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:

- "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;

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.

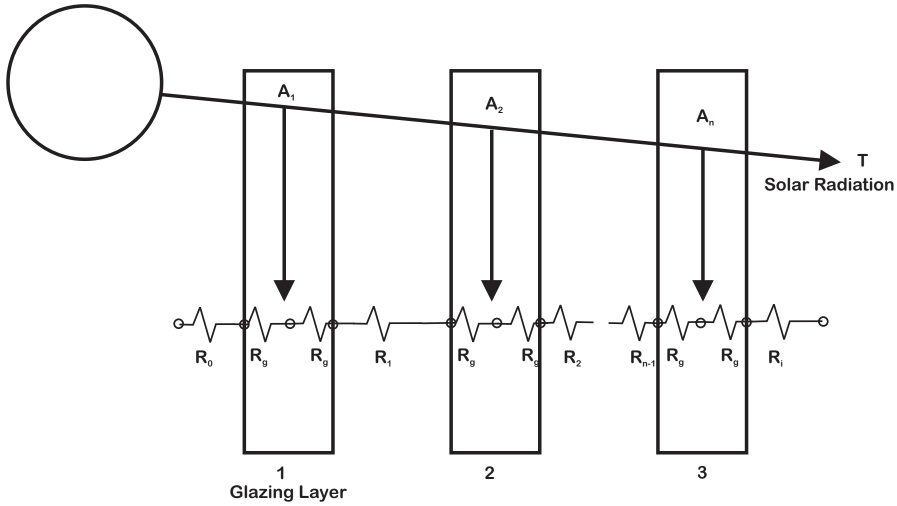


Figure 4-1. Resistance network used to model center-of-glazing heat transfer in WINDOW.

Two temperature nodes are assigned to each glazing layer (exterior and interior surface), along with outside air and inside 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.

Conductive/convective heat transfer coefficients are calculated based on empirical relationships. The outside film coefficient depends on the windspeed and the direction from which the wind is blowing. The inside film coefficient is a function of the difference between the inward-facing surface temperature, the inside temperature, and the height of the fenestration product. Gap heat transfer coefficients are computed from empirical equations for the Nusselt number. The Nusselt number relates the temperature difference between the surfaces bounding the gap, and width, height and thermophysical properties of the gap. 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.

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

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

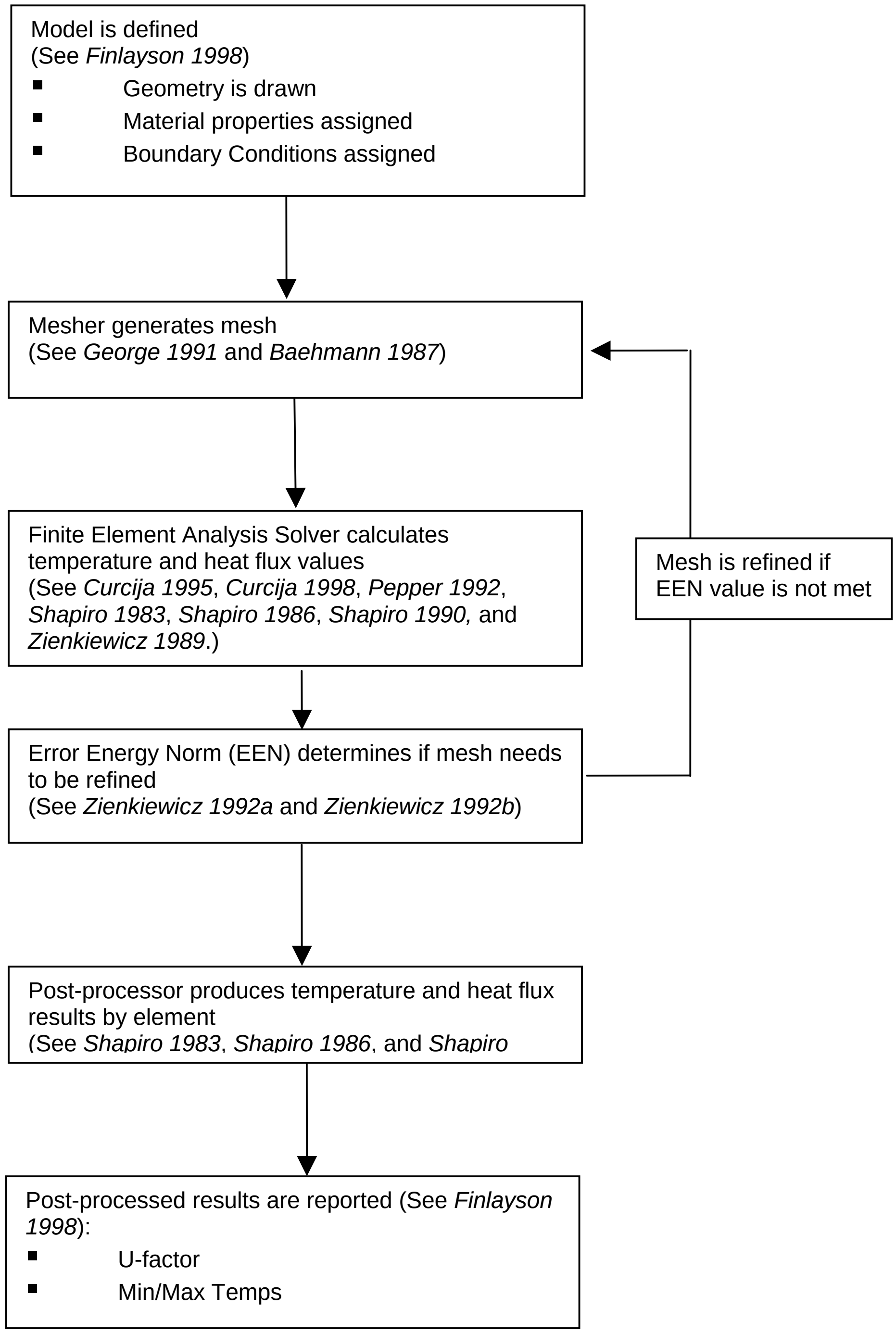


Figure 4-2. THERM program calculation procedures flow chart.

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".

[4-1]

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

Where:

U_t = Total product U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}F).

A_{pf} = Projected fenestration product area, m^2 (ft^2).

U_f = Frame U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}F).

A_f = Frame area, m^2 (ft^2).

U_d = Divider U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}F).

A_d = Divider area, m^2 (ft^2).

U_e = Edge-of-glazing U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}F).

A_e = Edge-of-glazing area, m^2 (ft^2).

U_{de} = Edge-of-divider U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}F).

A_{de} = Edge-of-divider Area, m^2 (ft^2).

U_c = Center-of-glazing U-factor, W/m^2-^{o}K , (Btu/hr-ft^2-^{o}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, m^2 (ft^2).

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

VT_e = Edge-of-glazing area, m^2 (ft^2).

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

VT_{de} = Edge-of-divider, m^2 (ft^2).

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

A_c = Center-of-glazing area, m^2 (ft^2).

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*.

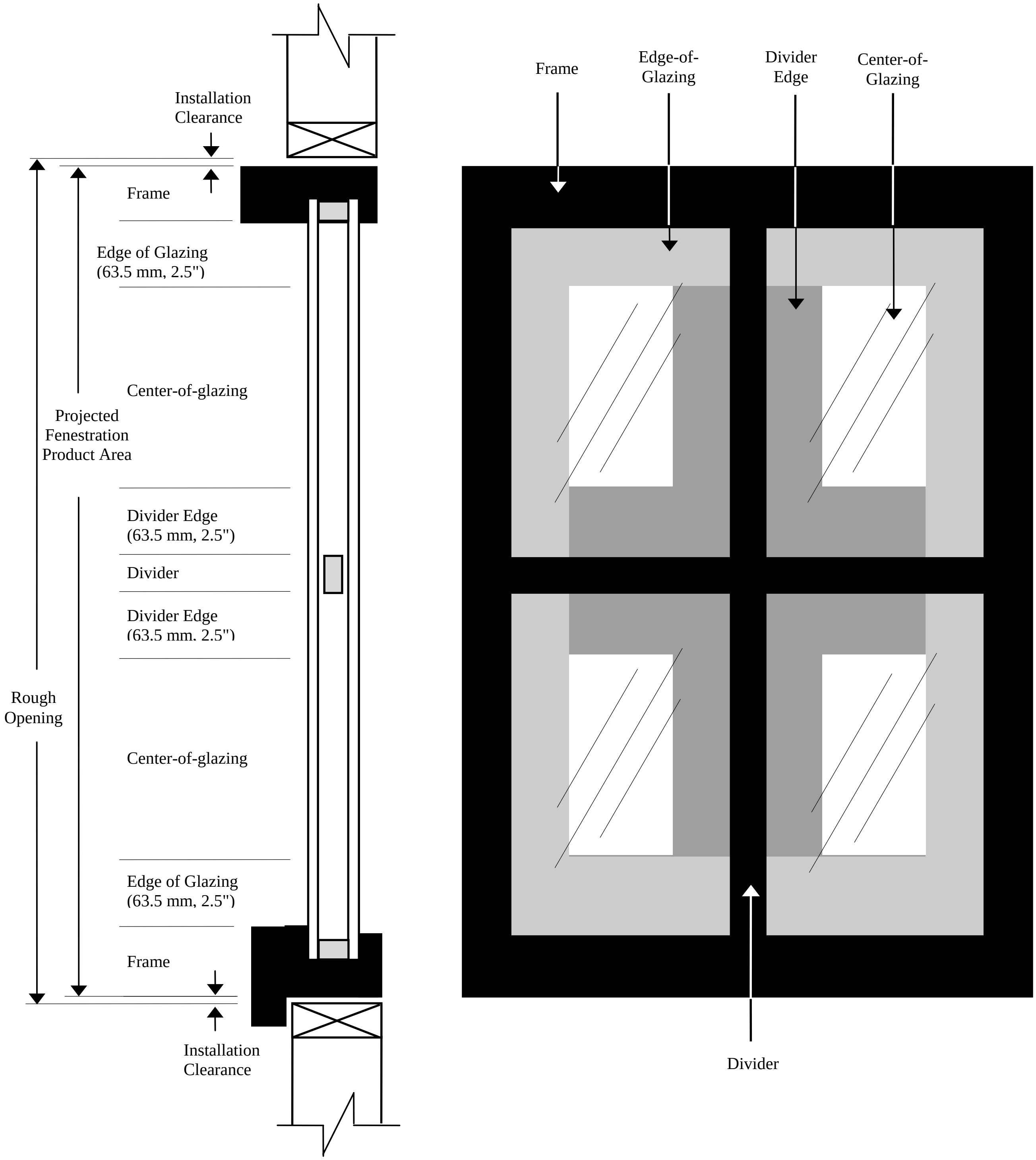
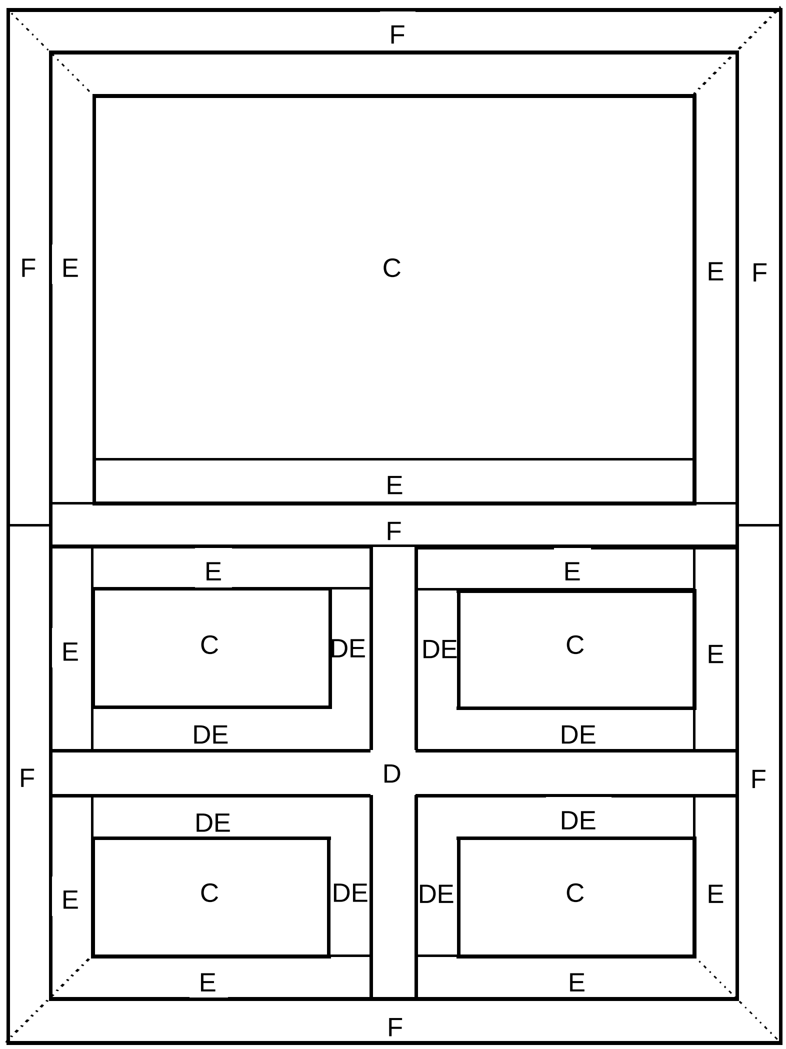


Figure 4-3. Components for the whole product area-weighted calculation. The view on the left is a section, and the view on the right is an elevation.

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.