VISION: A COMPUTER PROGRAM FOR THE DETAILED SIMULATION OF THE THERMAL PERFORMANCE OF INNOVATIVE GLAZING SYSTEMS

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Summary

VISION is a computer program that was initially developed for the National Research Council of Canada. This program is capable of modelling a wide variety of innovative glazing systems. VISION has evolved into a design tool that can be run on an IBM/PC. U-values and shading coefficients predicted by VISION were compared to a variety of measured and published data. VISION results and measured results agreed well. Discrepancies were smallest in cases where test sample properties were measured directly and the results used as input for the simulation.

Résumé

VISION est un système informatique qui a été développé initialement pour le Conseil de Recherche National du Canada. Ce programme-ci a l'abilité de simuler une grande variété de systèmes innovatifs de vitrages. VISION a évolué un outil de dessin qui peut être employé avec le système IBM/PC. Les valeurs "U" et coefficient antisolaire déterminées par VISION ont été comparées à une variété d'informations établies et publiées. Les résultats de VISION et les résultats mesurés étaient en accord. Les différences entre les deux groupes étaient les plus petits dans les cas où les caractéristiques des épreuves experimentales ont été mesurées directement et les résultats ont été utilisés comme information pour la simulation.

Kurzfassung

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Introduction

In light of the increasingly complex nature of glazing system design as well as the fundamental differences in infrared (IR) properties of some of the plastic films and coatings now being incorporated it has become apparent that conventional prediction methods are no longer adequate. In order to support the research effort of the National Research Council of Canada (NRCC) a glazing system computer program called VISION (1) was developed. VISION is capable of calculating U-values and shading coefficient (SC) for ASHRAE winter and summer design conditions plus user specified design conditions. A detailed hour-by-hour energy analysis can also be carried out. Glazing system features that can currently be modelled are shown in Table 1.

Table 1. Capabilities of the VISION glazing system analysis program

- Up to 6 glazings
- Tilt from 0 to 180°
- Substitute fill gasses and gas mixtures
- IR transparent glazings
- Asymmetric optical properties for any glazing
- Side fin, overhang and setback shading at any tilt
- Partial or hard vacuum
- Honeycomb convection suppression
- Input library for optical properties of glazings
- Graphic output

VISION has been used as the basis of a variety of studies. These include the development of a simplified seasonal thermal performance calculation method(2,3), the illustration of basic heat transfer characteristics unique to a specific class of glazing system(4) and the comparison of a selection of commercially available and prototype glazing systems(5,6). VISION has also been used in a modified form to research glazing systems that are particularly difficult to model(7).

Most recently, the VISION software has been undergoing development at the University of Waterloo. Recent modifications include a revised method for calculating U-value and shading coefficient, user specified
design conditions, an input library for optical properties of various glazings and graphic output.

Three research studies provide a comparison between VISION results and a variety of measured and published data. Laboratory results involve the use of the University of Waterloo Natural Convection Apparatus (8) to measure the heat flux across air layers containing Teflon film and bounded by plates of various emissivities. Heat transfer measurements have also been made across glazing systems with Teflon films used in conjunction with reflective metal coatings. Simulations were also carried out to check agreement of U-values and SC with figures reported by manufacturers for a number of commercially available glazing systems as well as glazing systems undergoing development (5).

**Recent Modifications**

VISION was designed to calculate U-value and SC for the ASHRAE winter and summer design conditions. These conditions are shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Inside Temperature (°C)</th>
<th>Outside Temperature (°C)</th>
<th>Wind Speed (m/sec)</th>
<th>Solar Radiation (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>21</td>
<td>-18</td>
<td>6.7</td>
<td>0</td>
</tr>
<tr>
<td>Summer</td>
<td>24</td>
<td>35</td>
<td>3.3</td>
<td>783</td>
</tr>
</tbody>
</table>

Under the winter design condition no solar radiation is incident. Therefore, it is not possible to calculate a shading coefficient and the U-value is found simply by dividing the heat flux from the building interior to the indoor glazing, \(-Q_1\), by the indoor/outdoor temperature difference. Figure 1 shows the location of various heat flux quantities as well as other details regarding the nomenclature.

![Figure 1. Glazing System Thermal Analysis Geometry](image-url)
Under the summer condition, solar radiation is present and the calculation is more complex. VISION, in its original configuration, could treat this situation by modelling a glazing system under two separate conditions. First, the summer condition was simulated but the solar radiation was set to zero. In this case the U-value was calculated in the same manner as it was for the winter condition. Second, the glazing system was modelled with solar radiation present but with the indoor/outdoor temperature difference set to zero. In this case the heat flux due to the indoor/outdoor temperature potential was taken as zero and the solar gain was equated to the sum of the directly transmitted solar radiation plus the total heat flux from the indoor glazing to the building interior, $Q_1$. Consequently, this solar gain could be used to calculate shading coefficient.

Recently, VISION was modified so that it can calculate both U-value and SC by simulating a single environmental condition involving indoor/outdoor temperature difference and incident solar radiation simultaneously. In order to carry out this calculation it is necessary to divide the heat flux from the indoor glazing to the building interior, $Q_1$, into two components - one that is driven by indoor/outdoor temperature difference and the other that results from the presence of solar radiation absorbed at each of the various glazings. The amount of solar radiation that is absorbed at the $i$th glazing, $S_i$, is calculated using the embedding technique of Edwards (9). The portion of $S_i$ that eventually finds its way to the building interior, $N_i$, is calculated according to the following method.

$$ N_i = \frac{n^{-1} \sum_{j=i}^{n-1} R_j}{R_{\text{tot}}} $$  \hspace{1cm} (1)

where the total thermal resistance is:

$$ R_{\text{tot}} = \frac{n^{-1} \sum_{i=1}^{n-1} R_i}{R_{\text{tot}}} $$  \hspace{1cm} (2)

and the thermal resistance between node $i$ and $i+1$ is:

$$ R_i = \frac{(T_{i+1} - T_i)}{Q_i} $$  \hspace{1cm} (3)

The total amount of incident solar radiation that makes its way to the building interior, $Q_{\text{sol}}$, is:

$$ Q_{\text{sol}} = \frac{n^{-1} \sum_{i=1}^{n-1} N_i S_i}{Q_{\text{sol}}} $$  \hspace{1cm} (4)

Finally, the shading coefficient is found using:

$$ SC = \frac{Q_{\text{sol}}}{Q_{\text{ref}}} $$  \hspace{1cm} (5)

where $Q_{\text{ref}}$ is equal to $Q_{\text{sol}}$ calculated under the same environmental conditions but for a reference single glazing. The U-value is given by:

$$ U = 1 / R_{\text{tot}} $$  \hspace{1cm} (6)
VISION provides the opportunity of modelling user specified conditions. Therefore, it is possible to calculate the summer U-value or shading coefficient according to the older method by specifying the ASHRAE summer condition while setting either the solar radiation or the indoor/outdoor temperature difference to zero, respectively.

When describing a glazing system it is possible to draw optical data from a library of glazing data files. This library resides in the computer storage. If data for a particular glazing does not exist in the library it is possible to enter the information manually and have it recorded. In this manner, a glazing system designer can gradually build a data bank and data pertaining to any one glazing is typed at the keyboard only once.

A VISION output file provides a detailed description of the glazing system as well as a variety of simulation results including U-value and SC. It is possible to produce graphic output on an HP-7470A or HP-7475A plotter. The graphic output is designed to supplement - not replace the output file. An example of plotted output for an argon filled glazing system is shown in Figure 2. The temperature profile is shown super-imposed on the glazing system cross-section. Incident solar radiation and the various amounts of absorbed solar radiation, S_i, are shown above the glazing profile. The heat transfer quantities, Q_i, their components and their flow directions are shown below the glazing profile.

**Validation/Comparison**

VISION incorporates a two band analysis in order to model the solar (λ < 3μm) and thermal* (3μm ≤ λ < 50μm) optical properties of a glazing system. In each of these wavelength bands optical properties are assumed to be grey. Because of the importance of the grey assumption it was decided to compare experimental results with simulation results.

Seven heat transfer tests were completed using the University of Waterloo Natural Convection Apparatus (8). This apparatus consists largely of a pair of parallel copper plates that can be maintained at different but constant temperatures. The warmer plate contains a guarded heater plate making it possible to measure the heat flux across the air layer between the two plates. The thermal resistance measured in this manner corresponds to the glass-to-glass resistance of a glazing system and includes neither the thermal resistance that exists between a window and its environment nor the experimental difficulty of providing reproducible film coefficients.

The corresponding simulations were carried out using a computer program called NFILM (10,11). NFILM is a forerunner of the thermal analysis model that is used in VISION.

The seven experiments were carried out by placing a sheet of Teflon! (FEP) film (0.0254 mm thick) centrally in a horizontal air

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* "infrared"(IR), "thermal" and "long-wave" are used interchangeably to describe wavelengths greater than 3 μm.

! Registered trademark of E.I. DuPont de Nemour and Co.
ASHRAE Summer Design Condition

Fill Gas: 2

Beam 783.0 (0. deg)
Diffuse .0
Clouds 100. %
Winds 3.35 m/s

SOLAR RADIATION (W/m²)

HEAT FLUX (W/m²)

Tot. 177.6
Rad. 45.6
Con. 10.4

U = 0.83 W/m²°C (R 6.9)  SC = .51

Figure 2. Sample Graphic Output from VISION
layer bounded by two polished copper plates. The test was repeated with one copper plate blackened and then with both plates blackened. In each case the hemispherical emissivities of the plates, $\varepsilon_{\text{hot}}$ and $\varepsilon_{\text{cold}}$, were measured using a Gier-Dunkel DB-100 Infrared Reflectometer. The air layer was heated from above to ensure that the air remained stagnant.

The long wave hemispherical optical properties of the Teflon film were estimated using optical properties for normal radiation which were measured and reported by Wilkinson (12). The hemispherical film properties were as follows: $\alpha_f=0.243$ and $\tau_f=0.634$.

The comparison between theory and experiment for the stagnant air layer was excellent, generally within 2%. The full set of results is reported in Table 3.

Table 3. NFILM Prediction versus Experimental Results

<table>
<thead>
<tr>
<th>$T_{\text{hot}}$ (K)</th>
<th>$T_{\text{cold}}$ (K)</th>
<th>Plate Spacing (mm)</th>
<th>$\varepsilon_{\text{hot}}$</th>
<th>$\varepsilon_{\text{cold}}$</th>
<th>$h_{\text{meas}}$ (W/m$^2$K)</th>
<th>$h_{\text{NFILM}}$ (W/m$^2$K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>308.4</td>
<td>299.2</td>
<td>19.18</td>
<td>0.065</td>
<td>0.065</td>
<td>1.61</td>
<td>1.59</td>
</tr>
<tr>
<td>303.2</td>
<td>292.0</td>
<td>19.30</td>
<td>0.065</td>
<td>0.889</td>
<td>2.08</td>
<td>2.06</td>
</tr>
<tr>
<td>304.9</td>
<td>292.1</td>
<td>19.30</td>
<td>0.065</td>
<td>0.889</td>
<td>2.05</td>
<td>2.07</td>
</tr>
<tr>
<td>308.4</td>
<td>291.4</td>
<td>19.30</td>
<td>0.889</td>
<td>0.889</td>
<td>2.08</td>
<td>2.08</td>
</tr>
<tr>
<td>310.9</td>
<td>293.2</td>
<td>19.30</td>
<td>0.889</td>
<td>0.889</td>
<td>5.38</td>
<td>5.34</td>
</tr>
<tr>
<td>304.6</td>
<td>292.6</td>
<td>19.30</td>
<td>0.889</td>
<td>0.889</td>
<td>5.23</td>
<td>5.19</td>
</tr>
<tr>
<td>300.6</td>
<td>292.5</td>
<td>19.30</td>
<td>0.889</td>
<td>0.889</td>
<td>5.18</td>
<td>5.10</td>
</tr>
</tbody>
</table>

More recently, ten U-value measurements were made for glazing systems containing either zero, one or two intermediate Teflon panes used in conjunction with either a gold or copper metal coating on one of the adjacent glass surfaces. The windows were vertical, the fill gas was air and the emissivity of the reflective surfaces was measured using the Gier Dunkel infrared reflectometer. The agreement between measured and simulated heat transfer rates was very good with discrepancies ranging as high as 7.6% but remaining under 3% in the majority of cases. Further details are available in a companion paper presented at this conference(13).

In a third study, nine glazing system designs were modelled using VISION. Estimates of U-value and SC were assembled from product literature and other studies. Glazing system designs ranged from a conventional double glazed system to a double glazed system containing silica aerogel. Detailed information regarding the various glazing systems and comparison results can be found in references (5) and (14).

In general, VISION results were found to be in good agreement with the available published data. The U-value estimates for most of the windows were within 10% of the published data. However, the U-values estimated for the two windows containing inner plastic glazings with low emissivity coatings were 15% and 30% high. Further investigation revealed that the long wave optical properties of this plastic glazing that had been measured and used in the simulation differed significantly from those claimed by the manufacturer. When the simulations were rerun

...
using the manufacturers optical data the VISION results agreed well with the U-values claimed by the manufacturer.

The discrepancy between calculated and published shading coefficients was consistently less than 3%.

Conclusions

VISION results and measured results agree very well. Discrepancies were smallest in cases where input variables (eg. surface emissivities, pane spacings, etc.) of the specific test samples were measured directly.

VISION has been shown to be a highly reliable research and design tool. It is useful not only for parametric and sensitivity investigations but can also be used with confidence to estimate U-values and shading coefficients of specific glazing systems.

References


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