

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 1 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.

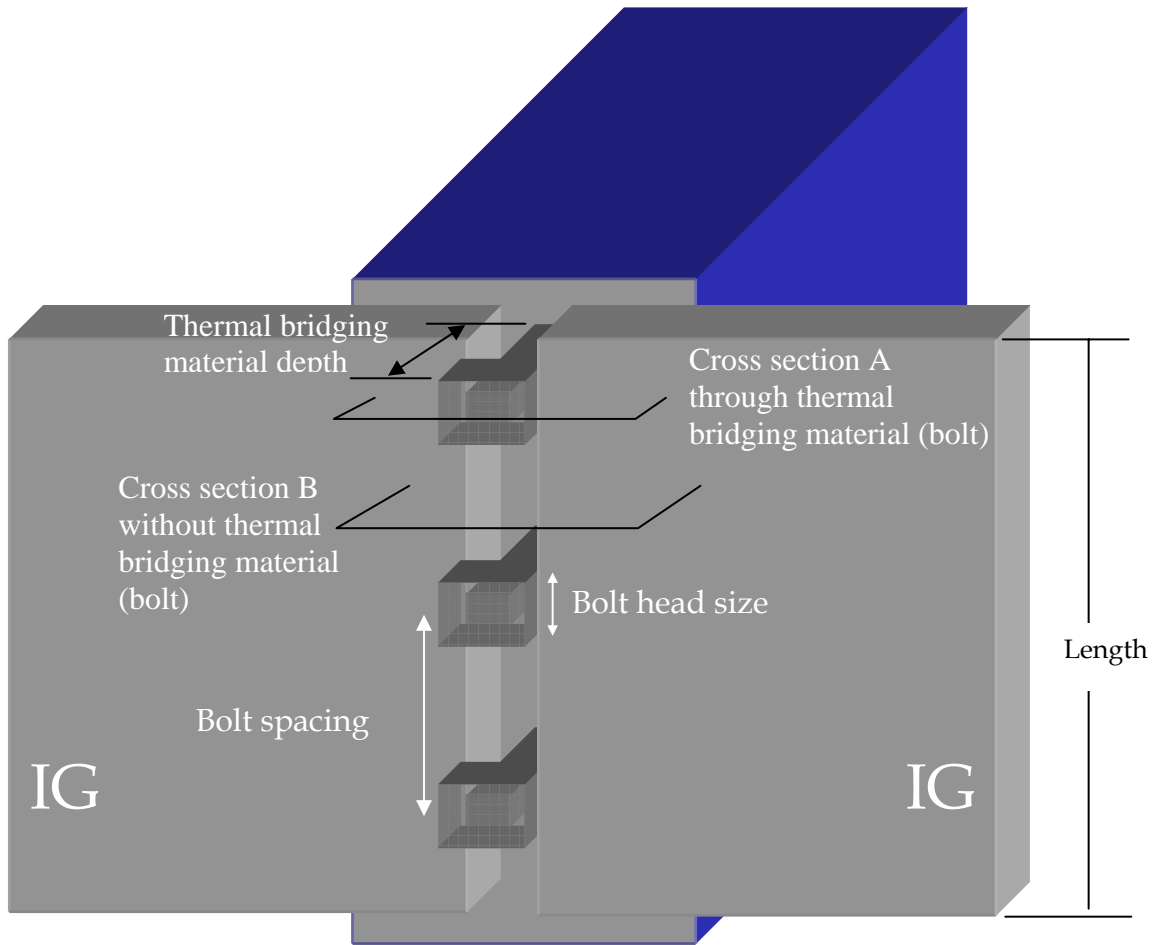


Figure 1. Example of a curtain wall system with regularly spaced bolts which act as thermal bridges.

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-°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.

Equations

Calculate the effective conductivity of thermal bridging elements (e.g., bolts, screws, etc.)

$$K_{eff} = F_b \cdot K_b + F_n \cdot K_n \quad \text{Equation 1}$$

where

- F_b = Fraction of the Length which contains the thermal bridging elements (see equation 4 below)
- F_n = the fraction of the Length which contains non-thermal bridging elements (see equation 5 below)
- K_b = conductivity of the thermal bridging elements
- K_n = conductivity of the non-thermal-bridging elements
(from the sum of the resistances, R_t, of individual elements from Equation 2 below)

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), ie, F_b < 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 ≤ F_b ≤ 0.05) and if the conductivity of the thermal bridging elements is more than 10 times the conductivity of the thermal break, then model the thermal bridging elements.

If more than 5% of the length is made of thermal bridging elements (F_b > 0.05), always model the thermal bridging elements. Calculate the total resistance of the non-thermal bridging elements, R_t, by summing individual resistances (non-thermal bridging element conductivity) for each non-thermal bridging element using the formula:

$$R_t = \sum(D / k) \quad \text{Equation 2}$$

Where:

R_t = Sum of the thermal resistances of the individual non-thermal bridging material.
Units: m²·K/W (SI), or hr ft²·°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·K (SI), or Btu/hr in·°F (IP), or Btu in/hr ft²·°F (alternate IP)

Therefore:

$$K_n = D_t / R_t \quad \text{Equation 3}$$

Where:

D_t = 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:

$$F_b = W_b / S_b \quad (\%F_b = F_b \cdot 100) \quad \text{Equation 4}$$

$$F_n = 1 - F_b$$

Equation 5

Where:

W_b = Bridging material width

S_b = Bridging material spacing

Example 1: Bolts in Curtain Wall

The following figures show two cross sections of the curtain wall in Figure 1. Figure 2 represents the cross section of the curtain wall where the bolt occurs (screw threads should be averaged and not drawn explicitly), and Figure 3 represents the cross section of the curtain wall where the bolt does not occur. The geometry of the cross-section in Figure 2 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 3 is drawn only to obtain the conductivity values for calculating the conductivity of this “averaged” material.

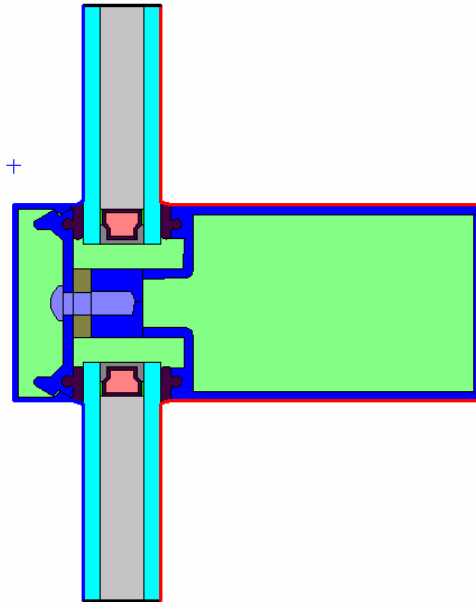


Figure 2. THERM cross section where the bolt occurs.

Figure 3 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 can be assumed to be 0.024 W/m-K.

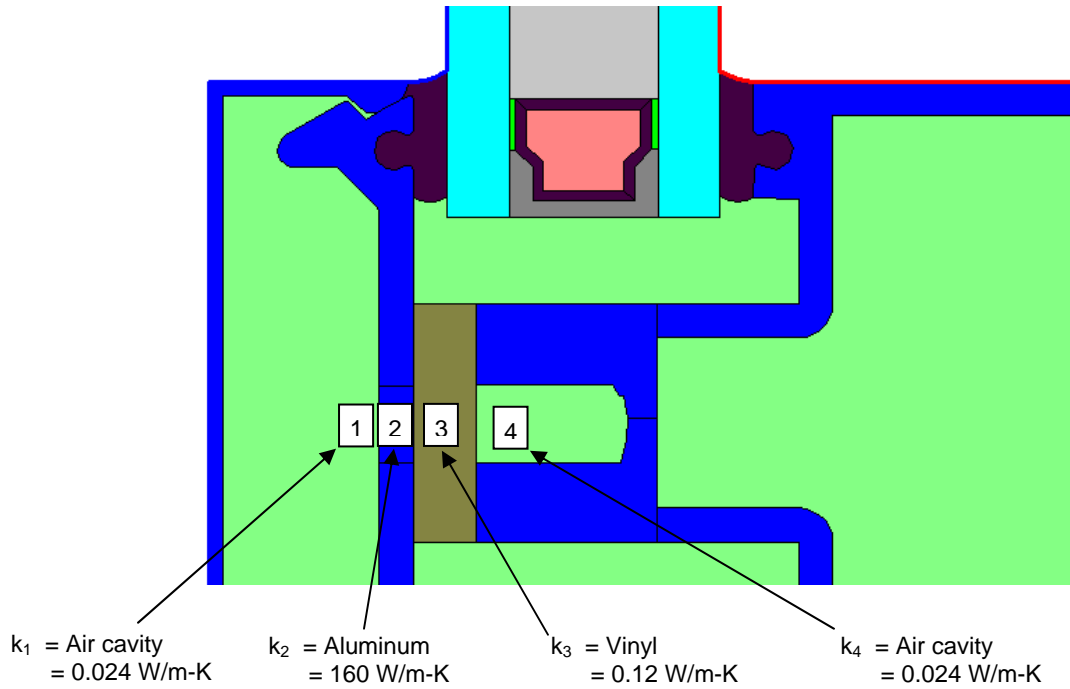


Figure 3. Materials in the non-bridging material cross section for which conductivities must be obtained.

Figure 4 shows the depths of each of the thermal bridging elements that are used in the Keff calculation.

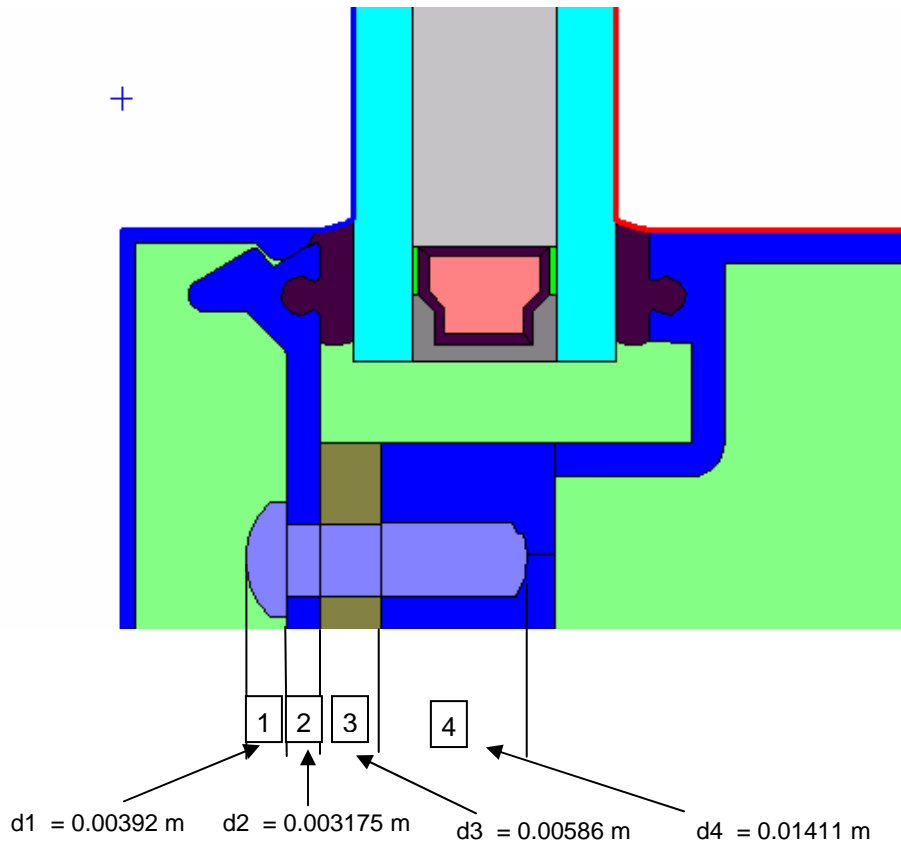


Figure 4. Material depths for the thermal bridging materials.

Table 1 shows the conductivity and depth values used to calculate the R for each non-thermal bridging element using Equation 2.

Table 1

| Cross Section Element | Material | Conductivity [W/mK] | Depth (m) | R [m ² K/W] |
|-----------------------|--|---------------------|----------------|------------------------|
| 1 | Air cavity (Keff from double clicking on cavity) | 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 (Keff from double clicking on cavity) | 0.024 | 0.01411 | 0.587917 |
| | Total | | 0.02706 | 0.800103 |

Calculate Rt as follows:

$$\begin{aligned}
 R_t &= \Sigma(d/k) \\
 &= (d_1/k_1) + (d_2/k_2) + (d_3/k_3) + (d_4/k_4) \\
 &= (0.00392 / 0.024) + (0.003175 / 160) + (0.00586 / 0.12) + (0.01411 / 0.024) \\
 &= 0.800103 \text{ m}^2\text{K/W} \\
 D_t &= 0.00392 \text{ m} + 0.003175 \text{ m} + 0.00586 \text{ m} + 0.01411 \text{ m} \\
 &= 0.02706 \text{ m}
 \end{aligned}$$

Calculate the conductivities as follows:

$$\begin{aligned}
 K_n &= D_t/R_t \\
 &= 0.02706 / 0.800103 \\
 &= 0.033821 \text{ W/m} \cdot \text{K} \\
 K_b &= 14.3 \text{ W/m} \cdot \text{K} \text{ (stainless steel)}
 \end{aligned}$$

Calculate the fraction of bolt to no bolt as follows:

$$\begin{aligned}
 W_b &= \text{Bolt head width} \\
 &= 11.1 \text{ mm} \\
 S_b &= \text{Bolt spacing } 12'' \\
 &= 304.8 \text{ mm} \\
 F_b &= W_b / S_b \\
 &= 11.1 \text{ mm} / 304.8 \text{ mm} \\
 &= 0.036 \text{ (\%Fb=0.036} \cdot 100 = 3.6\%) \\
 F_n &= 1-F_b \\
 &= 1- 0.036
 \end{aligned}$$

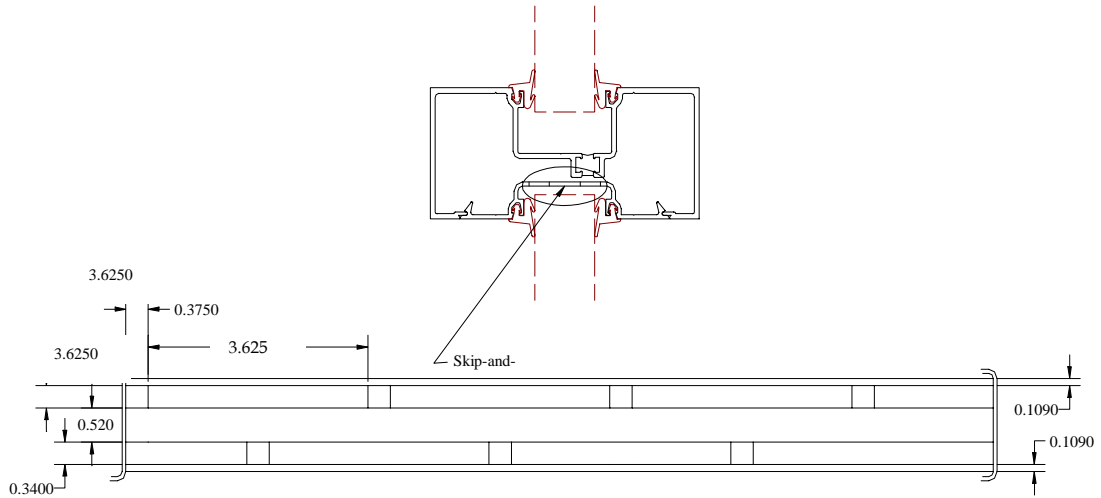
$$= 0.964$$

Calculate the new K_{eff} , which will be used in THERM as follows:

$$\begin{aligned} K_{eff} &= F_b \cdot K_b + F_n \cdot K_n \\ K_{eff} &= (0.036 \cdot 14.3) + (0.964 \cdot 0.033827) \\ &= 0.55 \text{ W/m}\cdot\text{K} \end{aligned}$$

In THERM, create a new material in the Material Library with this K_{eff} . 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.

Example 2: Thermally slotted cross-section



Step I

Skip = 0.375 in. (0.009525 m)

Debridge (Air) = 3.625 in. (0.092075 m)

Interval = 3.625 in. + 0.375 in.
 = 4 in. (0.009525m + 0.092075m)
 = 0.1016 m

Fb = 0.009525 m / 0.1016 m

= 0.094

Fn = 1 - Fb

= 1 - 0.094

= 0.906

Percent of thermal bridge = (Fb)*100
 = (0.094) * 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.

Kb = 160 W/m-K (conductivity of skipped debridge, in this case Aluminum)

$$\begin{aligned}
 R_t &= \sum (\text{Depth}/ \text{conductivity}) \\
 &= D_d/k_d \\
 &= (0.0086 \text{ m}/0.024\text{W}/\text{m-K}) \\
 &= 0.35833 \text{ m}^2\text{-K}/\text{W}
 \end{aligned}$$

where Depth is length of material in a direction of heat flow, and the air is assumed to have the conductivity of 0.024 W/m-K

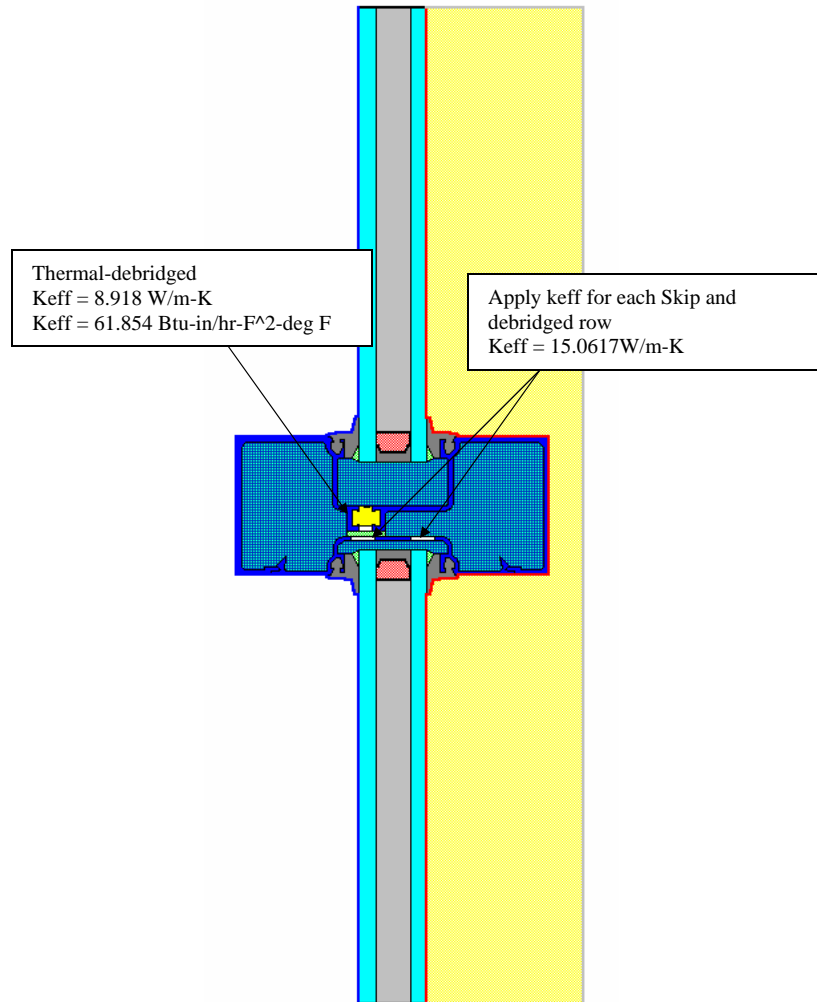
$$\begin{aligned}
 K_n &= \text{total depth}/R_t \\
 &= 0.0086\text{m}/ 0.35833 \text{ W}/\text{m-K} \\
 &= 0.024\text{W}/\text{m-K} \\
 K_{eff} &= F_b*K_b + F_n*K_n \\
 &= 0.094*160 \text{ W}/\text{m-K} + 0.906* 0.024\text{W}/\text{m-K} \\
 &= 15.062 \text{ W}/\text{m-K}
 \end{aligned}$$

To convert to IP:

$$\begin{aligned}
 K_{eff} &= 15.062 \text{ W}/\text{m-K} * 0.57782 \\
 &= 8.703 \text{ Btu}/\text{hr-ft-}^\circ\text{F}
 \end{aligned}$$

or in alternative IP units,

$$\begin{aligned}
 K_{eff} &= 15.062* 0.57782 * 12 \text{ in}/\text{ft} \\
 &= 104.436 \text{ Btu-in}/\text{hr-ft}^2\text{-}^\circ\text{F}
 \end{aligned}$$



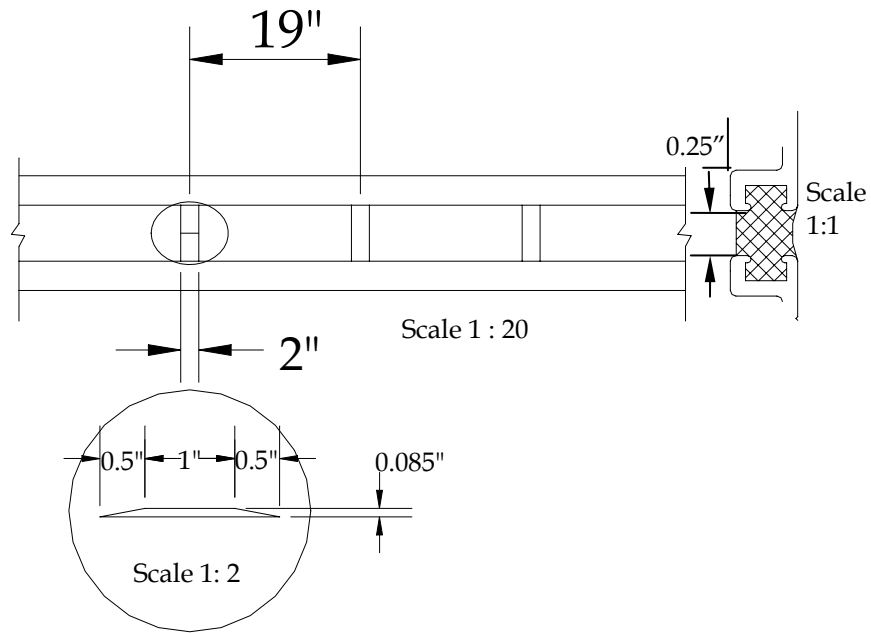
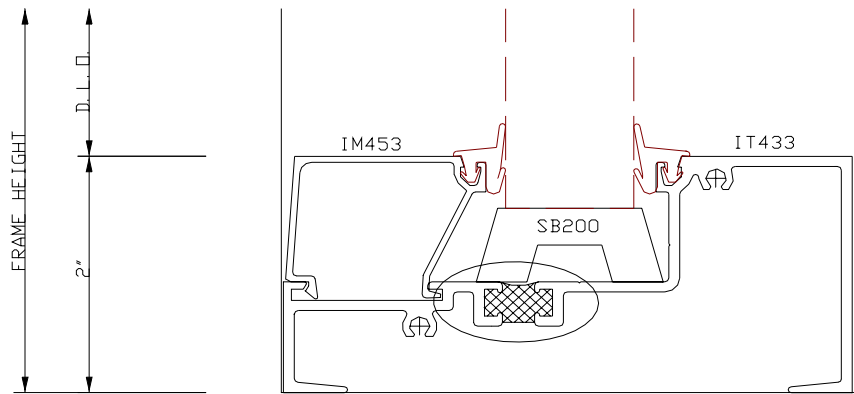
Step-2

Replace the strip of air-aluminum-air with new keff material of 15.078 W/m-K

Step 3

Define the Boundary condition and run the model to calculate the U-factor for frame and edge-of-glass.

Example 3: Skip-and-debridge:



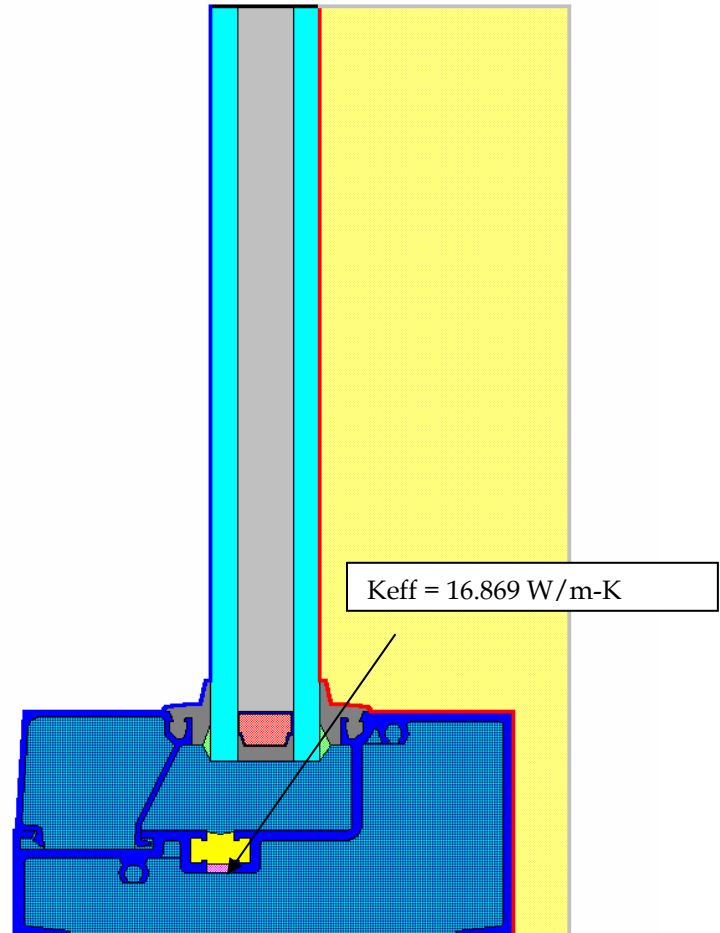
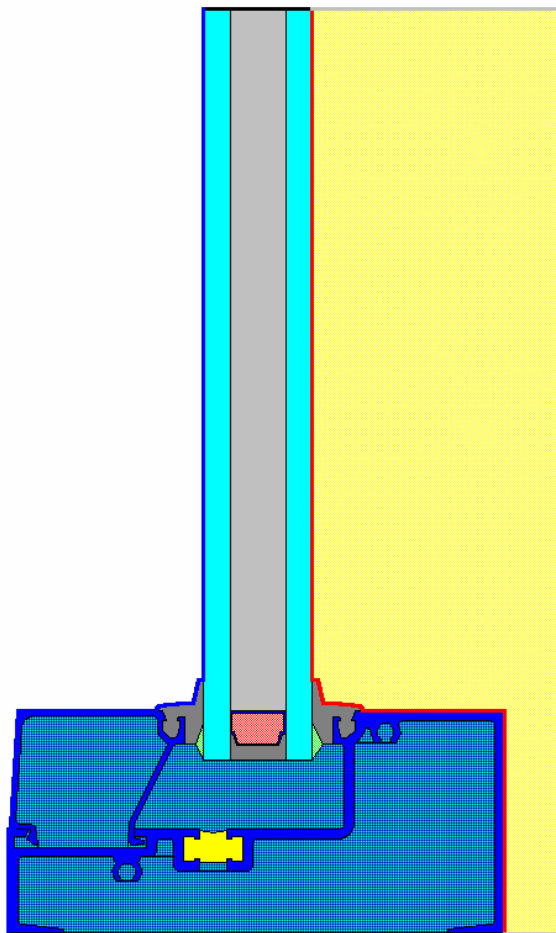
Note: the skip trapezoid shall be treated as a rectangle equal to the total length of the trapezoid.

STEP 1

Skip = 0.0508 m

Debridge (Air) = 0.4318 m

Interval = 0.508m + 0.4318m = 0.4826 m



$$F_b = 0.0508 \text{ m} / 0.4826 \text{ m} = 0.1053$$

$$F_n = 1 - F_b = 1 - 0.1053 = 0.4947$$

%F_b = (F_b) · 100 = (0.1053) · 100 = 10.53% (Skip-and-debridge needs to be calculated using Isothermal plane procedure).

K_b = 160 W/m-K (conductivity of skipped debridge, in this case aluminum)

$$R_t = \sum \text{Length} / \text{conductivity} = (0.00635 \text{ m} / 0.024 \text{ W/m-K}) = 0.2646 \text{ m}^2\text{-K/W}$$

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)

$$K_n = \text{length}/R_t = 0.00635\text{m}/0.2646 \text{ m}^2\text{-K}/\text{W} = 0.024 \text{ W}/\text{m-K}$$

$$K_{\text{eff}} = F_b \cdot K_b + F_n \cdot K_n = 0.1053 \cdot 160 \text{ W}/\text{m-K} + 0.8947 \cdot 0.024 \text{ W}/\text{m-K} \\ = 16.869 \text{ W}/\text{m-K}$$

To convert to IP:

$$K_{\text{eff}} = 16.869 * 0.57782 = 9.747 \text{ Btu}/\text{hr-ft-F (or in alternative IP Units: 116.97 Btu-in}/\text{hr-ft}^2\text{-F)}$$