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Proposed Methodology:

Calculation Methodology for Heat Transfer (U-Factor), Center-of-Glass Solar Heat Gain and Visible Light Transmittance of a 6-Layer Glazing Unit

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INTRODUCTION

The following methodology is proposed until the next version of WINDOW program is released, which would be capable of handling more than 5 layers. It is proposed to divide 6 layer glazing system into two three-layer glazing systems, which would be analyzed separately and then results “combined” into the 6-layer solution. The following steps are proposed:

1. Center-of-Glass U-Factor Calculations

The basic glazing unit with 6 glass panes is given in Fig 1. “e” and “i” refer to exterior and interior side respectively. The glass surfaces are numbered 1 through 12 starting from the exterior surface of the 1st glazing unit. q_1, q_2, \dots represent the heat flux in the glazing cavities.

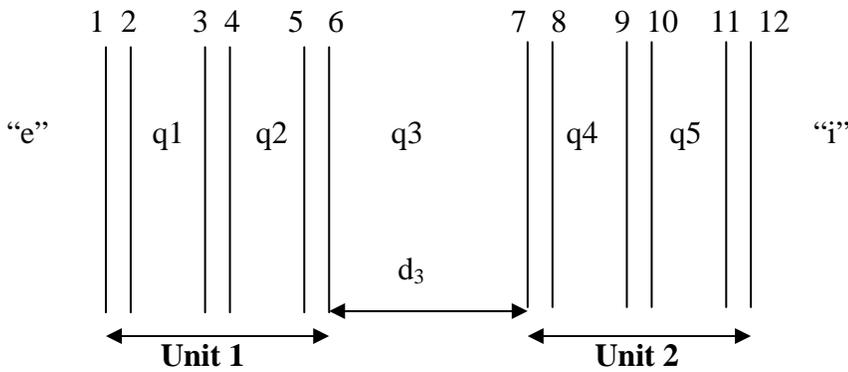
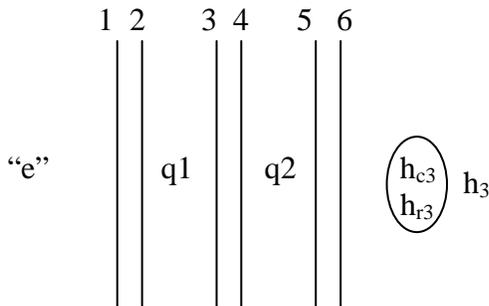


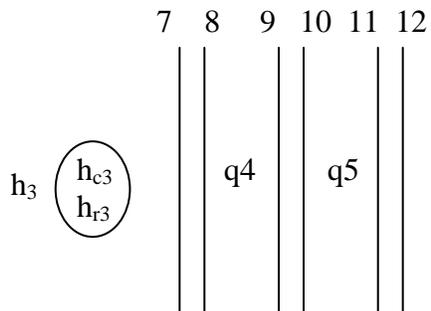
Fig 1. Glazing Unit Configuration

Run 1:



where $h_3 = f(\text{Nu}_3, T_7)$, and is calculated as per section 5, below; T_6 and T_7 temperatures are guessed for the initial calculations.

Run 2:



where $h_3 = f(\text{Nu}_3, T_6)$; T_6 is the temperature calculated in **Run 1**. Please note that h_3 has updated value due to updated temperature T_6 . As a result of this run, temperature T_7 is also calculated and both T_6 and T_7 can be compared to guessed values.

If this difference is larger than certain tolerance (i.e., 0.1 °C), update temperatures T_6 and T_7 and repeat runs 1 and 2 (lets call them runs 1a and 2a) and calculate again temperatures T_6 and T_7 . Compare T_6 and T_7 from runs 1a and 2a with values from runs 1 and 2 and if the tolerance is not met for both values, repeat those runs again with updated temperatures (now they are runs 1b and 2b). Repeat this iterative process (i.e., runs 1n and 2n) until the tolerance is met for both temperatures.

The heat flow through each of these two three layer glazing systems, should be identical once the solution converges. In order to calculate overall U-factor for the complete 6 layer glazing system, it is necessary to divide heat flux with the interior-exterior temperature difference (i.e., 39 °C). To obtain heat flux, one can multiply calculated U-factor for each glazing system with its temperature difference, so the final U-factor for the 6 layer glazing system will be:

$$U = U_1 \frac{T_6 - T_e}{T_i - T_e} = U_2 \frac{T_i - T_7}{T_i - T_e}$$

Where:

U_1 = WINDOW5 calculated U-factor of Unit 1.

U_2 = WINDOW5 calculated U-factor of Unit 2.

2. Center-of-Glass SHGC and VT Calculations

In order to calculate center of glass SHGC and VT for the 6 layer system, we will first calculate solar-optical properties of each three-layer glazing system and then create two dummy glasses each having solar-optical properties from the three-layer glazing system calculation and having conductivity, which is equal to composite conductivity of the three layer system. The overall glazing system SHGC will then be calculated as two layer glazing system, consisting of two dummy glasses created above and air space between the two three-layer glazing systems.

3. Frame and Edge-of-Glass Calculations

The next step is the modeling of frame and edge of glass sections. In order to model 6 layer glazing system in THERM, two three-layers glazing systems (i.e., Units 1 and 2) will need to be inserted as modeled in section 1 (use add glazing system option in Insert Glazing System menu in THERM, when inserting second glazing system). In terms of boundary conditions, automatically transferred boundary conditions from WINDOW 5 should be used for each three-layer glazing unit, while frame sections should be treated in much the same way as with standard THERM calculation (i.e., exterior surfaces should get NFRC 2001 exterior boundary condition and interior frame surfaces should get appropriate interior boundary condition). The only exception is the portion of frame surfaces that lie in between two glazing systems, which should be treated as adiabatic (in much the same way the adiabatic boundary conditions are applied on the spacer surface when condensation resistance model is applied in glazing cavity).

Since THERM accepts lowest and highest temperatures in the model when calculating U-factors, and since the lowest temperature in Unit 1 is -18 °C and highest in Unit 2 is 21 °C, THERM will correctly calculate U-factors using 39 °C temperature differential, so no further adjustments are necessary in THERM calculated U-factors for frame and edge-of-glass regions.

SHGC for frame sections will be calculated in the same way as in standard THERM run, by applying exterior SHGC boundary conditions on exterior surfaces of the frame.

4. Overall Window U-factor Calculations

As WINDOW5 cannot be used for the whole product calculation, due to erroneous U-factors calculated for each of individual glazing units (see section 1 for the procedure to adjust overall U-factor), area weighting calculations need to be done outside of WINDOW 5 (e.g., spreadsheet) for calculating the whole product U-Factor.

Overall product SHGC will be calculated, along with U-factor using the same area weighting procedure outside WINDOW 5.

5. h_{c3} and h_{r3} calculations:

h_{c3} and h_{r3} can be calculated using the following equations (ISO15099):

$$h_{c3} = Nu_3 \left(\frac{\lambda_3}{d_3} \right) \quad (1)$$

where d_3 is the thickness of the fill gas layer (or pane spacing between layer 3 and 4 (Fig1) and λ_{3i} is the thermal conductivity of the fill gas. Nu_3 is calculated using the following correlations based on experimental measurements:

The Rayleigh number can be expressed as:

$$Ra = \frac{\rho^2 d_3^3 g \beta C_p \Delta T}{\mu \lambda} \quad (\text{dimensionless}) \quad (2)$$

Treating the fill gas as a perfect gas the thermal expansion coefficient of the fill gas, β , is:

$$\beta = \frac{1}{T_m} \quad (3)$$

where T_m = fill gas mean temperature (K)

The aspect ratio of the fill gas cavity, is:

$$A = \frac{H}{d_3} \quad (4)$$

where H is the distance between the top and bottom of the fill gas cavity which is usually the same as the height of the window view area.

For vertical cavity, like in this case, Nu_3 can be calculated using the following correlation.

$$Nu_3 = [Nu_1, Nu_2]_{\max} \quad (5)$$

$$Nu_1 = 0,0673838 Ra^{1/3} \quad 5 \times 10^4 < Ra \quad (6)$$

$$Nu_1 = 0,028154 Ra^{0,4134} \quad 10^4 < Ra \leq 5 \times 10^4 \quad (7)$$

$$Nu_1 = 1 + 1,7596678 \times 10^{-10} Ra^{2,2984755} \quad Ra \leq 10^4 \quad (8)$$

$$Nu_2 = 0,242 \left[\frac{Ra}{A_{g,i}} \right]^{0,272} \quad (9)$$

And hr_3 is calculated as:

$$h_{r,3} = \frac{\varepsilon \sigma (T_7^4 - T_6^4)}{T_7 - T_6} \quad (10)$$

Where

$$\varepsilon = \frac{1}{\frac{1}{\varepsilon_7} + \frac{1}{\varepsilon_6} - 1}$$