TECHNICAL REPORT

Computer Modeling of Commercial Aluminum Framing Systems – U-Factor and Temperature Distribution

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This report consists of simulation study of typical commercial windows. The results are presented for NFRC Testing Round Robin 1999, 2000 and different Aluminum framing site built products.

1. Computer Modeling of Heat Transfer For NFRC 1999-2000 Testing Round Robin Window – U-Factor and CI Simulations

The Round Robin 1999 and 2000 were for typical commercial windows. The product selected for testing is a nominal 60''x36" horizontal slider window with Aluminum frame. Schematic representation of the window is shown in Fig. 1. Window 4.1 has been used to create the glazing system. The glazing unit consists of two panes of 0.129" sheets of clear PPG glass separated by a 0.003" thick heat mirror with coating on the inner side (ε=0.088) and two air spaces each of 0.244". The outer surface of inner glass has selective coating (ε=0.088).

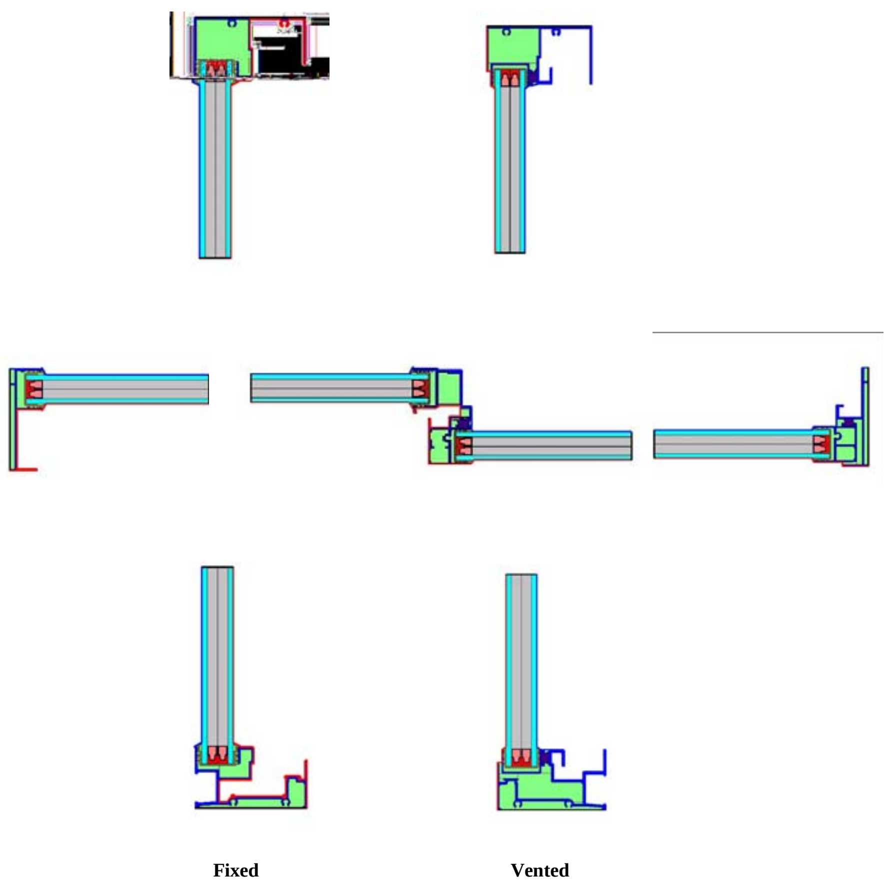


Fig. 1: Schematic Representation of Head, Jamb, Meeting Rail and Sill Cross-Section of whole Fenestration System

Table 1 shows the U factor for different sections and whole window assembly with and without the use of Radiation enclosure model in THERM.

Table 1: Frame, Edge and Overall U-factors (Btu/h-ft^2-F)

	Without Radiation		*With Radiation*	
Cross Section	*U-factor of frame*	*U-factor of edge-of-glass*	*U-factor of frame*	*U-factor of edge-of-glass*
Fix Head	2.455	0.386	1.727	0.361
Fix Sill	3.635	0.408	2.726	0.387
Fix Jamb	2.674	0.387	2.313	0.362
Meeting Rail	2.822	0.413	2.078	0.404
Vented Head	1.382	0.469	1.274	0.464
Vented Sill	1.374	0.470	1.268	0.464
Vented Jamb	1.345	0.468	1.241	0.461
	Overall U factor		Overall U factor	
Center of Glass	**0.31**		**0.31**	
Window Assembly	**0.615**		**0.549**	
Measured Average	**0.560**			

It is clear from the table that U factor changes significantly with the use of radiation enclosure and that the measured U-Factor, reported as an average of all the participating laboratories compares well with this value. The variation for individual component is as high as 25% while the overall U factor changes by about 10%.

Figs 2 and 3 show the temperature distribution along the fixed and vented parts respectively. The middle point in the graph corresponds to the center of glass temperature. Distance at X-axis corresponds to either the bottom of sill section to the top of the head section. Fig. 4 shows the distribution horizontally, starting from the fixed jamb through the meeting rail up to the vented jamb section.

Figs 2 through 4 also show some average value taken from Round Robin inter-laboratory test results for the same window. As Round Robin 2001 is inter-laboratory test results for the same window, the average values from these test results have also been plotted in these figures.

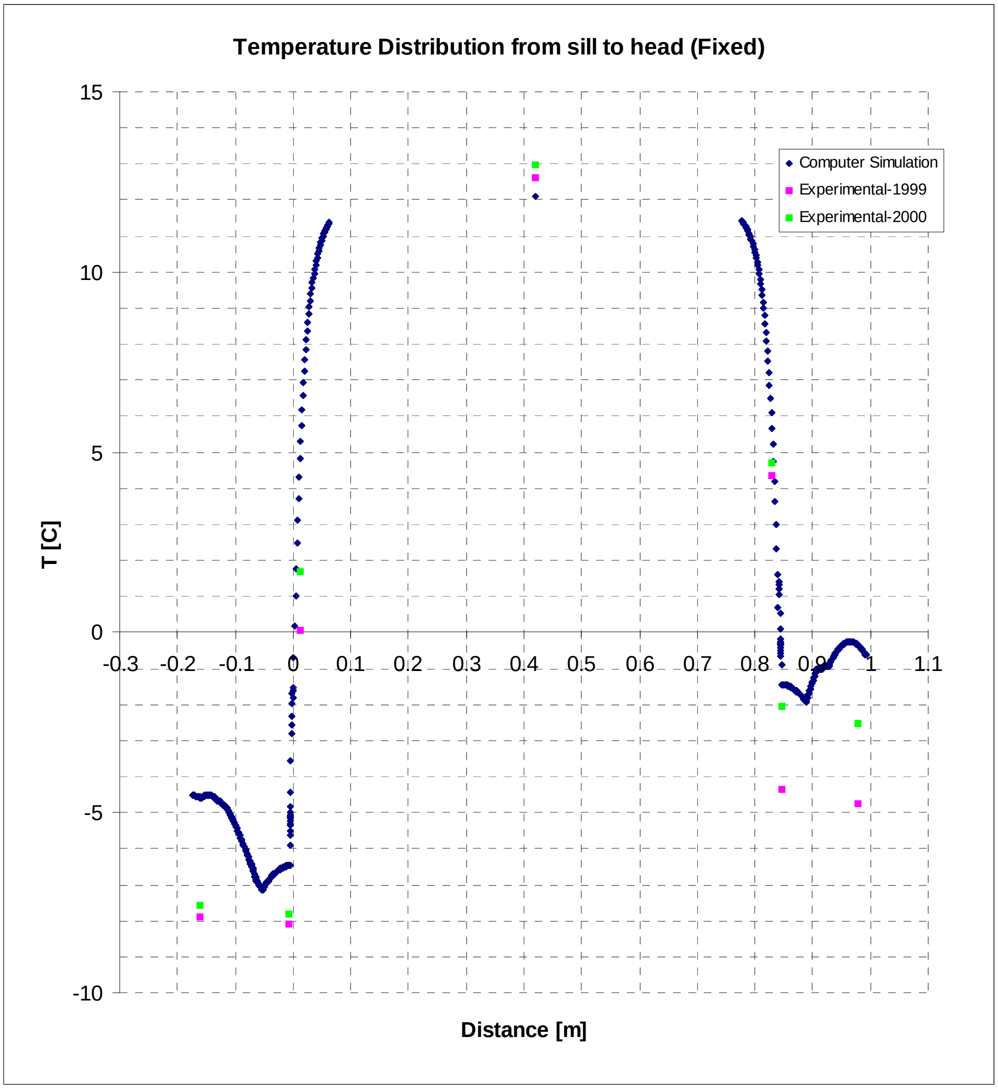


Figure 2: Temperature Distribution From Head To Sill (Fixed Section)

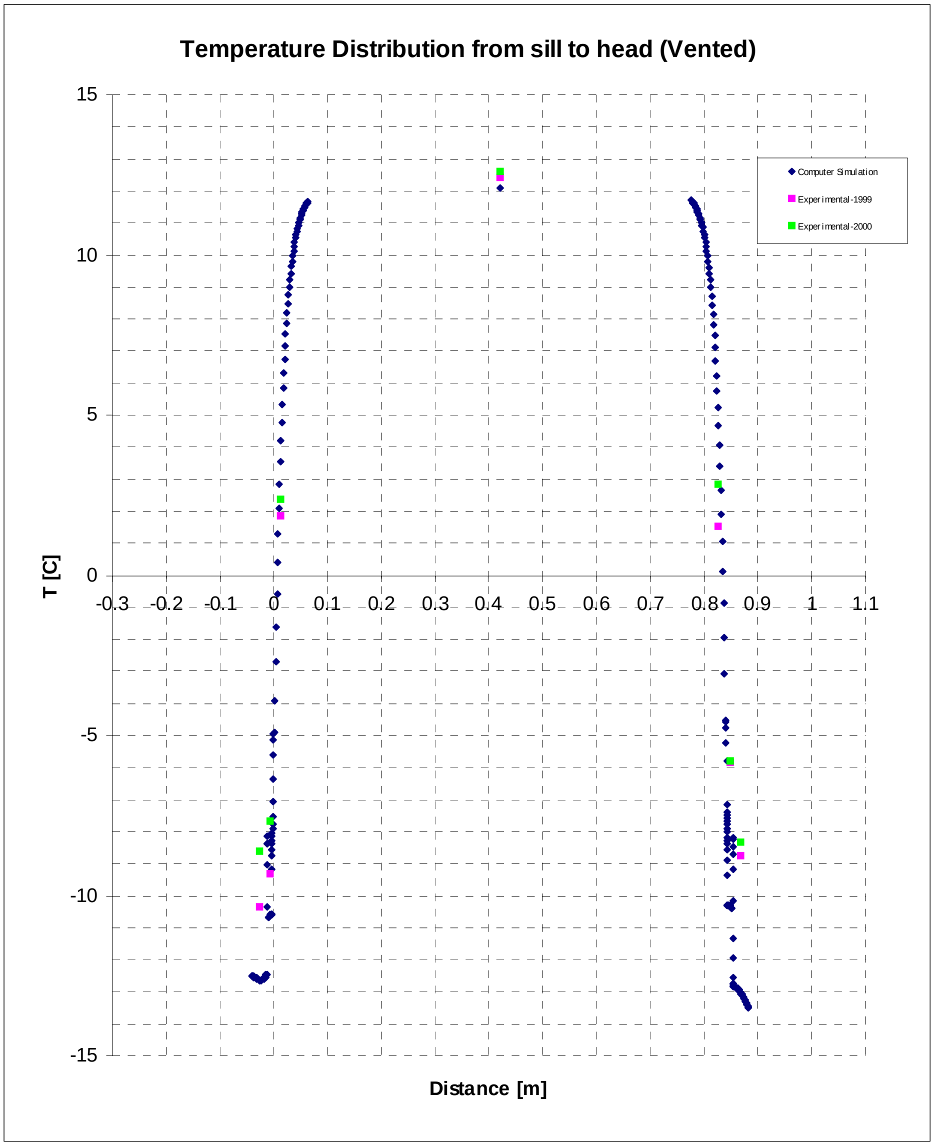


Figure 3: Temperature Distribution From Head To Sill (Vented Section)

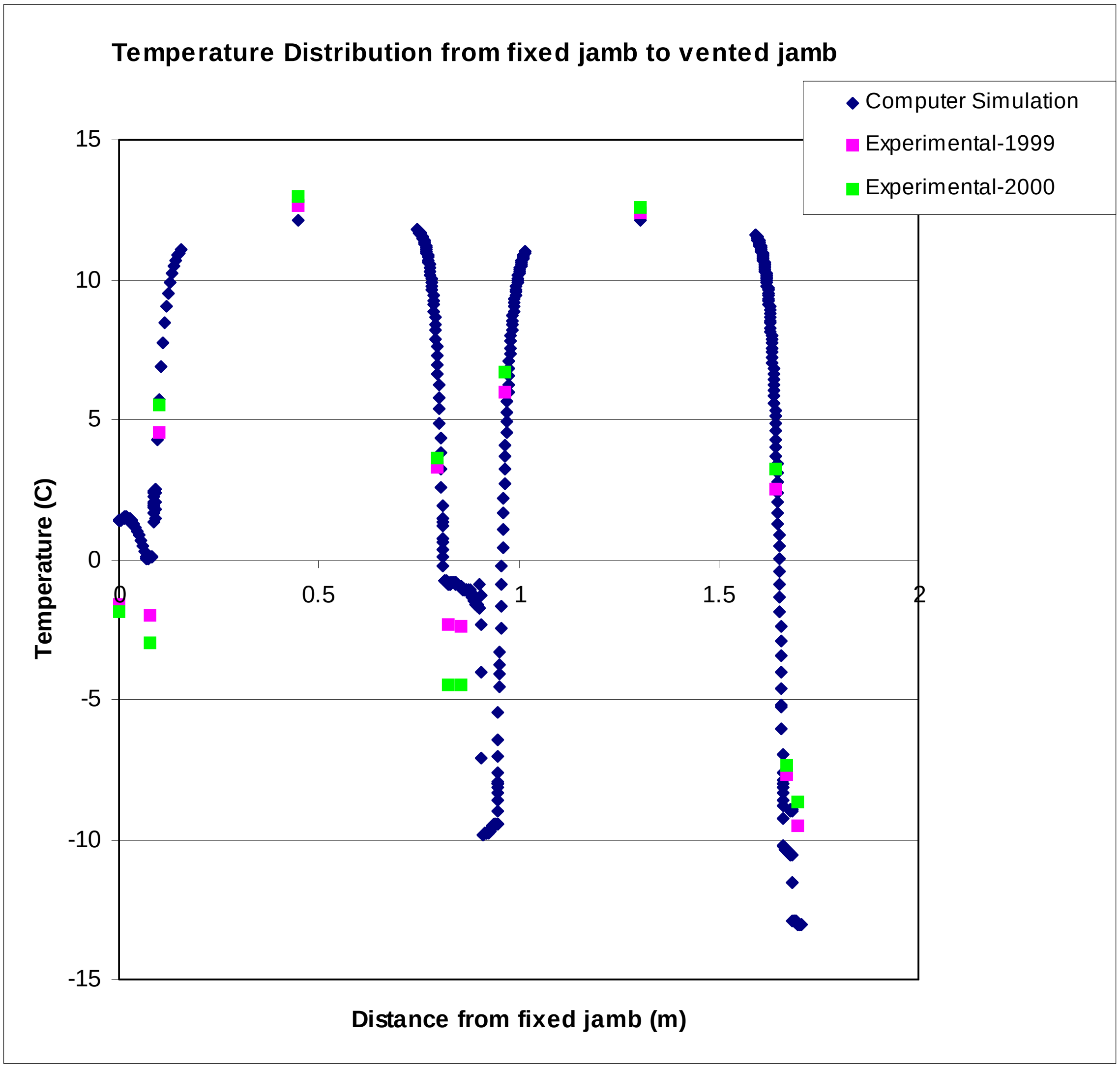


Figure 4: Temperature Distribution From Fixed Jamb Section To Vented Jamb Section

2. Site Built Products

The following test samples were simulated and a comparison was made with the test data.

1. Thermally Improved Aluminum Two-Lite Curtain Wall, non residential (451T front) *(Example 2)*

2. Thermally Improved Aluminum Two-Lite Curtain Wall, non residential (451T centered) *(Example 3)*

3. Thermally Improved Aluminum Two-Lite Curtain Wall, non residential (451T back) *(Example 4)*

4. Aluminum Two-Lite Curtain Wall, Standard (6000IB) *(Example 5)*

5. Thermally Broken Aluminum Two-Lite Curtain Wall, Standard (2250IG SSG) *(Example 7)*

6. Thermally Improved Aluminum Two-Lite Glazed Wall System, Standard (1600 System 5) *(Example 8)*

7. Thermally Improved Aluminum Two-Lite Glazed Wall System, Standard (1600 System 1) *(Example 10)*

Figs. 5 –11 show the schematic represented of the windows.

Table 3a: NFRC standard boundary conditions

Boundary Conditions		*Environmental Temperature (^oC)*	h_c	*Overall h*	ε
			(W/m^2K)		
Outdoor Side	Glazing	-17.77	N/A	29.03	0.84
	Frame		N/A	29.03	0.90
Indoor Side	Glazing	21.11	3.401	N/A	0.84
	Frame		2.896[1] 3.464[2]	N/A	0.90

1 used for 451T front, 451T centered and 451T back
2 used for 6000 IB and 2250IG SSG

Table 3b: Measured Convective Film Coefficients (as Reported in Test Reports)

Samples	*Environmental Temperature (^oC)*		h_c		*Overall h*	
			(W/m^2K)			
	Outdoor Side	Indoor Side	Outdoor Side	Indoor Side	Outdoor Side	Indoor Side
451T font	-17.67	20.94	N/A	4.5	26.12	N/A
451T centered	-17.72	20.83	N/A	4.37	26.12	N/A
451T back	-17.67	20.89	N/A	4.37	26.12	N/A
6000 IB	-17.8	21.11	N/A	6.1	28.45	N/A
2250IG SSG	-17.77	21.11	N/A	4.25	26.12	N/A

Table 3c: Modified Standard NFRC Boundary Conditions and Material Properties

	Modified information
1	Urethane (liquid) (k=0.31 W/mK) has been changed to urethane (k=0.12 W/mK)
2	Frame cavities were assumed as un-painted, so emissivity has been changed to 0.2
3	Convective film coefficient for frame sections is based on glazing value

The simulations for all products have been performed using measured convective film coefficients (Table 3b). For the sample 451T front, additional sets of boundary conditions were investigated, as detailed in Table 3a and 3c. Fig. 12 shows the temperature profile using the standard NFRC boundary conditions (Table 3a) for "451T front" window (i.e., example 2) and Figure 13 shows the temperature profile using modified NFRC standard boundary conditions and material properties, which are detailed in Table 3c. The vertical and horizontal temperature profiles for different window systems are given in Fig. 14 to 20.

Table 4 shows U value of these products using different methods.

Table 4: Comparison of U-Factors of Commercial Aluminum Framing Systems Determined from AAMA 1503 Test, NFRC 100 Test, NFRC simulation without Radiation Model, NFRC simulation with Radiation Model and Frame 4.0 Simulations by NFRC Lab

1" Clear IG

System	1 Encore system	2 451T front	3 451T centered	4 451T back	5 6000IB	6 2250 IG	7 2250IG SSG	8 1600 system5 captured	9 1600 system5 SSG	10 1600 system1 captured
Test Report #	32951.01	31804.04	31805-04	31806.04	34594.01	34122.02	37421.03	36730.02	37420.06	37422.05
AAMA Test	0.63	0.61	0.61	0.56	0.64	0.69	0.64	0.74	0.62	0.66
NFRC Test	0.59	0.58	0.59	0.55	0.58	--	0.55	0.64	0.54	0.57
Simulation WR		0.593	.578	0.563	.704/.698	.637	.585	0.677	0.576	0.636
Simulation WR – Test BC		0.60	0.59	0.58	0.75		0.59			
Simulation WR – Modif.		0.579			0.640			0.647		0.609
NFRC Sim WoR		0.597	.596	0.574	.733/.726*/ 0.666**	.658	.599	0.671	0.594	0.627
Frame 4.0 sim.	0.65	0.60	0.58	0.57	0.65	0.62	0.60	0.68	0.60	0.63

" Low e IG

System	1 Encore System	2 451T front	3 451T centered	4 451T back	5 6000 IB HP	6 2250 IG HP
Test Report #	32952.01	32094.04	32095.04	32096.04	34593.01	34595.01
AAMA Test	0.46	0.47	0.44	0.41	0.48	0.48
NFRC Test	0.45	0.45	0.43	0.41	0.47	0.48
NFRC Sim WR		.484	0.469	0.452		
NFRC Sim WoR		0.502/0.486*	0.485	0.463		
Frame 4.0 sim.	0.48	0.45	0.43	0.43	0.50	0.47

Notes: Test BC are simulations done with the set of boundary conditions detailed in Table 3b.
Modif. Are simulations done with modified boundary conditions and material information detailed in Table 3c.

* Simulations done with modified emissivities in frame cavities (i.e., 0.2 instead of 0.9)

** Simulation with standard NFRC boundary conditions and modified emissivities in frame cavities (i.e., 0.2 instead of 0.9)

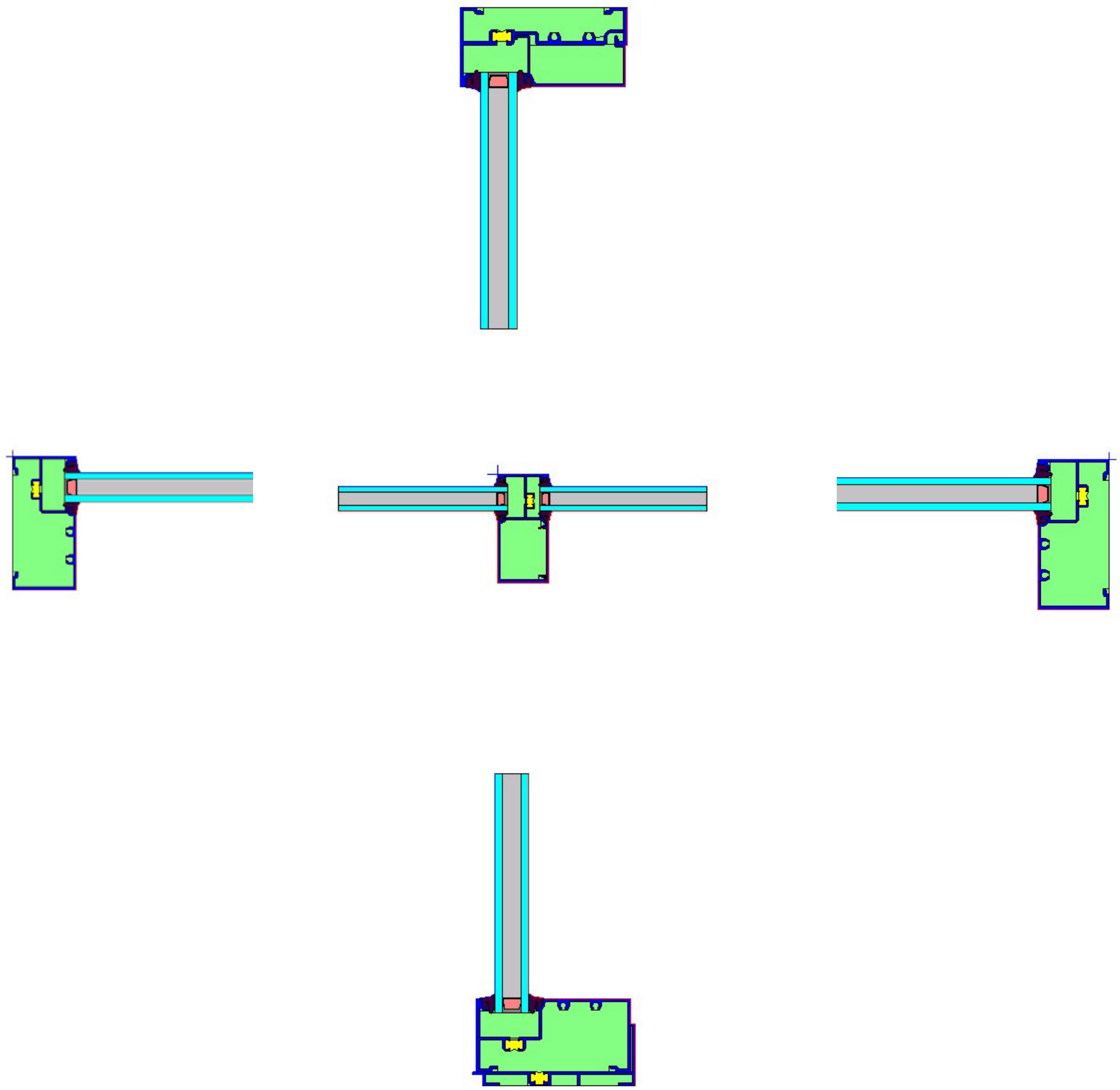


Fig. 5: Schematic representation of “451T Front” (Example 2) Window

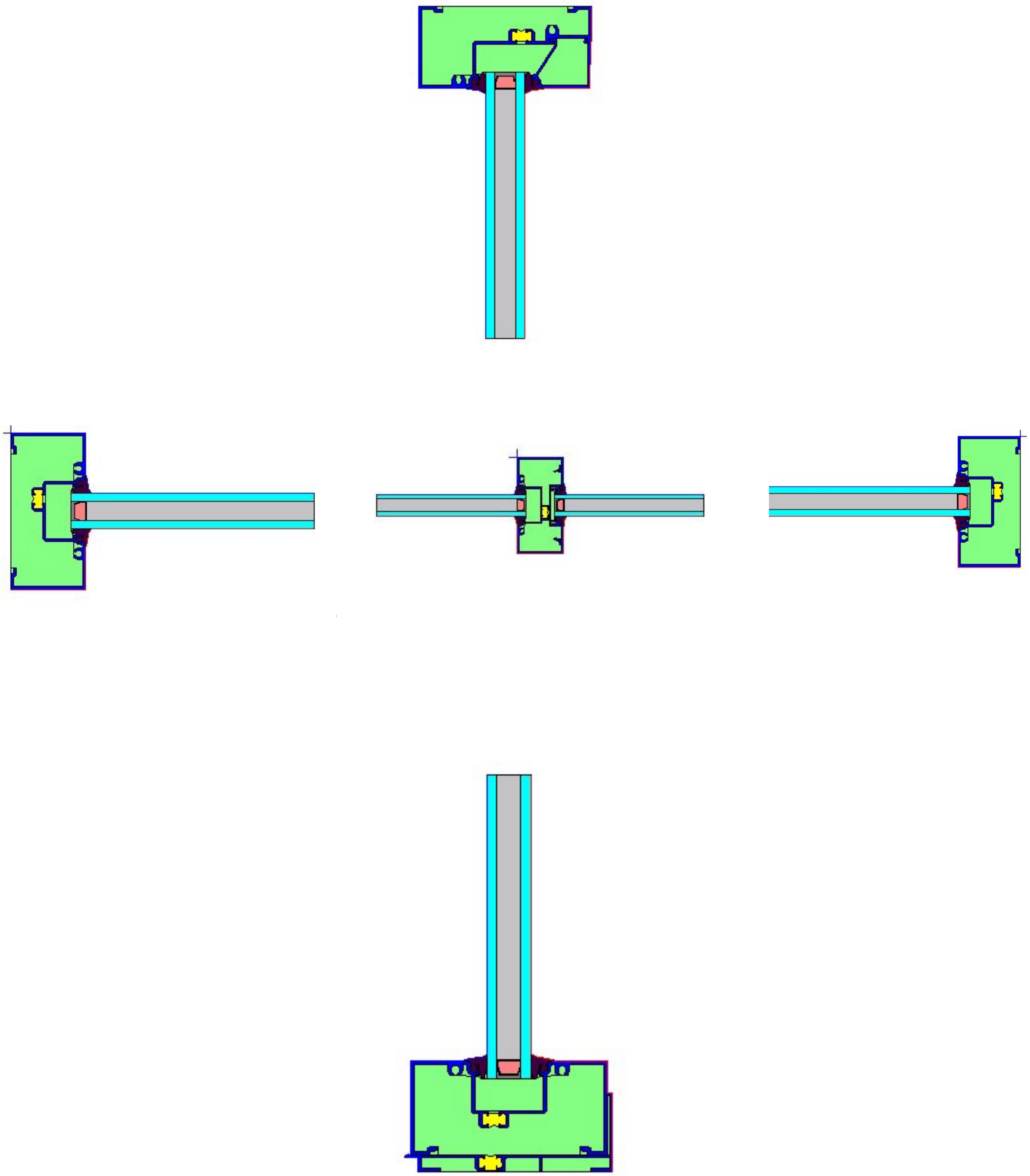


Fig. 6: Schematic representation of "451T centered" (Example 3) window

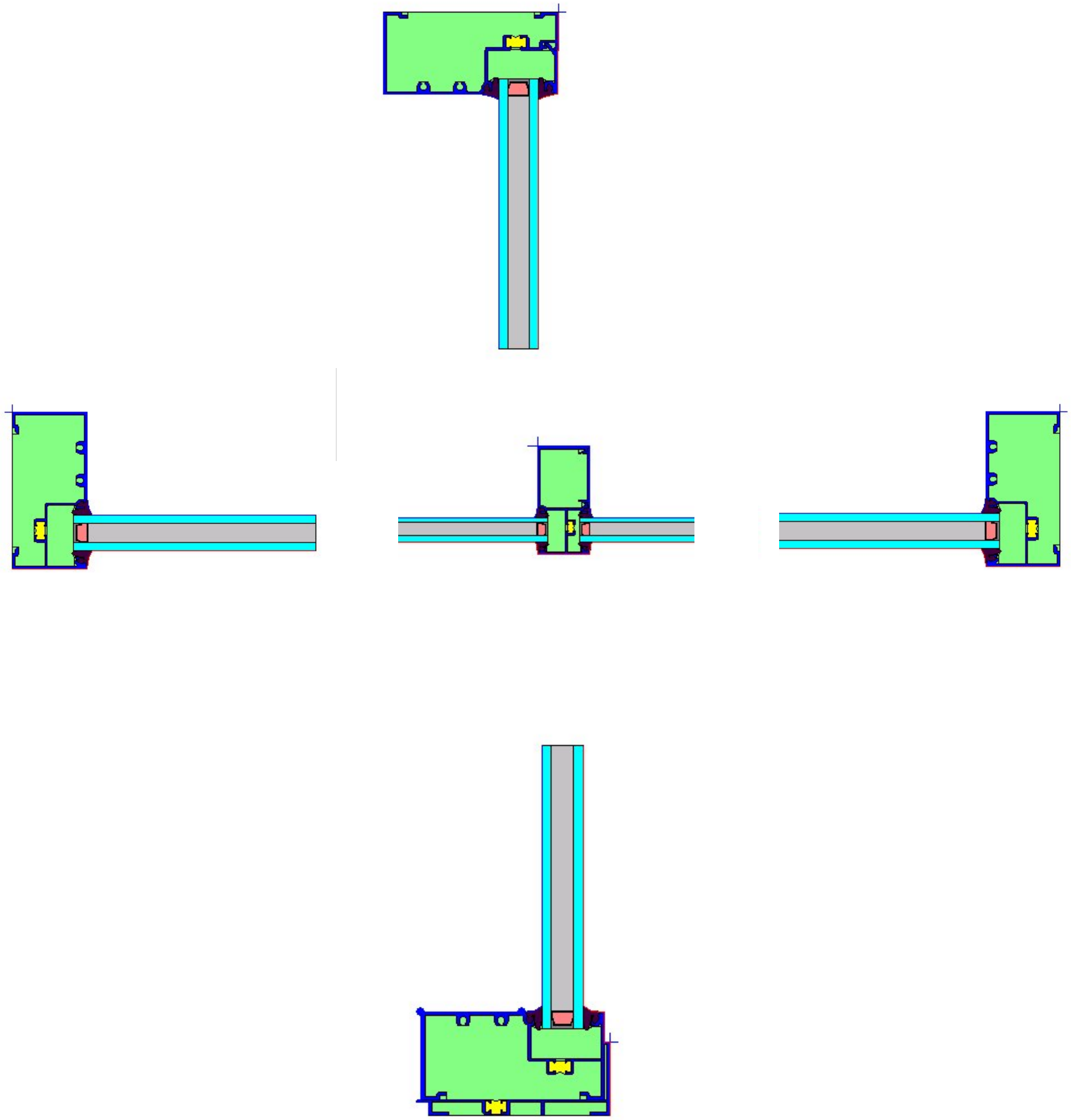


Fig. 7: Schematic representation of "451T back" (Example 4) Window

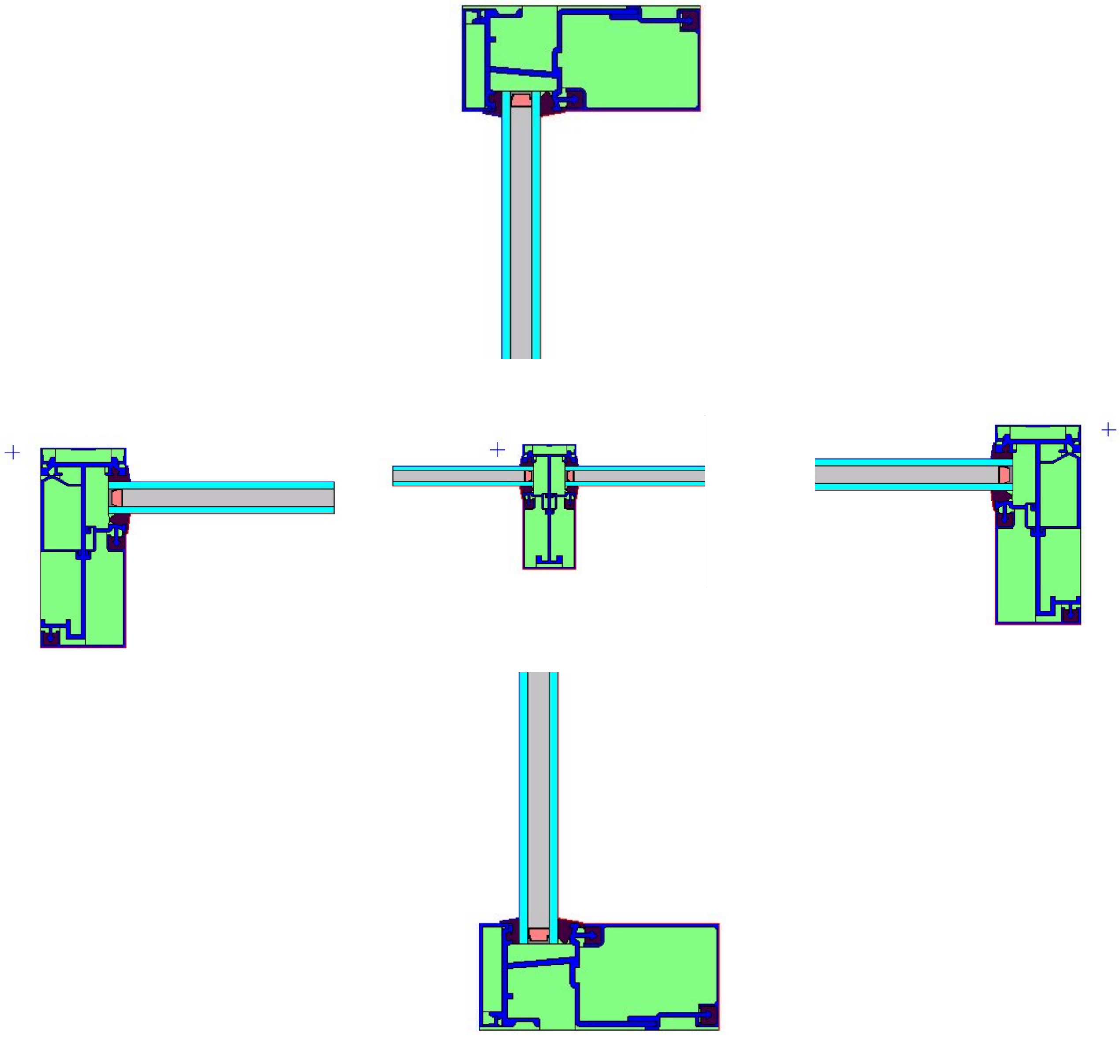


Fig. 8: Schematic representation of "6000IB" (Example 5) Window

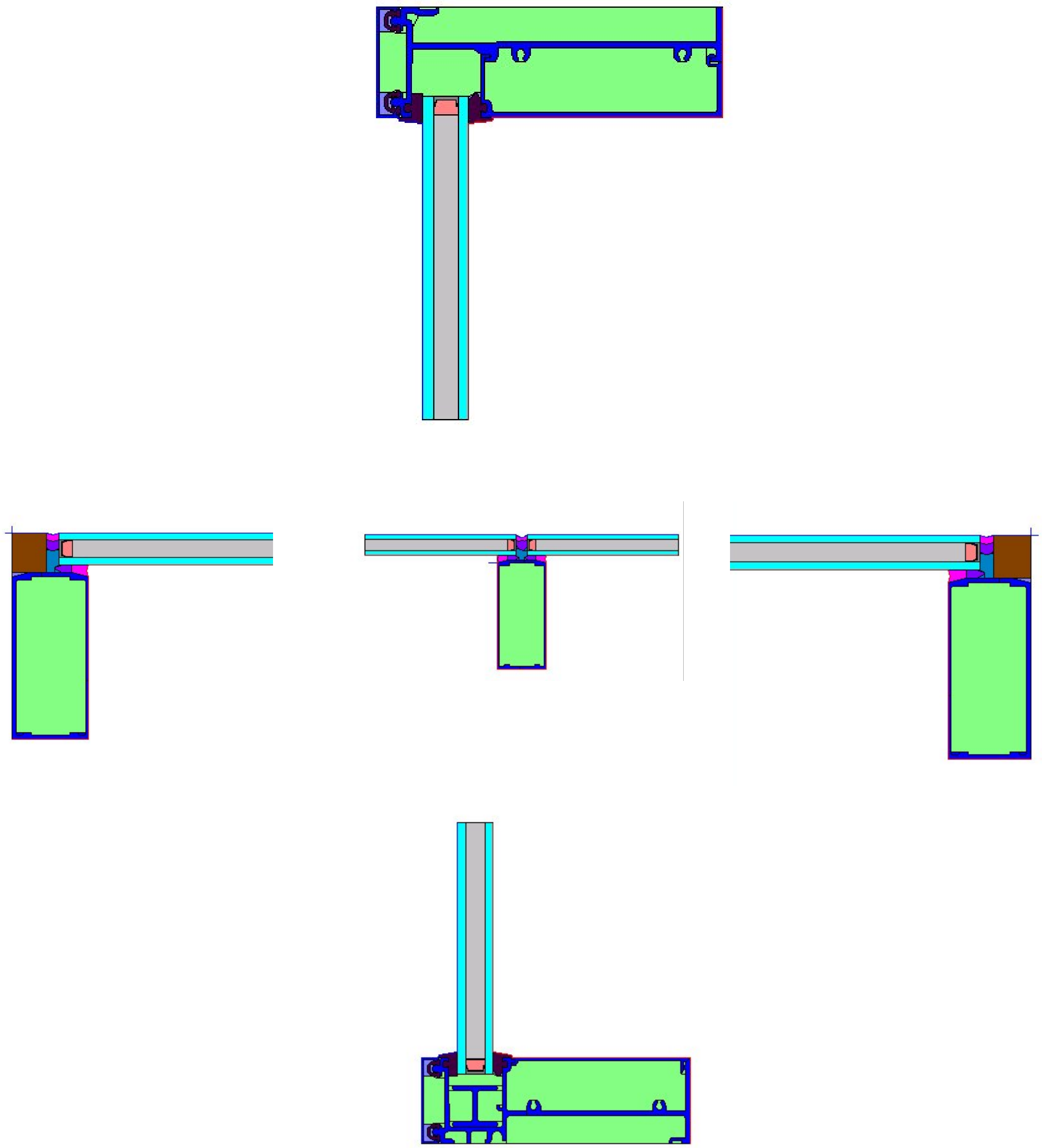


Fig. 9: Schematic representation of “2250IG SSG” (Example 7) Window

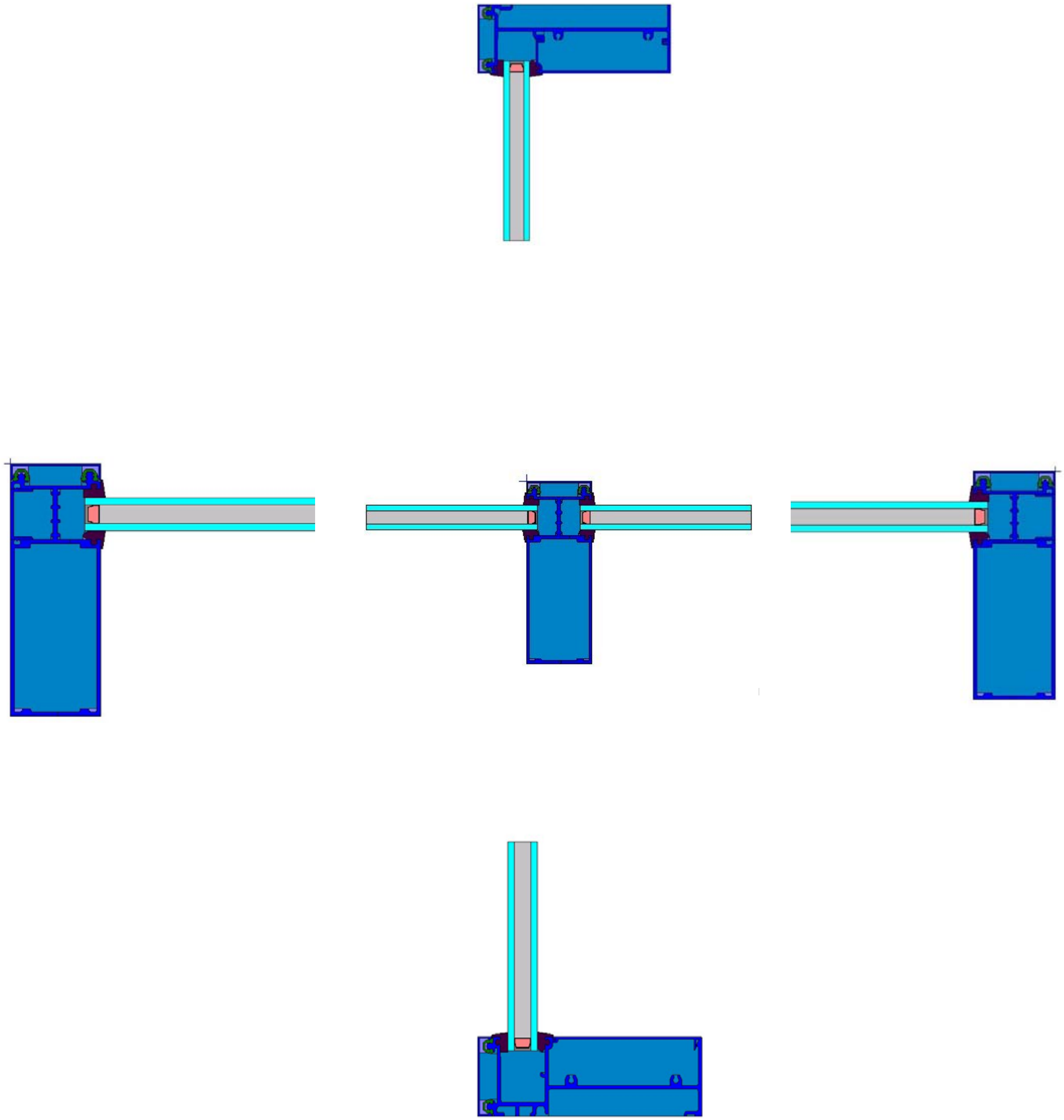


Fig 10: Schematic representation of "1600 System 5 captured" (Example 8) Window

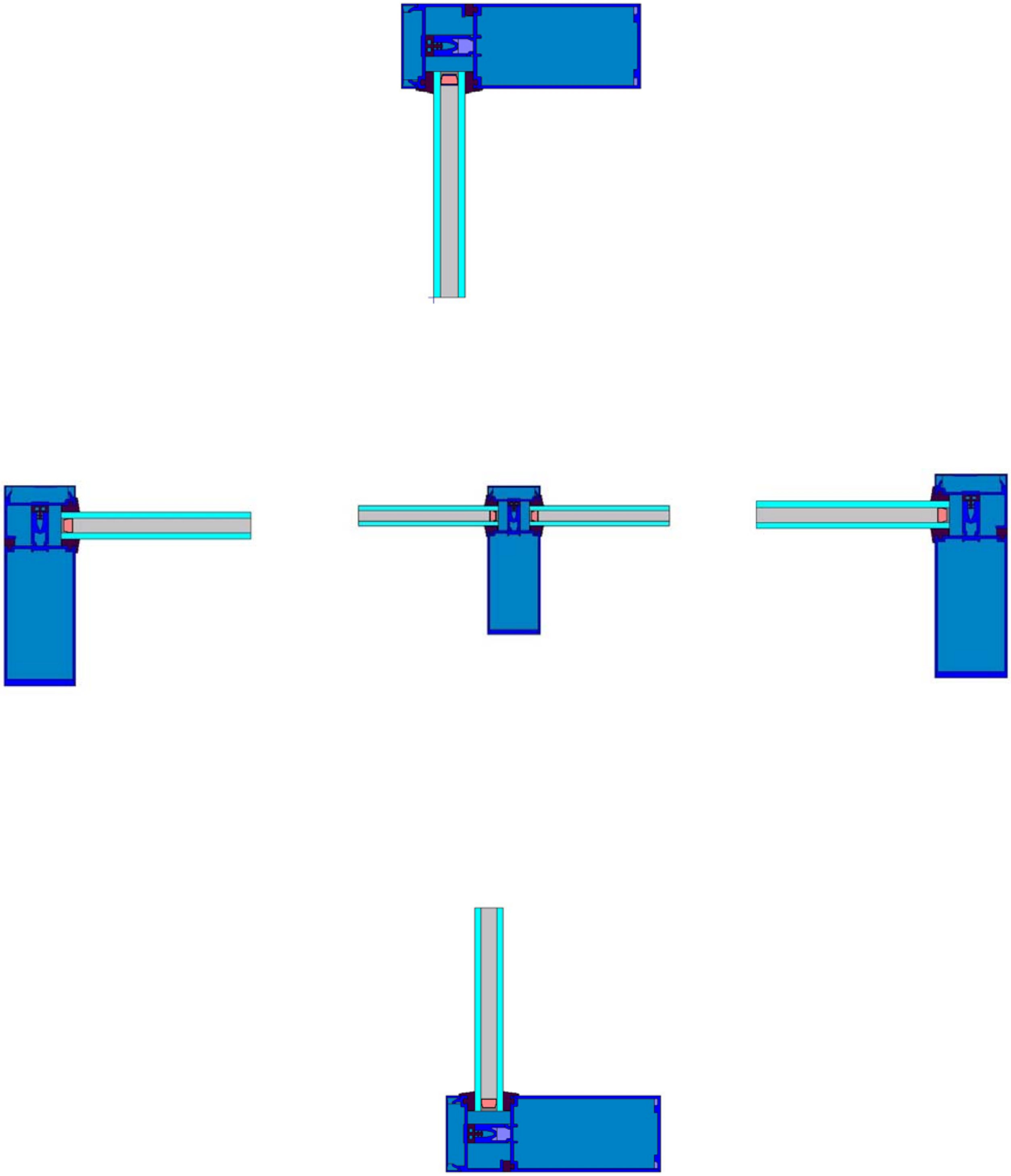
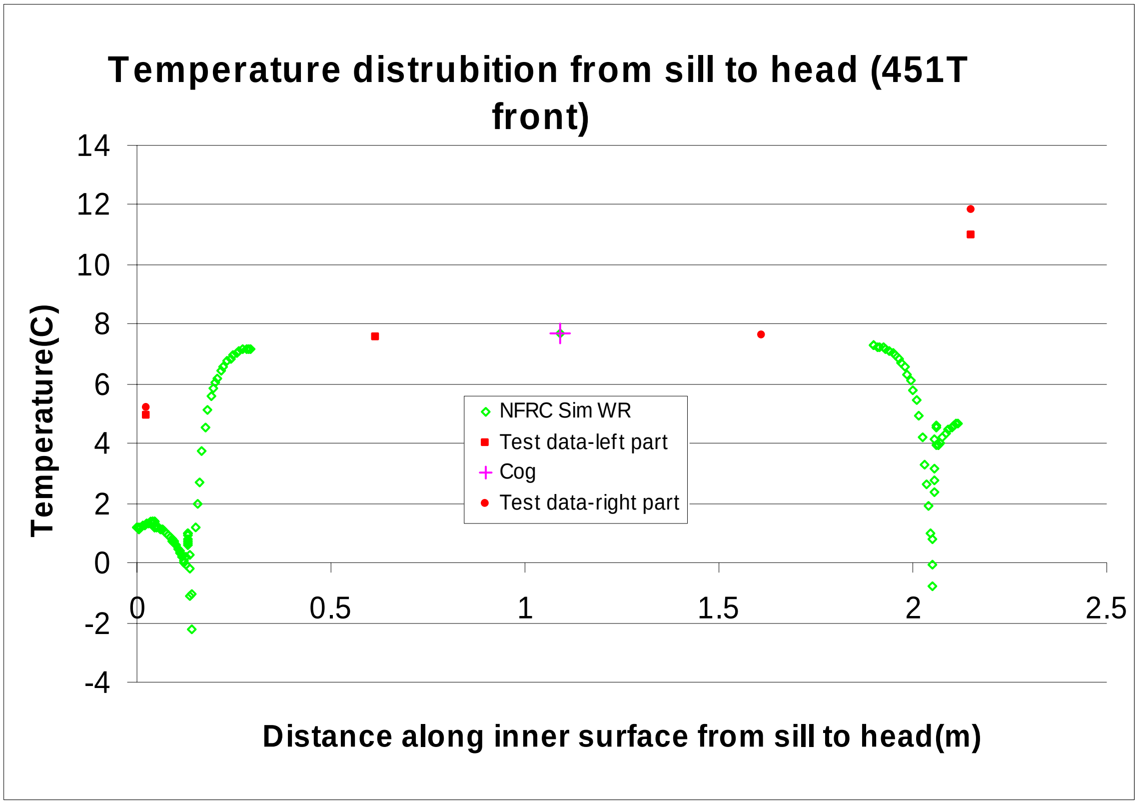


Fig 11: Schematic representation of "1600 System 1 captured" (Example 10) Window



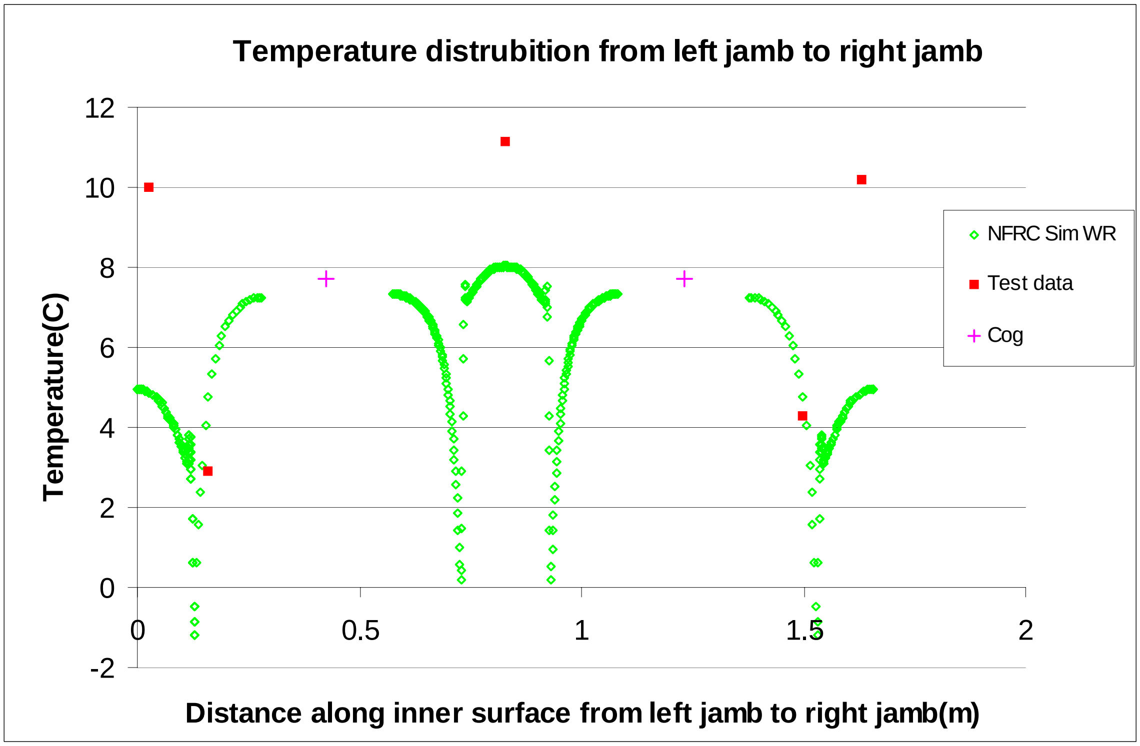
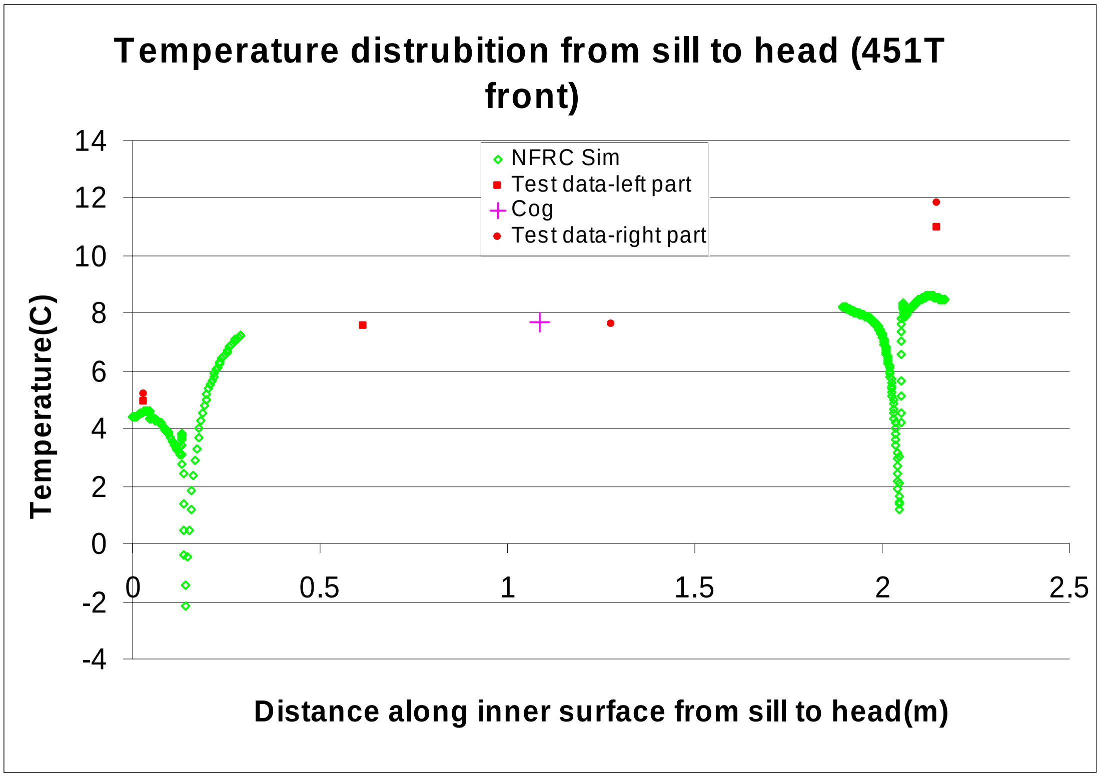


Fig. 12: Temperature Distribution For "451T Front" Window (Example 2) Using NFRC Standard BC (Table 3a)



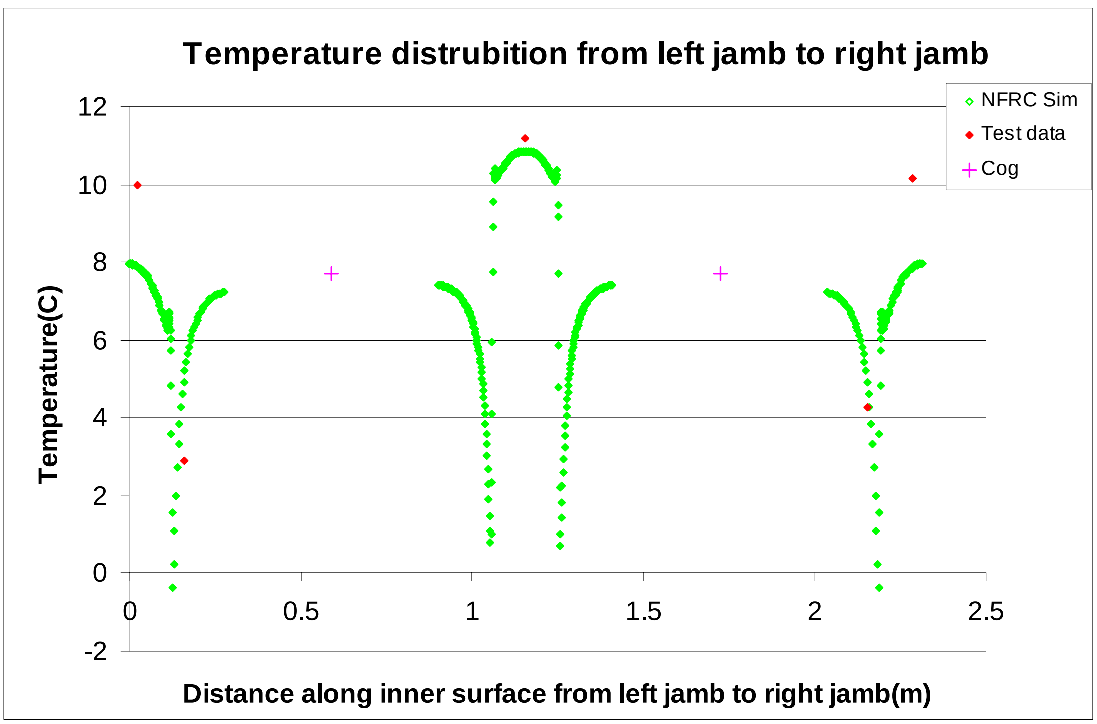
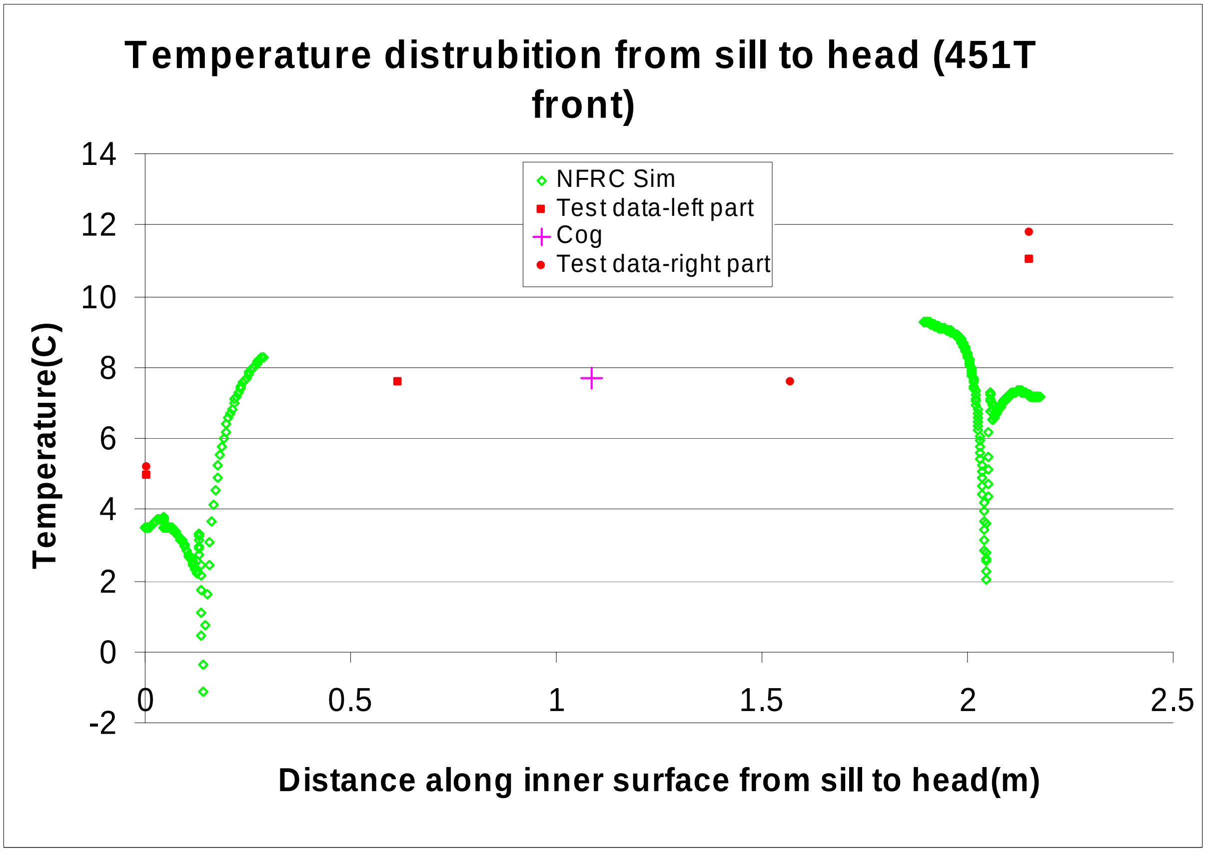


Fig. 13: Temperature Distribution For "451T Front" Window (Example 2) Using Modified Boundary Conditions and Material Properties (Table 3c).



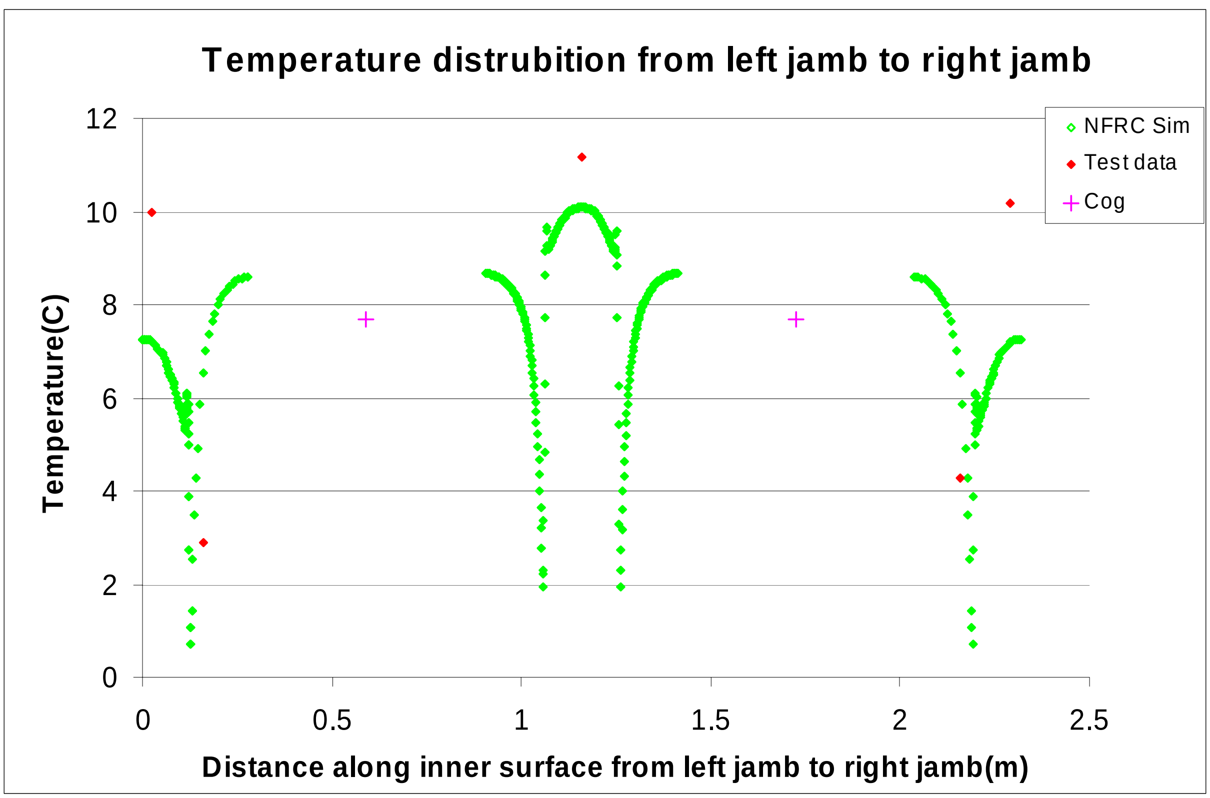


Fig. 14 a: Temperature Distribution For "451T Front" Window (Example 2) Using Measured film Coefficients (Table 3 B)

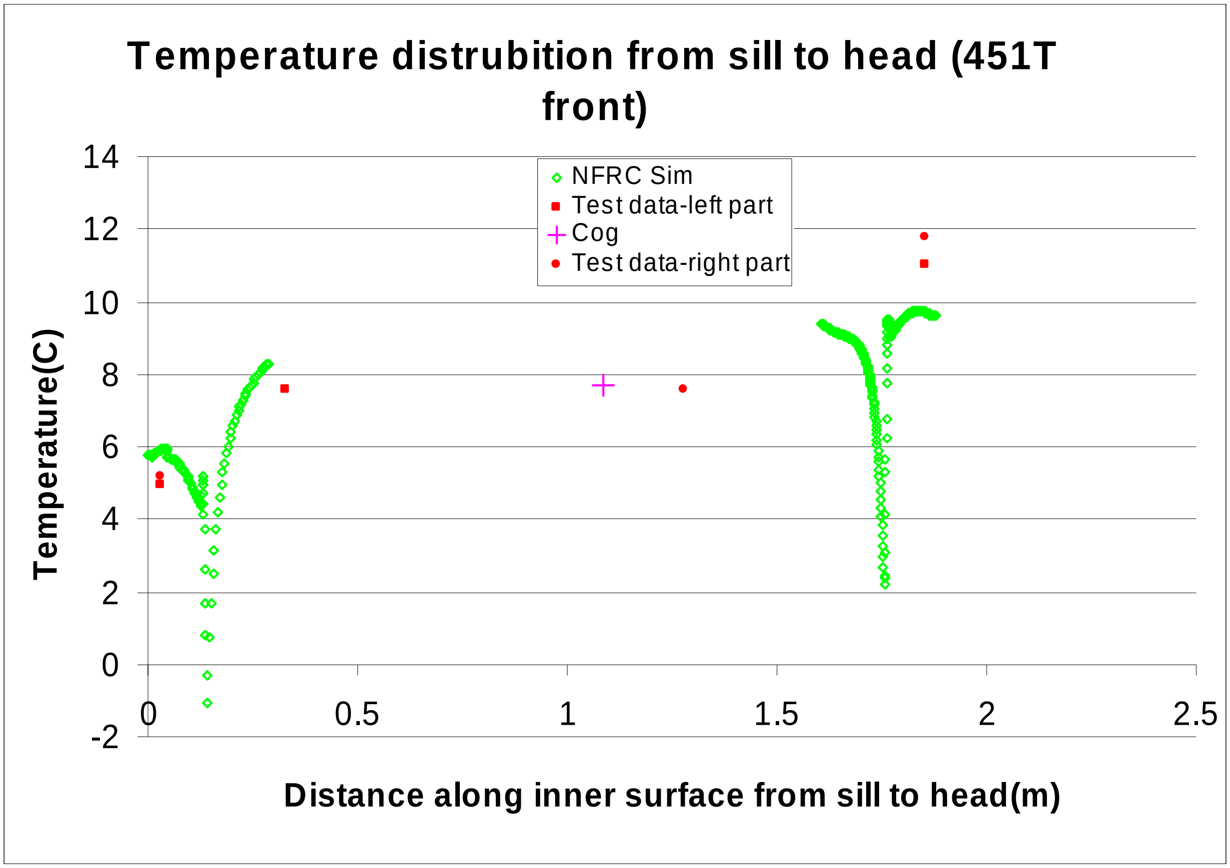
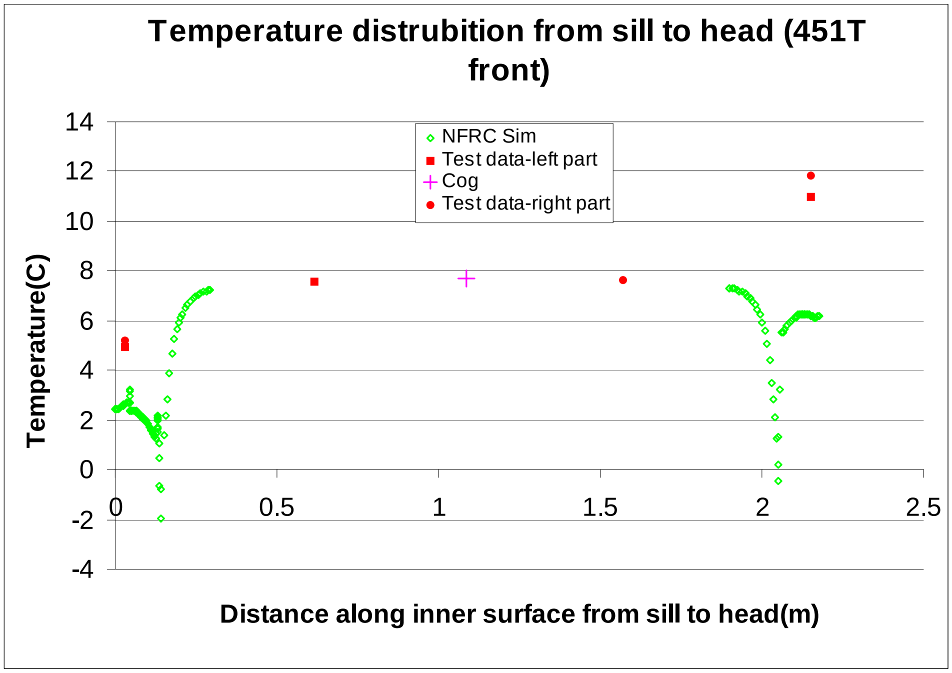


Fig. 14 b : Temperature Distribution For "451T Front" Window (Example 2) Using Measured film Coefficients (Table 1 B) and Updated Material Properties (Points 1 and 2 in Table 3c).



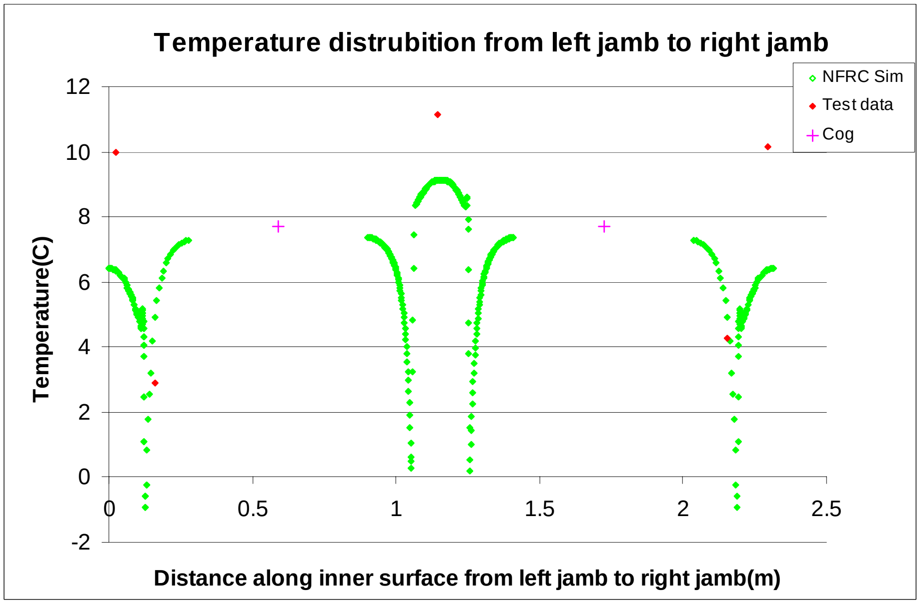
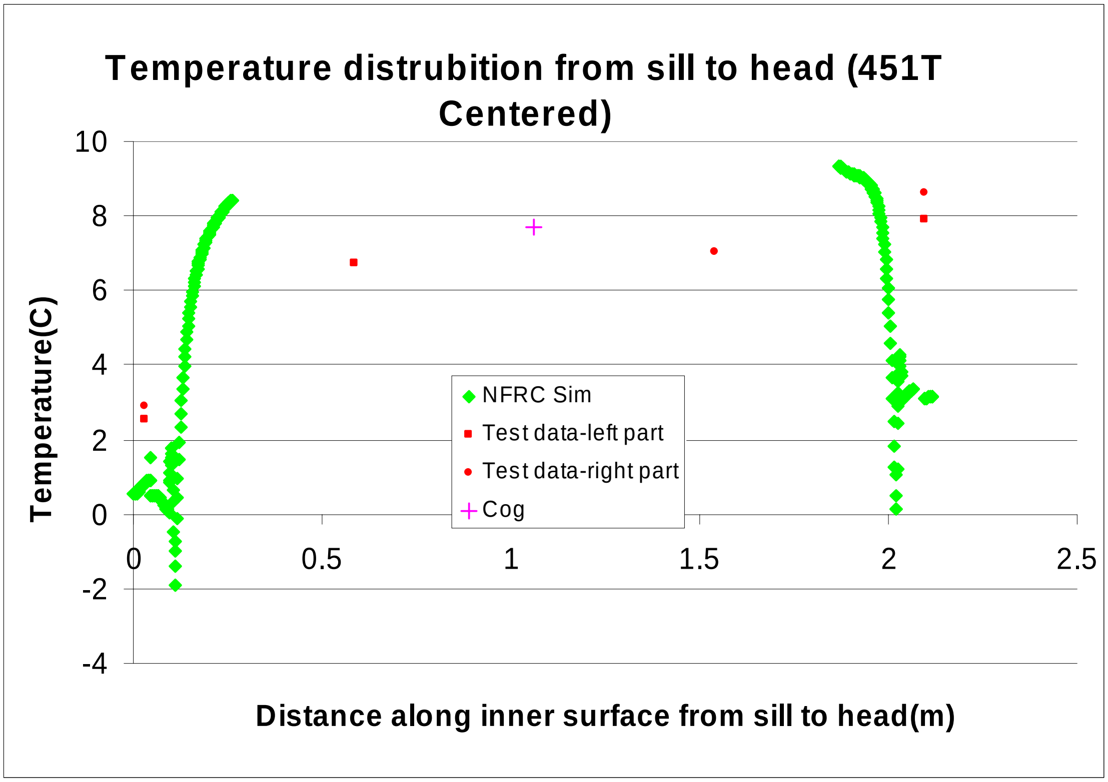


Fig. 14 c : Temperature Distribution For "451T Front" Window (Example 2) Using NFRC standard boundary conditions and Updated Material Properties (Points 1 and 2 in Table 3c).



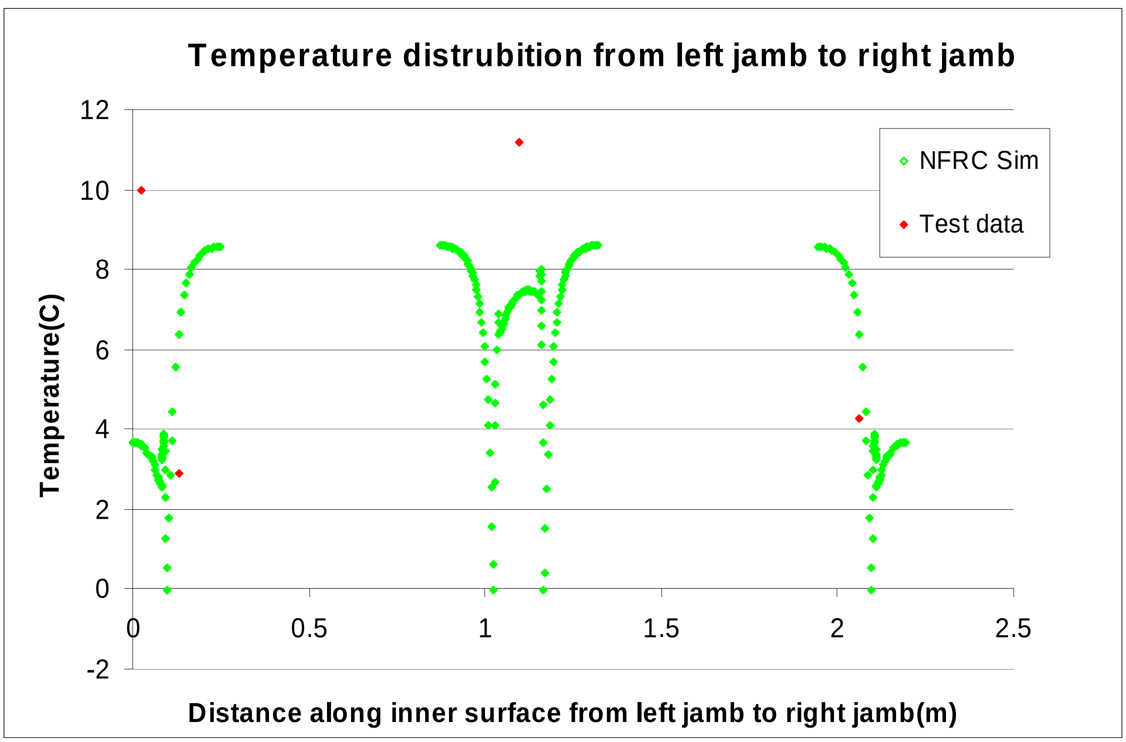
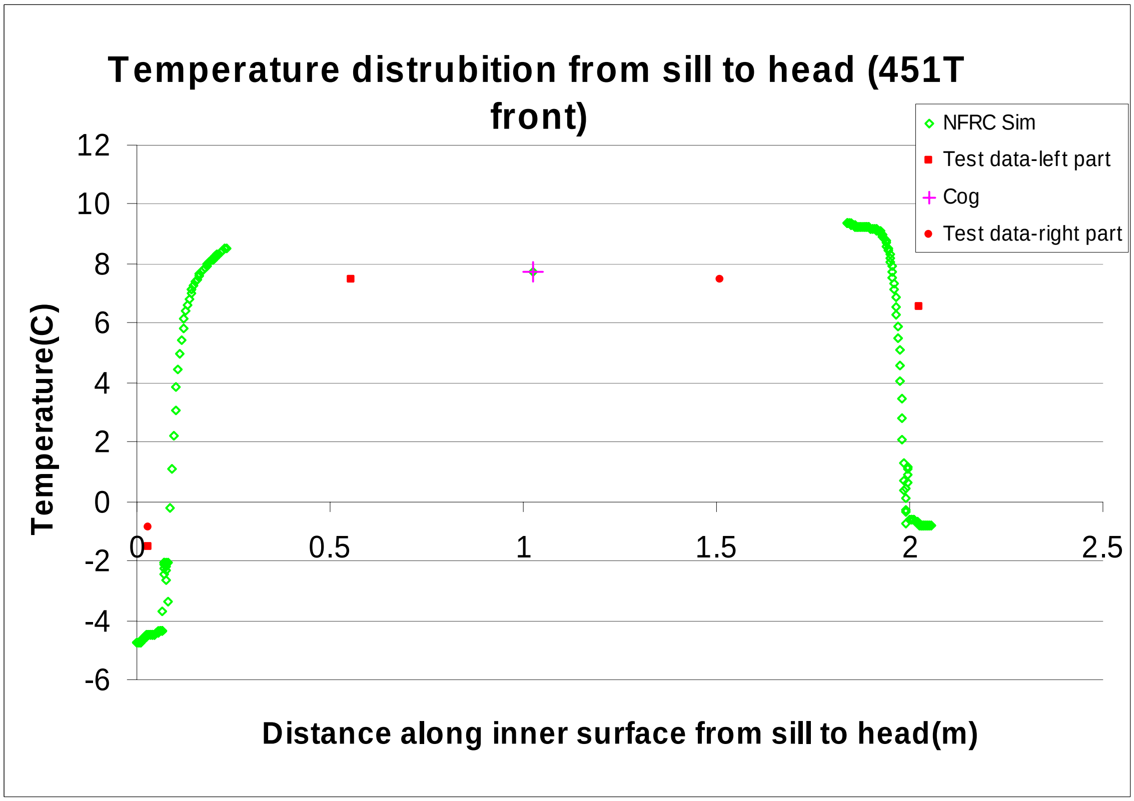


Fig. 15: Temperature Distribution For "451T Centered" (Example 3) Window Using Measured film Coefficients (Table3 B)



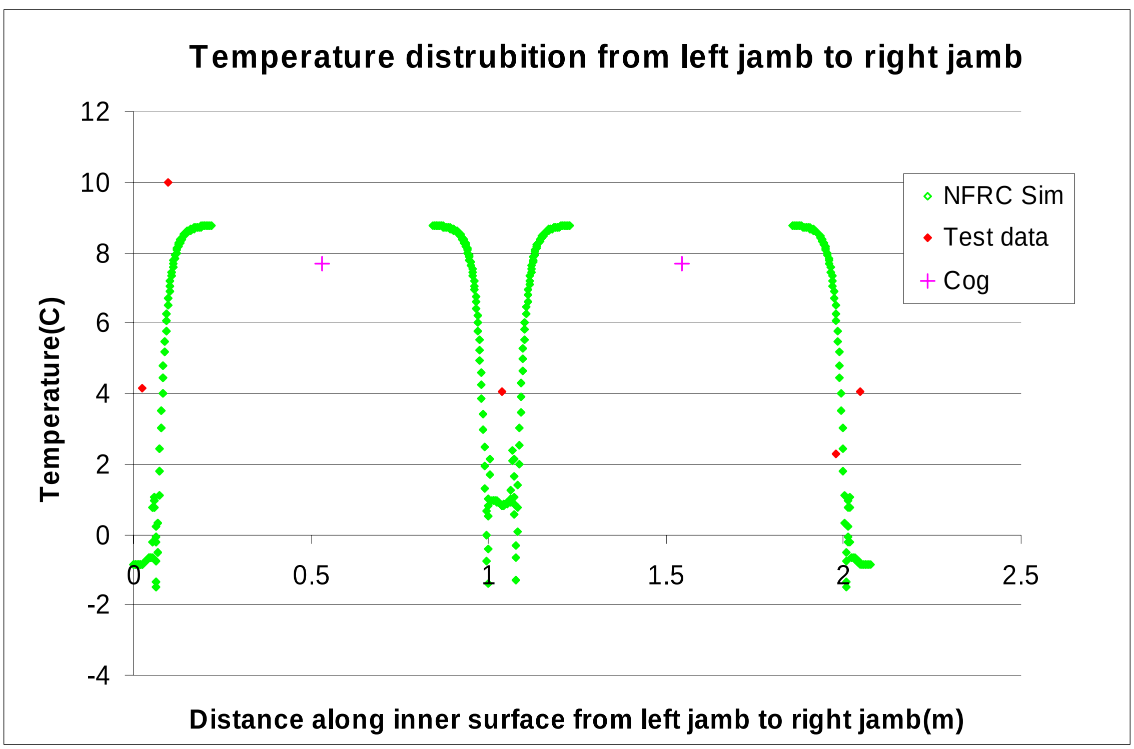
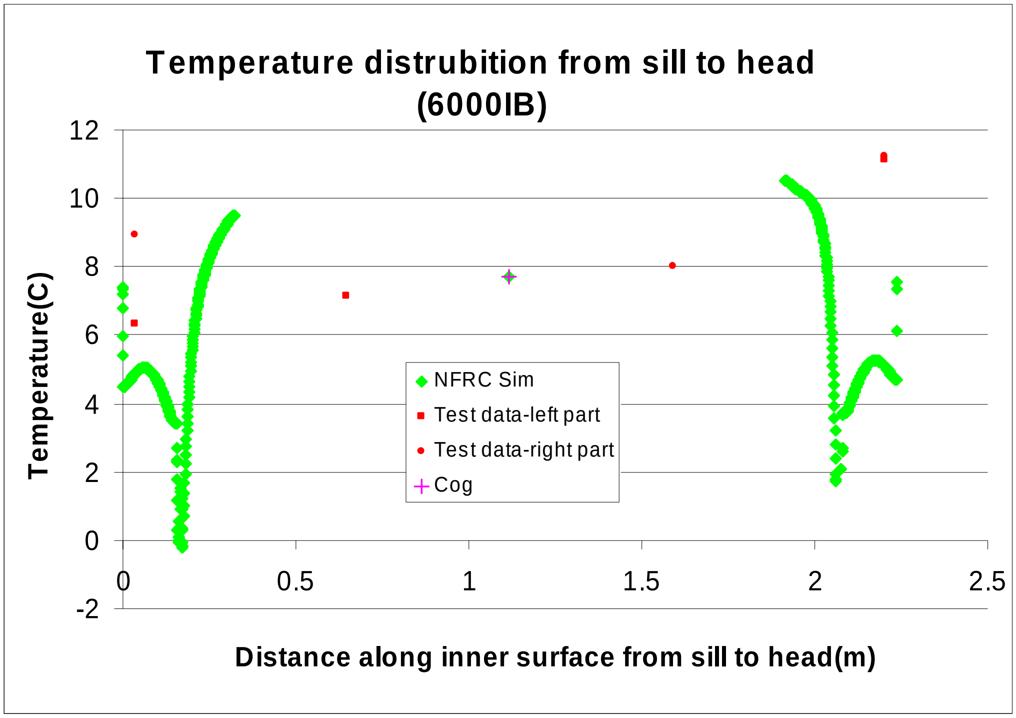


Fig. 16: Temperature Distribution For "451T Back" Window (Example 4) Using Measured film Coefficients (Table3 B)



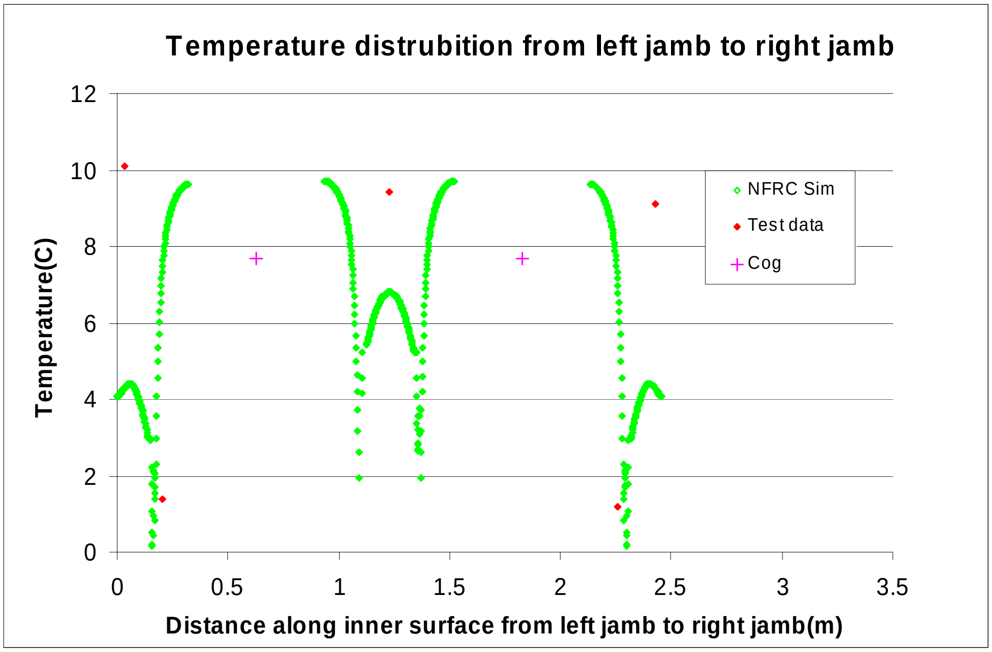
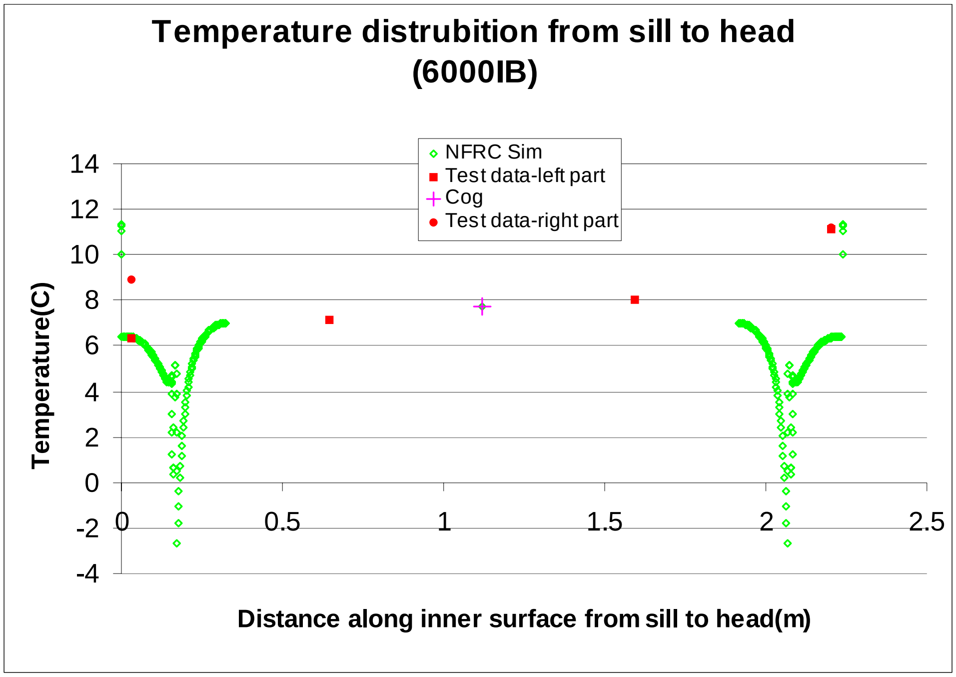


Fig. 17a: Temperature Distribution For "6000IB" Window (Example 5) Using Measured film Coefficients (Table3 B).



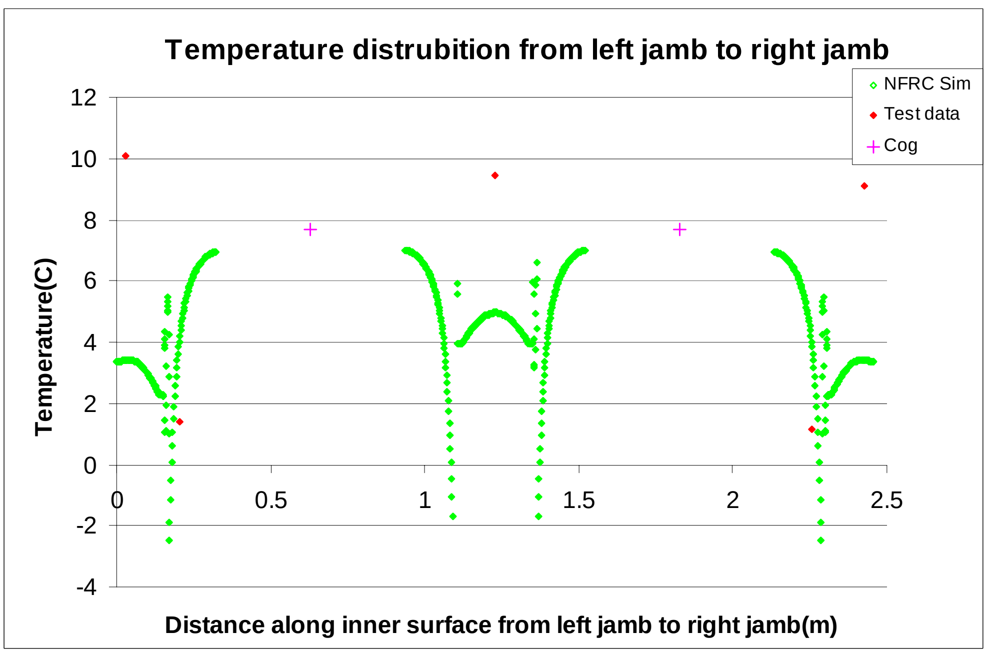
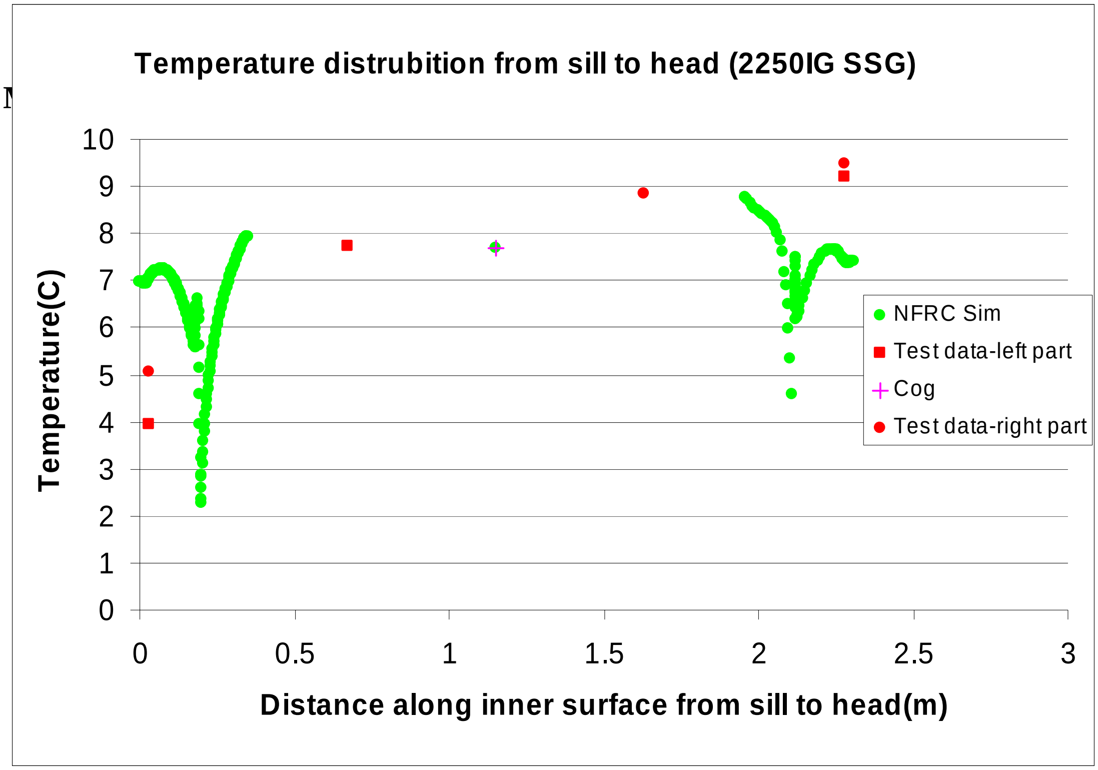


Fig. 17b: Temperature Distribution For "6000IB" Window (Example 5) using NFRC standard boundary conditions and Updated Material Properties (Point 2 in Table 3c).



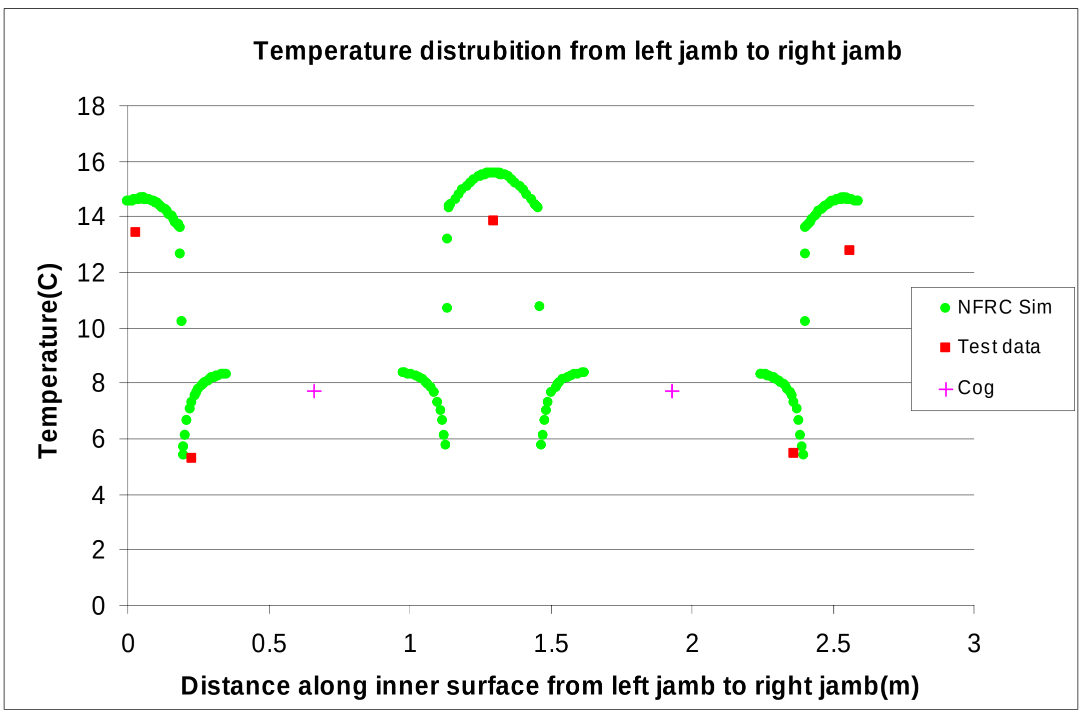
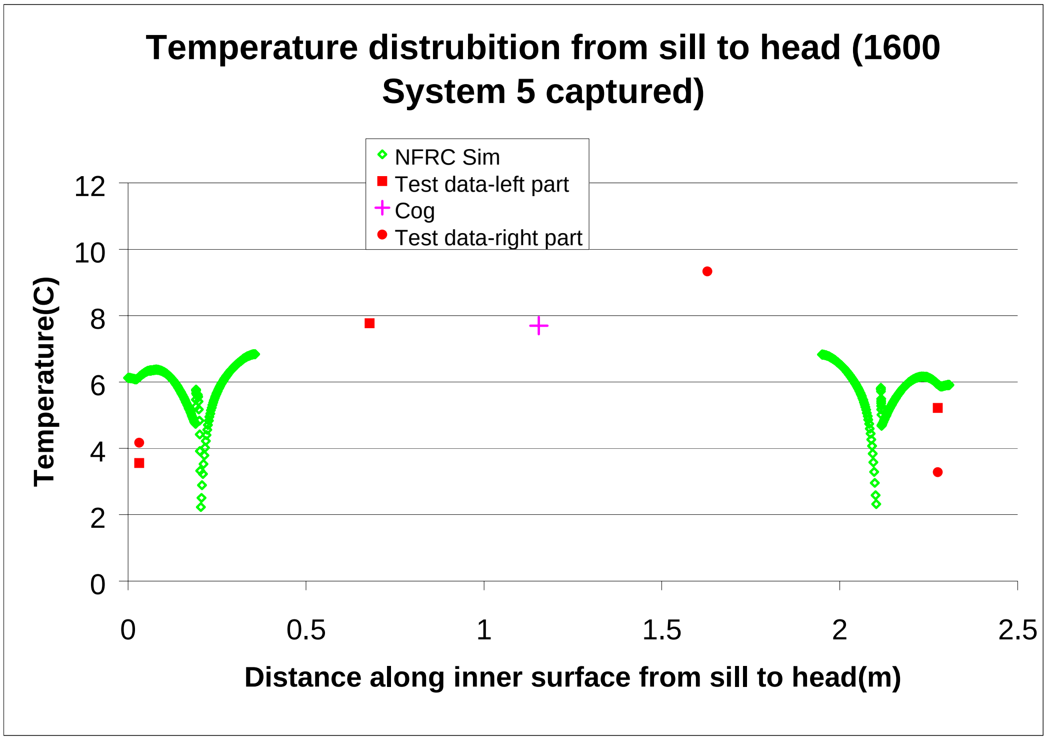


Fig. 18: Temperature Distribution For "2250IG SSG" Window (Example 7) Using Measured film Coefficients (Table3 B)



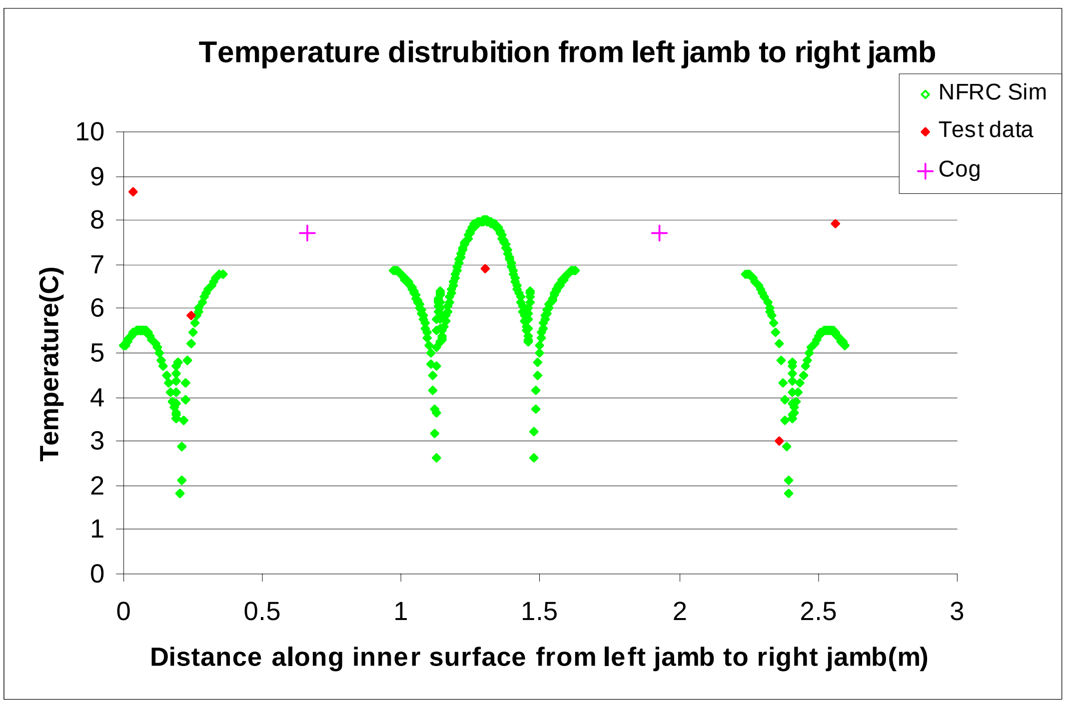


Fig. 19a: Temperature Distribution For "1600 System5 captured " Window (Example 8) using NFRC standard boundary conditions and Updated Material Properties (Point 2 in Table 3c).

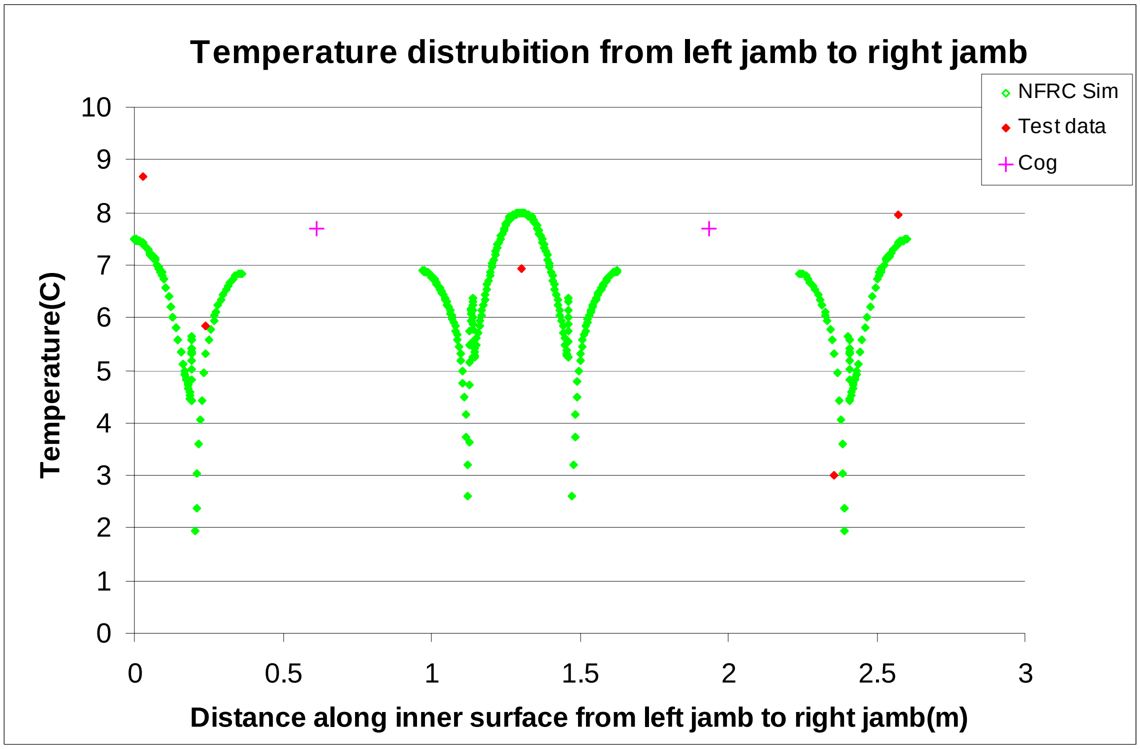
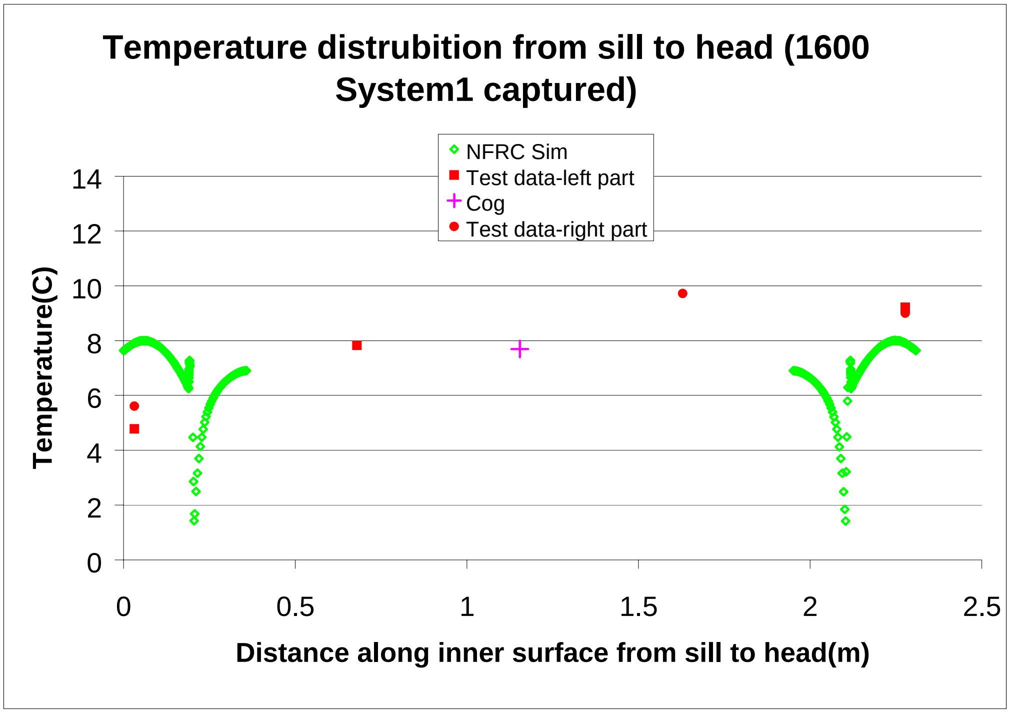


Fig. 19b: Temperature Distribution from left jamb to right jamb for "1600 System1 captured" Window (Example 8) using NFRC standard boundary conditions with horizontally flipped jamb section



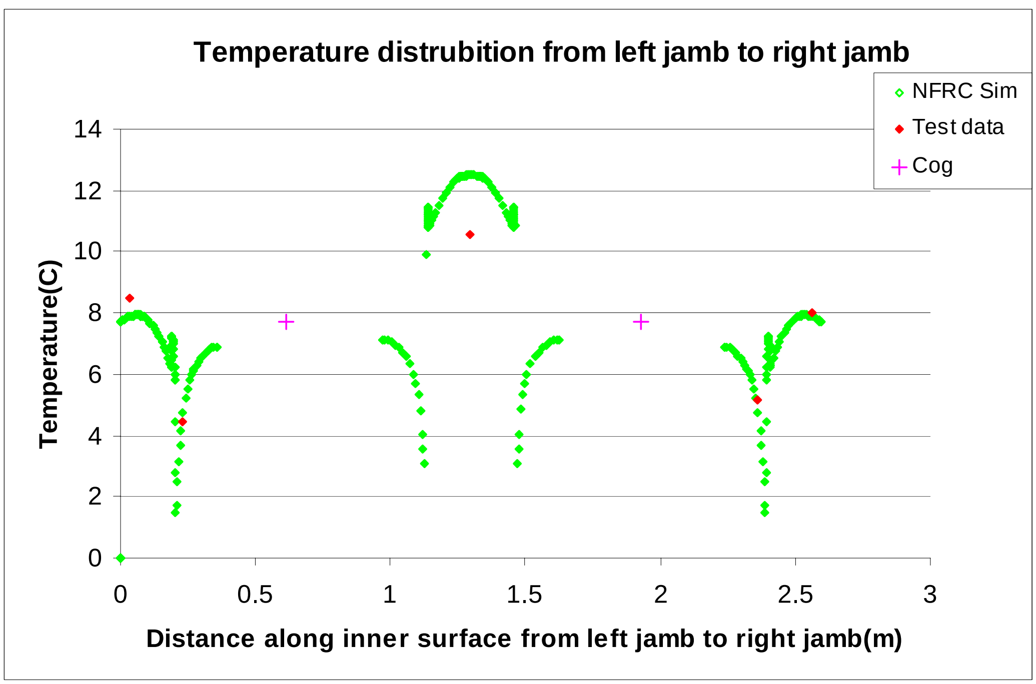


Fig. 20: Temperature Distribution from left jamb to right jamb for "1600 System1 captured" Window (Example10) using NFRC standard boundary conditions and Updated Material Properties (Point 2 in Table 3c).