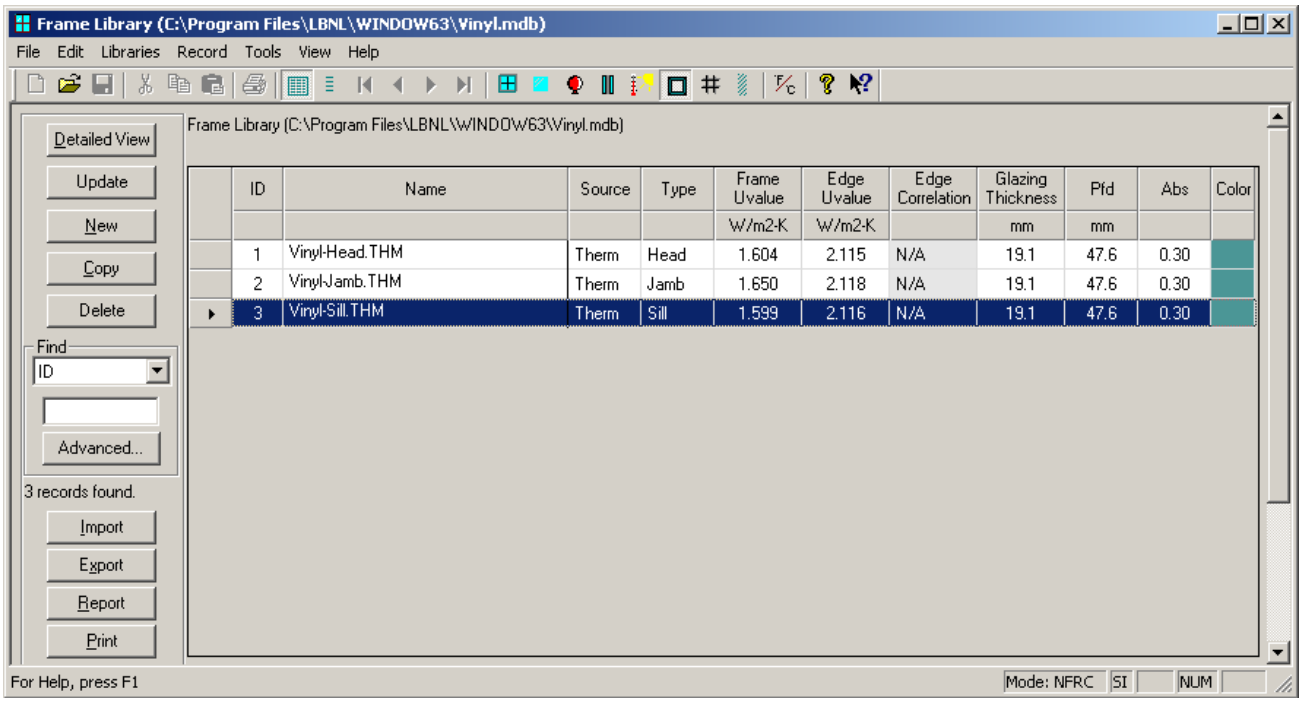


Figure 9-5. THERM cross section and U-factor results for the divider cross section.

9.2.5. Total Product U-Factor

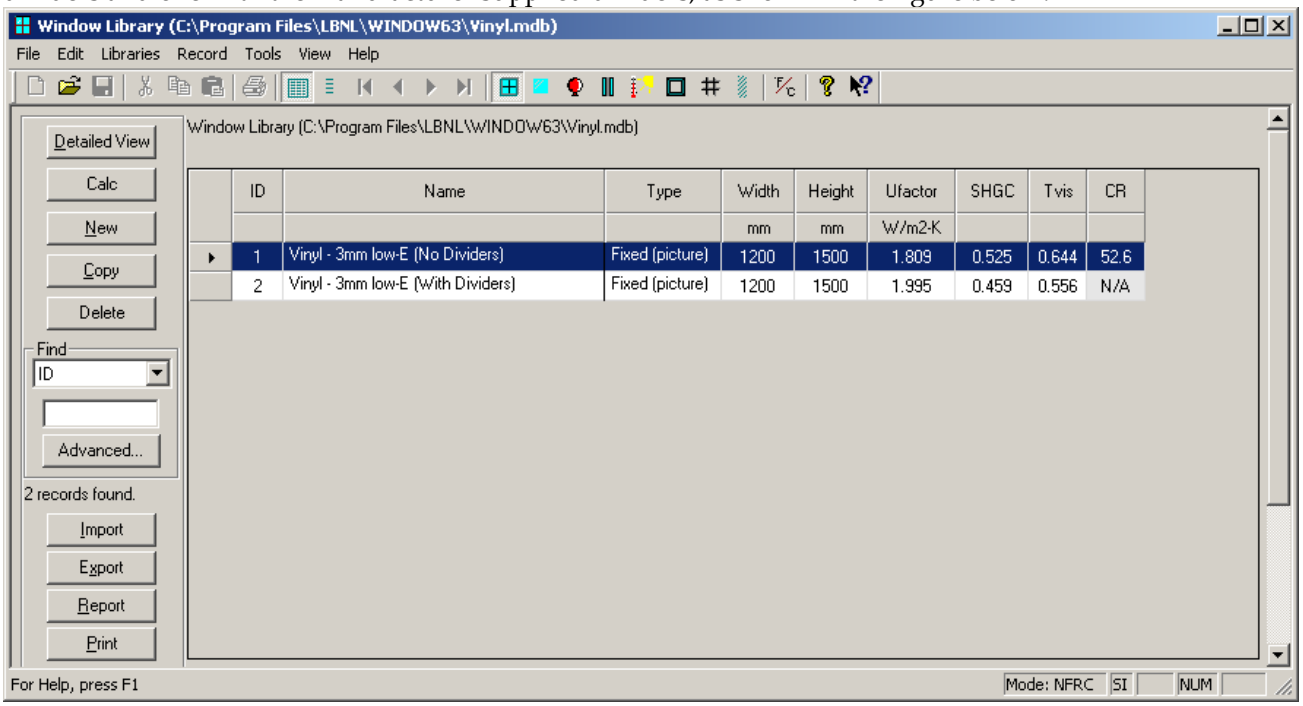
In WINDOW, import the THERM cross sections into the Frame Library.



ID	Name	Source	Type	Frame Uvalue	Edge Uvalue	Edge Correlation	Glazing Thickness	Pfd	Abs	Color
				W/m2-K	W/m2-K		mm	mm		
1	Vinyl-Head.THM	Therm	Head	1.604	2.115	N/A	19.1	47.6	0.30	
2	Vinyl-Jamb.THM	Therm	Jamb	1.650	2.118	N/A	19.1	47.6	0.30	
3	Vinyl-Sill.THM	Therm	Sill	1.599	2.116	N/A	19.1	47.6	0.30	

Figure 9-6. THERM files imported into the Frame Library.

In WINDOW, two records are created in the Window Library for the U-factor calculation – one without dividers and one with the manufacturer supplied dividers, as shown in the figure below.



ID	Name	Type	Width	Height	Ufactor	SHGC	Tvis	CR
			mm	mm	W/m2-K			
1	Vinyl - 3mm low-E (No Dividers)	Fixed (picture)	1200	1500	1.809	0.525	0.644	52.6
2	Vinyl - 3mm low-E (With Dividers)	Fixed (picture)	1200	1500	1.995	0.459	0.556	N/A

Figure 9-7. Window Library records for the product with and without dividers for the U-factor calculation.

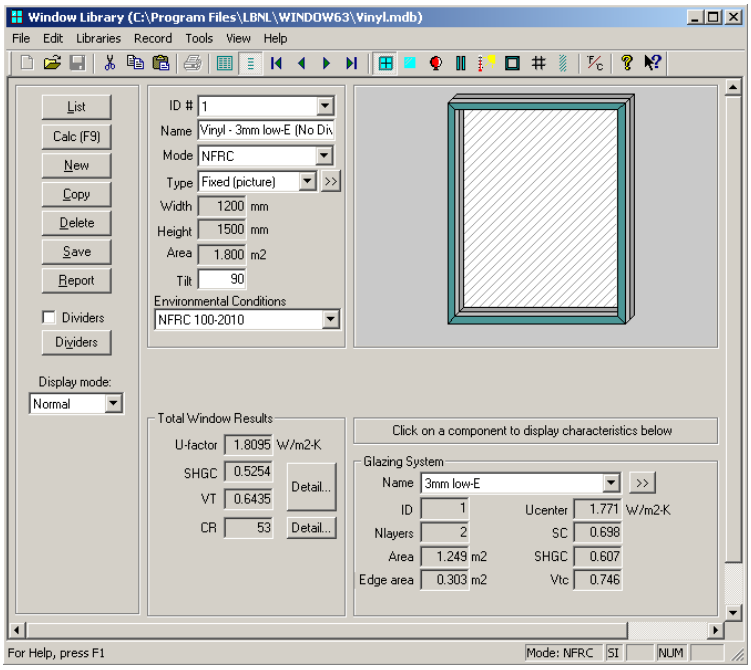


Figure 9-8. WINDOW total product U-factor calculation without dividers.

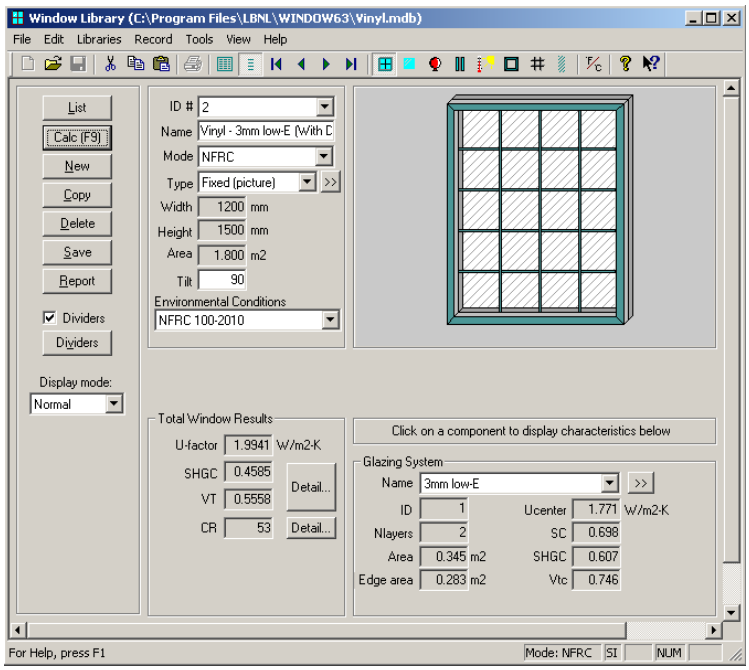


Figure 9-9. WINDOW total product U-factor calculation with dividers.

The following table shows the overall product U-factor from WINDOW, both with and without dividers.

Table 9-4. Total product U-factors.

Glazing Options19.05 mm (0.75”) overall thickness		**Total Product U-Factor**	
		W/m^2-°C	**Btu/hr-ft^2-°F**
1	Clear, Air, Low-E (without dividers)	1.8095	0.3187
2	Clear, Air, Low-E (with dividers)	1.9941	0.3512

9.2.6. Individual Product SHGC and VT using SHGC 0 & 1 and VT 0 & 1

The methodology for determining the Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) for products is outlined in NFRC 200 using values of $SHGC_0$, $SHGC_1$, VT_0 and VT_1. A detailed explanation of how to apply that methodology in WINDOW is presented in Section 7.4.1 of this manual. These values are calculated in WINDOW for the best glazing option modeled with the highest frame and edge U-factor frame, as outlined in NFRC 200, Section 4.2.3 (A). The values calculated from that one case are then used to calculate the SHGC and VT for any other glazing options using Equations 4-1 and 4-2 in NFRC 200. Do not use the $SHGC_0$, $SHGC_1$, VT_0 and VT_1 from WINDOW for every glazing option – just for the best glazing option.

Using this procedure, display the results for the $SHGC_0$, $SHGC_1$, VT_0 and VT_1 for the best glazing option (Clear, Air, Low-E), by clicking on the **Detail** button on the **Window Library Detailed View** screen, as shown in the figure below. The **SHGC and VT detail** dialog box will show the SHGC and VT values for the following three cases for this glazing option:

- No Dividers
- Dividers ≤ 25.4 mm (modeled as 19.5 mm)
- Dividers > 25.4 mm (modeled as 38.1 mm)

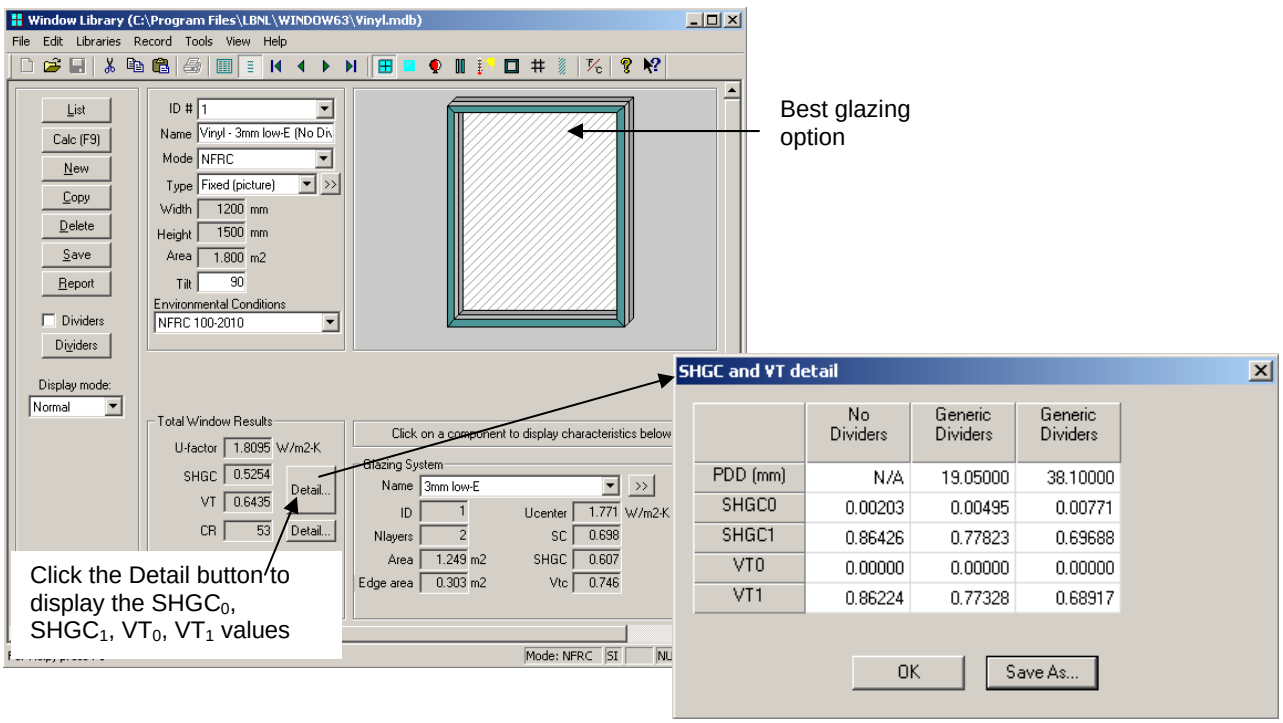


Figure 9-10. Window Library SHGC and VT values for the best glazing option, accessed from the Detail button.

Table 9-5. $SHGC_0$, $SHGC_1$, VT_0 and VT_1 data for the best glazing option in this product line (Clear, Air, Low-E).

	No Dividers	**Dividers ≤ 25.4 mm, modeled at 19.5 mm (≤ 1.0", modeled at 0.75")**	**Dividers > 25.4 mm, modeled at 38.1 mm (> 1.5", modeled at 1.5")**
$SHGC_0$	0.00203	0.00495	0.00771
$SHGC_1$	0.86426	0.77823	0.69688
VT_0	0.0	0.0	0.0
VT1	0.86224	0.77328	0.68917

SHGC Calculation Using Equation 4-1 from NFRC 200

Equation 4-1 from NFRC 200 is used to calculate the whole product SHGC from the $SHGC_0$, $SHGC_1$, and $SHGC_C$:

$$SHGC = SHGC_0 + SHGC_C\ (SHGC_1 - SHGC_0)$$

Where:

$SHGC_C$ =	center-of-glazing SHGC (calculated in the Glazing System Library of WINDOW for the best glazing option)
$SHGC_0$ =	total product SHGC values for a center-of-glazing SHGC of 0.0 (calculated in the Window Library of WINDOW for the best glazing option)
$SHGC_1$ =	total product SHGC values for a center-of-glazing SHGC of 1.0 (calculated in the Window Library of WINDOW for the best glazing option)
SHGC =	total product SHGC (calculated using Equation 4-1)

The SHGC data from Table 9-5 is used with Equation 4-1 to determine total product SHGC as follows:

Without Dividers:

SHGC = 0.00203+ 0.6079 (0.86426– 0.00203)
= 0.5262

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

SHGC = 0.00495 + 0.6067 (0.77823 – 0.00495)
= 0.4741

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

SHGC =0.00771+ 0.6067 (0.69688– 0.00771)
= 0.4258

Table 9-6. Total product SHGC for the best glazing option (Clear, Air, Low-E).

SHGC			
Glazing Option	**No Dividers**	**Dividers ≤ 25.4 mm, modeled at 19.5 mm (≤ 1.0”, modeled at 0.75”)**	**Dividers > 25.4 mm, modeled at 38.1 mm (> 1.5”, modeled at 1.5”)**
Clear, Air, Low-E	0.5262	0.4741	0.4258

VT Calculation Using Equation 4-2 from NFRC 200

Equation 4-2 from NFRC 200 is used to calculate the whole product VT from the VT_0, VT_1, and VT_C:

$VT = VT_0 + VT_C (VT_1 - VT_0)$

Where:

VTC =	center-of-glazing VT (calculated in the Glazing System Library of WINDOW for the best glazing option as "Tvis")
VT0 =	total product VT values for a center-of-glazing VT of 0.0 (calculated in the Window Library of WINDOW for the best glazing option)
VT1 =	total product VT values for a center-of-glazing VT of 1.0 (calculated in the Window Library of WINDOW for the best glazing option)
VT =	total product VT (calculated using Equation 4-2)

The VT data from Table 9-5 is used with Equation 4-1 to determine total product VT as follows:

Without Dividers:

VT = 0.0 + 0.7463 (0.86224– 0.0)
= 0.6435

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

VT = 0.0 + 0.7463 (0.77328– 0.0)
= 0.5771

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

VT = 0.0 + 0.7463 (0.68917– 0.0)
= 0.5143

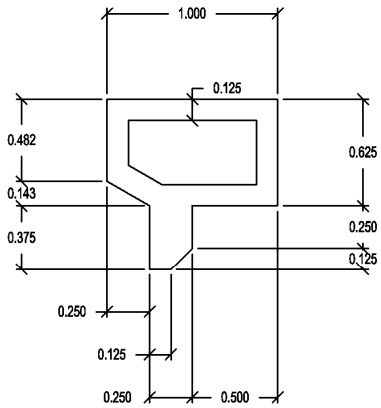
Table 9-7.. Total product VT for the best glazing option (Clear, Air, Low-E).

VT			
Glazing Option	**No Dividers**	**Dividers ≤ 25.4 mm, modeled at 19.5 mm (≤ 1.0", modeled at 0.75")**	**Dividers > 25.4 mm, modeled at 38.1 mm (> 1.5", modeled at 1.5")**
Clear, Air, Low-E	0.6435	0.5771	0.5143

9.2.7. Drawings Vinyl Fixed Window

The following pages contain detailed drawings for this window.

Head, Sill and Jamb



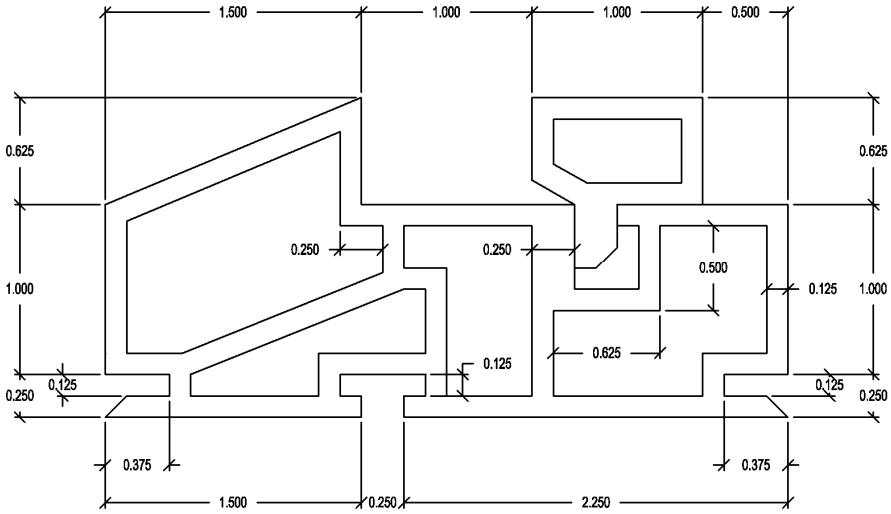


Figure 9-11. Dimensioned drawing for the frame and stop.

Spacer

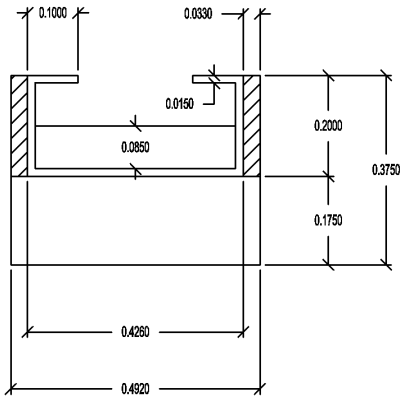


Figure 9-12. Dimensioned drawing for the spacer.

Divider

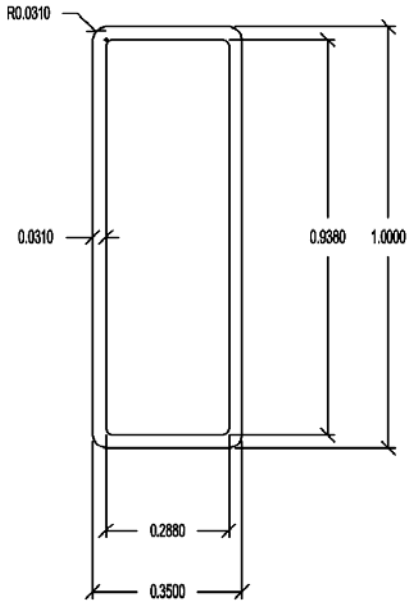


Figure 9-13. Dimensioned drawing for the divider.

9.3 Problem 2: Aluminum Horizontal Slider Window

For this aluminum horizontal slider window example, calculate the total product U-factor, SHGC, VT and the specialty products table.

9.3.1. Description

Window Type	Horizontal Slider
Overall Size	Width = 1500mm; Height = 1200mm
Frame Material	Aluminum painted white. Thermal breaks as indicated in the drawing assembly. The manufacturer indicated that the de-bridge width is 0.250" for all the cross sections. Thermal break material is poured in place polyurethane.
Spacer type	See drawings in Section 9.3.7.
Weather Strip	See drawings in Section 9.3.7.
Cross Sections	Section 9.3.7 contains the drawings for this example.
Dividers	Aluminum painted white. See drawing for dimensions. Manufacturer provides standard 12" on center or less horizontal and vertical grid pattern for his products.
Glazing System	Double glazing, 25.4 mm (1”) overall I.G. thickness. The manufacturer uses two different glass suppliers depending on the market availability and price factor. The manufacturer uses clear and Low-E coated glass from the same supplier. ▪ **Clear Glass**: from PPG or CIG with nominal thickness of 3 mm, 4 mm, 5 mm, and 6mm ▪ **Low-E Glass**: from PPG (Sungate100) or CIG (LoE 145) with nominal thickness of 3 mm, 4 mm, 5 mm, and 6mm
Spacer Type	Stainless steel spacer with PIB primary seal and silicone secondary seal.
Glazing Method	PVC U-channel.
Dividers	Aluminum grille pattern, painted white. See drawing in Section 9.3.7 for dimensions. The manufacturer provides standard 12” on center or less horizontal and vertical grid pattern for this product. Based on the drawings and the glazing cavity thickness, the dividers do not need to be modeled because the gap between the divider and the glass is greater than 3.0 mm (0.118”).
Cross Sections	See Section 9.3.7 for drawings of this product.

9.3.2. Glazing Matrix

The following table shows the glazing matrix that is to be simulated for this window. However, for this example, only Glazing Option 1 will be modeled using CIG glass.

Table 9-8. Matrix of glazing options for the aluminum horizontal slider.

	Glazing Options 25.4 mm (1.0”) overall thickness	**Grid Option**	**Manufacturer**
1	Clear (3mm), Argon (95%), Low-E (3mm)	Not modeled*	CIG
2	Clear (4mm), Argon (95%), Low-E (4mm)	Not modeled*	CIG
3	Clear (5mm), Argon (95%), Low-E (5mm)	Not modeled*	CIG
4	Clear (6mm), Argon (95%), Low-E (6mm)	Not modeled*	CIG
5	Clear (3mm), Argon (95%), Low-E (3mm)	Not modeled*	PPG
6	Clear (4mm), Argon (95%), Low-E (4mm)	Not modeled*	PPG
7	Clear (5mm), Argon (95%), Low-E (5mm)	Not modeled*	PPG
8	Clear (6mm), Argon (95%), Low-E (6mm)	Not modeled*	PPG

9.3.3. Center-of-glazing Modeling (WINDOW)

In WINDOW, create the glazing systems needed for the Glazing Matrix in Section 9.3.2. The figure below shows the record for Glazing Option 1 in the Glazing System Library.

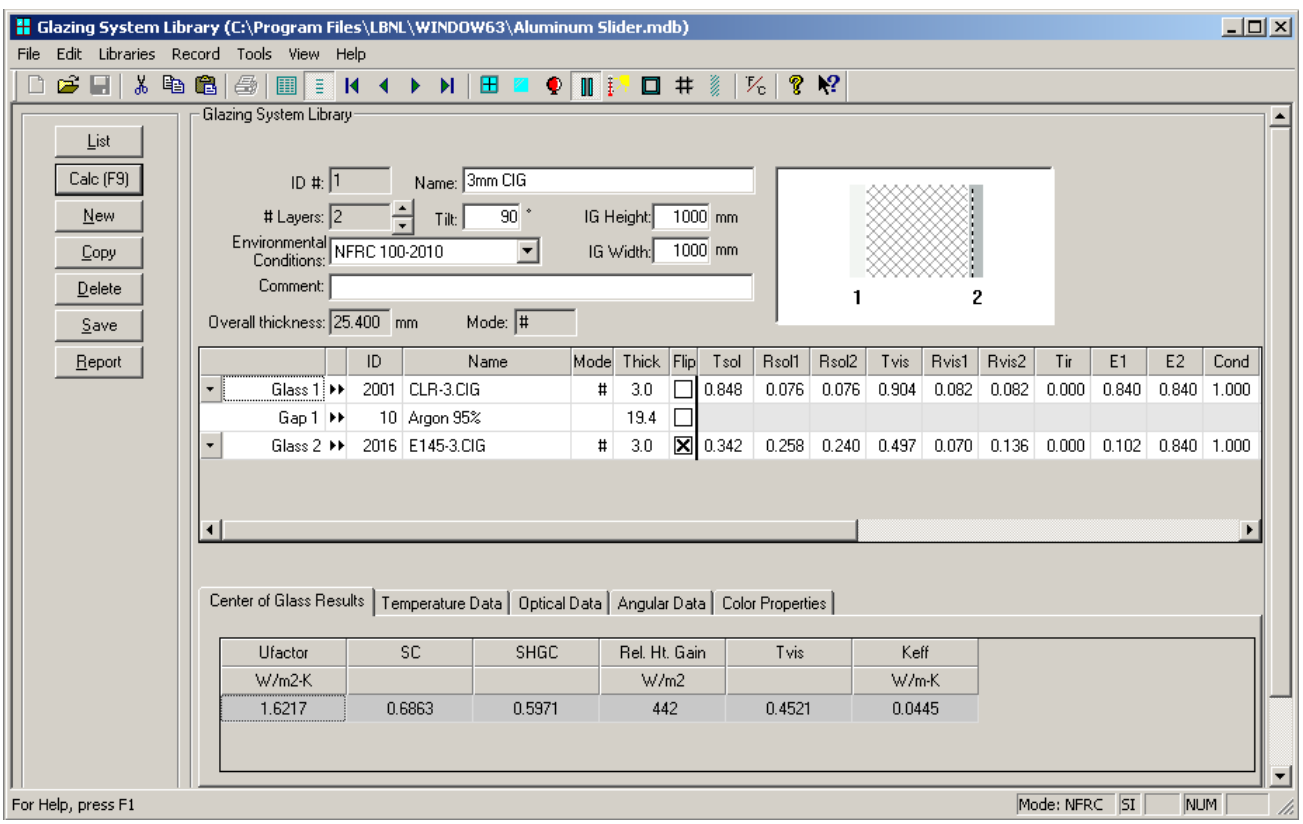


Figure 9-14. WINDOW Glazing System Library for Glazing Option 1 of the aluminum slider window.

The results for the center-of-glazing U-factor are shown in the following table:

Table 9-9. Center-of-glazing U-factor Results for Glazing Option 1 from WINDOW

Glazing Options 25.4 mm (1.0”) overall thickness		**Center-of-glazing U-Factor**	
		W/m^2-ºC	**BTU/hr-ft^2-ºF**
1	Clear (3mm), Argon (95%), Low-E (3mm)	1.6217	0.2856

These glazing systems will be used in THERM to calculate the frame and edge-of-glazing U-factors, and also in WINDOW to calculate the overall product U-factor.

9.3.4. Edge-of-glazing and Frame Modeling (THERM)

There are seven cross-sections that must be modeled for this product, listed in the table below.

Table 9-10. Cross sections and files associated with the aluminum horizontal slider example.

Cross Section	**DXF Filename**	**THERM Filename**
Sill Vent	Aluminum–Sill Vent.dxf	SV_01.thm
Sill Fixed	Aluminum–Sill Fixed.dxf	SF_01.thm
Head Vent	Aluminum–Head Vent.dxf	HV_01.thm
Head Fixed	Aluminum–Head Fixed.dxf	HF_01.thm
Jamb Vent	Aluminum–Jamb Vent.dxf	JV_01.thm
Jamb Fixed	Aluminum–Jamb Fixed.dxf	JF_01.thm
Meeting Rail	Aluminum–Meeting Rail.dxf	MR_01.thm

Note: The sample THERM files for this example were modeled with Glazing Option 1 only. Spacer geometry must be altered to accommodate the remaining glazing options.

Create THERM files for each cross section. The DXF files were not generated in a manner that would facilitate the use of the AutoConvert function in THERM, but the underlay can be used to trace the cross sections (see Chapter 5 “Drawing Cross Section Geometry” in the THERM User’s Manual).

Table 9-11 shows the resulting U-factors for the vinyl frame and divider cross sections.

Table 9-11. THERM results for the vinyl window cross sections.

	Frame U-Factor		**Edge U-Factor**	
Cross Section	**W/m^2-^{o}C**	**Btu/hr-ft^2-^{o}F**	**W/m^2-^{o}C**	**Btu/hr-ft^2-^{o}F**
Sill Vent	6.0714	1.0692	2.1744	0.3829
Sill Fixed	8.8507	1.5587	2.0555	0.3620
Head Vent	5.1152	0.9008	2.1201	0.3734
Head Fixed	7.1510	1.2594	2.0810	0.3665
Jamb Vent	5.3240	0.9376	2.1173	0.3729
Jamb Fixed	8.0264	1.4135	2.0708	0.3647
Meeting Rail	7.0598	1.2433	2.0251	0.3566

The figures on the following pages show THERM file cross sections and U-factor results for this window.

Sill Vent

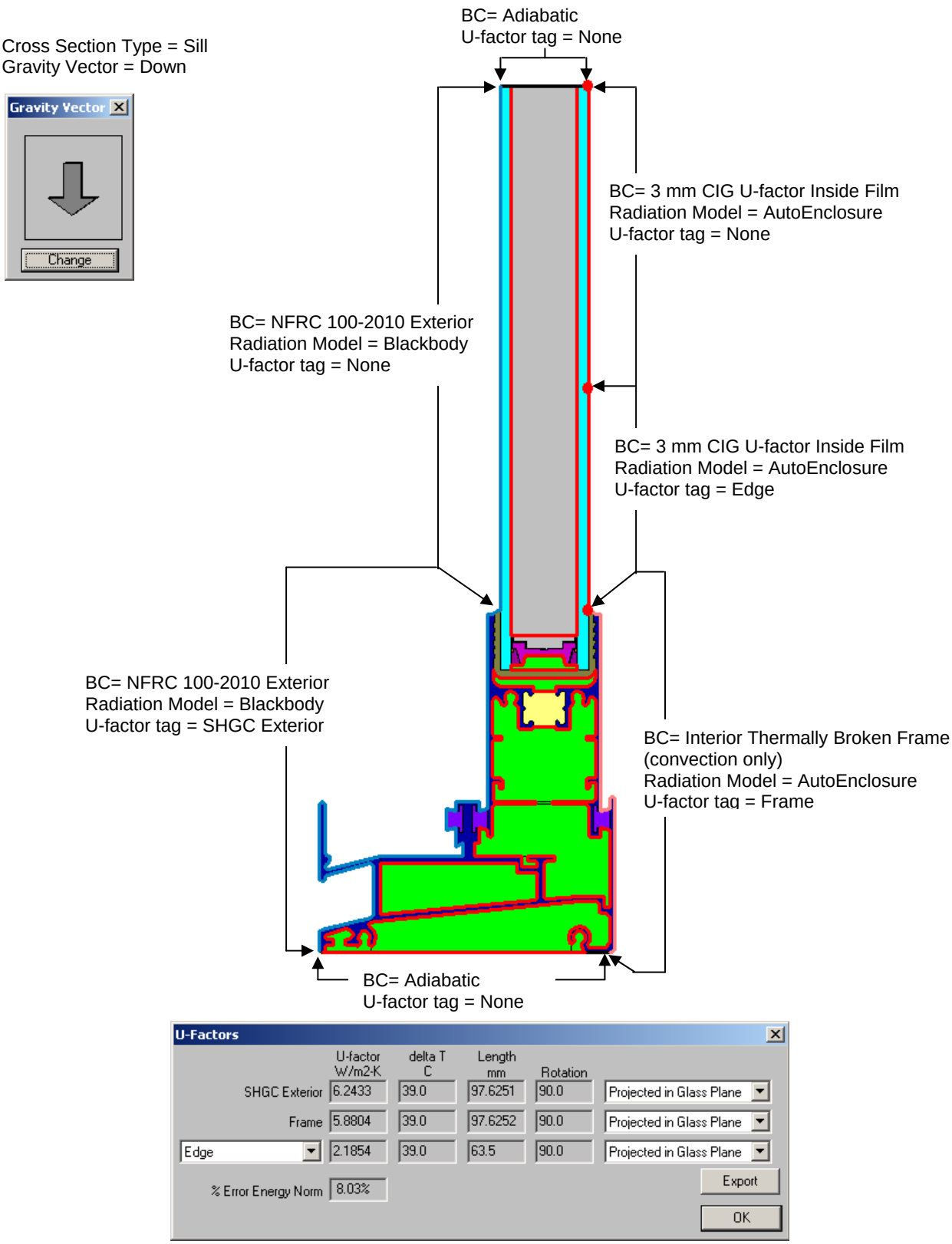


Figure 9-15. THERM cross section and U-factor results for sill vent cross section.

Sill Fixed

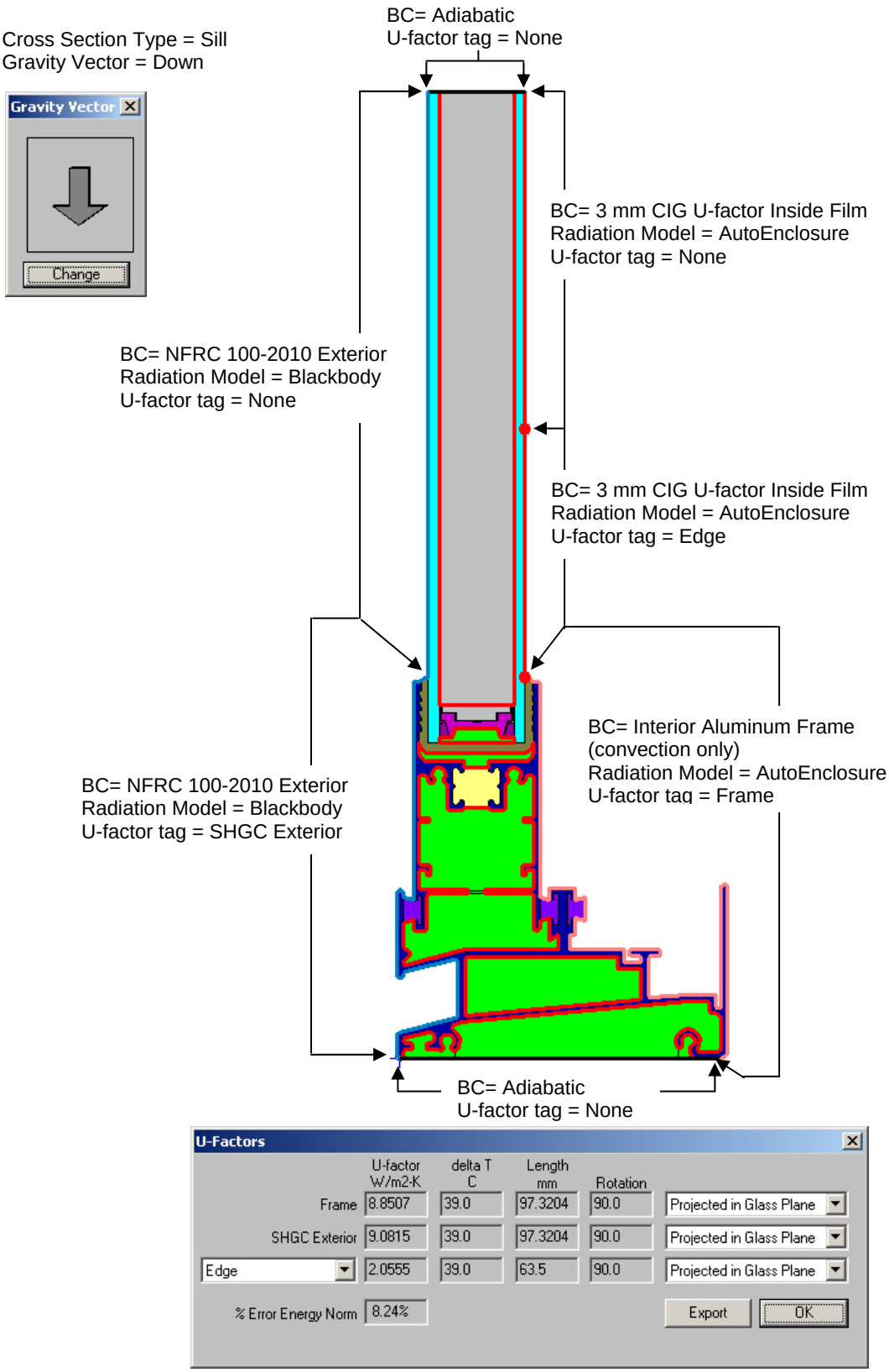


Figure 9-16. THERM cross section and U-factor results for the sill fixed cross section.

Jamb Vent

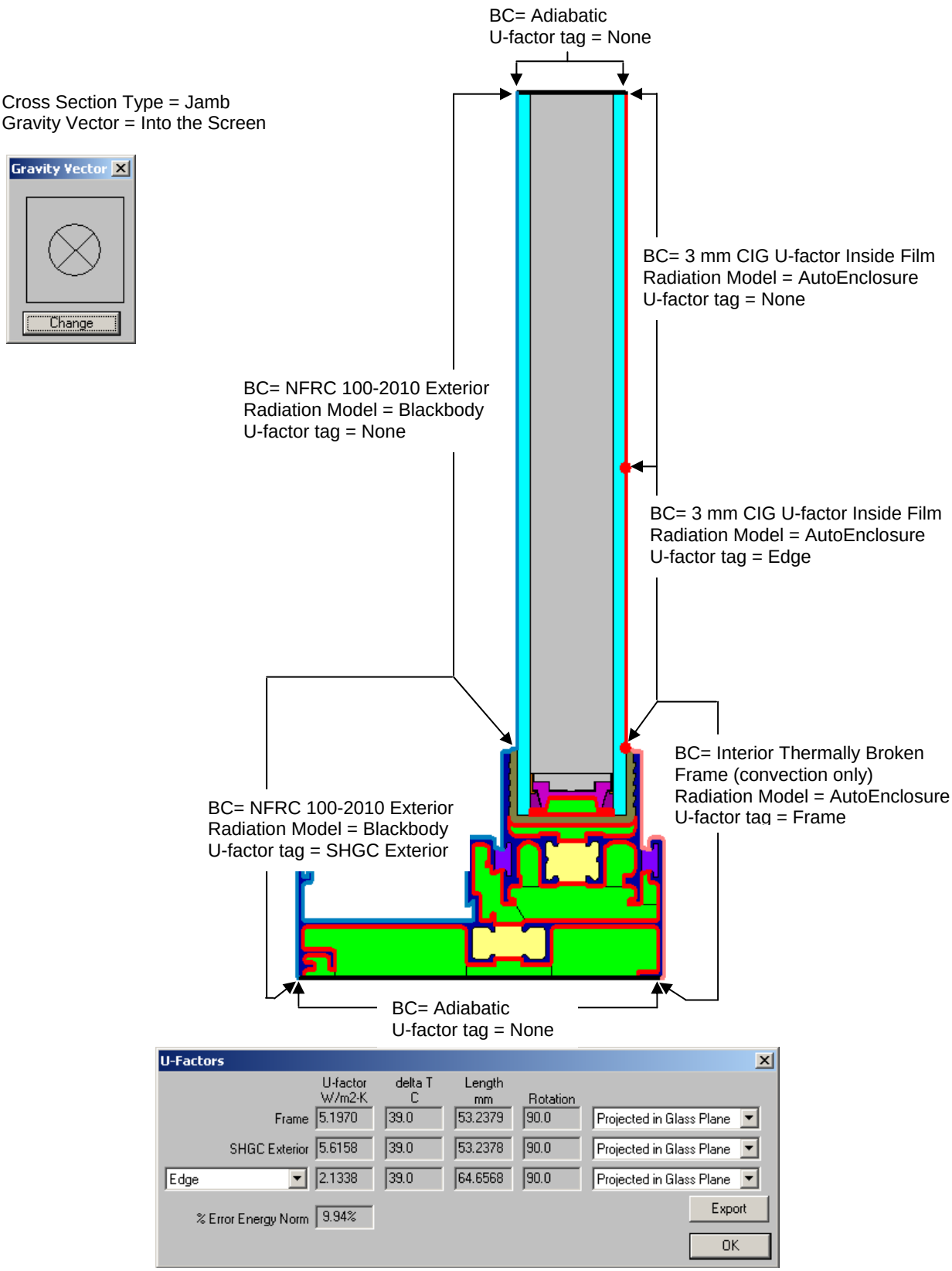


Figure 9-17. THERM cross section and U-factor results for the jamb vent cross section.

Jamb Fixed

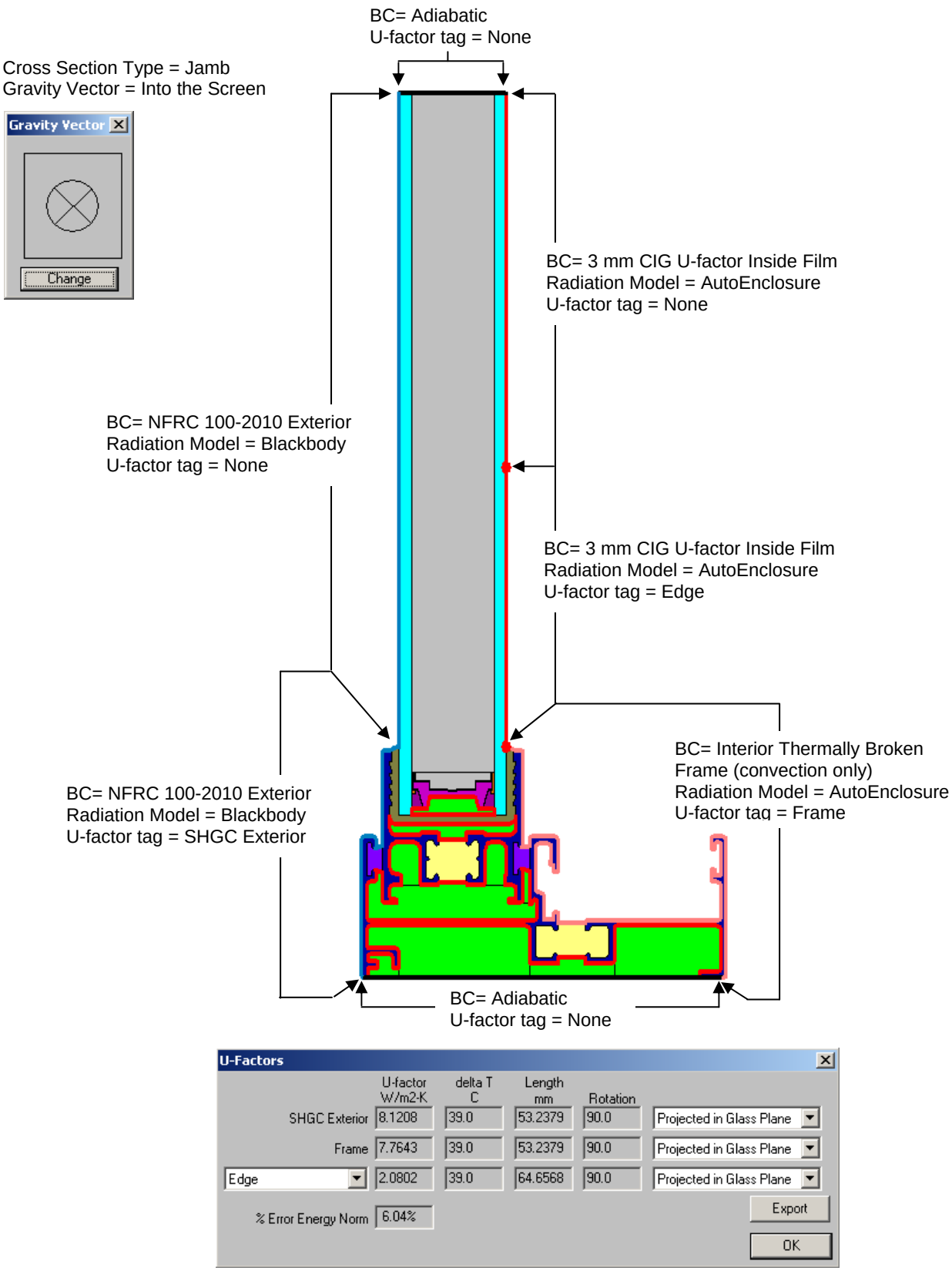


Figure 9-18. THERM cross section and U-factor results for jamb fixed cross section.

Head Vent

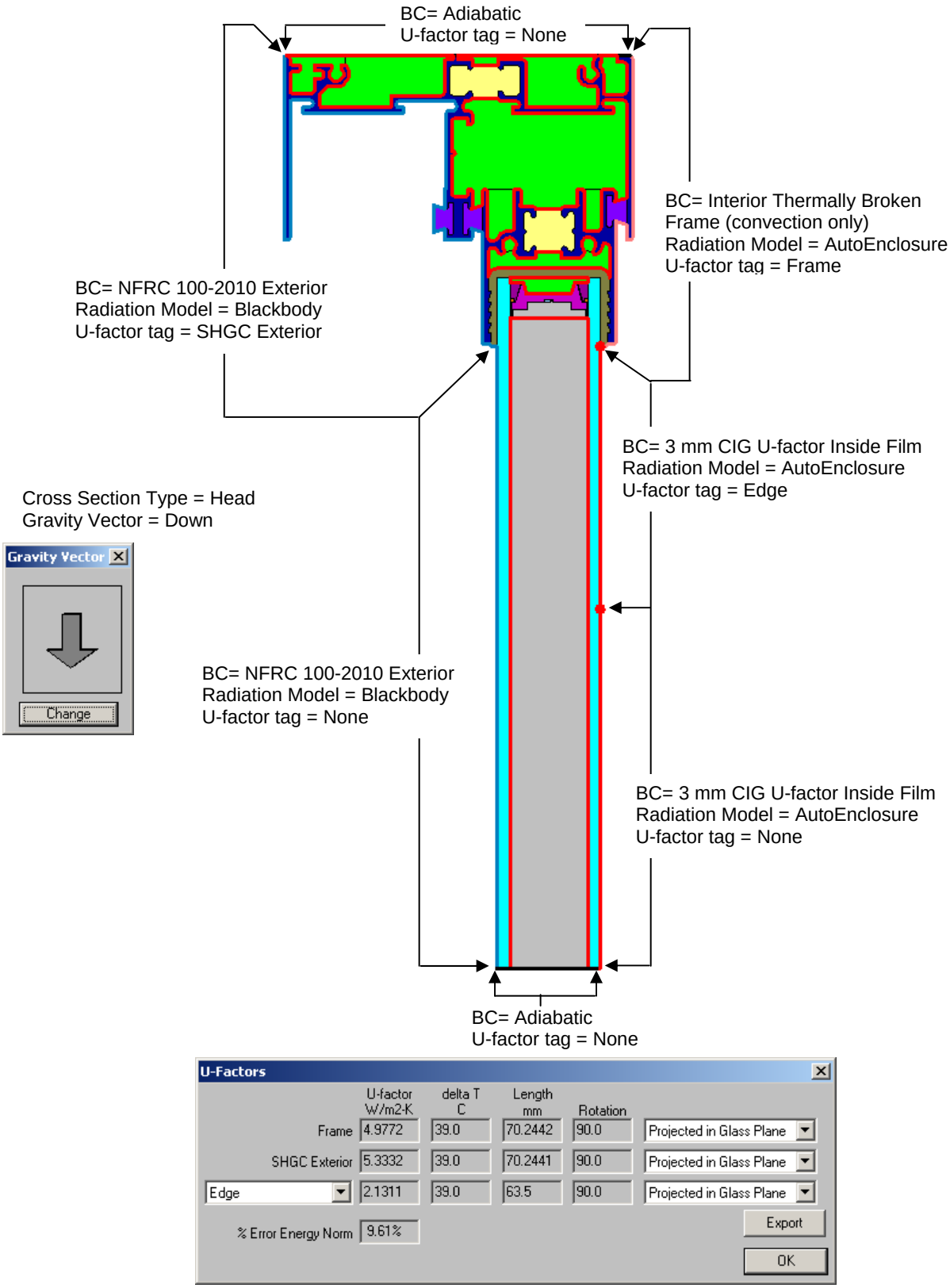


Figure 9-19. THERM cross section and U-factor results for head vent cross section.

Head Fixed

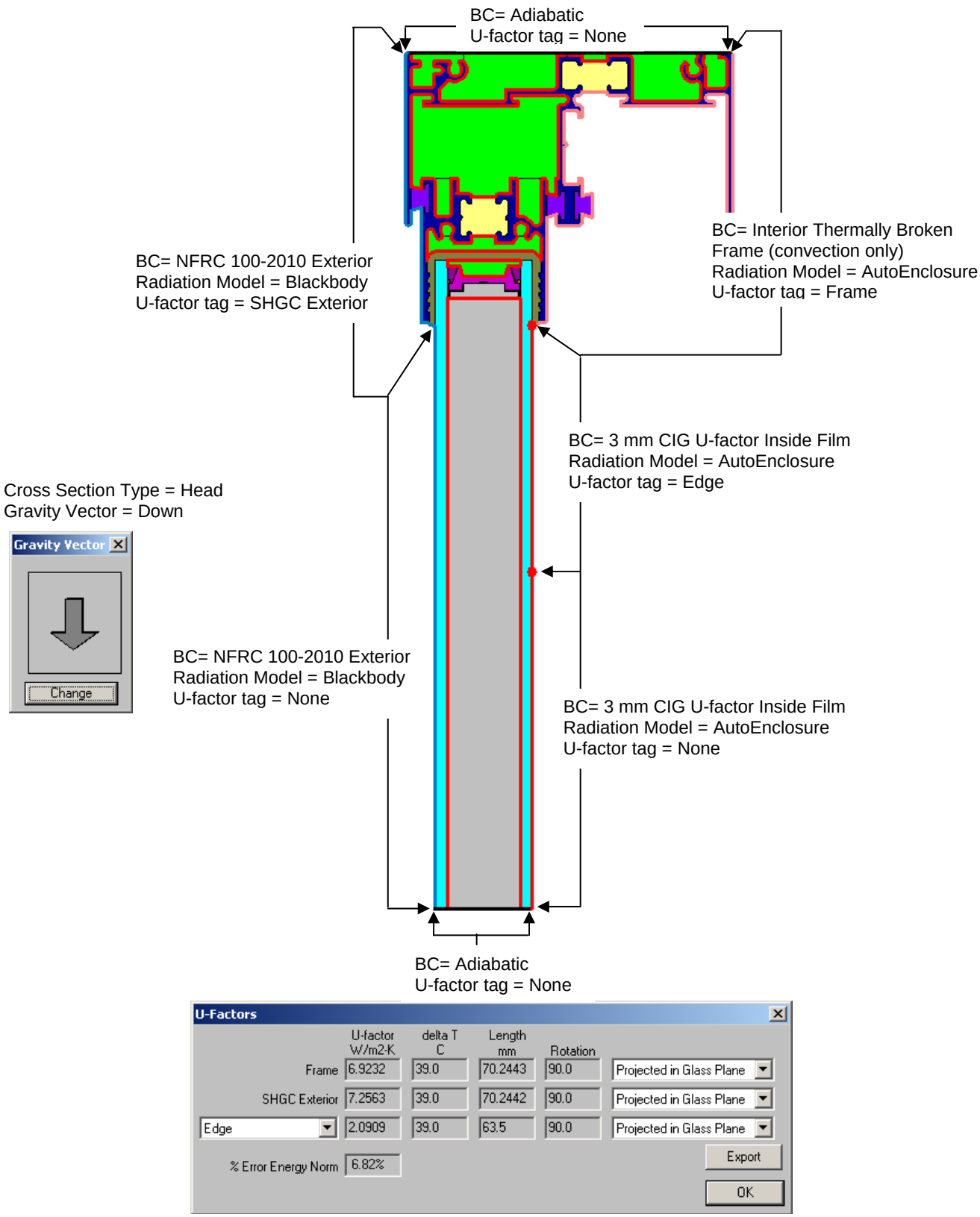


Figure 9-20. THERM cross section and U-factor results for Head Fixed Cross Section.

Meeting Rail

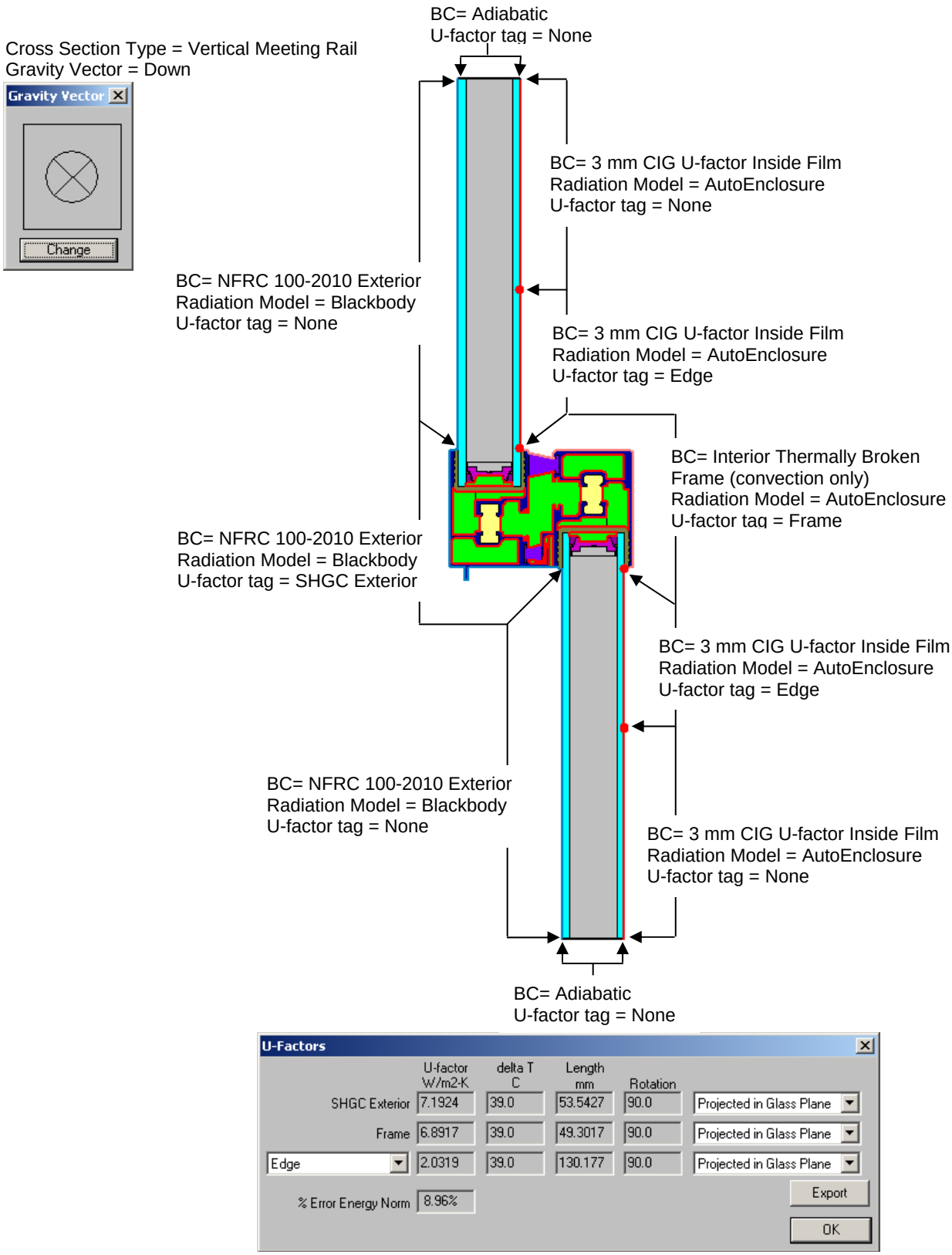
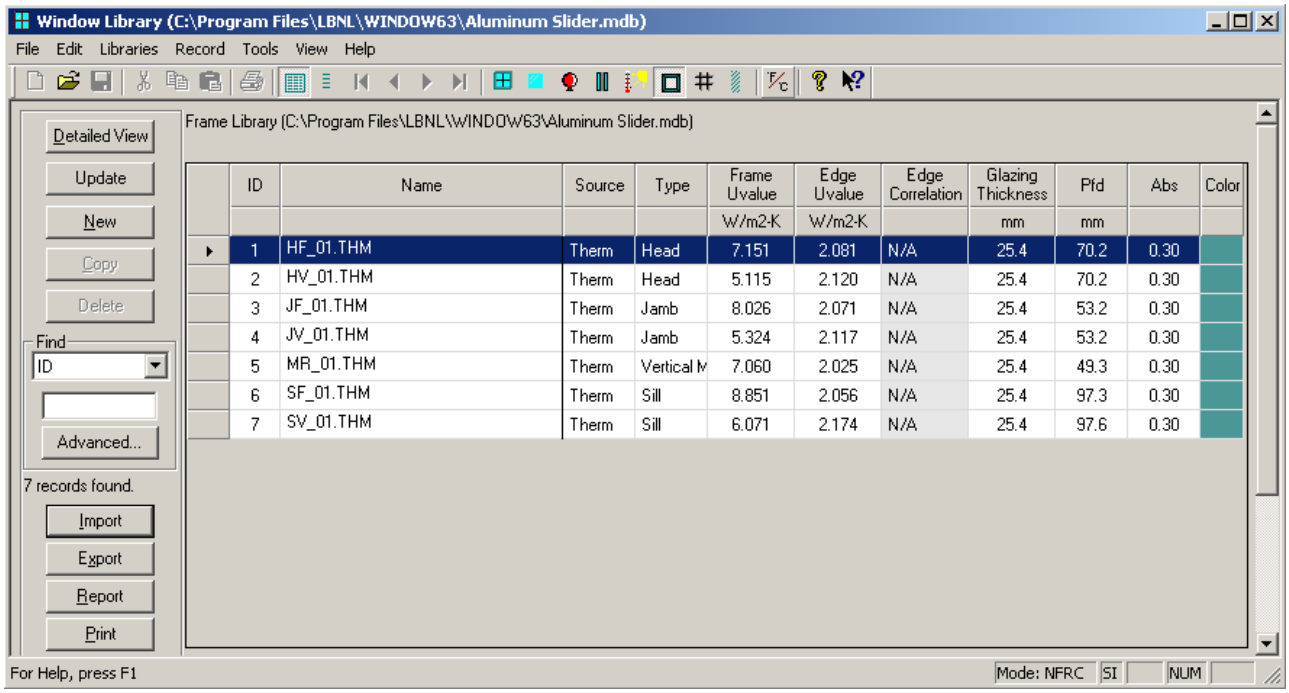


Figure 9-21. THERM cross section and U-factor results for Meeting Rail Cross Section.

9.3.5. Total Product U-Factor

In WINDOW, import the THERM cross sections into the Frame Library.



	ID	Name	Source	Type	Frame Uvalue	Edge Uvalue	Edge Correlation	Glazing Thickness	Pfd	Abs	Color
					W/m2-K	W/m2-K		mm	mm		
▸	1	HF_01.THM	Therm	Head	7.151	2.081	N/A	25.4	70.2	0.30	
	2	HV_01.THM	Therm	Head	5.115	2.120	N/A	25.4	70.2	0.30	
	3	JF_01.THM	Therm	Jamb	8.026	2.071	N/A	25.4	53.2	0.30	
	4	JV_01.THM	Therm	Jamb	5.324	2.117	N/A	25.4	53.2	0.30	
	5	MR_01.THM	Therm	Vertical M	7.060	2.025	N/A	25.4	49.3	0.30	
	6	SF_01.THM	Therm	Sill	8.851	2.056	N/A	25.4	97.3	0.30	
	7	SV_01.THM	Therm	Sill	6.071	2.174	N/A	25.4	97.6	0.30	

Figure 9-22. THERM files imported into the Frame Library.

In WINDOW, create a record in the Window Library using the appropriate THERM files from the Frame Library and glazing system from the Glazing System Library, as shown in the figure below.

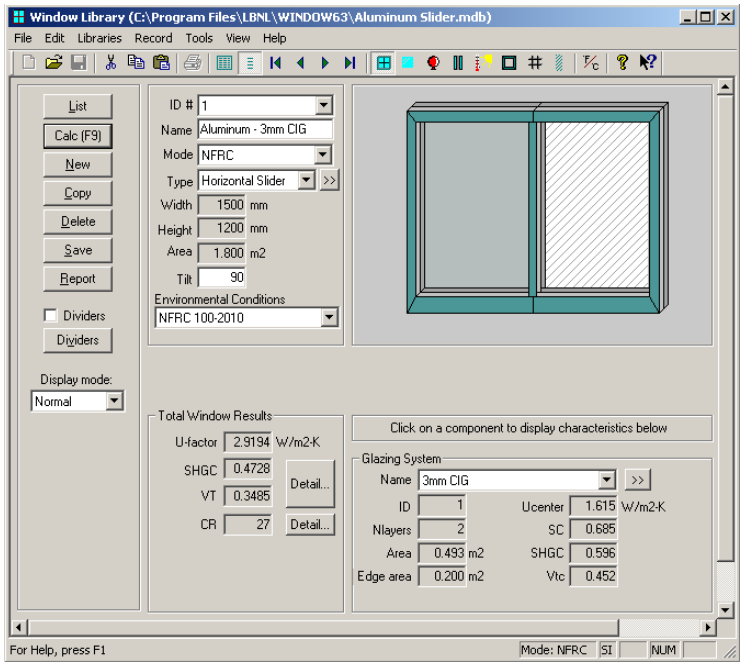


Figure 9-23. Window Library record for the aluminum horizontal slider.

The table below shows the overall product U-factor from WINDOW for Glazing Option 1.

Table 9-12. Total product U-factor.

Glazing Options 25.4 mm (1") overall thickness		Total Product U-Factor	
		W/m^2-°C	$Btu/hr\text{-}ft^2$-°F
1	Clear (3mm), Argon (95%), Low-E (3mm)	2.9194	0.5141

9.3.6. Individual Product SHGC and VT using SHGC 0 & 1 and VT 0 & 1

The methodology for determining the Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) for products is outlined in NFRC 200 using values of $SHGC_0$, $SHGC_1$, VT_0 and VT_1. These values are calculated in WINDOW for the best glazing option modeled with the highest frame and edge U-factor frame, as outlined in NFRC 200, Section 4.2.3 (A).

Since only Glazing Option 1 was modeled for this example, we will assume that it is the best glazing option for the purpose of determining SHGC and VT values.

Using this procedure, display the results for the $SHGC_0$, $SHGC_1$, VT_0 and VT_1 for the best glazing option (Clear, Air, Low-E), by clicking on the **Detail** button on the **Window Library Detailed View** screen, as shown in the figure below. The **SHGC and VT detail** dialog box will show the SHGC and VT values for the following three cases for this glazing option:

- No Dividers
- Dividers ≤ 25.4 mm (modeled as 19.5 mm)
- Dividers > 25.4 mm (modeled as 38.1 mm)

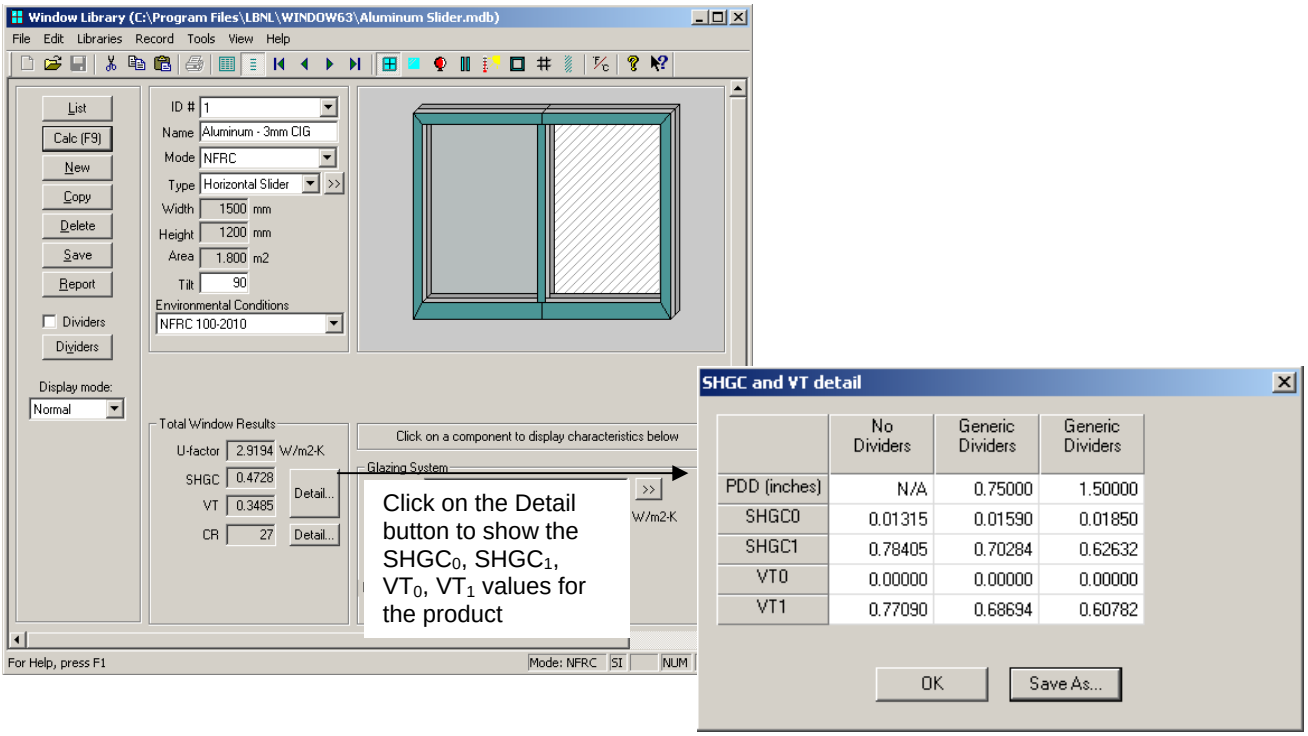


Figure 9-24. Window Library record for the best glazing option for the aluminum horizontal slider.

Table 9-13. $SHGC_0$, $SHGC_1$, VT_0 and VT_1 data for the best glazing option in this product line (Clear, Argon, Low-E)

	No Dividers	**Dividers < 1" (25.4 mm) (modeled at 0.75")**	**Dividers ≥ 1" (25.4 mm) (modeled at 1.5")**
$SHGC_0$	0.01315	0.01590	0.01850
$SHGC_1$	0.78405	0.70284	0.62632
VT_0	0.0	0.0	0.0
VT_1	0.77090	0.68694	0.60782

SHGC Calculation Using Equation 4-1 from NFRC 200

Using Equation 4-1 from NFRC 200 and the data from Table 9-11, calculate the whole product SHGC from the $SHGC_0$, $SHGC_1$, and $SHGC_C$:

$$SHGC = SHGC_0 + SHGC_C\ (SHGC_1 - SHGC_0)$$

Without Dividers:

SHGC = 0.01315 + 0.5971 (0.78405 – 0.01315)
= 0.4735

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

SHGC = 0.01590 + 0.5971 (0.70284 – 0.01590)
= 0.4261

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

SHGC = 0.01850 + 0.5971 (0.62632 – 0.01850)
= 0.3814

Table 9-14. Total product SHGC for the best glazing option (Clear, Argon, Low-E).

SHGC			
Glazing Option	**No Dividers**	**Dividers ≤ 25.4 mm, modeled at 19.5 mm (≤ 1.0", modeled at 0.75")**	**Dividers > 25.4 mm, modeled at 38.1 mm (> 1.5", modeled at 1.5")**
Clear, Argon, Low-E	0.4735	0.4261	0.3814

VT Calculation Using Equation 4-2 from NFRC 200

Using Equation 4-2 from NFRC 200 and the data from Table 9-11, calculate the whole product VT from the VT_0, VT_1, and VT_C:

$$VT = VT_0 + VT_C\ (VT_1 - VT_0)$$

Without Dividers:

VT = 0.0 + 0.4521 (0.77090 – 0.0)
= 0.3485

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

VT = 0.0 + 0.4521 (0.68694 – 0.0)

= 0.3106

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

VT = 0.0 + 0.4521 (0.60782 – 0.0)

= 0.2748

Table 9-15. Total product VT for the best glazing option (Clear, Argon, Low-E).

VT			
Glazing Option	**No Dividers**	**Dividers ≤ 25.4 mm, modeled at 19.5 mm (≤ 1.0", modeled at 0.75")**	**Dividers > 25.4 mm, modeled at 38.1 mm (> 1.5", modeled at 1.5")**
Clear, Argon, Low-E	0.6434	0.5771	0.5143

9.3.7. Drawings for Aluminum Horizontal Slider

The following pages contain detailed drawings for this window.

Sill Vent

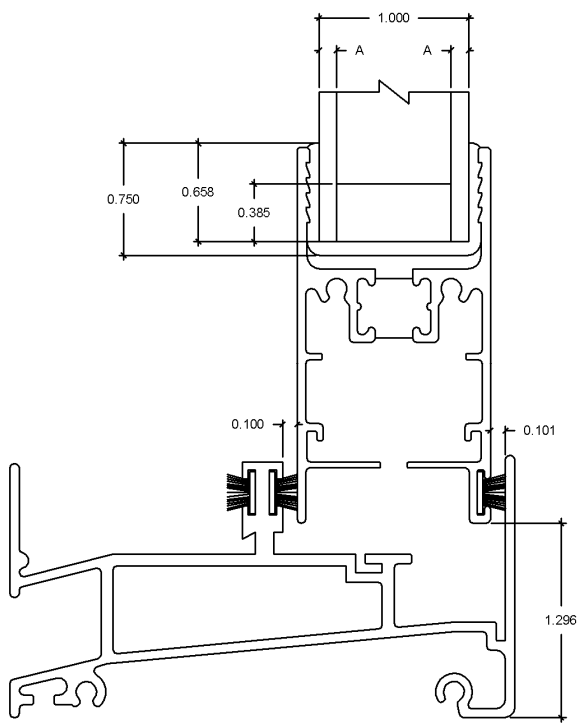


Figure 9-25. Dimensioned drawing for the sill vent cross section.

Sill Fixed

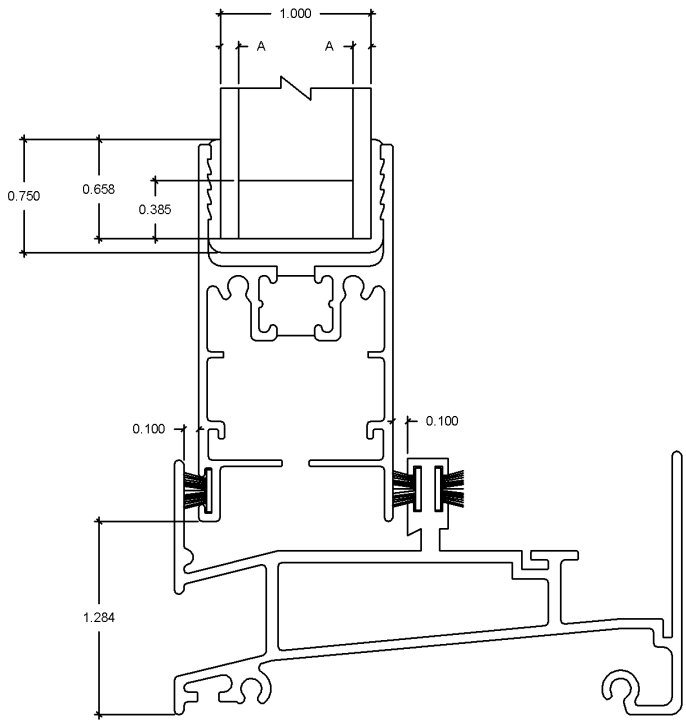


Figure 9-26. Dimensioned drawing for the sill fixed cross section.

Jamb Vent

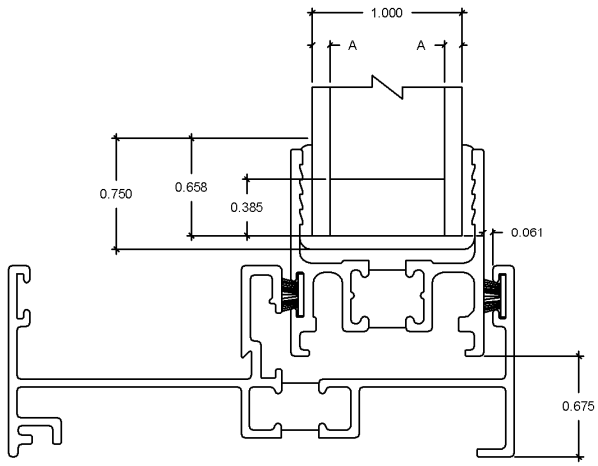


Figure 9-27. Dimensioned drawing for the jamb vent cross section.

Jamb Fixed

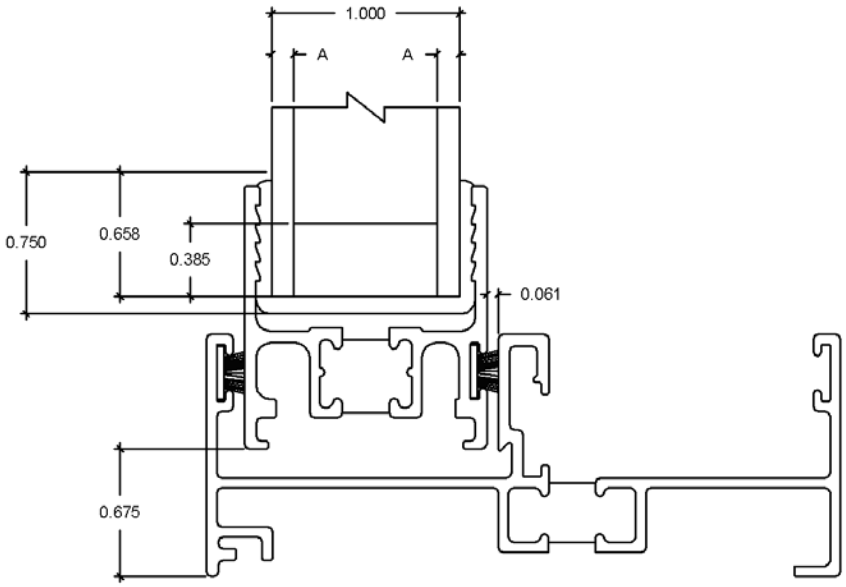


Figure 9-28. Dimensioned drawing for the jamb fixed cross section.

Head Vent

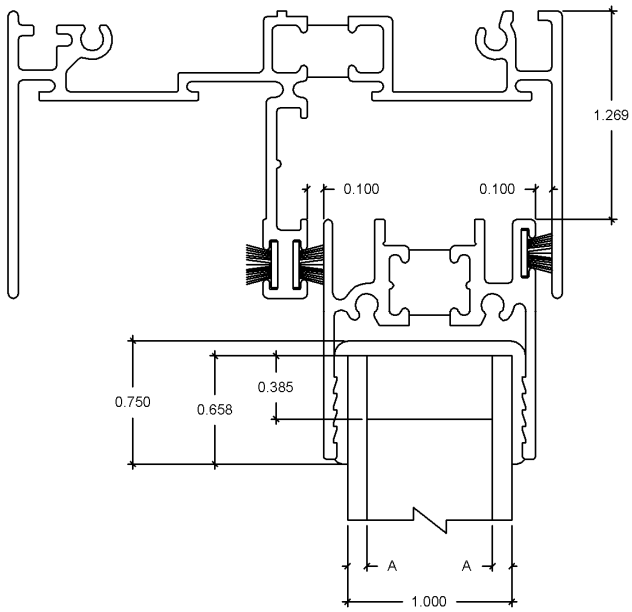


Figure 9-29. Dimensioned drawing for the head vent cross section.

Head Fixed

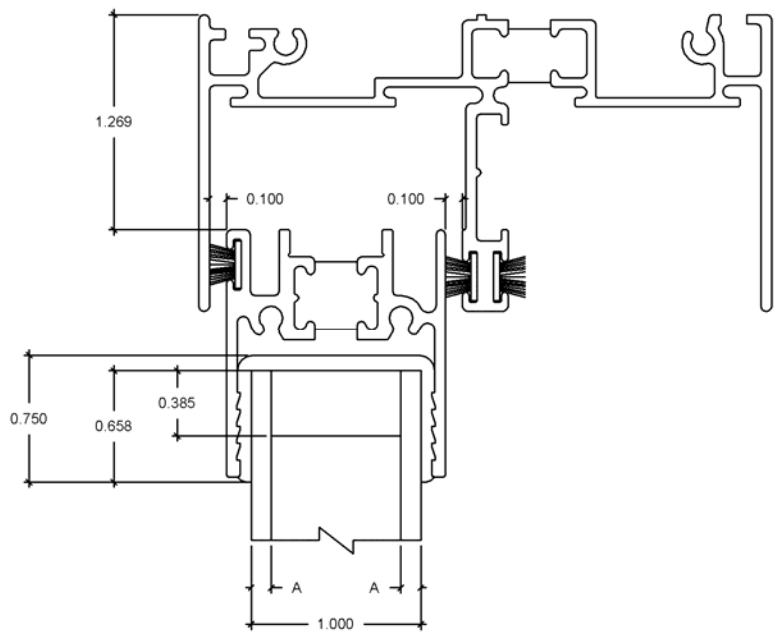


Figure 9-30. Dimensioned drawing for the head fixed cross section.

Meeting Rail

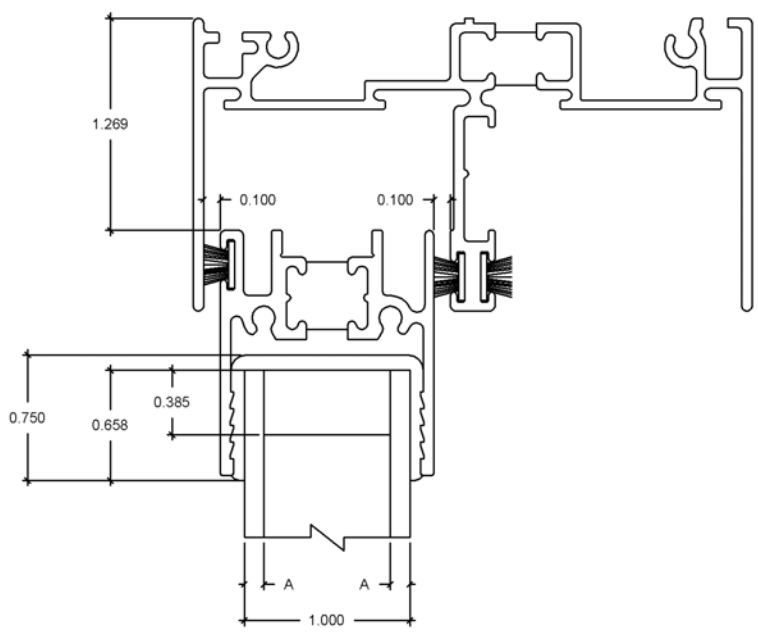


Figure 9-31. Dimensioned drawing for the meeting rail cross section.

Spacer

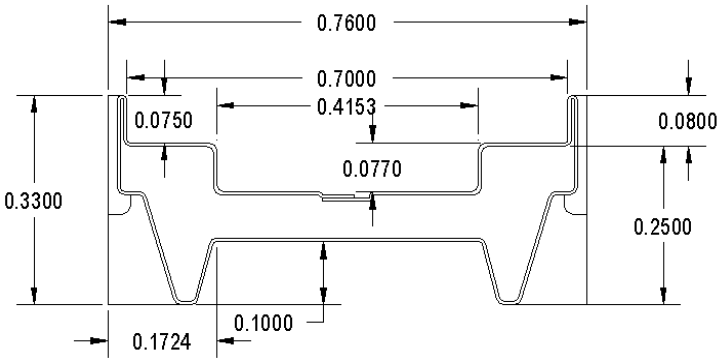


Figure 9-32. Dimensioned drawing for the spacer.

Divider

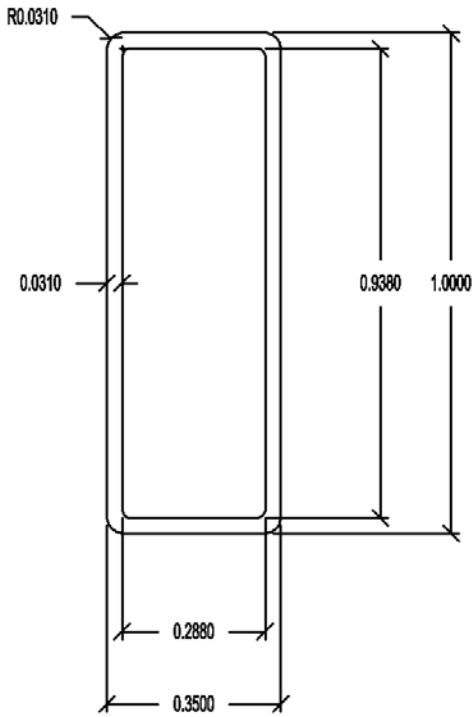


Figure 9-33. Dimensioned drawing for the divider.

9.4 Problem 3: Skylight

9.4.1. Description

Window Type	Skylight.
Overall Size	Width = 1200 mm; Height = 1200 mm
Frame Material	Wood.
Glazing System	Double glazing, 17.0 mm (0.669") overall I.G. thickness. Both the inboard and outboard lites are generic 3 mm clear glass. The glazing cavity is air filled.
Spacer Type	Aluminum folded spacer.
Glazing Method	Butyl rubber sealant.
Dividers	N/A
Cross Sections	See Section 9.4.7 for drawings of this product.

9.4.2. Glazing Matrix

The following table shows the glazing matrix that is to be simulated for the skylight.

Table 9-16. Matrix of glazing options for the skylight.

	Glazing Options 17 mm (0.669") overall thickness	**Grid Option**	**Manufacturer**
1	Clear (3mm), Air, Clear (3mm)	N/A	Generic

9.4.3. Center-of-glazing Modeling (WINDOW)

In WINDOW, create a record for the glazing system using generic 3 mm clear glass for both lites and a 10.9 mm (0.429”) air space (air filled). Make sure to set the “Tilt” to 20º.

The following figure shows the WINDOW Glazing System Library for this glazing system.

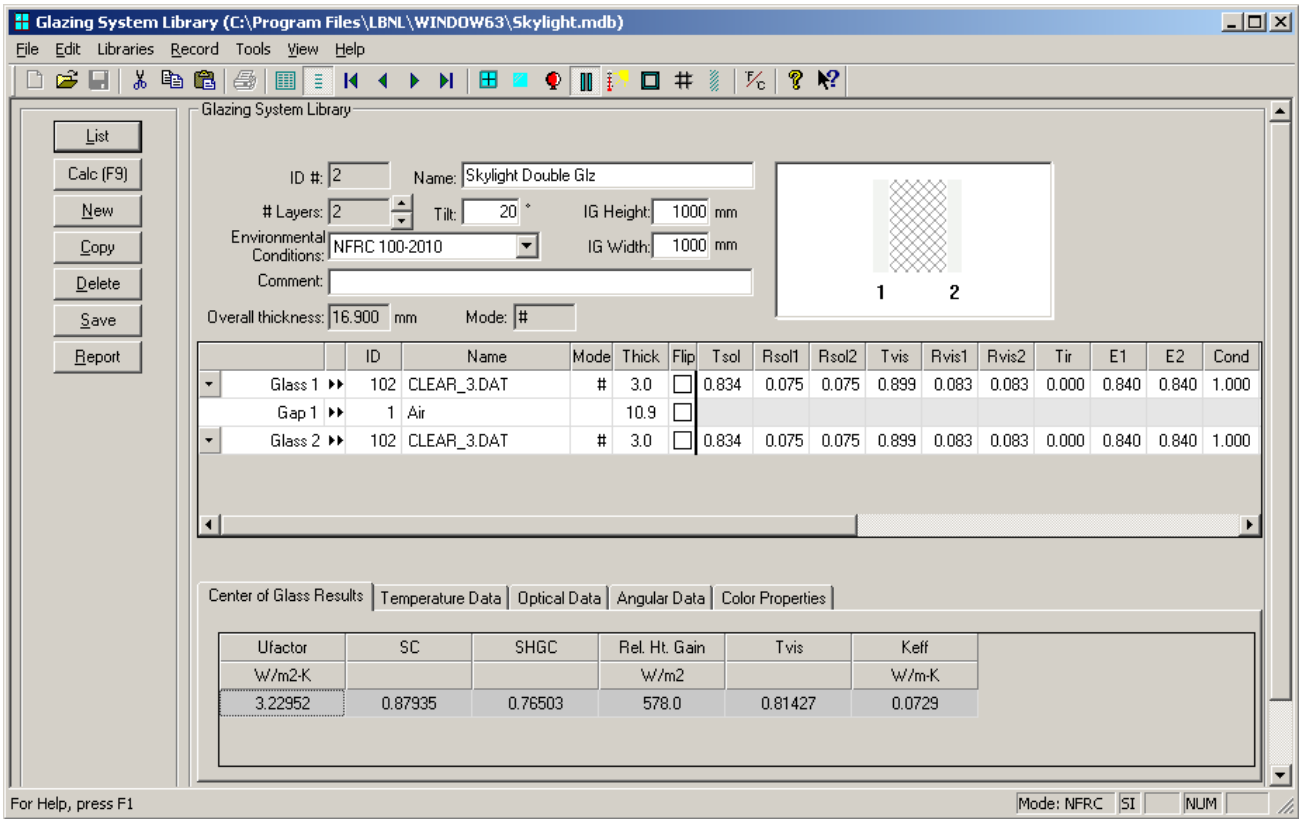


Figure 9-34. WINDOW Glazing System Library for the skylight.

The results for the center-of-glazing U-factor are shown in the following table.

Table 9-17. Center-of-glazing U-factor results from WINDOW

Glazing Options 17 mm (0.669”) overall thickness		**Center-of-glazing U-Factor**	
		W/m^2-ºC	**BTU/hr-ft^2-ºF**
1	Clear (3 mm), Air, Clear (3 mm)	3.22952	0.56875

This glazing system will be used in THERM to calculate the frame and edge-of-glazing U-factors, and also in WINDOW to calculate the overall product U-factor.

9.4.4. Edge-of-glazing and Frame Modeling (THERM)

Skylights are modeled in the same manner as other window products – with separate THERM files for the sill, head, jamb, and so forth. See Section 8-5 of this manual for detailed instructions on modeling skylights. For this example, we will assume that the skylight is flush-mounted.

The following table shows the files for this example.

Table 9-18. Files associated with the skylight example.

Cross Section	DXF Filename	THERM Filename
Sill	Skylight–Frame.dxf	SL.thm
Head	Skylight–Frame.dxf	HD.thm
Jamb	Skylight–Frame.dxf	JB.thm

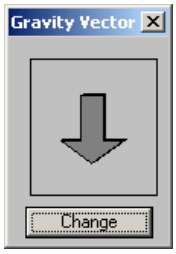
The table below shows the resulting U-factors for the skylight cross sections.

Table 9-19. THERM results for the skylight cross sections.

	Frame U-Factor		Edge U-Factor	
Cross Section	W/m^2-°C	Btu/hr-ft^2-°F	W/m^2-°C	Btu/hr-ft^2-°F
Sill	4.7604	0.8383	3.5507	0.6253
Head	4.7955	0.8445	3.5527	0.6257
Jamb	4.8084	0.8468	3.5455	0.6244

The figures on the following pages show the THERM cross sections and U-factor results for this window.

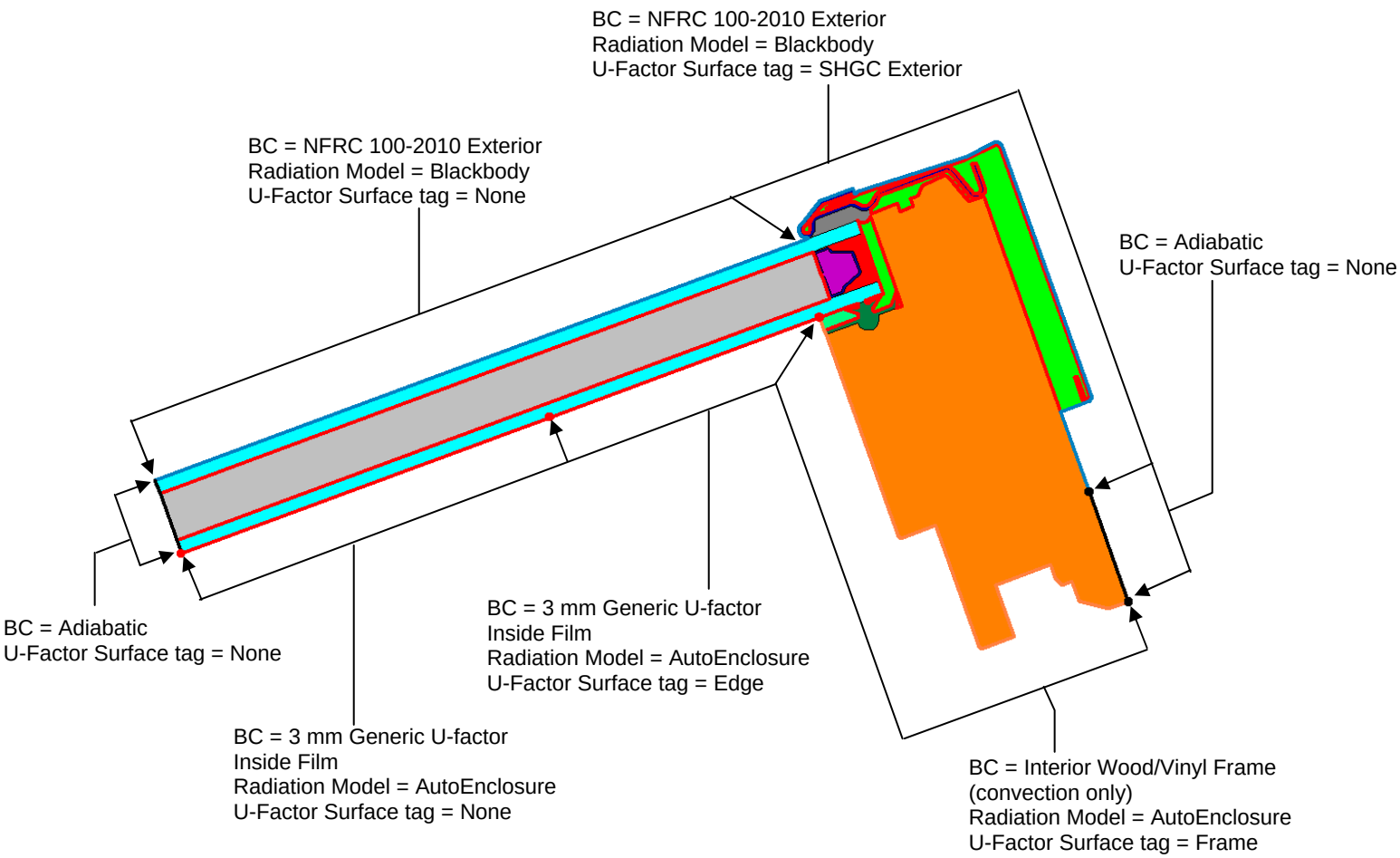
Head



Skylight Head

Modeling Assumptions:

- Cross Section Type = Head
- Gravity Arrow = Down
- Glazing System = Down
- File Rotation = 70° Clockwise



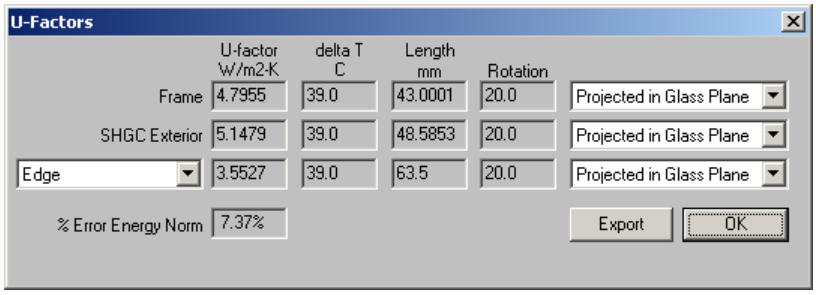
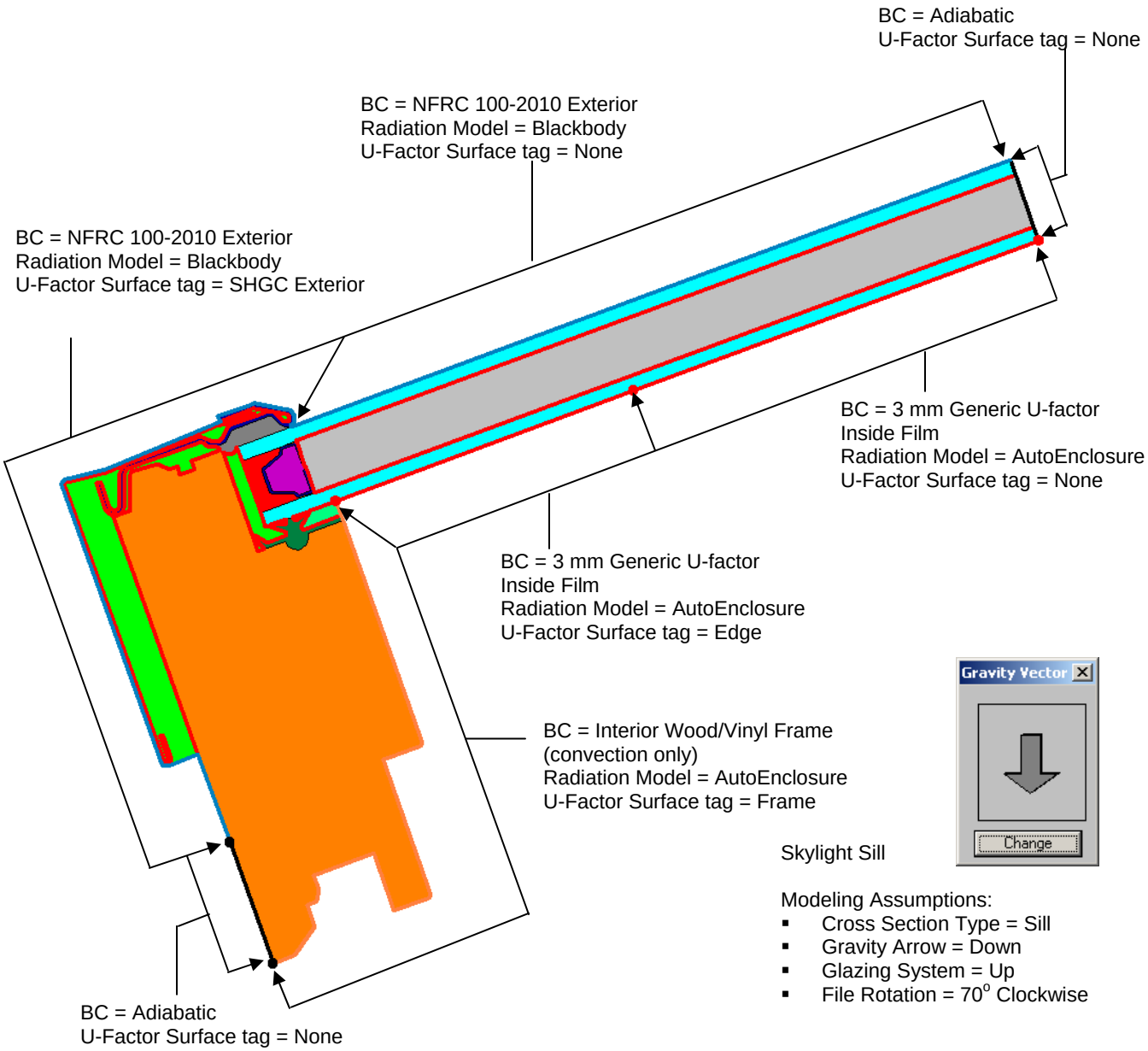


Figure 9-35. THERM cross section and U-factor results for the head cross section.

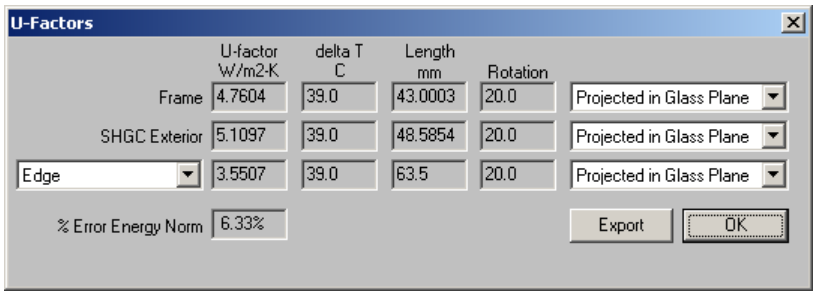
Sill



Skylight Sill

Modeling Assumptions:

- Cross Section Type = Sill
- Gravity Arrow = Down
- Glazing System = Up
- File Rotation = 70° Clockwise



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Frame	4.7604	39.0	43.0003	20.0	Projected in Glass Plane
SHGC Exterior	5.1097	39.0	48.5854	20.0	Projected in Glass Plane
Edge	3.5507	39.0	63.5	20.0	Projected in Glass Plane

% Error Energy Norm 6.33%

Export OK

Figure 9-36. THERM cross section and U-factor results for the sill cross section.

Jamb

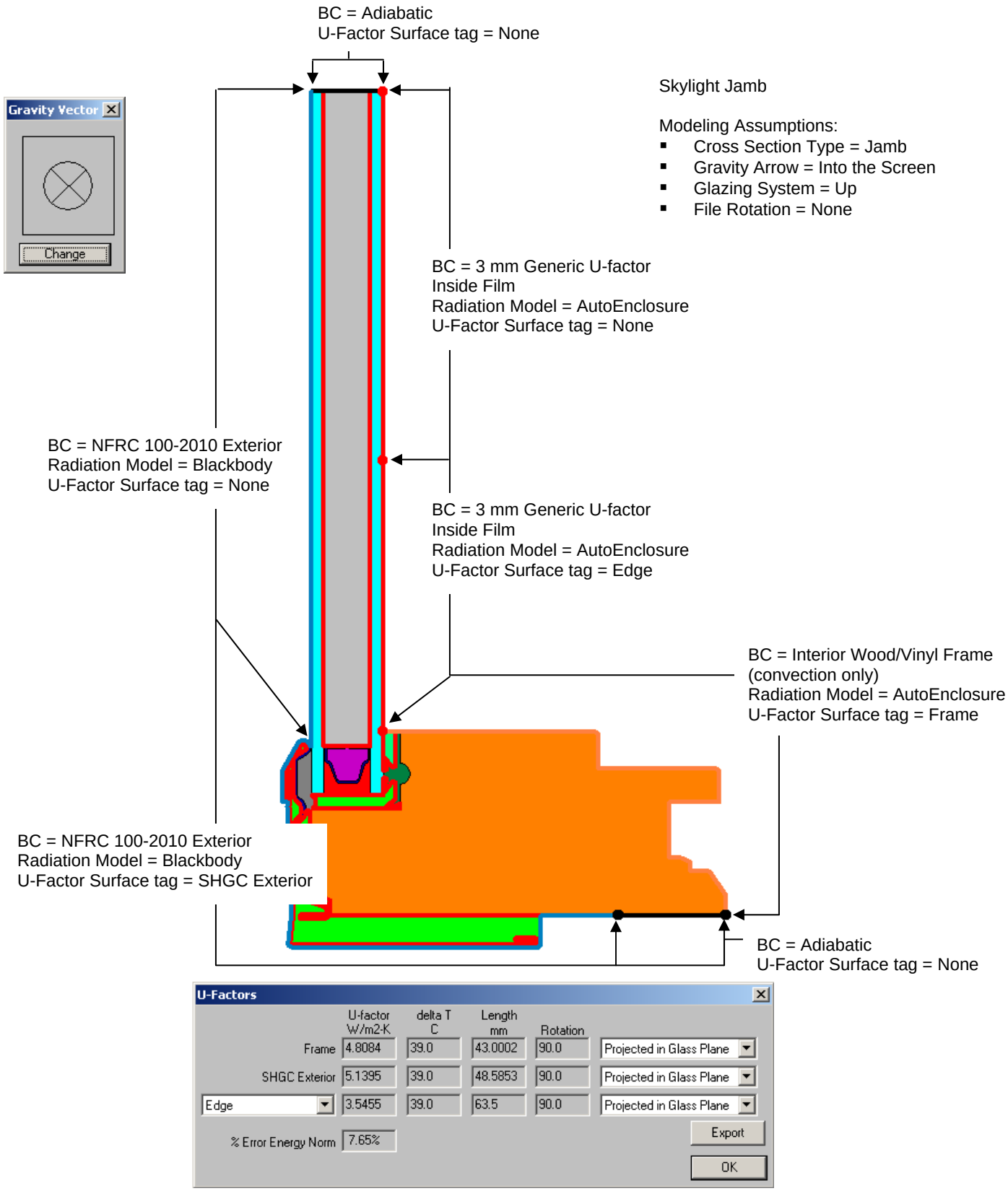


Figure 9-37. THERM cross section and U-factor results for the jamb cross section.

9.4.5. Total Product U-Factor

In WINDOW, import the THERM cross sections into the Frame Library.

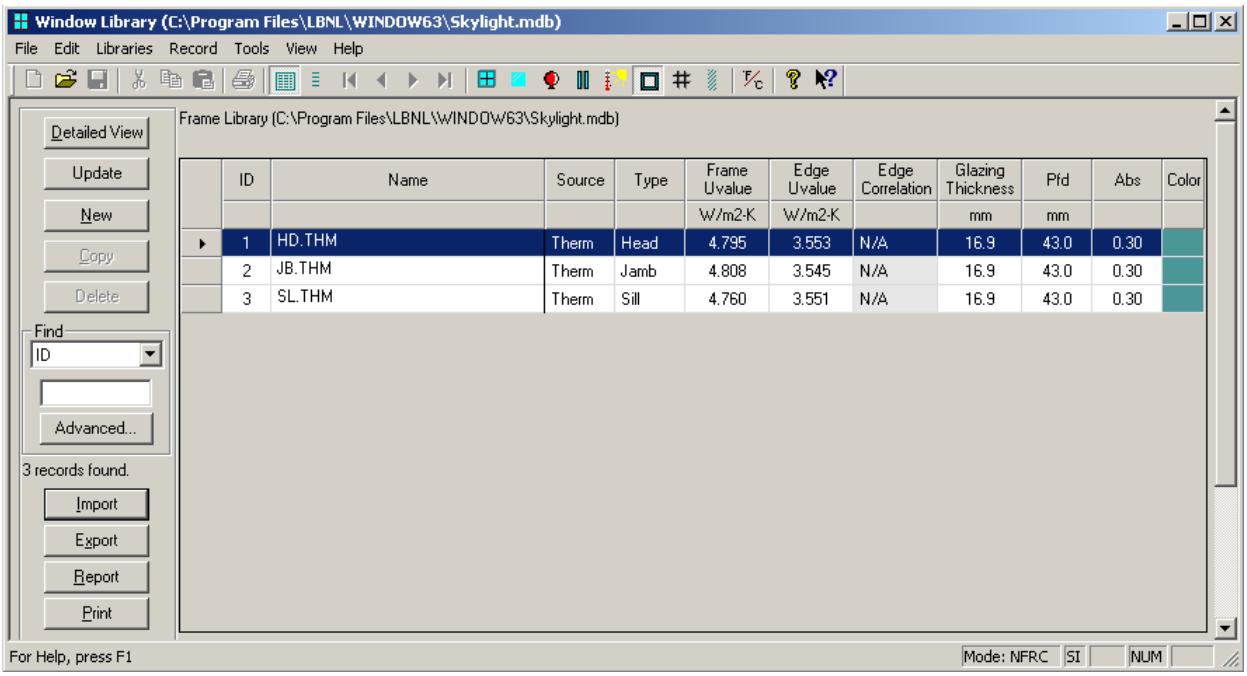


Figure 9-38. WINDOW Frame Library.

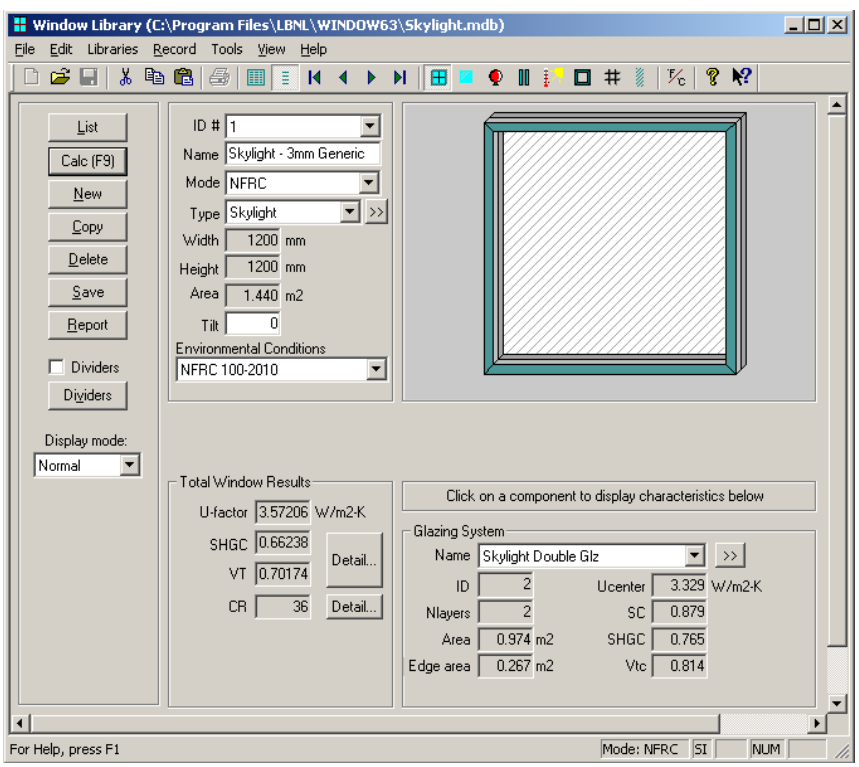


Figure 9-39. Window Library record for the skylight.

Table 9-20. Total product U-factors.

Glazing Options 17 mm (0.669”) overall thickness		Total Product U-Factor	
		W/m^2-°C	Btu/hr-ft^2-°F
1	Clear, Air, Clear	3.57206	0.62908

9.4.6. Individual Product SHGC and VT using SHGC 0 & 1 and VT 0 & 1

The methodology for determining the Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) for products is outlined in NFRC 200 using values of $SHGC_0$, $SHGC_1$, VT_0 and VT_1. These values are calculated in WINDOW for the best glazing option modeled with the highest frame and edge U-factor frame, as outlined in NFRC 200, Section 4.2.3 (A).

Display the results for the $SHGC_0$, $SHGC_1$, VT_0 and VT_1 for the best glazing option (Clear, Air, Clear), as shown in Figure 9-40.

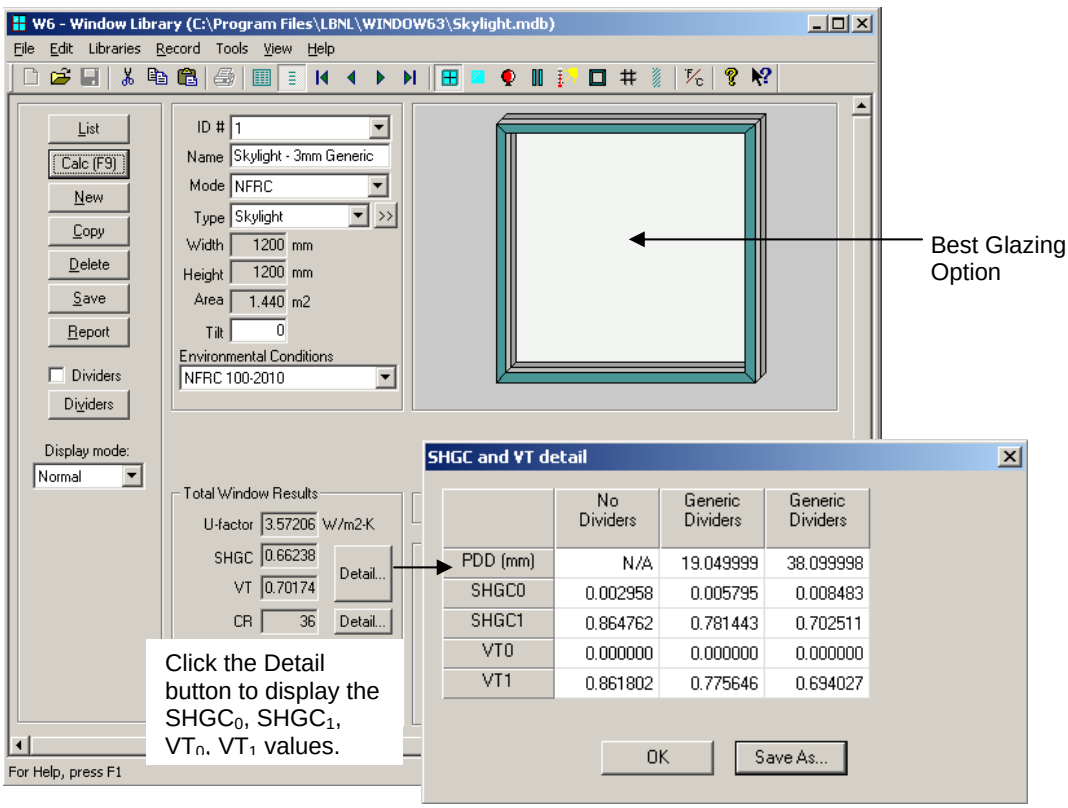


Figure 9-40. Window Library record for the best glazing option.

Table 9-21. $SHGC_0$, $SHGC_1$, VT_0 and VT_1 data for the best glazing option in this product line (Clear, Air, Clear)

	No Dividers	**Dividers < 1" (25.4 mm) (modeled at 0.75")**	**Dividers ≥ 1" (25.4 mm) (modeled at 1.5")**
$SHGC_0$	0.002958	0.005795	0.008483
$SHGC_1$	0.864762	0.781443	0.702511
VT_0	0.0	0.0	0.0
VT_1	0.861802	0.775647	0.694027

SHGC Calculation Using Equation 4-1 from NFRC 200

Using Equation 4-1 from NFRC 200 and the data from Table 9-21, calculate the whole product SHGC from the $SHGC_0$, $SHGC_1$, and $SHGC_C$:

$$SHGC = SHGC_0 + SHGC_C\ (SHGC_1 - SHGC_0)$$

Without Dividers:

SHGC = 0.002958 + 0.76504 (0.864762 – 0.002958)

= 0.66227

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

SHGC = 0.005795 +0.76504 (0.0.781443 – 0.005795)

= 0.59920

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

SHGC = 0.008483 + 0.76504 (0.702511 – 0.008490)

= 0.53944

Table 9-22. Total product SHGC for the best glazing option (Clear, Air, Clear).

SHGC			
Glazing Option	**No Dividers**	**Dividers < 1" (25.4 mm) (modeled at 0.75")**	**Dividers ≥ 1" (25.4 mm) (modeled at 1.5")**
Clear, Air, Clear	0.66227	0.59920	0.53944

VT Calculation Using Equation 4-2 from NFRC 200

Using Equation 4-2 from NFRC 200 and the data from Table 9-21, calculate the whole product VT from the VT_0, VT_1, and VT_C:

$$VT = VT_0 + VT_C (VT_1 - VT_0)$$

Without Dividers:

VT = 0.0 + 0.81427 (0.861802– 0.0)
= 0.7017

With Dividers < 1″ (25.4mm) – modeled at 0.75″:

VT = 0.0 + 0.81427 (0.775647– 0.0)
= 0.6316

With Dividers ≥ 1″ (25.4mm) modeled at 0.75″:

VT = 0.0 + 0.81427 (0.694027– 0.0)
= 0.5651

Table 9-23. Total product VT for the best glazing option (Clear, Air, Clear).

VT			
Glazing Option	**No Dividers**	**Dividers < 1” (25.4 mm) (modeled at 0.75”)**	**Dividers ≥ 1” (25.4 mm) (modeled at 1.5”)**
Clear, Air, Clear	0.7017	0.6316	0.5651

9.4.7. Skylight Drawings.

The following are detailed drawings for the skylight.

Head, Sill and Jamb

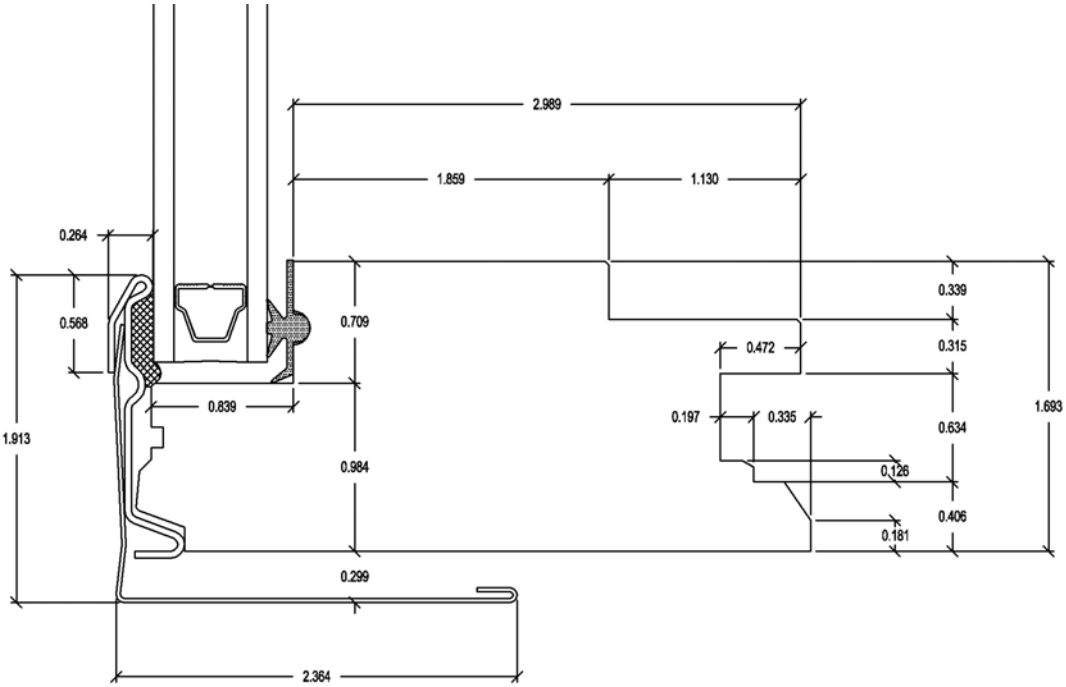


Figure 9-41. Dimensioned drawing for the frame.

Spacer

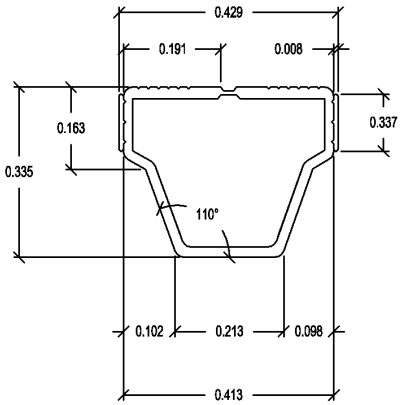


Figure 9-42. Dimensioned drawing for the spacer.

9.5 Problem 4: Door

For this wood stile and rail door, calculate the U-factor, SHGC and VT.

9.5.1. Description

Door Type	Wood stile-and-rail door.
Overall Size	Width = 1000 mm; Height = 2000 mm
Frame Material	Wood with a thermal-break aluminum sill.
Glazing System	Double glazing, 12.7 mm (0.5″) overall IG thickness. There are four glass options, all with two layers of 3 mm (0.129″) PPG glass.
Spacer Type	Intercept spacer with butyl sealant on three sides.
Glazing Tape	Wet glazed with silicone (on both sides).
Dividers	N/A
Cross Sections	See Section 9.5.7 for drawings of this product.

9.5.2. Glazing Matrix

The table below shows the glazing matrix that is to be simulated for the door.

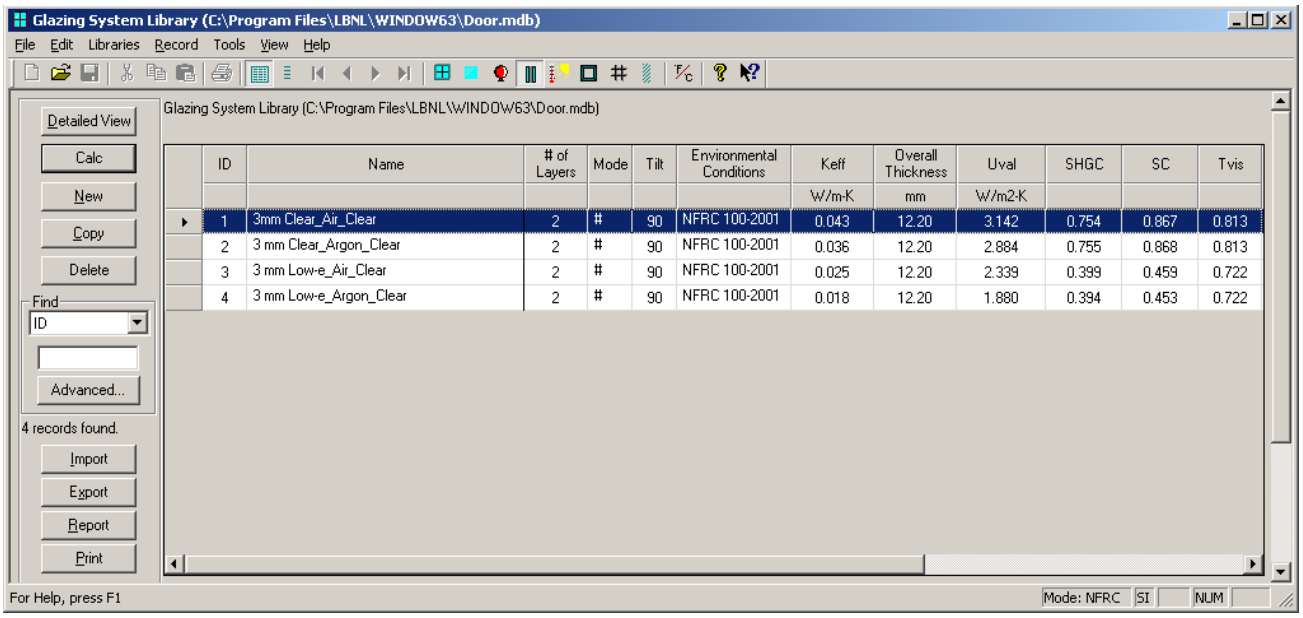
Table 9-24. Matrix of glazing options for the door.

	Glazing Options 12.7 mm (0.5”) overall thickness	**Grid Option**	**Manufacturer**
1	Clear (3mm), Air, Clear (3mm)	N/A	PPG
2	Clear (3mm), Argon (95%), Clear (3mm)	N/A	PPG
3	Low-E (3mm), Air, Clear (3mm)	N/A	PPG
4	Low-E (3mm), Argon (95%), Clear (3mm)	N/A	PPG

9.5.3. Center-of-Glazing Modeling (WINDOW)

In WINDOW, create four records for the glazing systems described in the glazing matrix.

The figure below shows the WINDOW Glazing System Library for this glazing system.



	ID	Name	# of Layers	Mode	Tilt	Environmental Conditions	Keff	Overall Thickness	Uval	SHGC	SC	Tvis
							W/m-K	mm	W/m2-K			
▸	1	3mm Clear_Air_Clear	2	#	90	NFRC 100-2001	0.043	12.20	3.142	0.754	0.867	0.813
	2	3 mm Clear_Argon_Clear	2	#	90	NFRC 100-2001	0.036	12.20	2.884	0.755	0.868	0.813
	3	3 mm Low-e_Air_Clear	2	#	90	NFRC 100-2001	0.025	12.20	2.339	0.399	0.459	0.722
	4	3 mm Low-e_Argon_Clear	2	#	90	NFRC 100-2001	0.018	12.20	1.880	0.394	0.453	0.722

Figure 9-43. WINDOW Glazing System Library for the door.

The results for the center-of-glazing U-factors are shown in Table 9-35.

Table 9-25. Center-of-glazing U-factor results from WINDOW.

Glazing Options 12.7 mm (0.5”) overall thickness		Center-of-glazing U-Factor	
		W/m^2-ºC	BTU/hr-ft^2-ºF
1	Clear (3mm), Air, Clear (3mm)	3.14238	0.55340
2	Clear (3mm), Argon (95%), Clear (3mm)	2.88406	0.50791
3	Low-E (3mm), Air, Clear (3mm)	2.33880	0.41189
4	Low-E (3mm), Argon (95%), Clear (3mm)	1.87978	0.33105

These U-factors will be used with the edge-of-glazing and frame values from THERM to calculate the overall U-factor for the door in Section 9.5.6 (note that four significant digits have been included as these values will be entered into a spreadsheet in order to calculate overall U-factors).

9.5.4. Edge-of-glazing and Frame Modeling for U-Factor (THERM)

There are a minimum of six and a maximum of ten cross sections that must be modeled for an entry door system:

- Head
- Lock Jamb
- Hinge Jamb
- Sill
- Panel Edge
- Panel Core
- Door Core
- Door Lite Head
- Door Lite Sill
- Door Lite Jamb

The door in this example has identical cross sections for both jambs, so only one jamb model will be required. The door core model has been added to the head model, and the panel core model has been added to the panel edge model.

Some simulations required additional lites to be modeled for each door lite cross section (head, sill and jamb) – one for each glass option. To generate the additional glazing options, a "base" file for each Door Lite cross section has been created using Glazing Option 1. As shown in Figure 9-44, add the remaining options in the Glazing System Options dialog box. When the base file is simulated, the additional door lite options will be automatically created.

Window5 does not recognize any U-factor surface tags other than "Edge", "Frame", or "None". If you import door THERM files into WINDOW with U-factor surface tags on the interior boundaries other than those values, the WINDOW fields will not be correct. If you intend to import these files into WINDOW use only the "Edge", "Frame", or "None" U-factor surface tags for the THERM file interior boundary surfaces. Because of this, as well as the fact that WINDOW can not area-weight the opaque portions of the door models, total product values must be manually calculated externally, by inputting the center-of-glazing results from WINDOW and the frame and edge results from THERM into a spreadsheet.

The table below shows the files for this example.

Table 9-26. Files associated with the door example.

Cross Section	DXF Filename	THERM Filename
Head	Door-Frame.dxf	HD.thm
Lock & Hinge Jambs	Door-Frame.dxf	JB.thm
Sill	Door-Sill.dxf	SL.thm
Panel Edge	Door-Panel Edge.dxf	PE.thm
Door Lite Sill Base Case	Door-Lite.dxf	LT-SL.thm
Door Lite Head Base Case	Door-Lite.dxf	LT-HD.thm
Door Lite Jamb Base Case	Door-Lite.dxf	LT-JB.thm
Door Lite Sill Option 1		LT-SL_001.thm
Door Lite Head Option 1		LT-HD_001.thm
Door Lite Jamb Option 1		LT-JB_001.thm
Door Lite Sill Option 2		LT-SL _002.thm
Door Lite Head Option 2		LT-HD_002.thm
Door Lite Jamb Option 2		LT-JB_002.thm
Door Lite Sill Option 3		LT-SL_003.thm
Door Lite Head Option 3		LT-HD_003.thm
Door Lite Jamb Option 3		LT-JB_003.thm
Door Lite Sill Option 4		LT-SL_004.thm
Door Lite Head Option 4		LT-HD_004.thm
Door Lite Jamb Option 4		LT-JB_004.thm

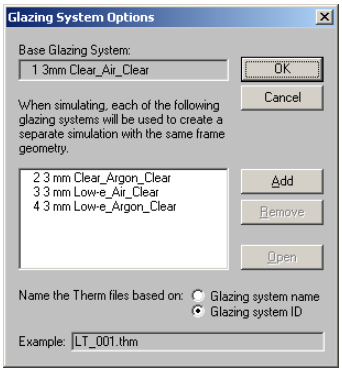


Figure 9-44. Glazing System Options for Lite.thm.

Table 9-27 shows the resulting U-factors for the door cross section.

Table 9-27. THERM results for the door cross sections.

	Frame U-Factor		Edge U-Factor	
Cross Section	**W/m^2-ºC**	**BTU/hr-ft^2-ºF**	**W/m^2-ºC**	**BTU/hr-ft^2-ºF**
Head	2.0449	0.3417	N/A	N/A
Jamb	1.9347	0.3407	N/A	N/A
Sill	2.3649	0.4165	N/A	N/A
Door Core (HD.thm)	2.0449	0.3601	N/A	N/A
Panel Edge	2.7580	0.4857	N/A	N/A
Panel Core (PE.thm)	2.5888	0.4559	N/A	N/A
Door Lite Sill Option 1	2.8372	0.4997	3.2705	0.5760
Door Lite Sill Option 2	2.8217	0.4969	3.0615	0.5392
Door Lite Sill Option 3	2.7911	0.4915	2.6284	0.4629
Door Lite Sill Option 4	2.7675	0.4874	2.2718	0.4001
Door Lite Head Option 1	2.8375	0.4997	3.2705	0.5760
Door Lite Head Option 2	0.8219	0.4970	3.0613	0.5391
Door Lite Head Option 3	2.7914	0.4916	2.6281	0.4628
Door Lite Head Option 4	2.7677	0.4874	2.2715	0.4000
Door Lite Jamb Option 1	2.8372	0.4997	3.2705	5760
Door Lite Jamb Option 2	2.8217	0.4969	3.0615	0.5392
Door Lite Jamb Option 3	2.7911	0.4915	2.6284	0.1629
Door Lite Jamb Option 4	2.7675	0.4874	2.2718	0.4001

The following table shows the dimensions of the frame and edge portions of each cross section. These dimensions will be used later to determine total product U-factors.

Table 9-28. Frame and Edge dimensions.

	Frame Height		Edge Height	
Cross Section	**mm**	**inch**	**mm**	**inch**
Head	22.225	0.875	63.500	2.500
Jamb	22.225	0.875	63.500	2.500
Sill	39.696	1.563	63.500	2.500
Door Core	N/A	N/A	N/A	N/A
Panel Edge	25.400	1.000	76.597	3.016
Panel Core	N/A	N/A	N/A	N/A
Door Lite	42.063	1.656	63.500	2.500

The figures on the following pages show the THERM cross sections and U-factor results for this window.

Sill

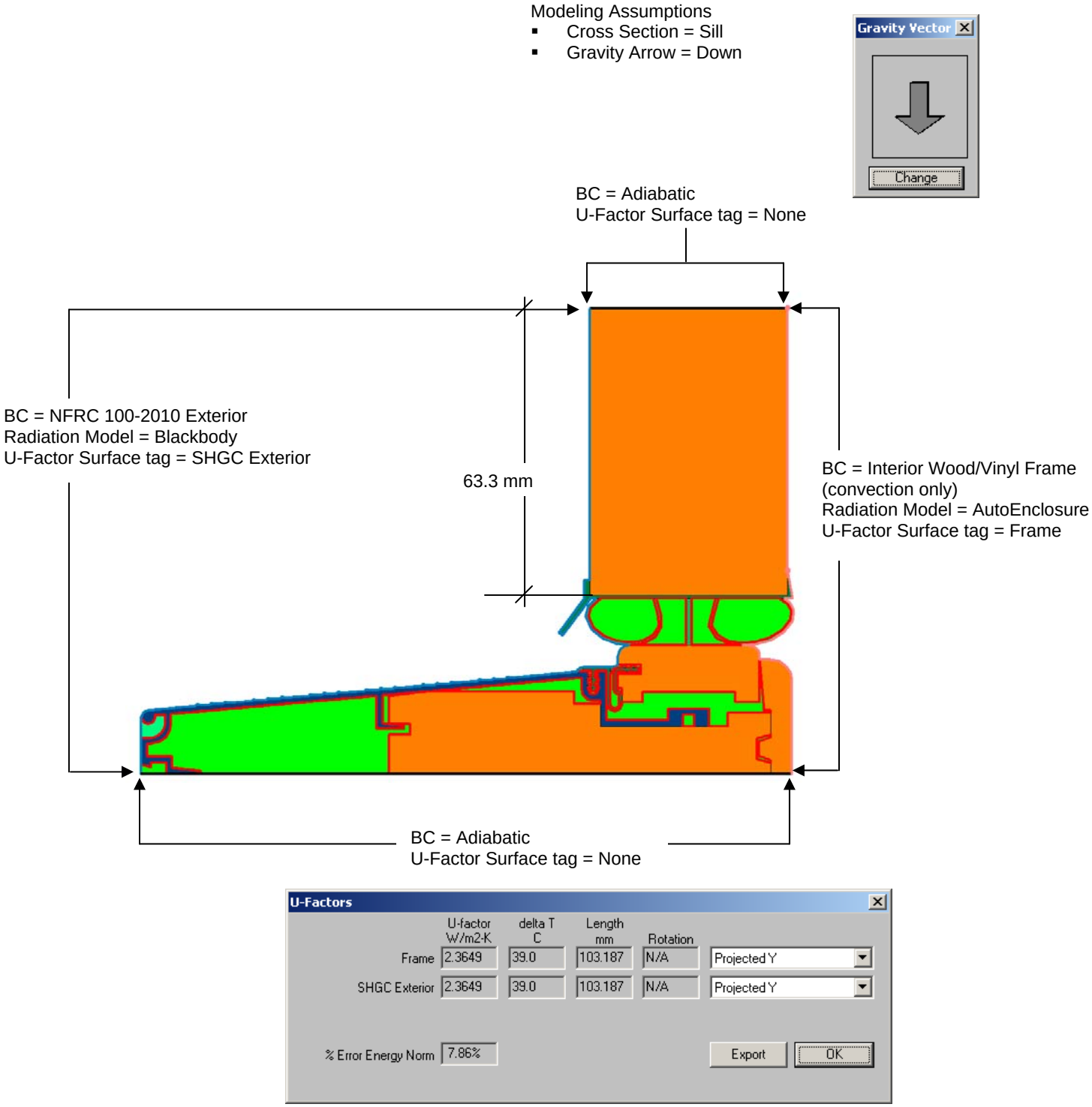
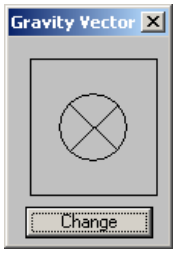
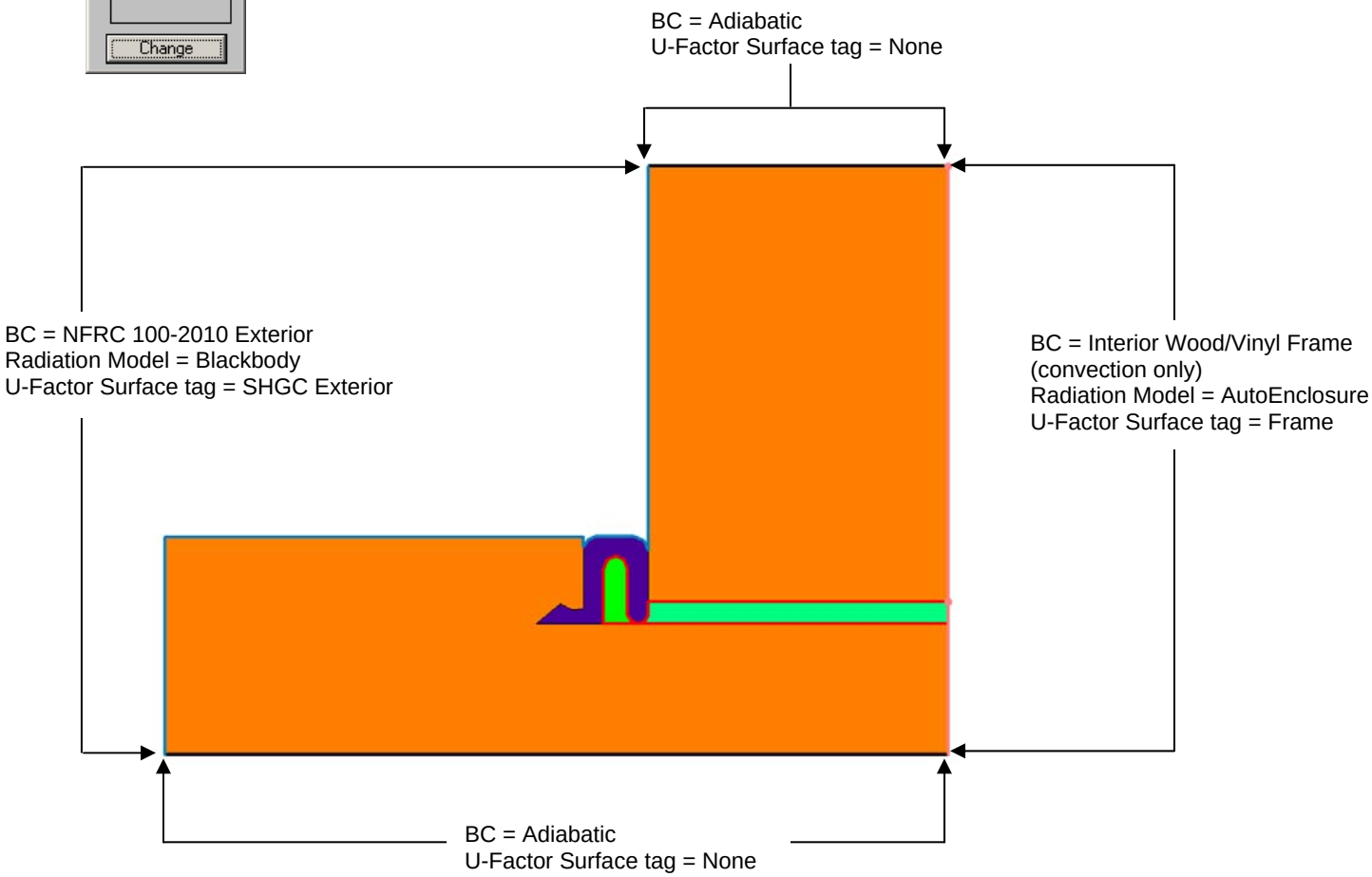


Figure 9-45. THERM cross section and U-factor results for the sill cross section.

Jamb



Modeling Assumptions:
- Cross Section = Jamb
- Gravity Arrow = Into the screen



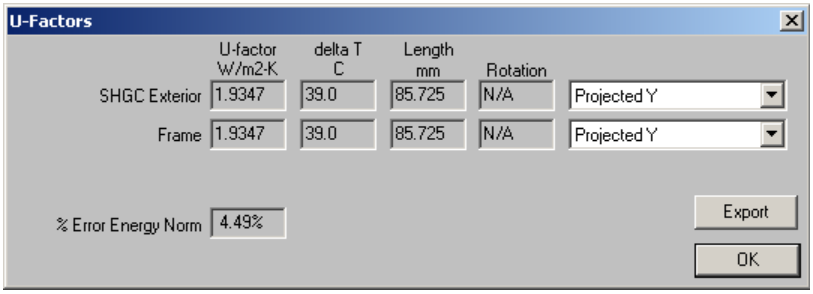
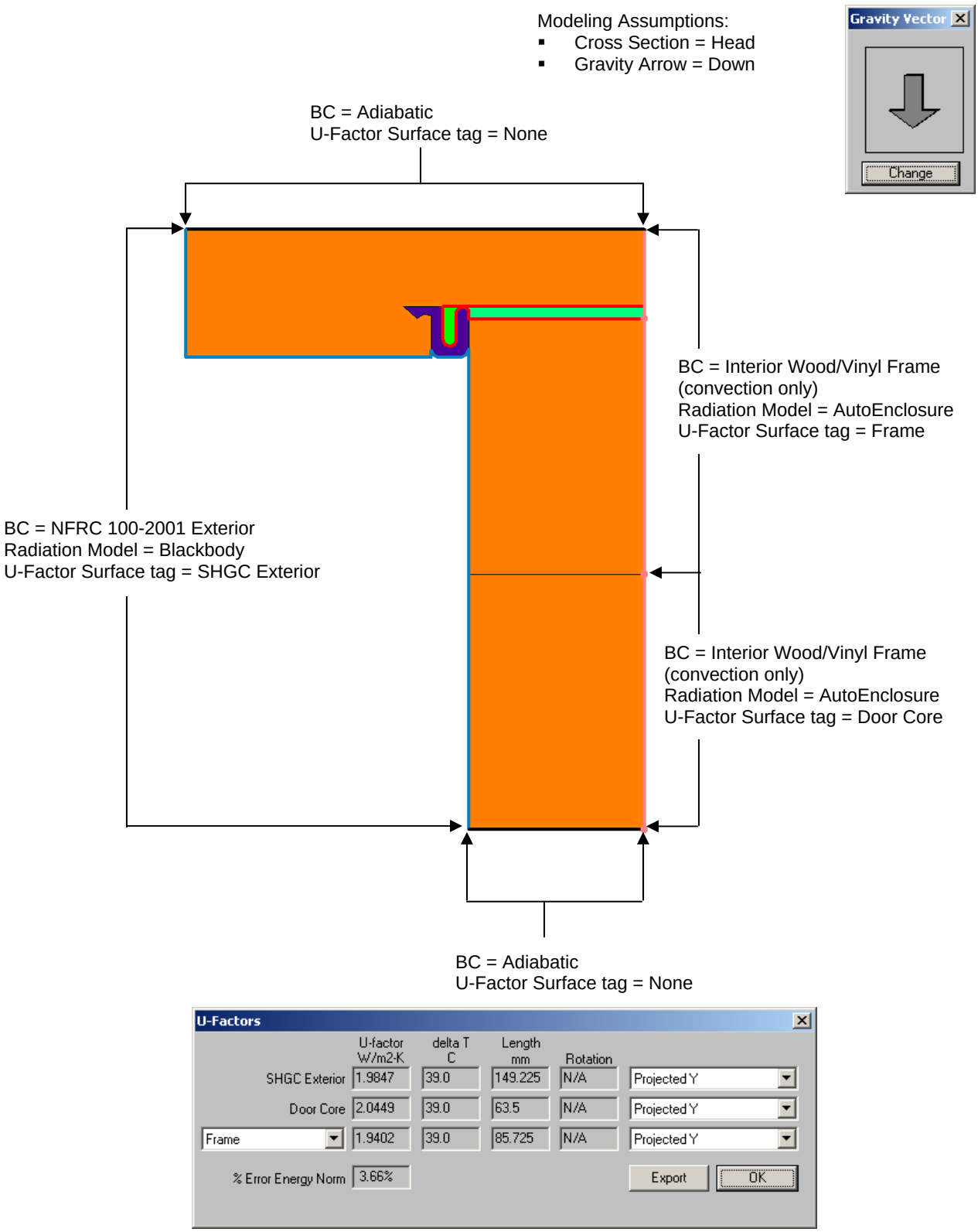


Figure 9-46. THERM cross section and U-factor results for the jamb cross section.

Head



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
SHGC Exterior	1.9847	39.0	149.225	N/A	Projected Y
Door Core	2.0449	39.0	63.5	N/A	Projected Y
Frame	1.9402	39.0	85.725	N/A	Projected Y
% Error Energy Norm	3.66%				

Export OK

Figure 9-47. THERM cross section and U-factor results for the head cross section.

Panel Edge

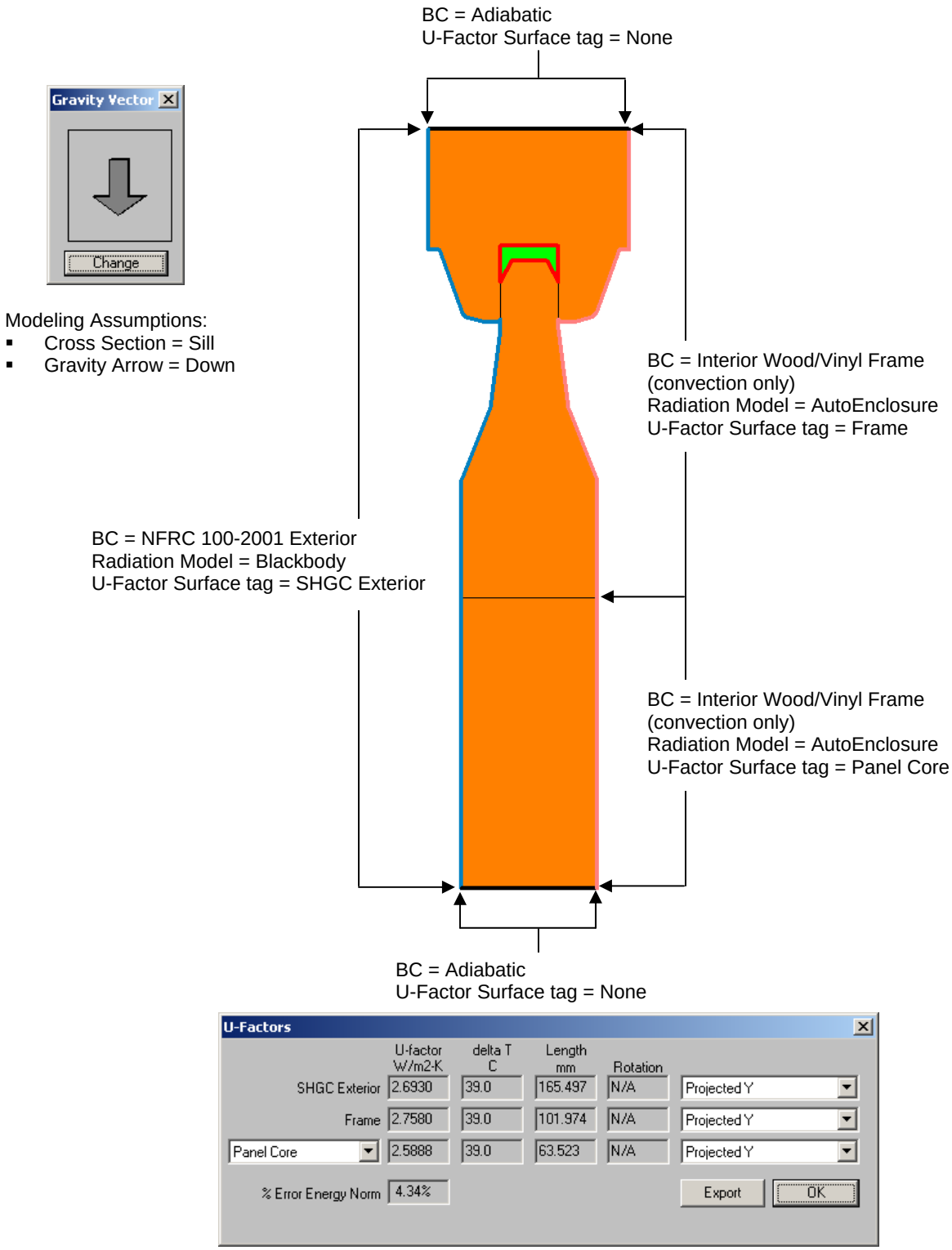
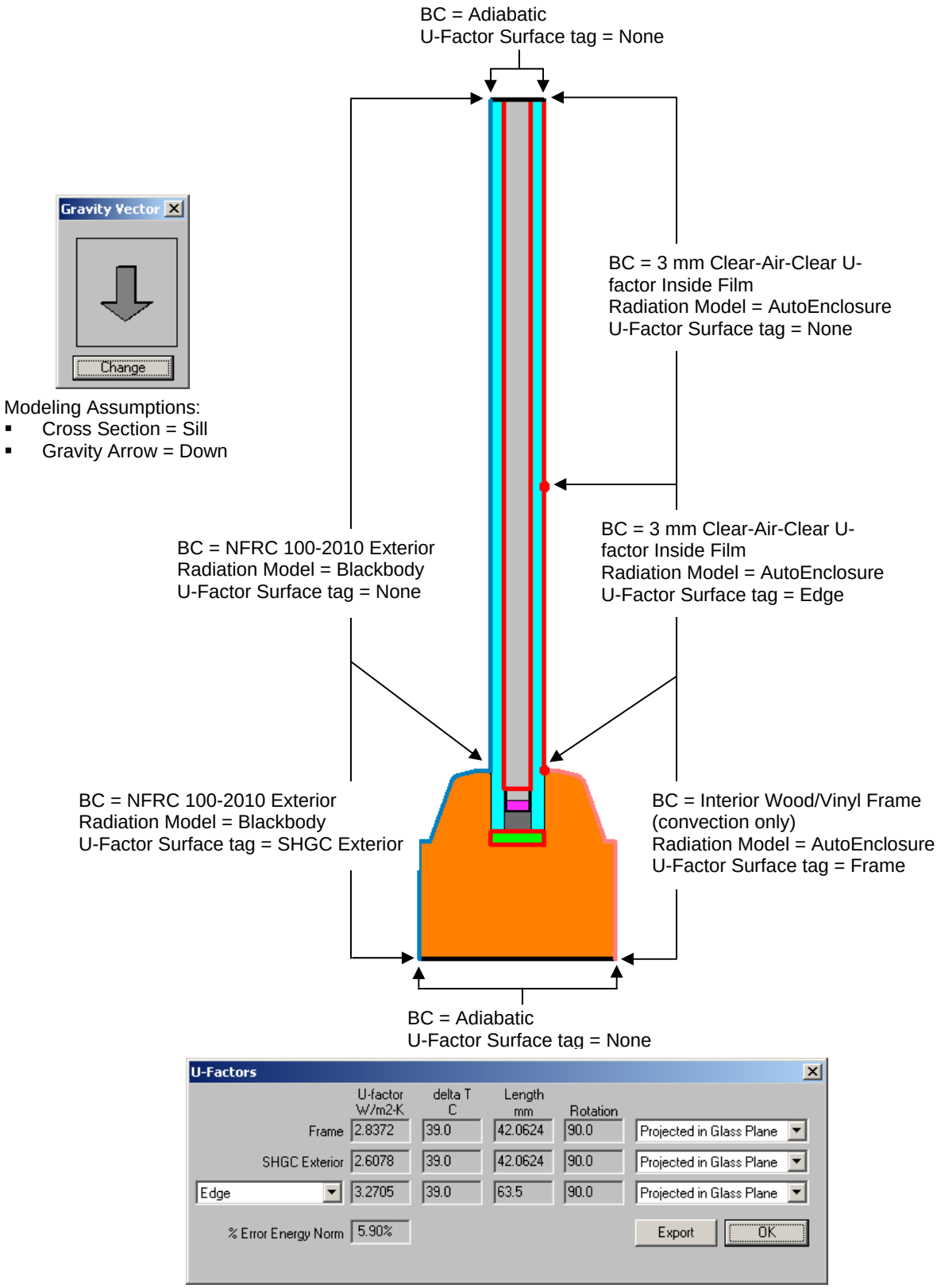


Figure 9-48. THERM cross section and U-factor results for the panel edge cross section.

Door Lite -- Sill



U-Factors

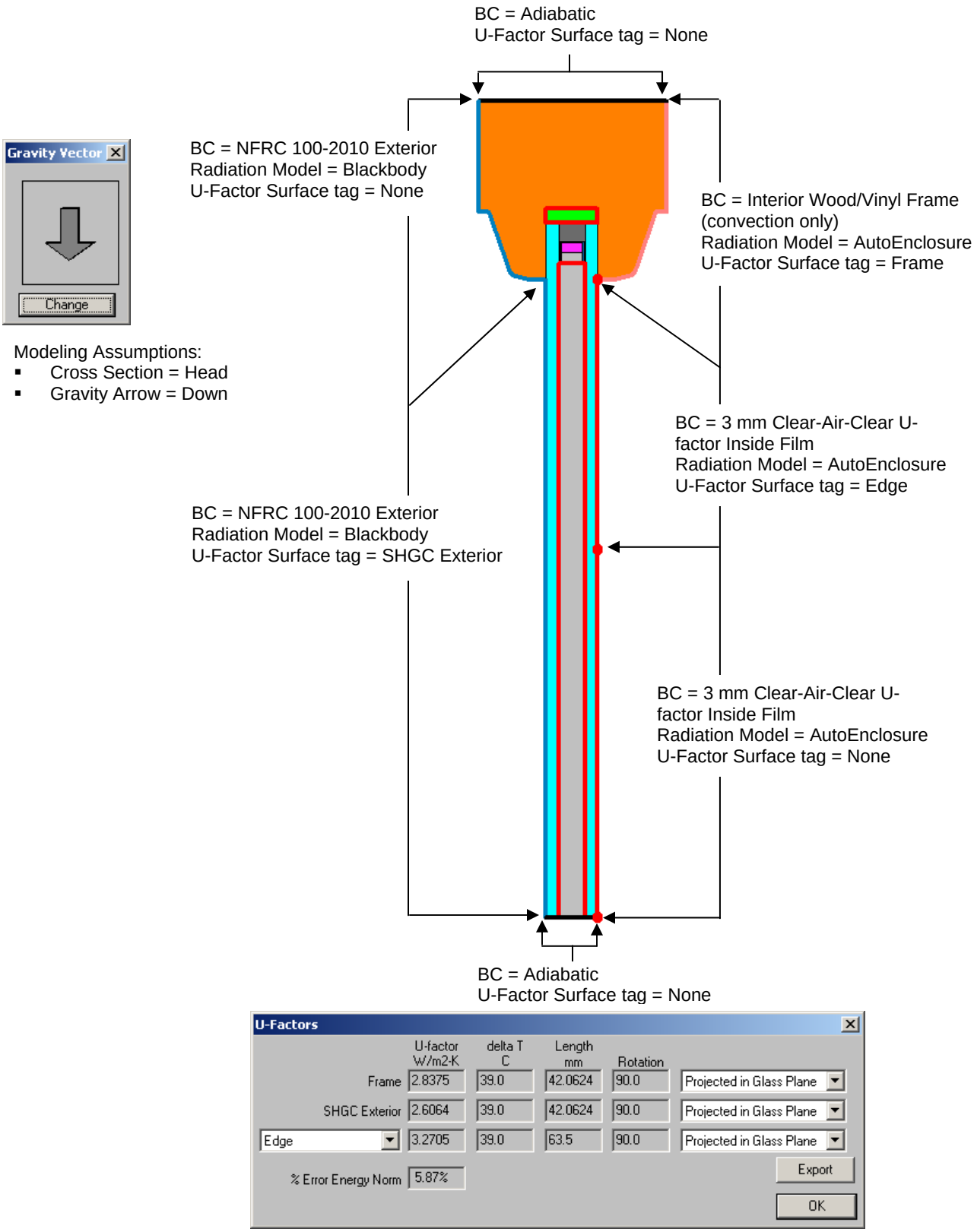
	U-factor W/m2-K	delta T C	Length mm	Rotation	
Frame	2.8372	39.0	42.0624	90.0	Projected in Glass Plane
SHGC Exterior	2.6078	39.0	42.0624	90.0	Projected in Glass Plane
Edge	3.2705	39.0	63.5	90.0	Projected in Glass Plane

% Error Energy Norm 5.90%

Export OK

Figure 9-49. THERM cross section and U-factor results for the door lite cross section.

Door Lite -- Head



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Frame	2.8375	39.0	42.0624	90.0	Projected in Glass Plane
SHGC Exterior	2.6064	39.0	42.0624	90.0	Projected in Glass Plane
Edge	3.2705	39.0	63.5	90.0	Projected in Glass Plane

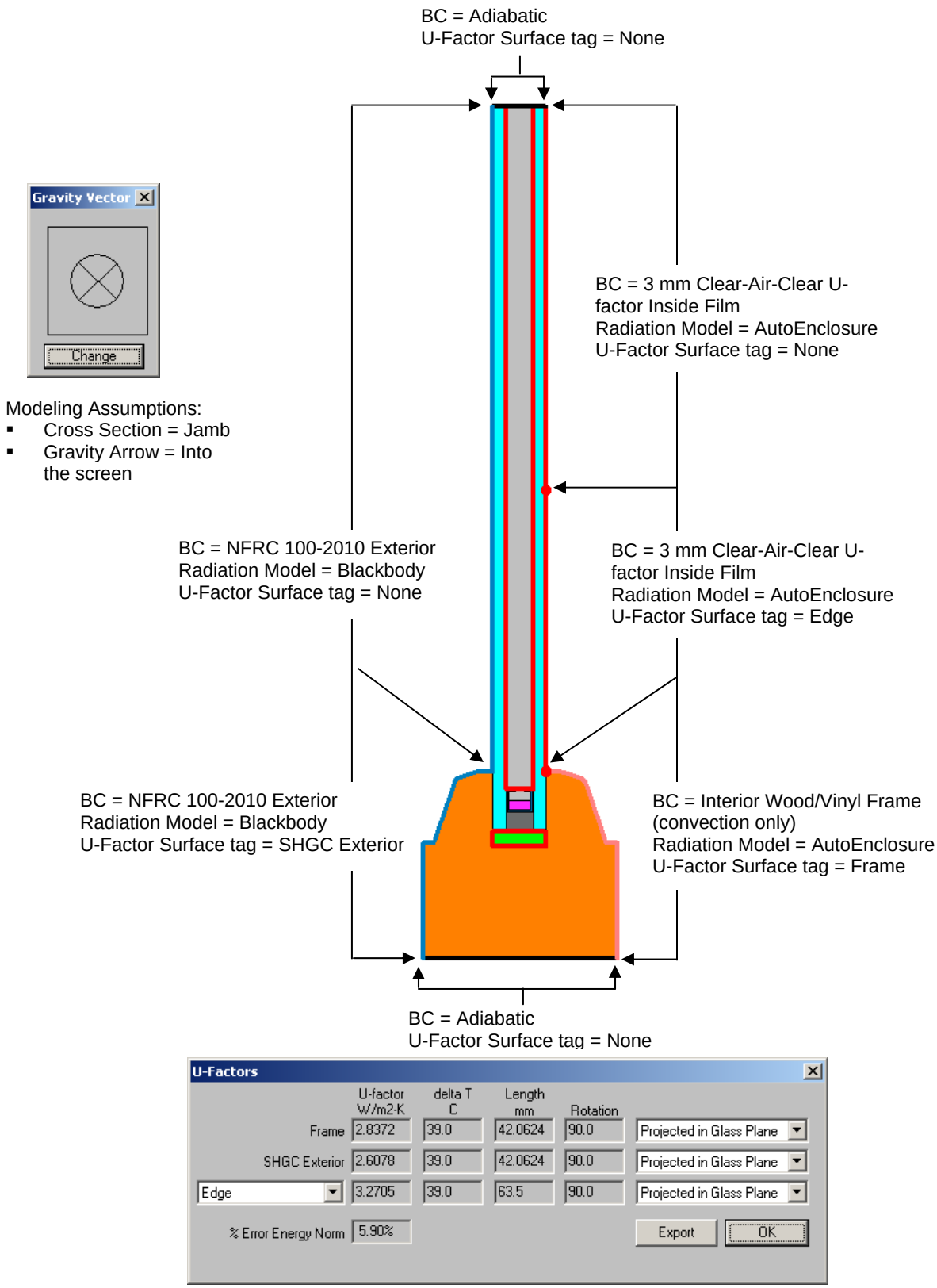
% Error Energy Norm 5.87%

Export

OK

Figure 9-50. THERM cross section and U-factor results for the door lite cross section.

Door Lite -- Jamb



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Frame	2.8372	39.0	42.0624	90.0	Projected in Glass Plane
SHGC Exterior	2.6078	39.0	42.0624	90.0	Projected in Glass Plane
Edge	3.2705	39.0	63.5	90.0	Projected in Glass Plane

% Error Energy Norm 5.90%

Export OK

Figure 9-51. THERM cross section and U-factor results for the door lite cross section.

9.5.5. Total Product U-Factor, SHGC and VT

Total product U-factor, SHGC and VT values for door products cannot be calculated in the same manner as window and skylight products. Because WINDOW cannot area-weight the opaque portions of the door models, and cannot read the results from THERM files with tags other than “Frame”, “Edge” or “None”, total product values must be manually calculated outside of WINDOW, by inputting the center-of-glazing results from WINDOW and the frame and edge results from THERM into a spreadsheet. The spreadsheet calculation is outside the scope of this manual, and is therefore not included in this example.

9.5.6. Wood Stile and Rail Door Drawings.

The following pages contain detailed drawings for this door.

Half-Panel with Glass Layout

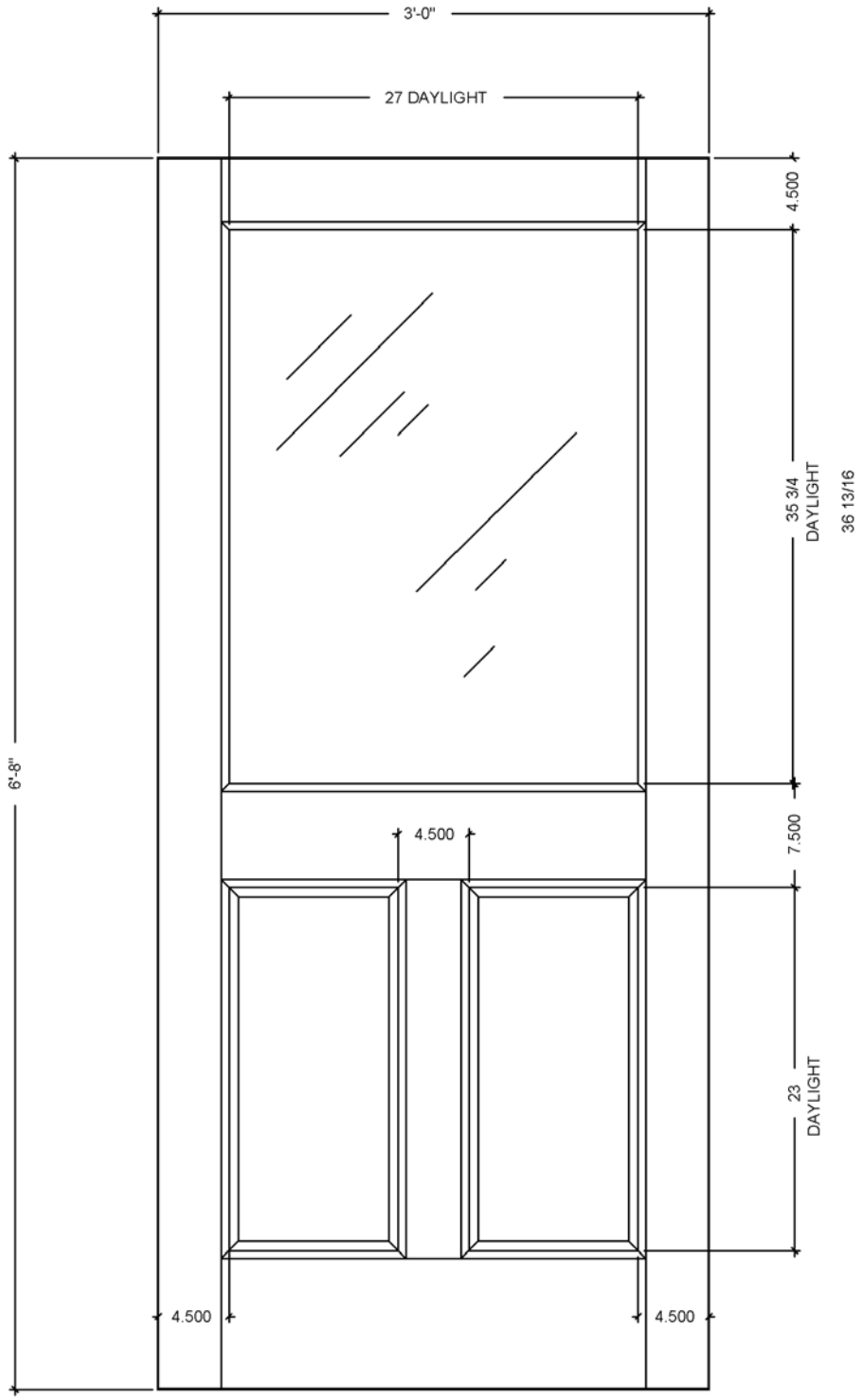


Figure 9-52. Half-Panel with Glass Layout.

Half-Panel with Glass Section

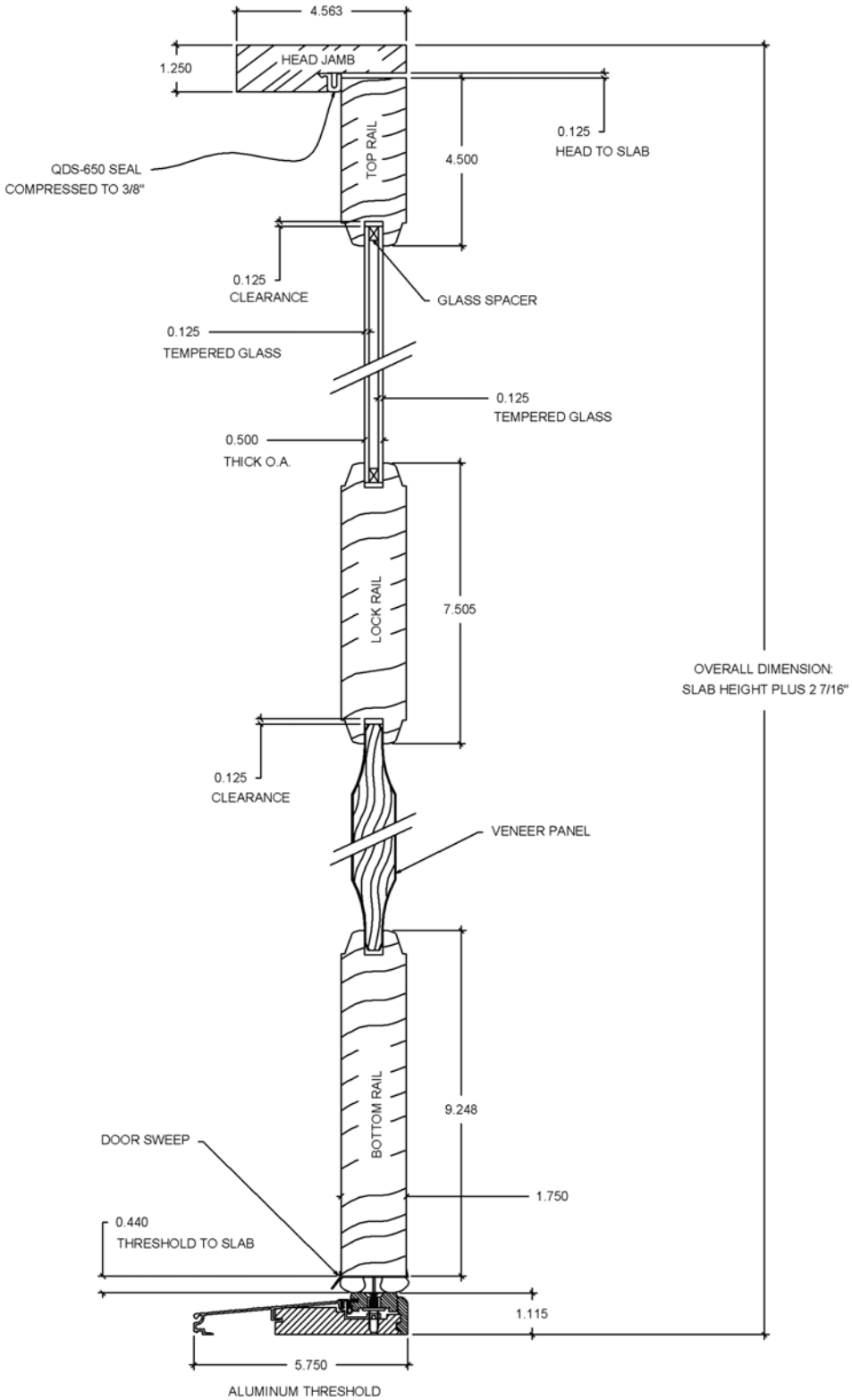
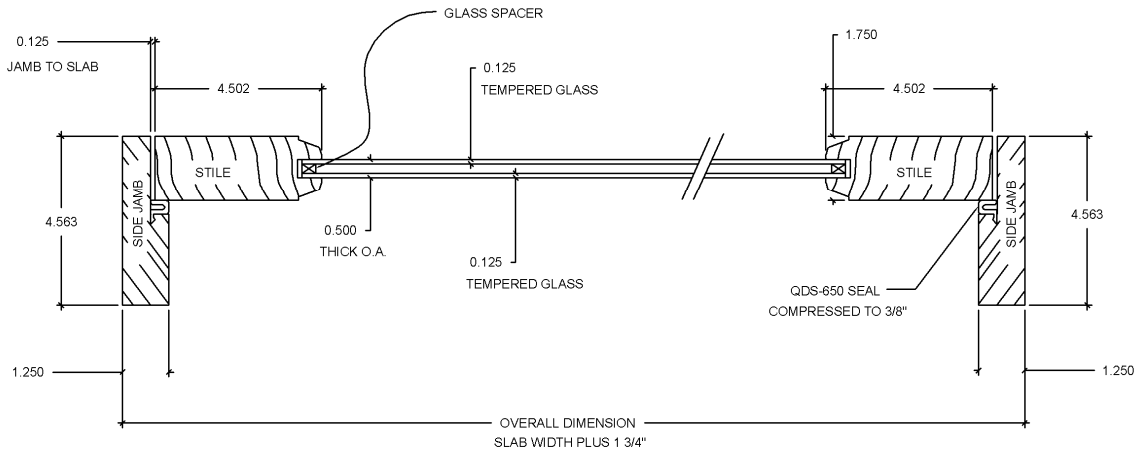
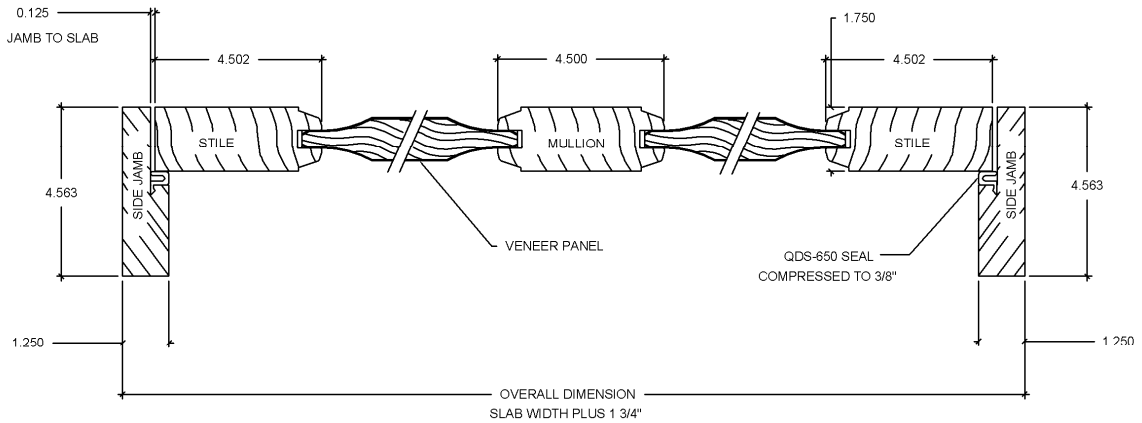


Figure 9-53. Half Panel with Glass Vertical Section.

Half-Panel with Glass Section



UPPER HORIZONTAL CROSS SECTION



LOWER HORIZONTAL CROSS SECTION

Figure 9-54. *Half Panel with Glass Horizontal Section.*

Sill

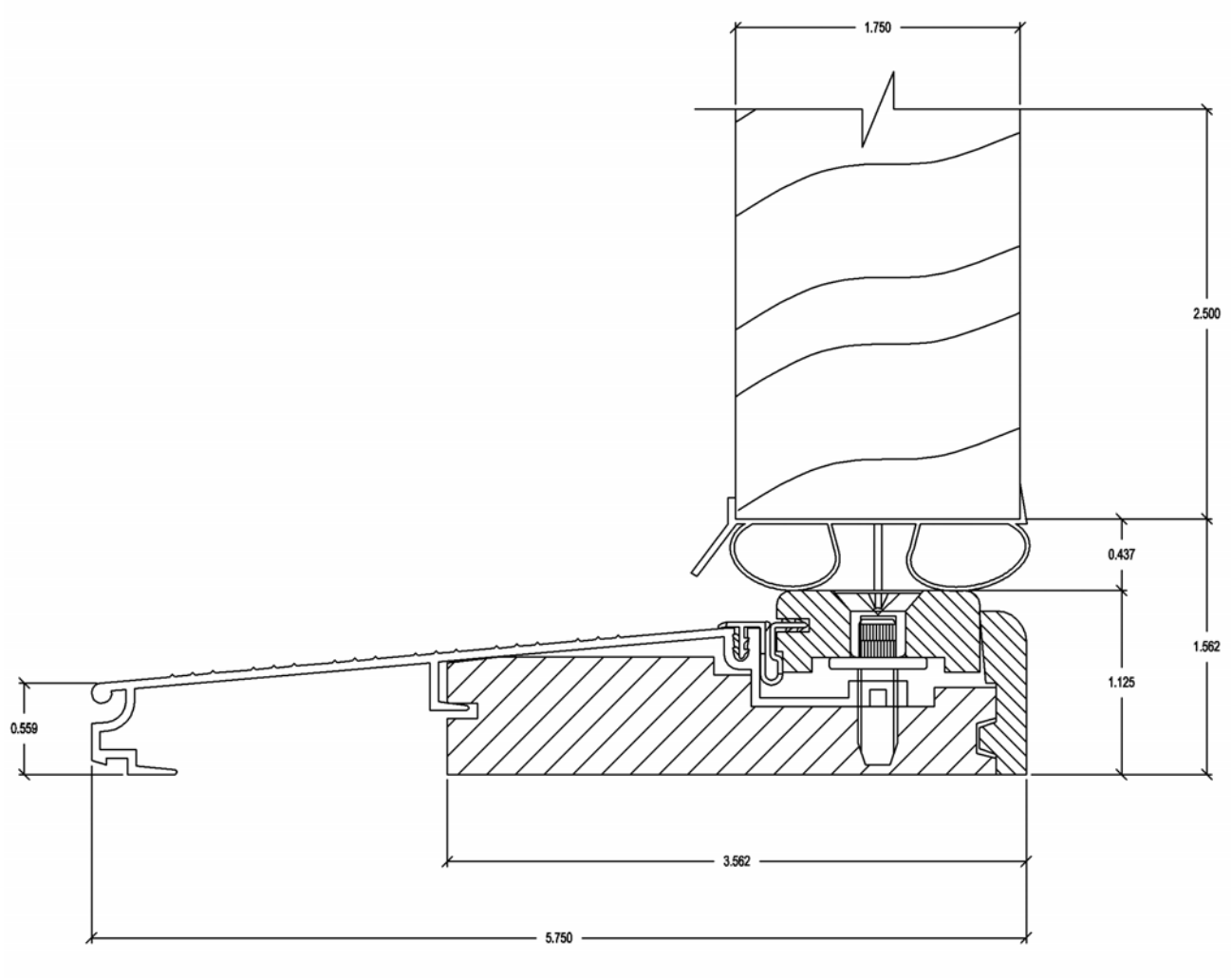


Figure 9-55. Dimensioned drawing for the sill cross section.

Jamb

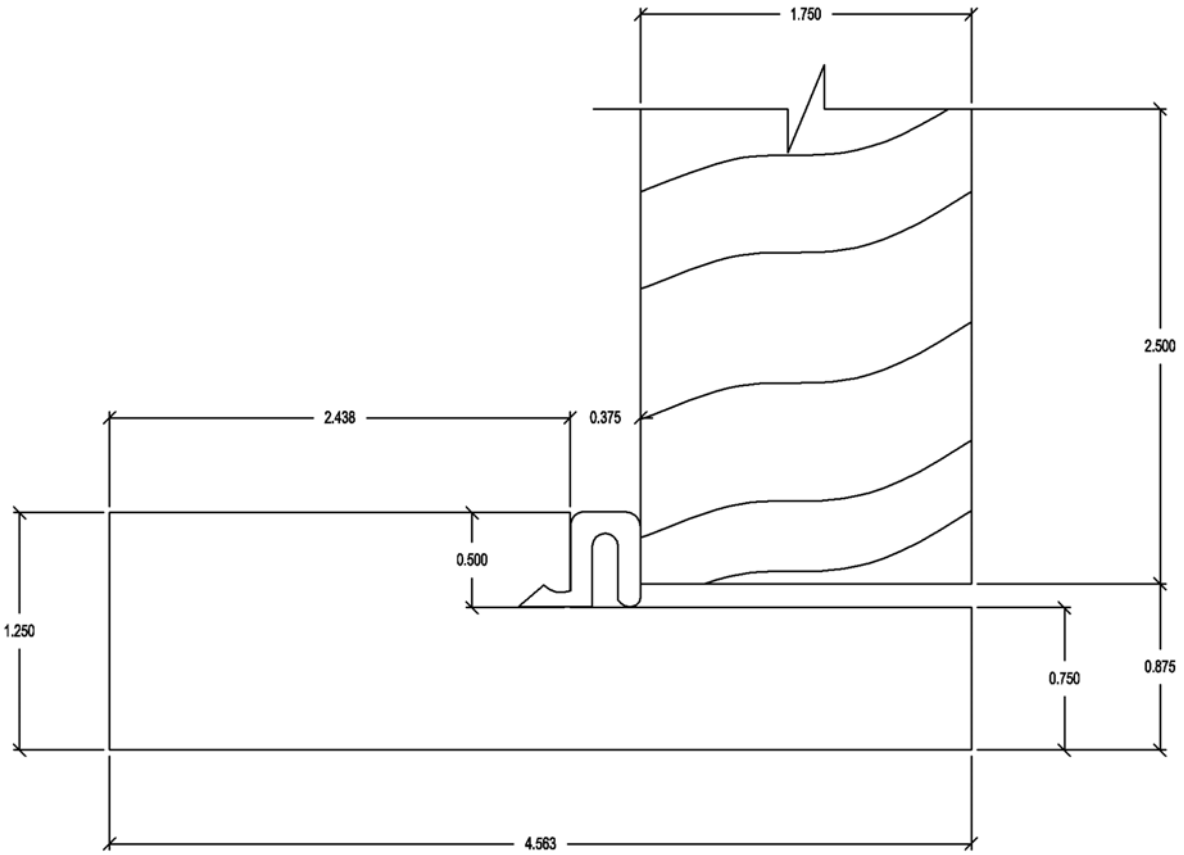


Figure 9-56. Dimensioned drawing for the jamb cross section.

Head

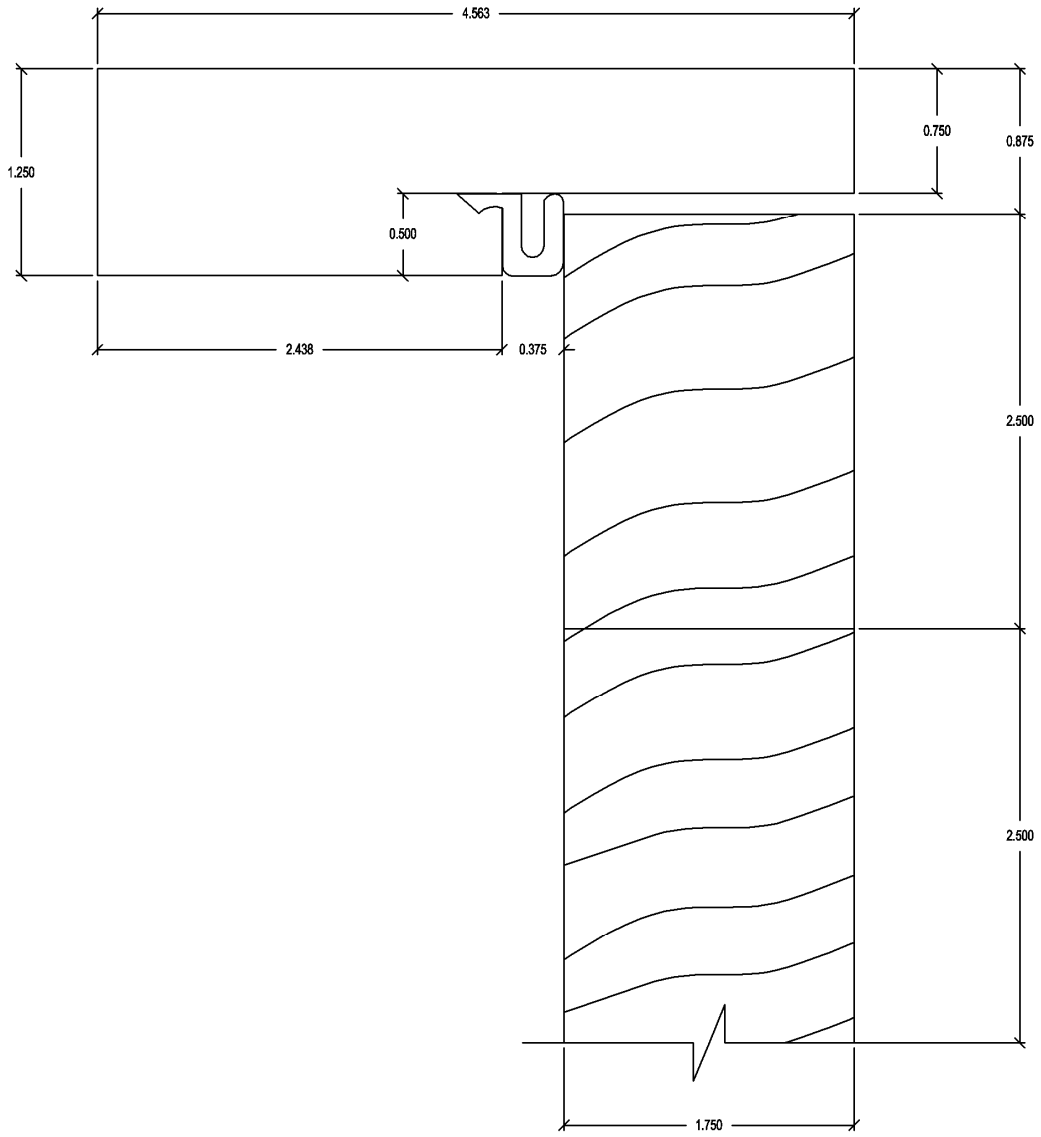


Figure 9-57. Dimensioned drawing for the head cross section.

Panel Edge

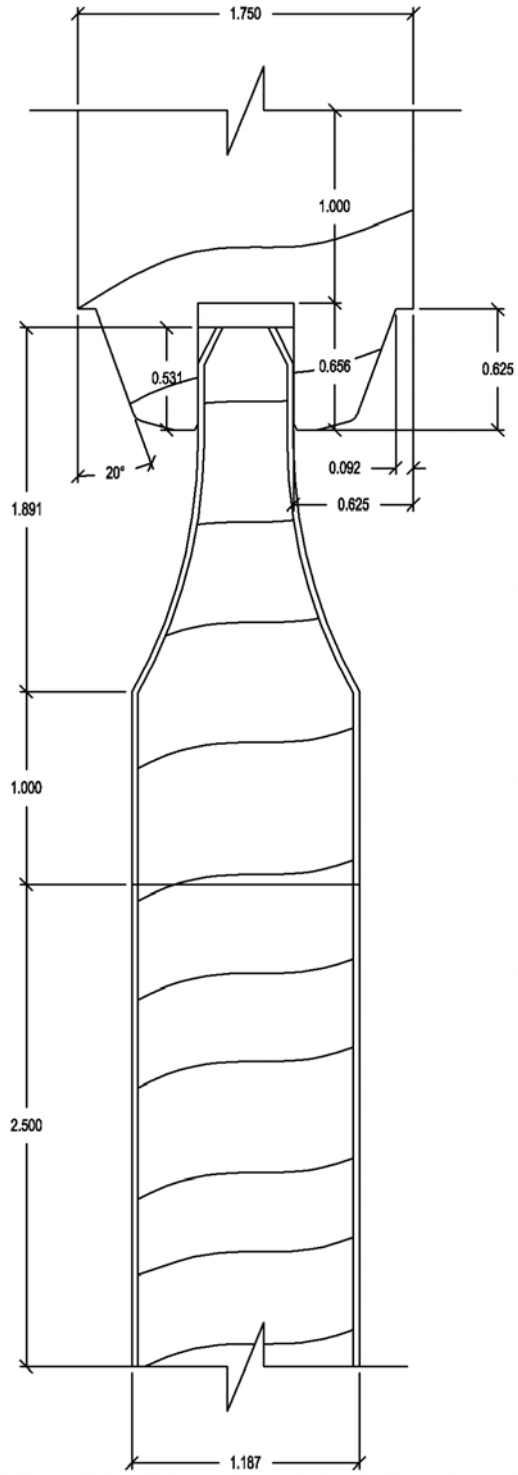


Figure 9-58. Dimensioned drawing for the panel edge cross section.

Door Lite

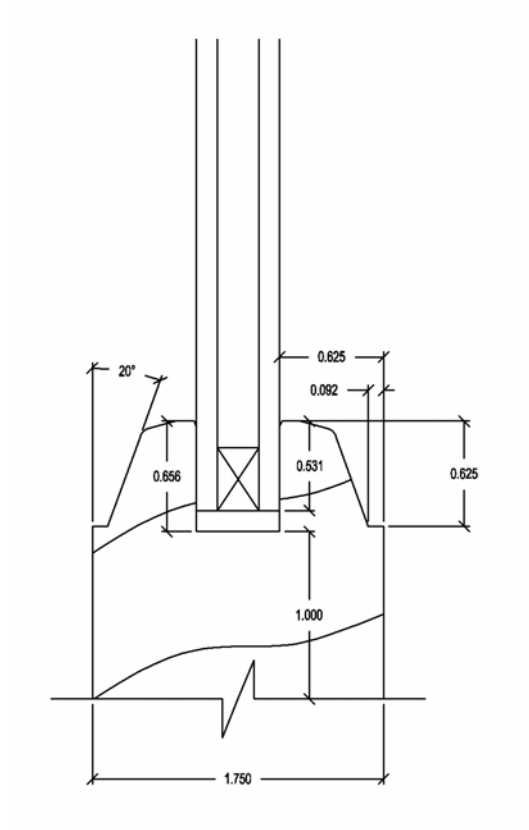


Figure 9-59. Dimensioned drawing for the door lite cross section.

Spacer

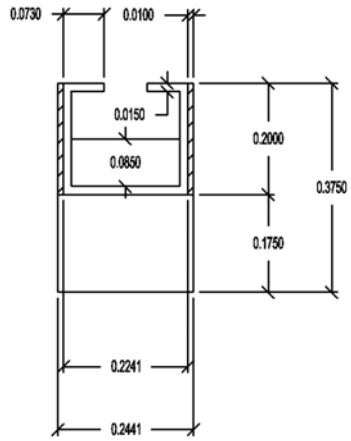


Figure 9-60. Dimensioned drawing for the spacer.

10. ACKNOWLEDGEMENTS

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, Office of Building Systems of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The program authors wish to thank the window manufacturers who supplied data and drawings on their products for use in this manual; Jeff Baker, Marles McDonald, Marcia Falke, Randy Van Voorst, Ross DePaola, Bipin Shah and Dennis Anderson for writing sections of the manual and reviewing draft versions; and the many members of the NFRC community who contributed suggestions and ideas.

APPENDIX A. The Application of ISO 15099 to NFRC 100 and 200

Software utilized in computing NFRC U-factors (NFRC 100-02) and SHGCs (NFRC 200-02) will be based on the recently completed ISO 15099 document (FDIS, September 21, 2001). In several cases, ISO 15099 suggests that individual national standards will need to be more specific and in other cases the ISO document gives users the choice of two options. This document clarifies these specific issues as they are to be implemented in NFRC approved software/algorithms:

1) Section 4.1: For calculating the overall U-factor, ISO 15099 offers a choice between the linear thermal transmittance (4.1.2) and the area weighted method (4.1.3). The area weighted method (4.1.3) shall be used.
2) Frame and divider SHGC's shall be calculated in accordance with Section 4.2.2. The alternate approach in section 8.6 shall not be used. [Note: current research is aimed at assessing which method is more accurate; at some point in the future, this recommendation may be revised.]
3) Section 6.4 refers the issue of material properties to national standards. Material conductivities and emissivities shall be determined in accordance with the NFRC Simulation Manual or more currently adopted NFRC standard on this topic.
4) Section 7 on Shading Systems is currently excluded from NFRC procedures.
5) Section 8.2 addresses environmental conditions. The following are defined by NFRC:

   For U-factor calculations:

   T_{in} = 21 °C

   T_{out} = -18 °C

   V = 5.5 m/s

   $T_{\mathrm{rm,out}}=T_{out}$

   $T_{\mathrm{rm,in}}=T_{in}$

   I_s=0 W/m^2

   For SHGC calculations:

   T_{in} = 24 °C

   T_{out} = 32 °C

   V = 2.75 m/s

   $T_{\mathrm{rm,out}}=T_{out}$

   $T_{\mathrm{rm,in}}=T_{in}$

   I_s=783 W/m^2

6) Section 8.3 addresses convective film coefficients on the interior and exterior of the window product. In section 8.3.1, NFRC simulations shall use the convective heat transfer coefficient based on the center of glass temperature and the entire window height; this film coefficient shall be used on all glass and edge of glass indoor surfaces. Frame section indoor convective film coefficients shall be constants which depend on frame material type; these shall be determined using the algorithms in ISO15099 and using representative frame surface temperatures for each frame material type (to be included in the Simulation Manual). In section 8.3.2, the formula from this section shall be applied to all outdoor exposed surfaces.

7) Section 8.4.2 presents two possible approaches for incorporating the impacts of self-viewing surfaces on interior radiative heat transfer calculations. NFRC shall use the method in section 8.4.2.1 (Two-Dimensional Element To Element View Factor Based Radiation Heat Transfer Calculation). This is also the method referenced in NFRC 500 for CI calculations. Furthermore, in the interests of consistency and accuracy, this method shall be used for all products, including planar products, for U-factor calculations as well as CI calculations. The use of this method makes the use of Slightly or Partially Ventilated cavities (see section 6.7.1) on the interior of frame surfaces redundant. The standard frame convective film coefficients (hc) referenced in 6) above will thus be applied to all interior frame surfaces.

APPENDIX B. REFERENCES

1997 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Arasteh, D. K. Finlayson, E. U., and Huizenga, C. 1994. "WINDOW 4.1: A PC Program for Analyzing Window Thermal Performance in Accordance with Standard NFRC Procedures." LBL Report 35298. Berkeley, CA.

ASHRAE Standard 142P, Standard Method for Determining and Expressing the Heat Transfer and Total Optical Properties of Fenestration Products, Public Review Draft, October 1996, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

Baehmann, P. L. Wittchen, S.L., Shephard, M.S., Grice, K.R. and Yerry, M.A., 1987. "Robust, Geometrically Based, Automatic Two-Dimensional Mesh Generation." *International Journal for Numerical Methods in Engineering*. 24, 1043 - 1078..

Curcija, D.; Power, J. P.; and Goss, W. P. 1995. "CONRAD: A Finite Element Method Based Computer Program Module for Analyzing 2-D Conductive and Radiative Heat Transfer in Fenestration Systems". Draft Report, University of Massachusetts at Amherst.

Curcija; D., and Goss, W. P. The 'Variable-h' Model For Improved Prediction of Surface Temperatures in Fenestration Systems, DRAFT June 1998 University of Massachusetts Report.

Curcija, D. June 20, 2006. "Conrad 5 and Viewer 5 Technical and Programming Documentation", Carli, Inc. Amherst, MA.

Finlayson, E. U., Arasteh, D. K., Huizenga, C., Rubin, and M. D., Reilly, M. S., 1993. "WINDOW 4.0: Documentation of Calculation Procedures." LBL Report 33943. Berkeley CA.

Finlayson, E.U., Mitchell, R., Arasteh, D., Huizenga, C., Curcija, D.. 1998. "THERM 2.0: Program Description, A PC Program for Analyzing the Two-Dimensional Heat Transfer Through Building Products". LBL-37371 Rev 2.

George, P.L. *Automatic Mesh Generation, Application to Finite Element Methods*. John Wiley & Sons.

Pepper, P. W. and Heinrich, J. C. 1992. *The Finite Element Method Basic Concepts and Applications*. Hemisphere Publishing Corporation, Washington.

Carmody, J., Selkowitz, Arasteh, D., S., Heschong, L., *Residential Windows: A Guide to New Technologies and Energy Performance*, Second Edition, 2000, W. W. Norton & Company.

Rohsenow, W. M., Harnett, J. P., and Ganic, E. N., 1985. *Handbook of Heat Transfer Fundamentals*, 2nd Edition, McGraw Hill.

Shapiro, A. B. 1986. "TOPAZ2D - A Two-Dimensional Finite Element Code for Heat Transfer Analysis, Electrostatic, and Magnetostatic Problems" Lawrence Livermore National Laboratory, Rept. UCID-20824.

Shapiro, A. B. 1990. "TOPAZ2D Heat Transfer Code Users Manual and Thermal Property Data Base", Lawrence Livermore National Laboratory, Rept. UCRL-ID-104558, May 1990.

Shapiro, A. B., 1983. FACET – A Radiation View Factor Computer Code for Axisymetric, 2D Planar, and 3D Geometries with Shadowing. Lawrence Livermore National Laboratory, Rept. UCID-19887.

Thermal Performance of Windows, Doors and Shading Devices – Detailed Calculations, ISO/FDIS 15099, ISO TC 163.

Zhao, Y., Curcija, D., and Goss, W. P., 1996, Condensation Resistance Validation Project - Detailed Computer Simulations Using Finite - Element Methods. PP 508-515, *ASHRAE Transactions*, Vol 102, Part 2.

Zienkiewicz, O. C.; and Taylor, R. L. 1989. *The Finite Element Method*. 4th ed. Vol. 1. McGraw Hill, Maidenhead, UK.

Zienkiewicz, O.C. and Zhu, J.Z. 1992a. "The Superconvergent Patch Recovery and A Posteriori Error Estimates. Part 1: The Recovery Technique." *International Journal for Numerical Methods in Engineering*. Vol 33. pp. 1331-1364.

Zienkiewicz, O.C. and Zhu, J.Z., 1992b. "The superconvergent patch recovery and a posteriori error estimates. Part 2. The error estimates and adaptivity." *International Journal for Numerical Methods in Engineering*. Vol 33. pp. 1365-1382.