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Using of Gambit 2.0 and Fluent 6.0 software for 3-Dim heat transfer window modeling

Laboratory report, A. I. F.

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It is not tutorial but guideline and introduction in amazing world of 3-Dim fenestration modeling.

In this report we describe our experience of creating 3-Dim model of Marvin Picture Wood (PFM) window using defined AutoCAD's drawing of a frame cross-section and data of glazing unit. We compare obtained simulation results with Therm's [1] results under the same boundary conditions. This report can be useful during 3-Dim modeling of another similar windows.

1. Creating of geometry and meshing of the window model

1.1 The geometric dimensions and boundary conditions

We defined the general geometric window dimensions for casement single window and boundary conditions according to NFRC 100 standard [2]. Figures 1 and 2 show geometry and boundary conditions of the PFM window used in the modeling. We consider a three-dimensional symmetrical representation of the window.

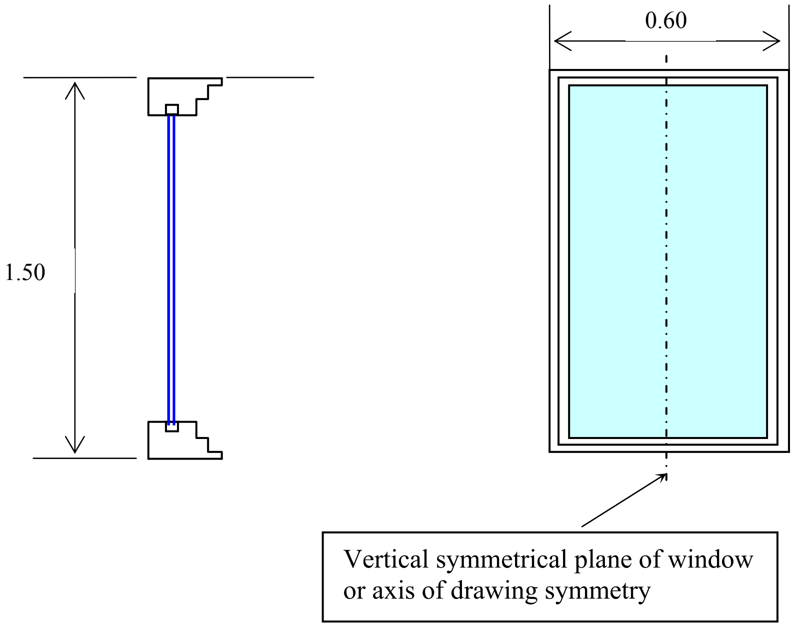

Figure 1. Geometry and dimensions of the modeled window (not to scale).

So far as geometry of the window is symmetrical and effect of environment on heat transfer through window also is symmetrical relative to vertical middle line (Fig. 1) we modeled only half of the window that is reflected in the boundary conditions (Figure 2).

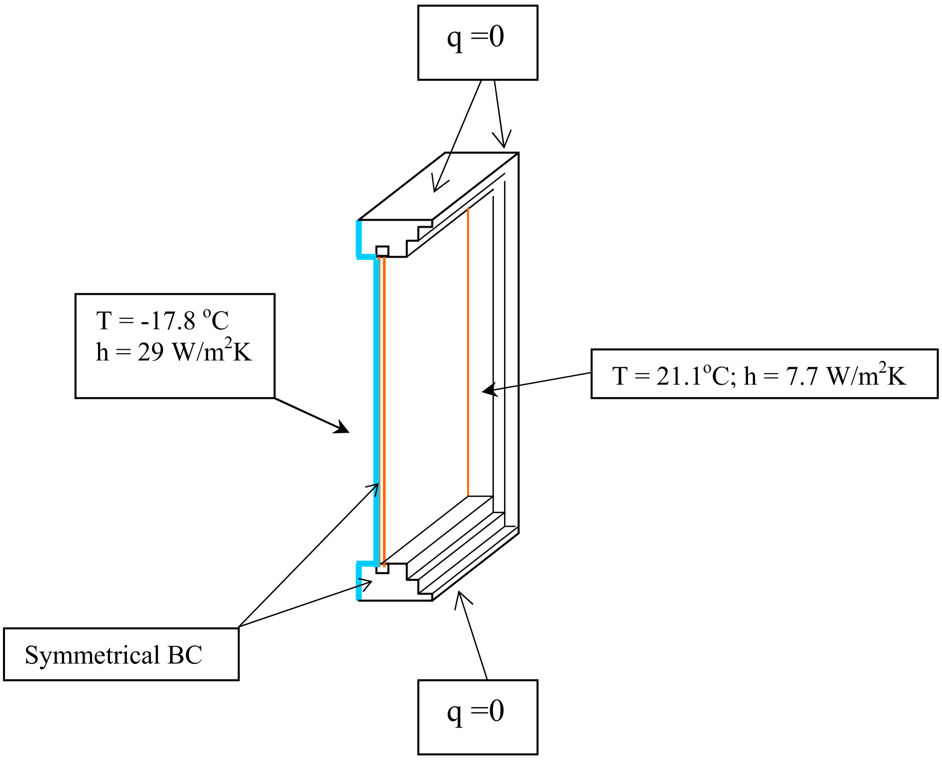

Figure 2. Boundary conditions of the modeled window.

1.2 Import geometry of a frame cross-section to GAMBIT.

To import geometry of frame section we used ACIS file created and exported by AutoCAD from accessible DXF file contained necessary geometric information.

STEP 1. *Creating ACIS file in AutoCAD.*

To form closed planar loops (faces) in imported drawings (DXF/DWG files) it needs to apply command ***Region.*** AutoCAD converts closed 2D and exploded planar 3D polylines in the selection set to separate regions and then converts polylines, lines, and curves to form closed planar loops (outer boundaries and holes of a region). The boundary of the region consists of end-connected curves where each point shares only two edges. Then command ***Export/ACIS***-file is executed.

STEP 2. *Importing ACIS file in GAMBIT.*

To import an ACIS file it needs to use **Import ACIS File** form (GAMBIT User's Guide, section 4.1.9 Import [3]).

STEP 3. *Cleaning up imported geometry.*

The imported geometry often contains entities (faces, edges and vertices) placed on the top of other entities. Duplicate entities need to be removed before resumption of any other work in GAMBIT.

There are some simple useful rules for cleaning up stage:

- Each edge may contain only couple of vertices that constitutes its end points.
- Any couple of vertices must be belonged to one and only **one edge** (faces adjacent to such edge are named **connected**).
- All faces in the model must **be connected**.

The sample of imported in GAMBIT geometry of PFM window frame cross-section is shown in Figure 3. Glazing edges are deleted.

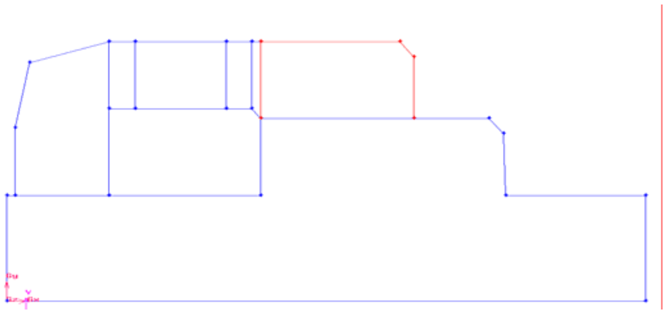

Figure 3. Gambit's representation of geometry of PFM window frame cross-section.

1.3 Components of 3-Dim window model.

The process of creating and assembly of 3-Dim window model has many features similar to process of manufacturing of real windows. In Figure 4 we show components of future window model that must be created and assembled.

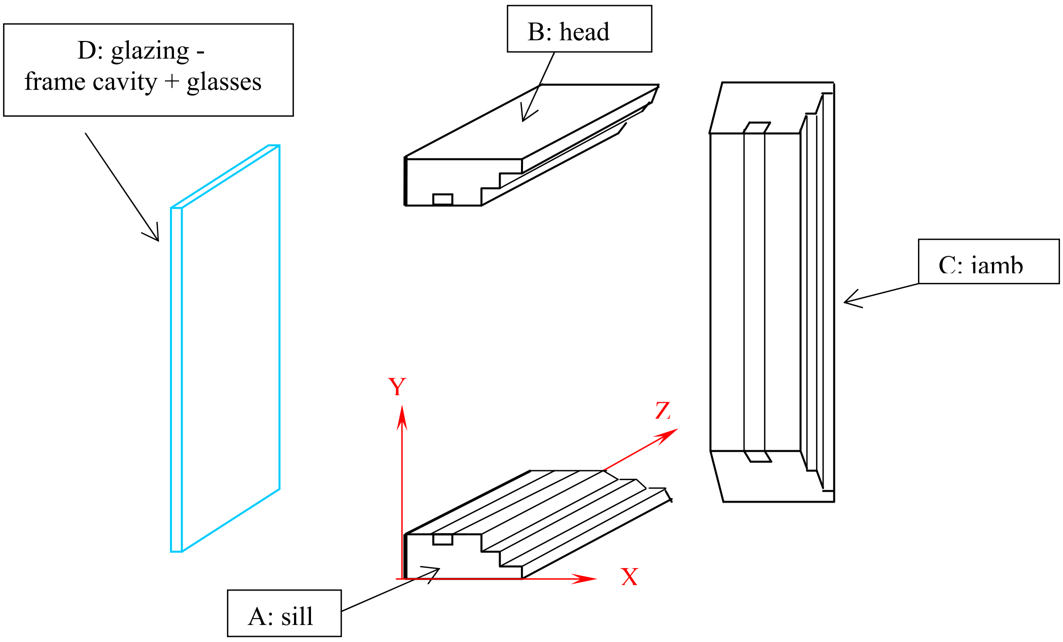

Figure 4. Components of the window model and the order of ones creating.

1.4 Creating 3-Dim components of the window model.

A: Sill

To create part **A** of the window model (see Figure 4) we used GAMBIT's volume command/form ***Sweep Real Faces*** along axis Z on 0.15 m (analogue operation in the frame manufacturing names extrusion).

The next operation is the cutting of the extrusion end at angle 45°. To cut volumes it needs beforehand to create cutting tool – rectangle face at angle 45° to horizontal plane (XOZ) and translate it in the end of the extrusion. We used command/form ***Split Volume* by face** to split each volume in extrusion and command/form ***Delete*** to delete cut parts of the extrusion.

Now the extrusion (part A) is ready for meshing that need to begin by meshing of the faces of initial frame cross-section profile. It needs to keep in mind that spacer edge faced to future glazing cavity must has fine mesh for adequate modeling convection in cavity. An example of meshed frame cross-section profile is shown in Figure 5.

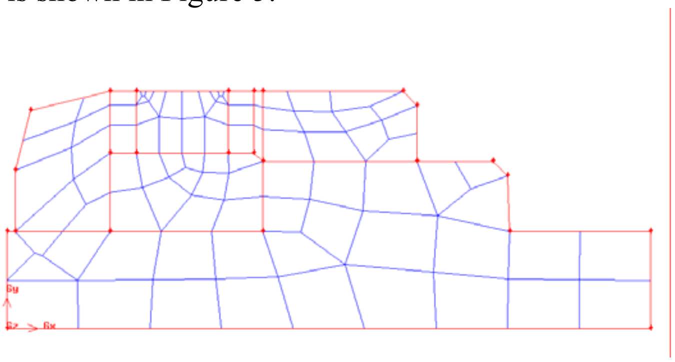

Figure 5. Meshed PFM window frame cross-section profile.

The next step is mapping of all faces parallel to axis Z that needs to begin by grading edges along axis Z. In described case of PFM window number of intervals along edges was 7. For meshing of extrusion volumes we used a Cooper meshing scheme. The mesh of the sill and glazing parts of the window model are depicted in Figure 6.

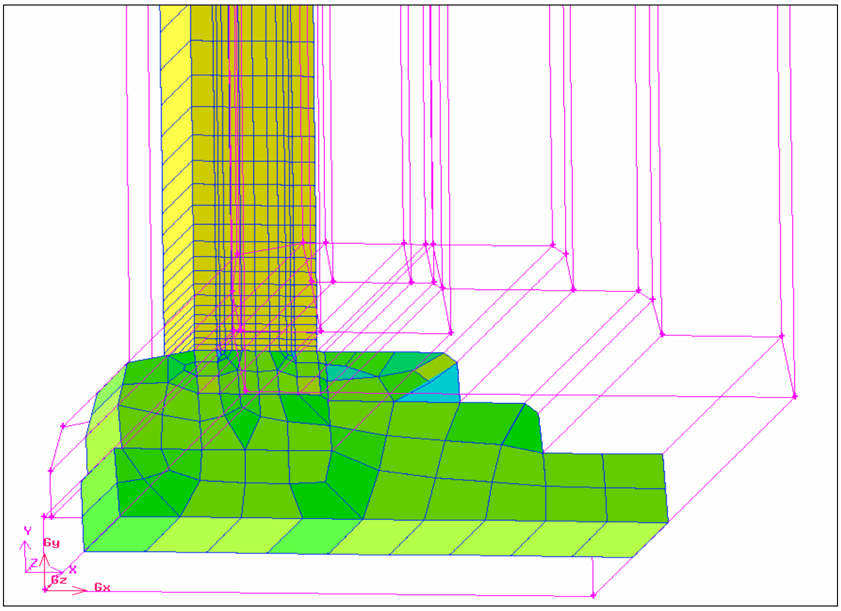

Figure 6. Elements of the PFM model mesh.

B: Head

To create part **B** – head of the window model (see Figure 4) we used the following commands: ***Copy*** part **A**, ***Reflect*** with respect to plane XOZ and ***Translate*** at 1.5 m along axis Y.

C: Jamb

To create part **C** – jamb there are several possible ways:

- It needs to connect corresponding vertices of the sill and head; then create faces and volumes of the jamb. It is very simple and long but reliable way.
- The second way is to sweep frame cross-section profile at 1.5 m, then cut both ends of the extrusion at angle 45^{o} and translate this part of the window model in the place of window jamb. It needs also to connect all faces of the jamb cuts with corresponding faces of head and sill.

We used the second way to create and place the jamb of the window model. Meshing of the jamb can be delayed until creating and meshing of the glazing.

D: Glazing

To create part D – glazing it needs to connect corresponding vertices of the sill and head and define faces and volumes of the glasses and glazing cavity. For meshing of the glazing cavity we used parameters pointed in Table 1.

Table 1. Meshing parameters of the glazing cavity dimensions

Mesh grading parameter	**Width (axis X)**	**Height (axis Y)**	**Depth (axis Z)**
Interval count (number)	10	80	7
Last First Ratio	4	50	2

The grading parameter for cavity height was used for meshing jamb of the window model. For meshing of the glazing cavity we used a map scheme and a Cooper meshing scheme for jamb. The mesh of the jamb and glazing of the window model are shown in Figure 7 and Figure 8.

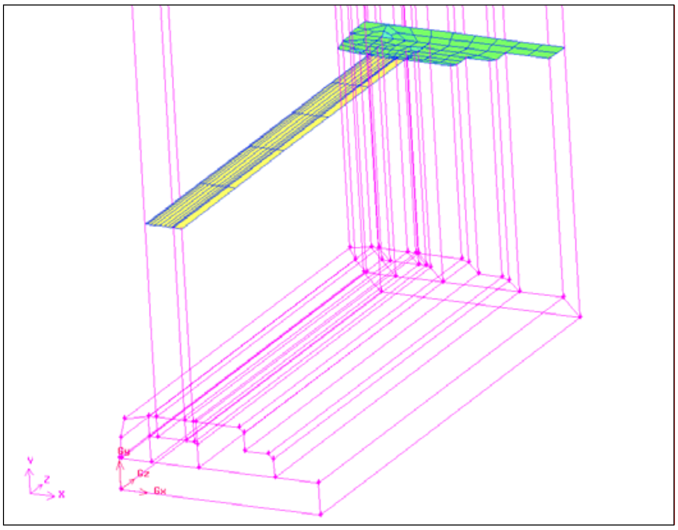

Figure 7. Horizontal section of the window model.

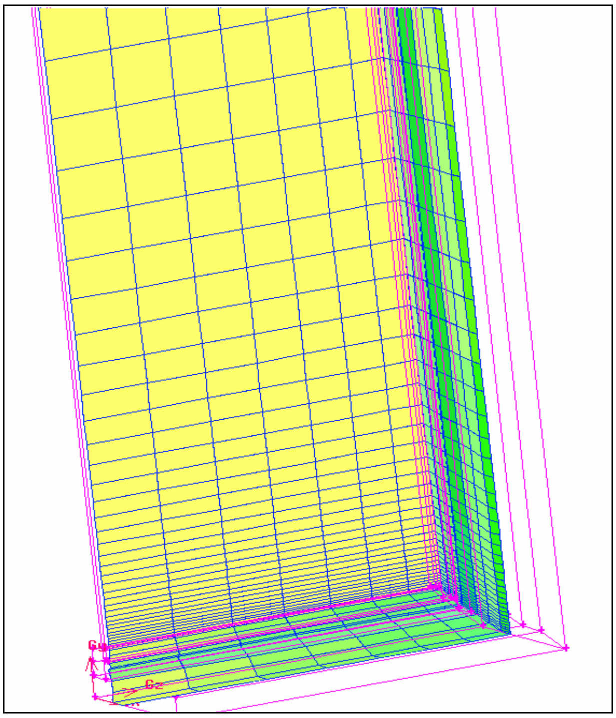

Figure 8. Vertical section of the window model.

2. Getting results in Fluent.

Our PFM window 3-Dim model has about 14000 mesh elements and had been eaten by Fluent without any problem. View of the model is shown in Figure 9 (used form Grid, options: faces, light on).

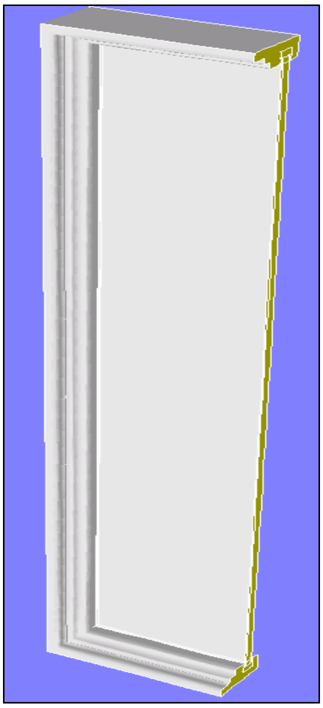

Figure 9. PFM window model in Fluent.

2.1 Defined material properties and boundary conditions.

In the window model we used material thermo-physical properties given in Table 2.

Table 2. Material thermo-physical properties

Material/Component	Conductivity, W/(m-K)	Emissivity
Pine or Douglas Fir	0.14	
Glass	0.90	0.84
Glass with low ε coating	0.90	0.16
Polyfoam tape	0.24	
Spacer	1.29* eff.	0.90
Frame cavity	0.128* eff.	

*Note: Effective conductivity values were calculated by THERM 5 [1].

Boundary conditions were defined according to scheme in Figure 2.

2.2 Solution procedure.

We used segregated solver with the next settings: implicit formulation, steady calculation, energy equation and default laminar viscous model.

Radiation model was defined as Discrete Transfer Radiation Model (DTRM) with angle parameters: theta divisions 4, phi divisions 8.

Solution controls: under-relaxation factors (RF) for all equations (variables) were defined as default.

Method discretization: pressure equation – PRESTO; pressure-velocity coupling – SIMPLEC; momentum – POWER LAW; energy – first order scheme.

The solution reached convergence after approximately 120 iterations. Real time of calculation was about 12 min.

2.3 Results.

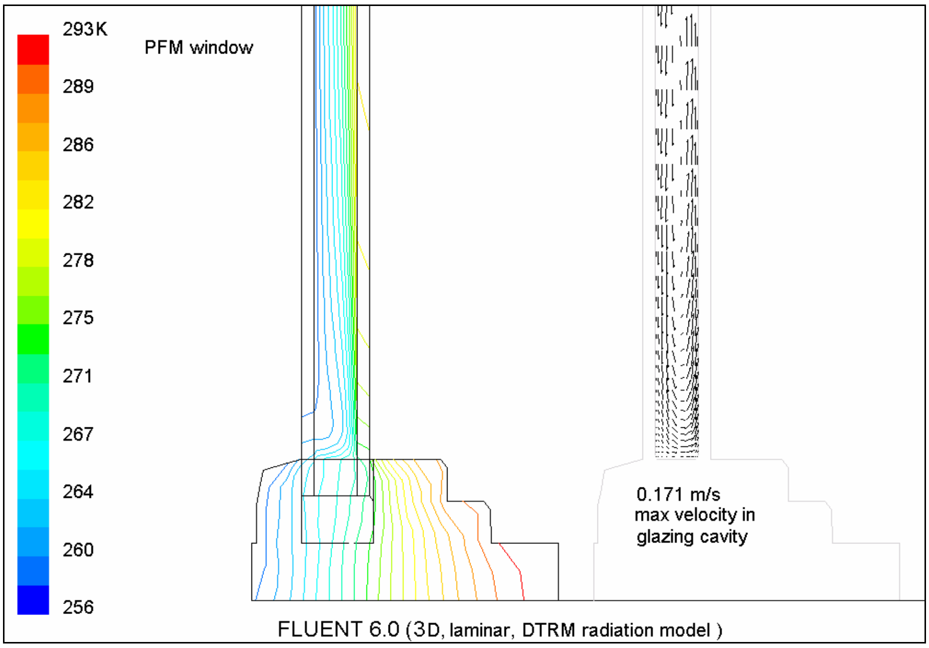

Figure 10. Temperature and velocity fields in vertical section of the window model.

Temperature distribution and velocity vector field in the vertical section plane near the symmetry plane (see Fig. 1) of the window model are shown in Figure 10. Isotherms and filled temperature contours on inside surface of glazing are shown in Figure 11 and are very similar thermograph pictures but more precisely of course.

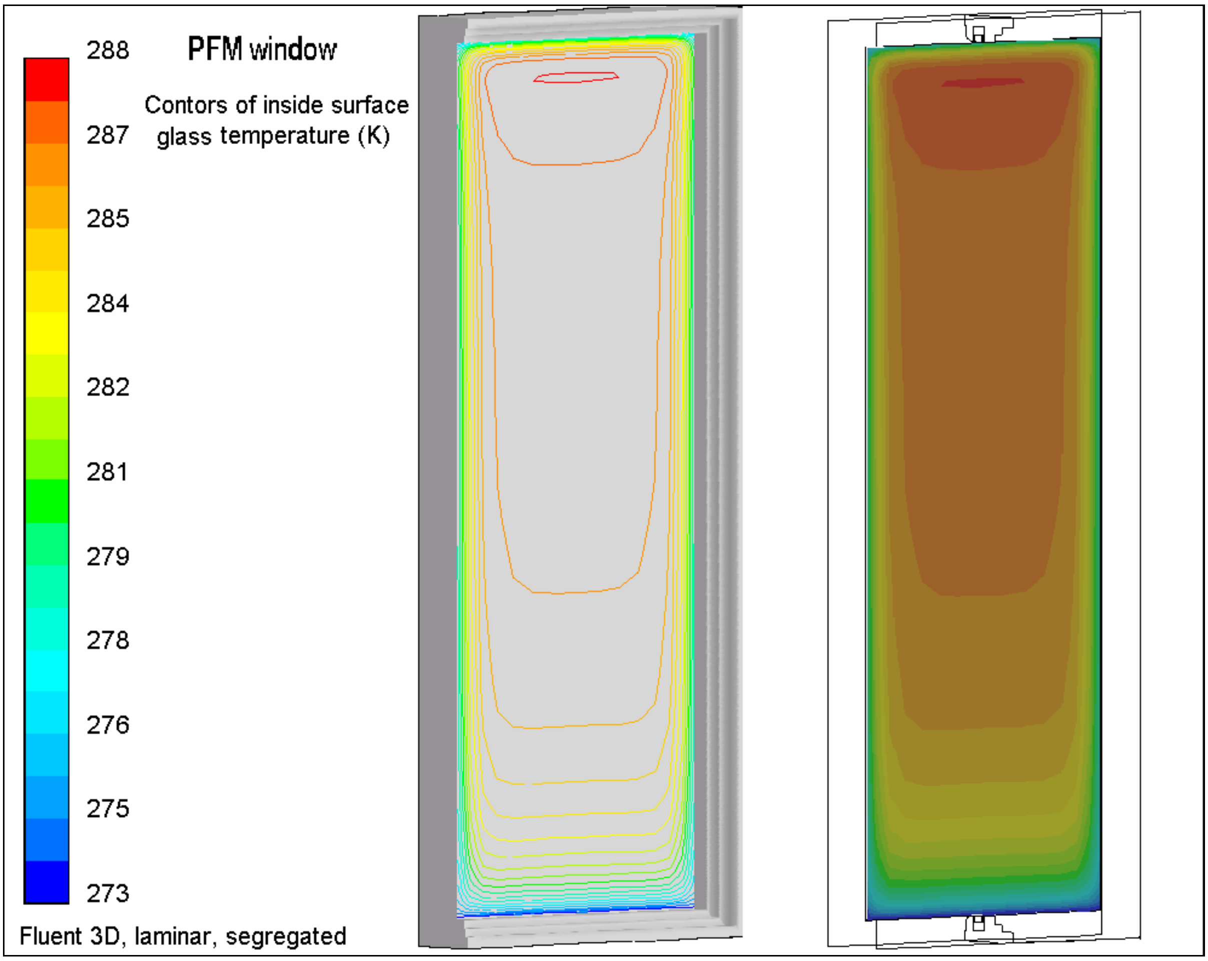

Figure 11. Isotherms and filled temperature contours on inside surface of window glazing.

But it is pictures useful only for quality analysis. Quantity analysis of obtained results and getting new knowledge about research object is possible when we compare our results with previous ones.

On the next page in Figure 12 we give comparison of temperature distribution on inside surfaces for 2-Dim and 3-Dim PFM window models (for 3-Dim model only for glazing). It is obviously that in the vertical middle plane (vertical symmetrical plane of window, Figure 1) we can expect a good agreement between 2-Dim and 3-Dim models. But in the edge area of glazing (1 cm from the jamb) surface glazing temperature is lower then in the middle part on 5.5 ^{o}C.

Comparison of overall U-factors for both models of PFM window are given in Table 3. Difference is about 2%.

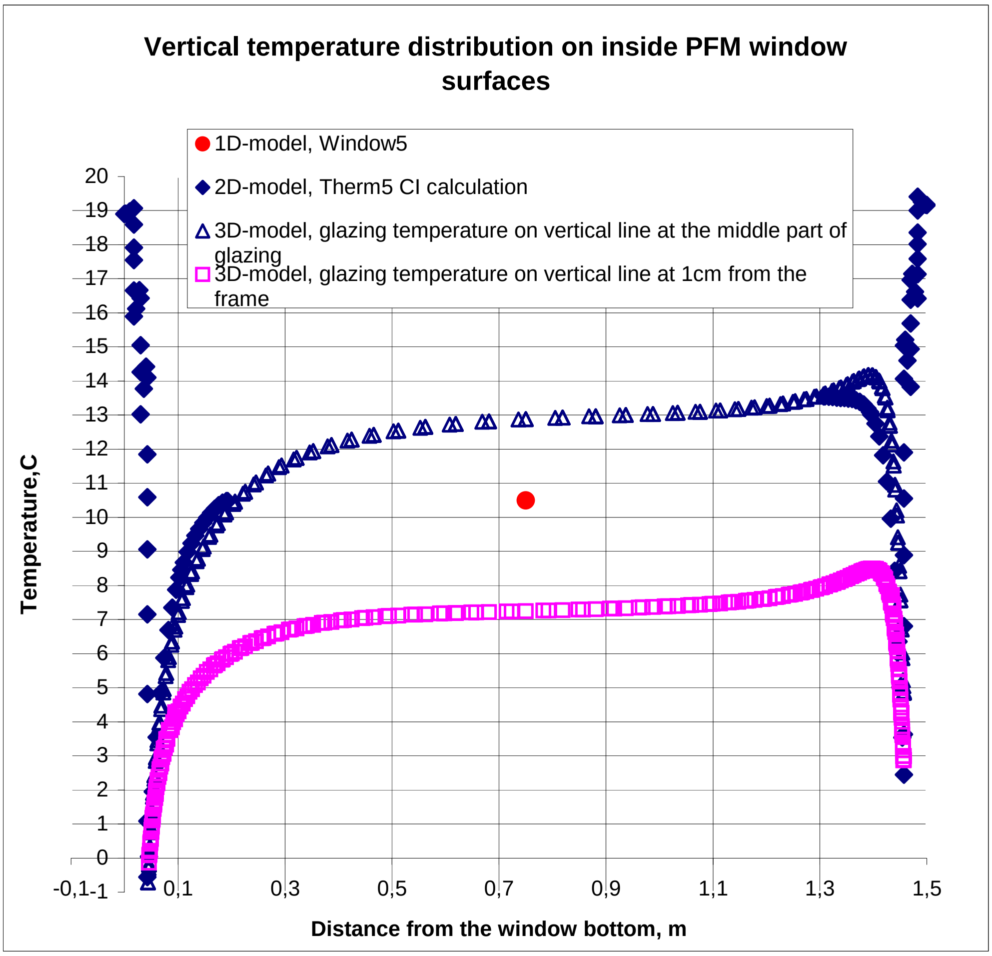

Figure 12. Comparison of temperature distribution on inside surfaces for 2-Dim and 3-Dim window models.

Table 3. Comparison of overall U-factors for PFM window.

Model & modeling tools	**U-factor, W/(m^2K)**
2-Dim, Therm 5 + Window 5 (CI case)	2.007
3-Dim, Gambit 2 + Fluent 6	1.965

3. Conclusions

In this report was described our experience of creating 3-Dim model of Marvin Picture Wood (PFM) window using software Gambit 2.0 and Fluent 6.0 as modeling tools and AutoCAD’s drawing of a frame cross-section and glazing unit as sources of geometry datum. Results of the model calculation compare very well with Therm 5 results under the same boundary conditions.

Described approach can be used for 3-Dim modeling of another fenestration products with symmetrical geometry relative to middle vertical plane. This report can be also considered as the first step of development of 3-Dim fenestration modeling manual.

References

1. THERM 5. A PC Program for Analyzing Two-Dimensional Heat Transfer Through Building Products. 1995-2002. LBL.
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3. FDI 2000. “Gambit 1.3.2 Users and Reference Manual”. Fluid Dynamics International, Fluid Dynamics Analysis Package Revision 1.3.2, Evanston, IL.
4 FDI 2001. FLUENT 6.0. Users and Reference Manual. Fluid Dynamics International, Fluid Dynamics Analysis Package. Fluent Inc. November 2001.