Center for Energy Efficiency and Renewable Energy

C E E R E

Building Energy Efficiency Program

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Computer Modeling of Heat Transfer For NFRC 2002 Simulation Round Robin (SRR02) Representing Curtain Wall with Bolt – U-Factor and CR Simulations Using WINDOW 4.1 and THERM 2.1a

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DESCRIPTION OF THE SPECIMEN

The product selected for simulation is a nominal 80”x80” Aluminum Curtain Wall. Thermo physical properties of different frame material are given in Table 1 and schematic representation of the material locations for a sill section is shown in Fig. 1.

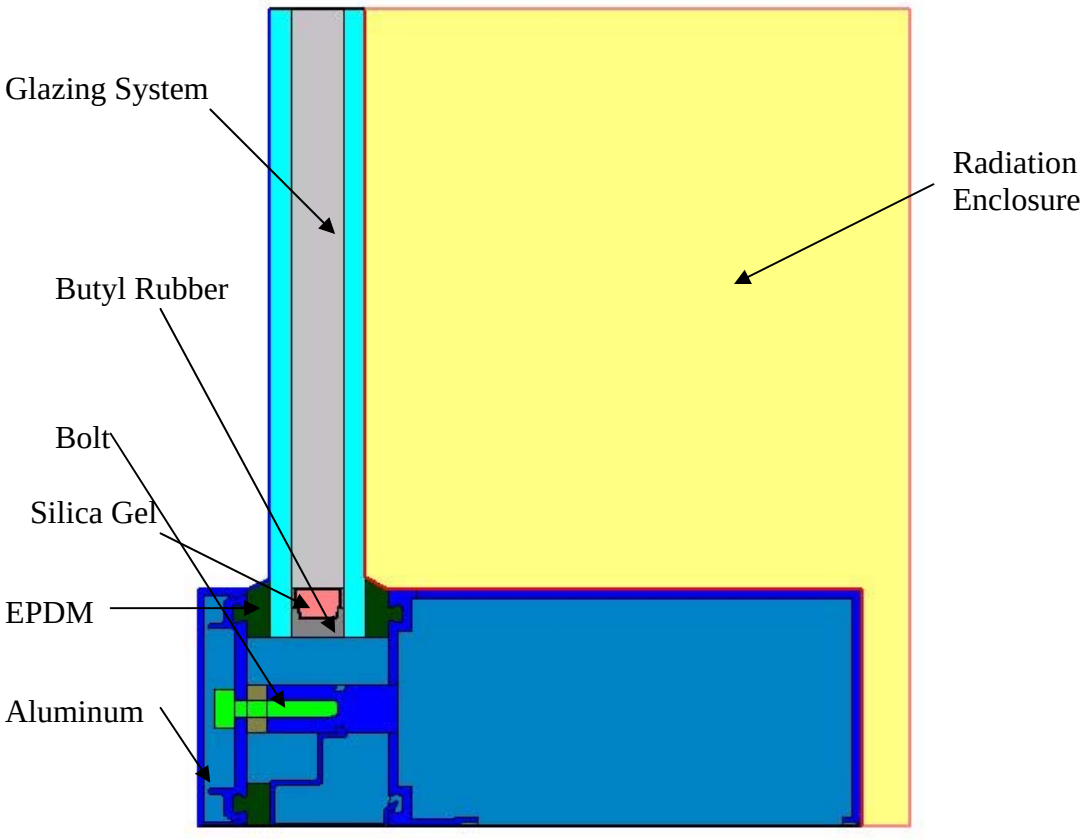


Fig. 1: Schematic Representations Of Frame Materials In A Sill Cross-Section Of Frame

Table 1: Material Thermo Physical Properties

Material	*k* (Btu/h-ft-F)	ε
Aluminum	92.448	0.2/0.9
EPDM	0.1444	0.9
Silica Gel (desiccant)	0.0173	0.9
Butyl Rubber	0.1386	0.9
Bolt*	0.47	0.9

*:The effective conductivity of the Bolt has been calculated by procedure given in Appendix 3.

The glazing was double-glazed, consisting of nominal 1" thick insulating glass fabricated from two 0.225" sheets of glass, and 0.550" air space. The spacer assembly is a dual seal Aluminum spacer. WINDOW 4.1 was used to calculate center of glass and overall product indices. THERM 2.1a was used to model frame and edge-of-glass performance of all cross sections. The detailed reports from WINDOW 4.1 are given in Appendix A.

U-factor as well as CR calculations have been performed using the boundary conditions given in Table 2 with radiation enclosure.

Table 2: Boundary Conditions For Indoor And Outdoor Side Of Window System For U-Factor Calculation With Radiation Enclosure And CR Calculation

Boundary Conditions		*Environmental Temperature (F)*	h_c	*Overall h*	ε
			(Btu/h-ft^2-F)		
Outdoor Side	Glazing	0	N/A	5.112	0.84
	Frame		N/A	5.112	-
Indoor Side	Glazing	70	0.598	N/A	0.84
	Frame		0.509	N/A	0.90/0.20

The isotherms for different cross sections of the window system are shown in Fig.2 and Fig. 3 for inside frame emissiivity of 0.9 and 0.2 respectively

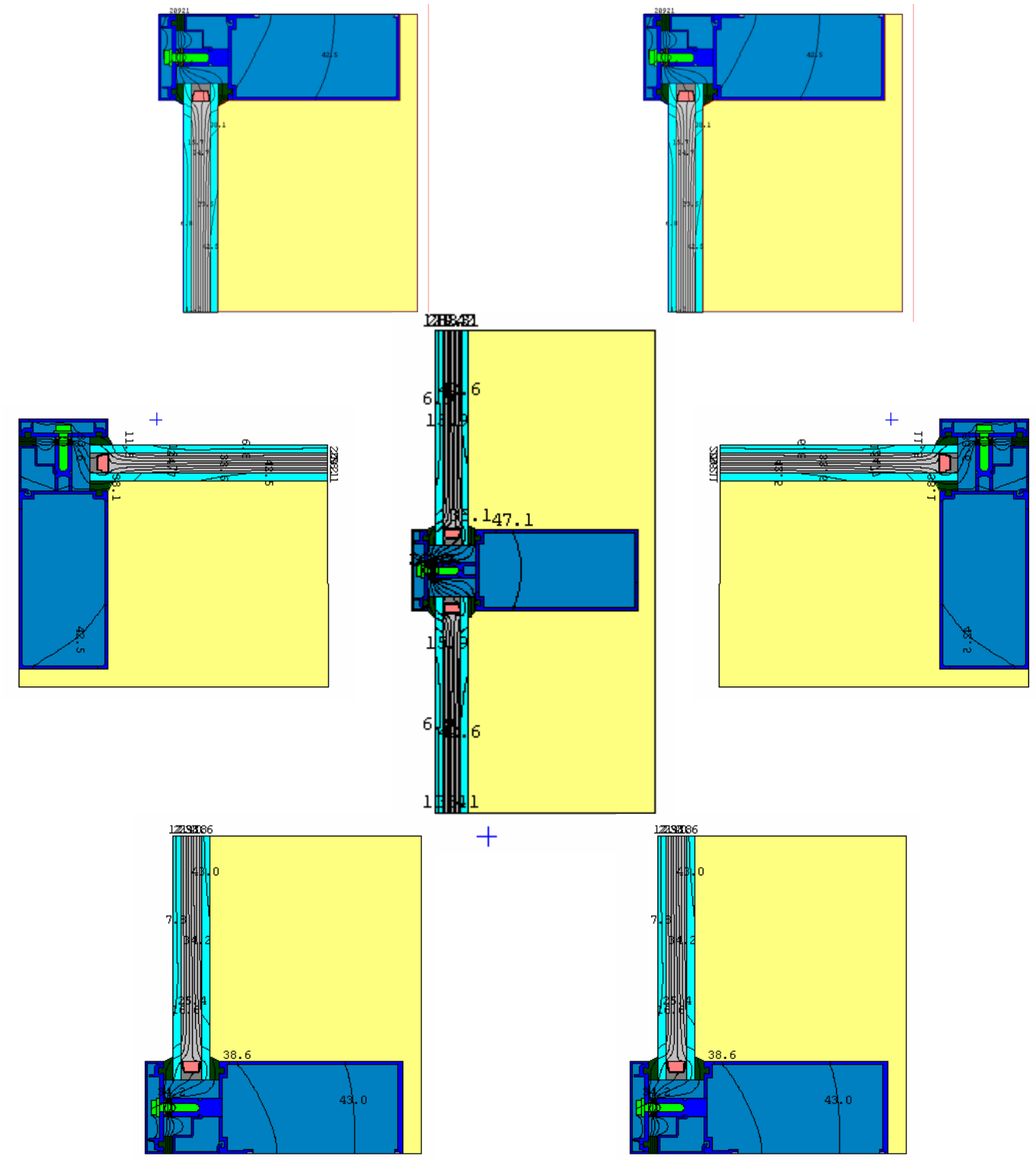


Fig. 2: Isotherms For All Cross Sections of Emissivity 0.9 for frames

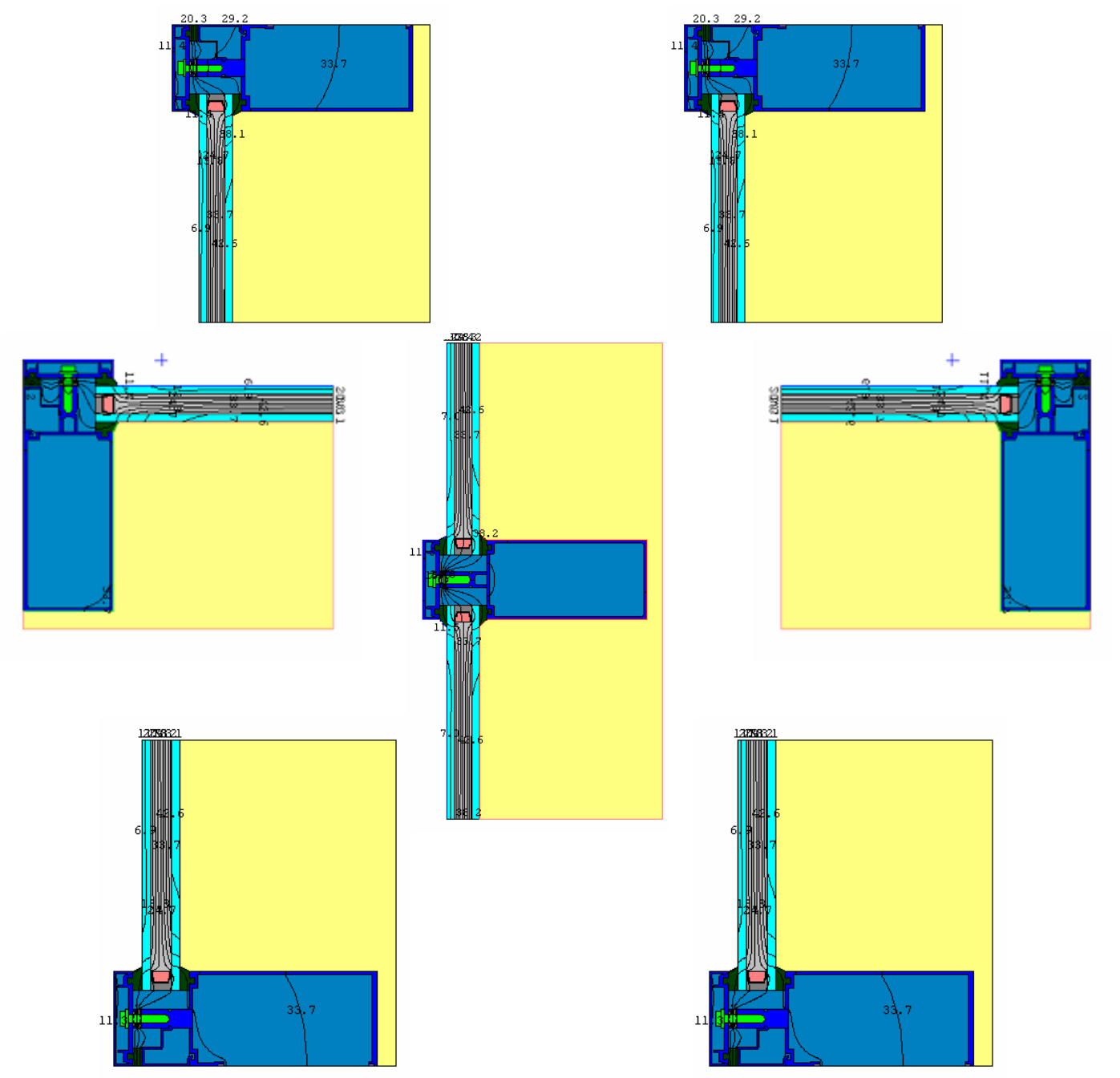


Fig. 3: Isotherms For All Cross Sections of Emissivity 0.2 for frames

The frame and edge cross-sections U-factors and overall U-factors for the models with emissivity 0.9 or 0.2 for the frame section are given in Tables 3, and Table 4, respectively.

Table 3: Frame, Edge And Overall U-Factors With Emissivity 0.9 for frame

Cross Section	*Name of THERM data file*	*Project Y of frame(inches)*	*U-factor of frame(Btu/h-ft^2-F)*	*U-factor of edge-of-glass(Btu/h-ft^2-F)*
Head Left	No2Head.thm	2.63745	1.3321	0.4833
Head Right	No2Head.thm	2.63745	1.3321	0.4833
Sill Left	No2Sill.thm	2.63745	1.3817	0.4927
Sill Right	No2Sill.thm	2.63745	1.3817	0.4927
Jamb Left	No2Jamb.thm	2.64809	1.4128	0.4808
Jamb Right	No2Jamb.thm	2.64809	1.4128	0.4808
Meeting Rail	No2Meetingrail.thm	2.8962	1.6040	0.4791
		U-Factor (Btu/h-ft^2-F)	*SHGC*	*VT*
Center of glass		0.481	0.69	0.78
Window assembly		0.635	0.621	0.657

Table 4: Frame, Edge And Overall U-Factors With Emissivity 0.2 for frame

Cross Section	*Name of THERM data file*	*Project Y of frame(inches)*	*U-factor of frame(Btu/h-ft^2-F)*	*U-factor of edge-of-glass(Btu/h-ft^2-F)*
Head Left	No3Head.thm	2.63745	1.0253	0.5293
Head Right	No3Head.thm	2.63745	1.0253	0.5293
Sill Left	No3Sill.thm	2.63745	1.0363	0.5299
Sill Right	No3Sill.thm	2.63745	1.0363	0.5299
Jamb Left	No3Jamb.thm	2.64809	1.0727	0.5275
Jamb Right	No3Jamb.thm	2.64809	1.0727	0.5275
Meeting Rail	No3MR.thm	2.8962	1.3075	0.5139
		U-Factor (Btu/h-ft^2-F)	*SHGC*	*VT*
Center of glass		0.481	0.69	0.81
Window assembly		0.589	0.612	0.657

Condensation Index:

Condensation Index (CI) has been calculated with the boundary conditions given in Table 2.

Figure 4 and Figure 5 show the schematic representation of head, jambs, meeting rail and sill cross of CI calculation model for the two cases. The radiation enclosure has been used for the detailed radiation heat transfer calculations. CI Calculations have been performed by the spreadsheets using current NFRC500 procedure.

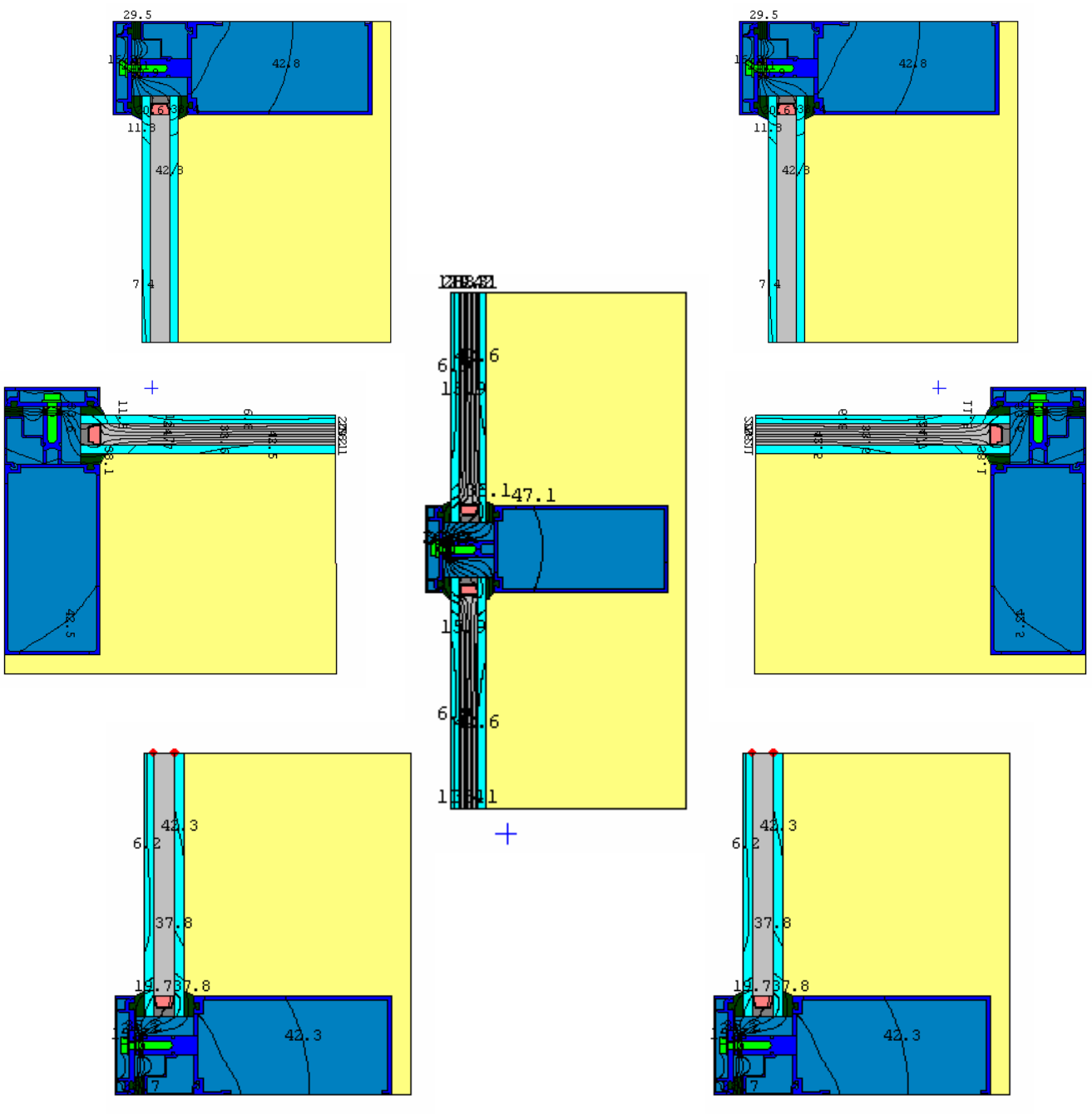


Fig. 4: Isotherms For All Cross Sections of Emissivity 0.9 for frames of CI Model

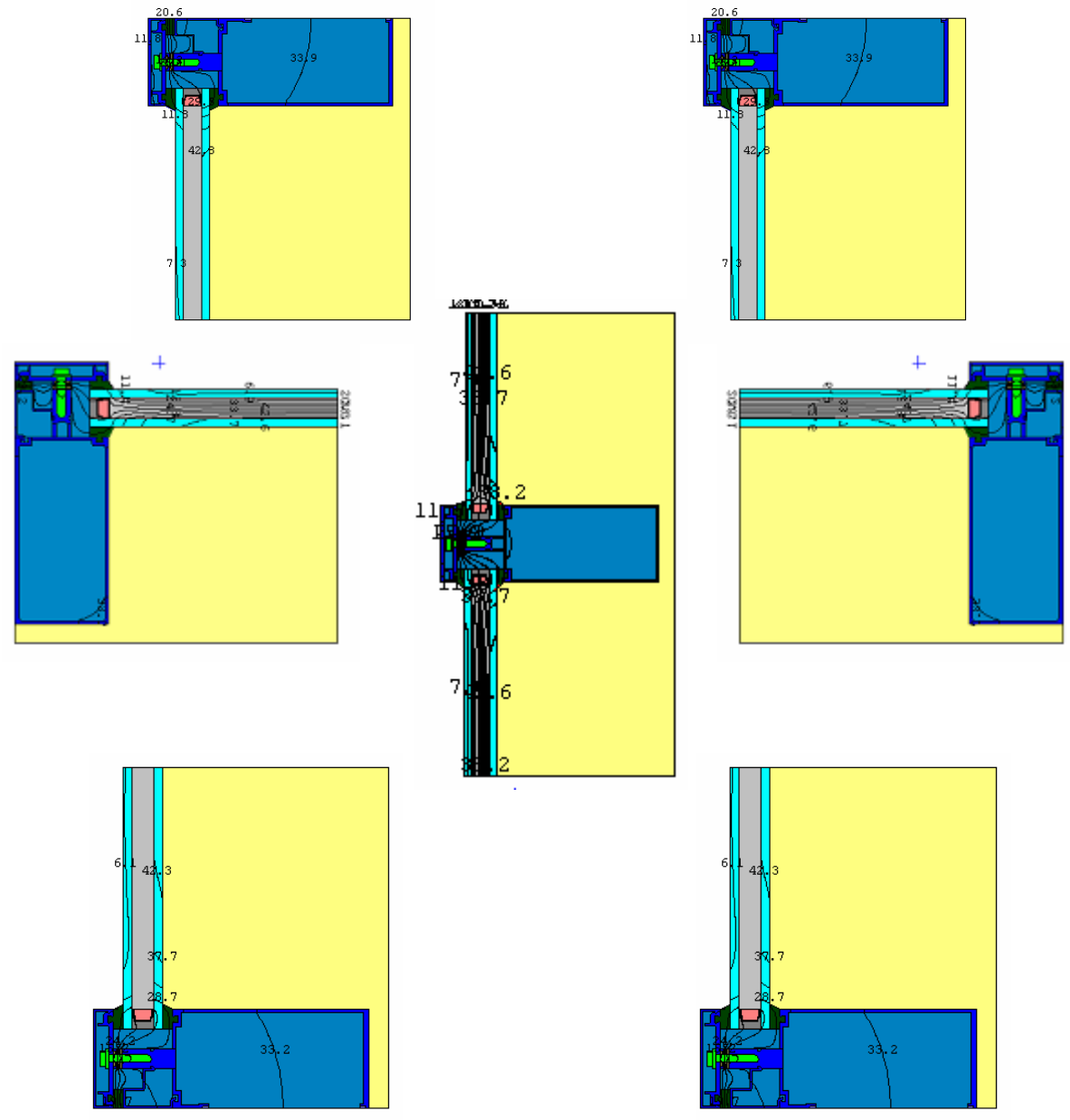


Fig. 5: Isotherms For All Cross Sections of Emissivity 0.2 for frames of CI Model

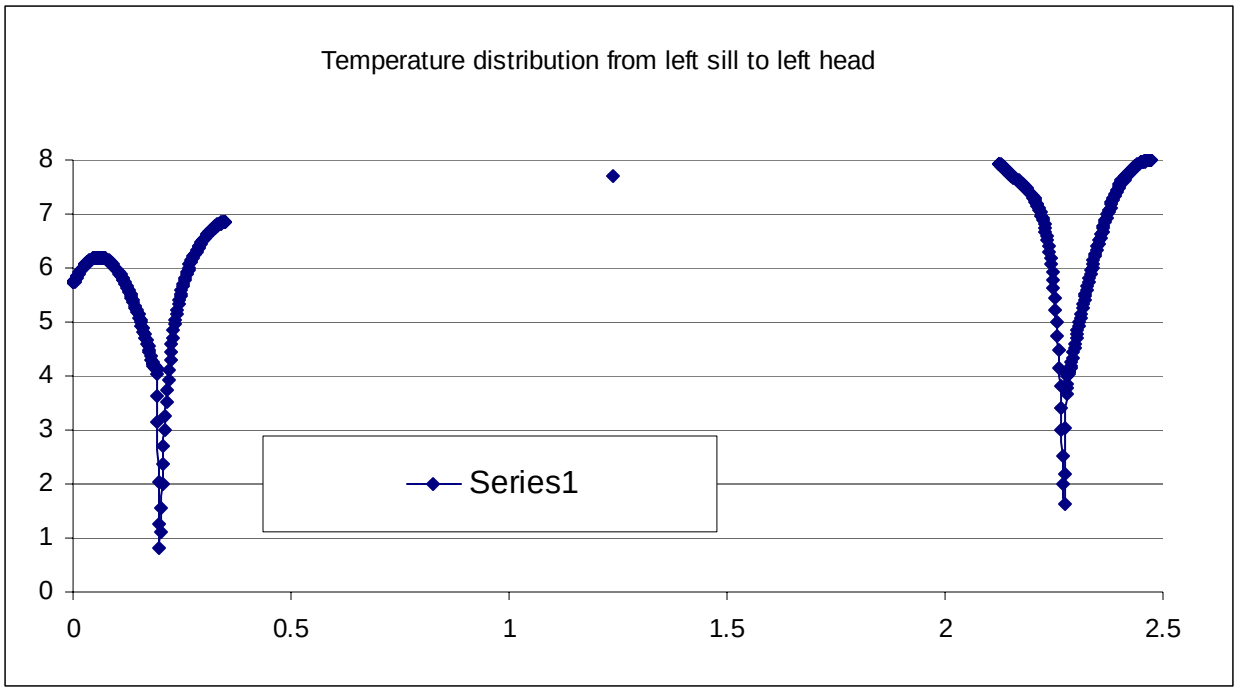
The results of CI calculation obtained are given in Table 5.

Table 5: CI Results

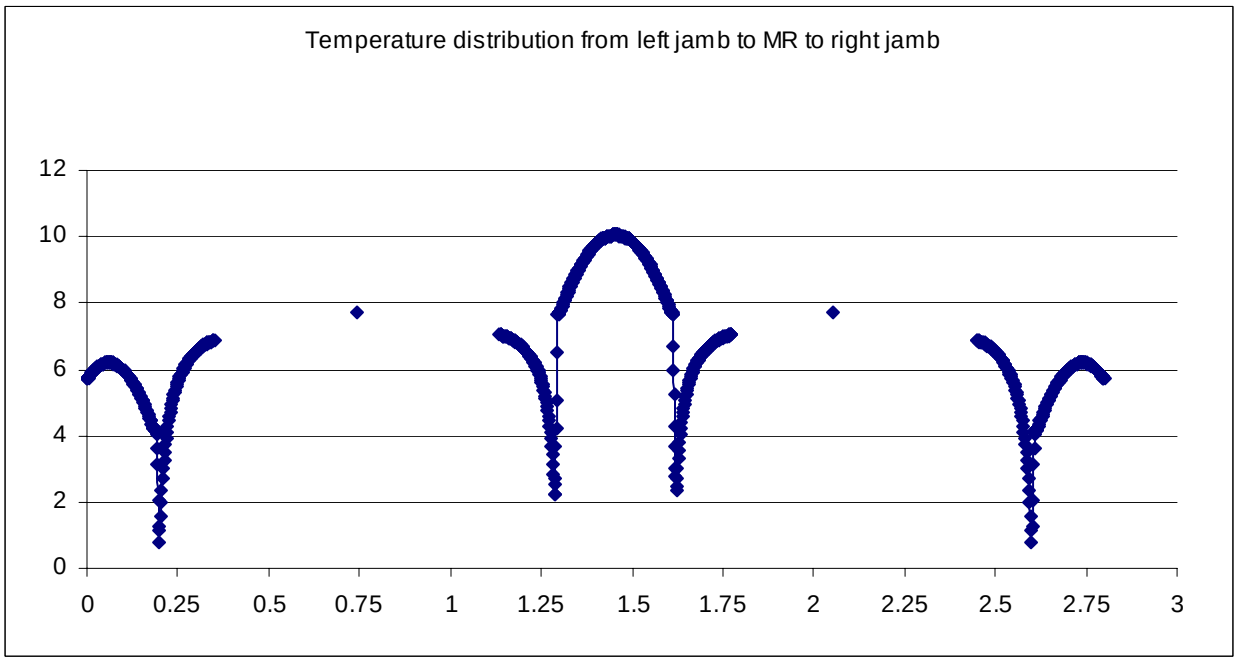
CI	**Spreadsheet W4&Therm2 (Emissivity=0.9)**	**Spreadsheet W4&Therm2 (Emissivity=0.2)**
CI_f	47.88	35.12
Ci_g	51.21	51.21
CI_e	44.80	44.28
CI	44.80	35.12

Temperature Distribution along the Inner Surface of the Window:

Figure 6 and Figure 7 show the temperature variation along the inside surface for the window. The middle point in the graph corresponds to the center of glass temperature. Distance at X-axis corresponds to either from the bottom of left sill section to the top of the left head section, or from the left jamb section to meeting rail, and then to the right jamb section.

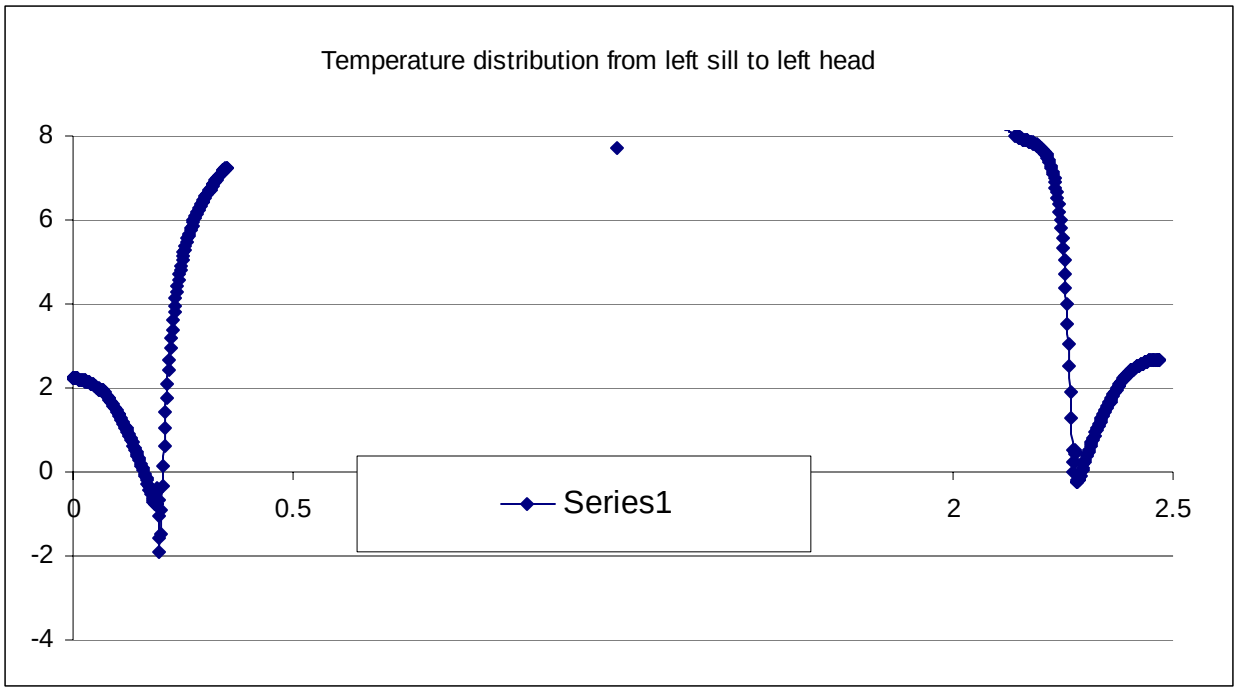


From Left Sill to Left Head

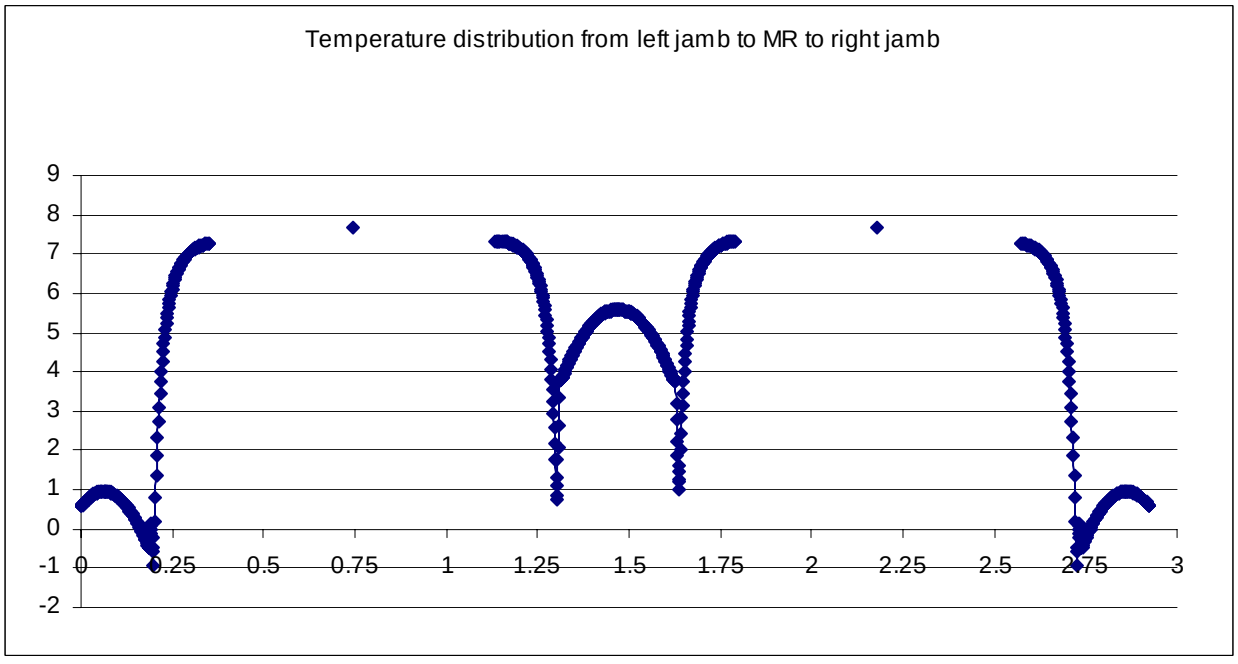


From Left Jamb to Meeting Rail to Right Jamb

Figure 6. Temperature Distribution along Inside Surface for Emissivity=0.9



From Left Sill to Left Head



From Left Jamb to Meeting Rail to Right Jamb

Figure 7. Temperature Distribution along Inside Surface for Emissivity=0.2

Appendix 1--Window 4 Report for Emissivity =0.9

```
WINDOW 4.1  Report                  Page 1                    03/04/02 15:47:17
      ID:New                             FrID: 14      FrID: 14
    Name:update                          ================================
    Mode:Design                          ||             ||             ||
 EnvCond:1                               ||GlzSysID:  7 ||GlzSysID:  7 |
                                         ||  Wid:38.56" || Wid:33.24" ||
    Type:Horz Slider        FrID: 15     ||  Div ID:  0 ||  Div ID:  0||FrID: 15
    Tilt: 90                             ||             ||             ||
    Size:Glzd Wall BB                    ||             ||             ||
   Width:  80.00"                        ||          FrID: 16          ||
  Height:  80.00"                        ||             ||             ||
    Area: 44.45 ft2                      ================================
                                              FrID: 17      FrID: 17
 U-value: 0.635 Btu/h-ft2-F
      SC: 0.722
    SHGC: 0.621
      Vt: 0.657
```

Data for Glazing Systems

ID	Name	COG Area ft2	#Lay	Tilt	Uc Btu/h-ft2	SCc	SHGCc	Vtc	RHG
7	glass103new	16.252	2	90	0.481	0.81	0.69	0.78	169
7	glass103new	13.677	2	90	0.481	0.81	0.69	0.78	169

Glass and Gas Data for Glazing System '7 glass103new'

ID	Name	D(in)	Tsol	1 Rsol	2 Rsol	Tvis	1 Rvis	2 Rvis	Tir	1 Emis	2 Emis	Keff
Outside												
103	CLEAR_6.DAT	0.225	.770	.070	.070	.883	.080	.080	.000	.840	.840	.520
1	Air	0.550										.042
103	CLEAR_6.DAT	0.225	.770	.070	.070	.883	.080	.080	.000	.840	.840	.520
Inside												

Frame Data

Location	ID	Name	Source	Frame Area ft2	Edge Area ft2	Uframe Btu/h-ft2-F	Uedge
Left Jamb	15	09NO2J~1.T2W	FRAME Sill	1.423	1.254	1.4128	0.4808
Left Header	14	09NO2H~1.T2W	FRAME Head	0.757	0.626	1.3321	0.4833
Mullion	16	09NO2M~1.T2W	FRAME Rail	1.503	2.508	1.6040	0.4791
Left Sill	17	09NO2S~1.T2W	FRAME Sill	0.757	0.626	1.3817	0.4927
Right Header	14	09NO2H~1.T2W	FRAME Head	0.660	0.534	1.3321	0.4833
Right Jamb	15	09NO2J~1.T2W	FRAME Sill	1.423	1.254	1.4128	0.4808
Right Sill	17	09NO2S~1.T2W	FRAME Sill	0.660	0.534	1.3817	0.4927

Gas Data

ID	Name	Cond Btu/h-ft-F	dCond Btu/h-ft-F2 x e-5	Visc lb-s/ft2 x e-5	dVisc lb-s/ft2-F x e-8	Dens lb/ft3	dDens lb/ft3-F	Pran	dPran
1	Air	.0139	2.4395	0.0361	0.1161	0.0805	-0.0002	.7200	.00100

Environmental Conditions: 1 NFRC/ASHRAE

	Tout (F)	Tin (F)	WndSpd (mph)	Wnd Dir	Solar (Btu/h-ft2)	Tsky (F)	Esky
Uvalue	0.0	70.0	15.00	Windward	0.0	0.0	1.00
Solar	89.0	75.0	7.50	Windward	248.2	89.0	1.00

Frame Library Data

ID	Name	Source	U-value Frame Btu/h-ft2-F	U-value Edge Btu/h-ft2-F	Edge Corr	GlzSys Width in	GlzSys Uc Btu/h-ft2-F	Width (PFD) in	Abs
15	09NO2J~1.T2W	FRAME Sill	1.41	0.48	N/A	1.0000	0.481	2.648	0.50
14	09NO2H~1.T2W	FRAME Head	1.33	0.48	N/A	1.0000	0.481	2.637	0.50
16	09NO2M~1.T2W	FRAME Rail	1.60	0.48	N/A	1.0000	0.481	2.896	0.50
17	09NO2S~1.T2W	FRAME Sill	1.38	0.49	N/A	1.0000	0.481	2.637	0.50

Divider Library Data

ID	Name	Source	U-value Div Btu/h-ft2-F	U-value Edge Btu/h-ft2-F	Edge Corr	GlzSys Width in	GlzSys Uc Btu/h-ft2-F	Width (PFD) in	Abs

No Dividers for this Glazing System

Optical Properties for Glazing System '7 glass103new'

Angle	0	10	20	30	40	50	60	70	80	90	Hemis

Vtc : 0.784
Rf : 0.143
Rb : 0.143

Tsol : 0.596
Rf : 0.112
Rb : 0.112

Abs 1: 0.168
Abs 2: 0.124
Abs 3:
Abs 4:
Abs 5:
Abs 6:
SHGCc: 0.694

		DomWL	Purity	L*	a*	b*
SCc: 0.81	Color Properties					
Tdw: N/A	Transmittance	um	%			
Tuv: N/A	Reflectance	um	%			

Temperature Distribution (degrees F) for '7 glass103new'

Env. Conditions:	1 NFRC/ASHRAE	U-value	Condensation RH	Solar
	Outside Air	0.0		89.0
	Outer Surface	6.7	N/A	99.0
Layer 1	Center	7.3		99.7
	Inner Surface	7.9		99.6
	Outer Surface	44.6		97.6
Layer 2	Center	45.2		97.5
	Inner Surface	45.8	41.9%	96.9
	Inside Air	70.0		75.0

Appendix 2--Window 4 Report for Emissivity =0.2

```
WINDOW 4.1  Report                  Page 1                    03/04/02 15:52:04
      ID:New                             FrID: 10      FrID: 10
    Name:update                          ================================
    Mode:Design                          ||             ||             ||
 EnvCond:1                               ||GlzSysID:  7 ||GlzSysID:  7 |
                                         ||  Wid:41.21" || Wid:30.60" ||
    Type:Horz Slider        FrID: 11     ||  Div ID:  0 ||  Div ID:  0||FrID: 11
    Tilt: 90                             ||             ||             ||
    Size:Glzd Wall BB                    ||             ||             ||
   Width:  80.00"                        ||          FrID: 12          ||
  Height:  80.00"                        ||             ||             ||
    Area: 44.45 ft2                      ================================
                                              FrID: 13      FrID: 13
 U-value: 0.589 Btu/h-ft2-F
      SC: 0.712
    SHGC: 0.612
      Vt: 0.657
```

Data for Glazing Systems

ID	Name	COG Area ft2	#Lay	Tilt	Uc Btu/h-ft2	SCc	SHGCc	Vtc	RHG
7	glass103new	17.534	2	90	0.481	0.81	0.69	0.78	169
7	glass103new	12.395	2	90	0.481	0.81	0.69	0.78	169

Glass and Gas Data for Glazing System '7 glass103new'

ID	Name	D(in)	Tsol	1 Rsol	2 Rsol	Tvis	1 Rvis	2 Rvis	Tir	1 Emis	2 Emis	Keff
Outside												
103	CLEAR_6.DAT	0.225	.770	.070	.070	.883	.080	.080	.000	.840	.840	.520
1	Air	0.550										.042
103	CLEAR_6.DAT	0.225	.770	.070	.070	.883	.080	.080	.000	.840	.840	.520
Inside												

Frame Data

Location	ID	Name	Source	Frame Area ft2	Edge Area ft2	Uframe Btu/h-ft2-F	Uedge
Left Jamb	11	02NO2J~1.T2W	FRAME Jamb	1.423	1.254	1.0727	0.5275
Left Header	10	02NO2H~1.T2W	FRAME Head	0.806	0.672	1.0253	0.5293
Mullion	12	02NO2M~1.T2W	FRAME Rail	1.503	2.508	1.3075	0.5139
Left Sill	13	02NO2S~1.T2W	FRAME Sill	0.806	0.672	1.0363	0.5299
Right Header	10	02NO2H~1.T2W	FRAME Head	0.611	0.488	1.0253	0.5293
Right Jamb	11	02NO2J~1.T2W	FRAME Jamb	1.423	1.254	1.0727	0.5275
Right Sill	13	02NO2S~1.T2W	FRAME Sill	0.611	0.488	1.0363	0.5299

Gas Data

ID	Name	Cond Btu/h-ft-F	dCond Btu/h-ft-F2 x e-5	Visc lb-s/ft2 x e-5	dVisc lb-s/ft2-F x e-8	Dens lb/ft3	dDens lb/ft3-F	Pran	dPran
1	Air	.0139	2.4395	0.0361	0.1161	0.0805	-0.0002	.7200	.00100

Environmental Conditions: 1 NFRC/ASHRAE

	Tout (F)	Tin (F)	WndSpd (mph)	Wnd Dir	Solar (Btu/h-ft2)	Tsky (F)	Esky
Uvalue	0.0	70.0	15.00	Windward	0.0	0.0	1.00
Solar	89.0	75.0	7.50	Windward	248.2	89.0	1.00

Frame Library Data

ID	Name	Source	U-value Frame Btu/h-ft2-F	U-value Edge Btu/h-ft2-F	Edge Corr	GlzSys Width in	GlzSys Uc Btu/h-ft2-F	Width (PFD) in	Abs
11	02NO2J~1.T2W	FRAME Jamb	1.07	0.53	N/A	1.0000	0.481	2.648	0.50
10	02NO2H~1.T2W	FRAME Head	1.03	0.53	N/A	1.0000	0.481	2.637	0.50
12	02NO2M~1.T2W	FRAME Rail	1.31	0.51	N/A	1.0000	0.481	2.896	0.50
13	02NO2S~1.T2W	FRAME Sill	1.04	0.53	N/A	1.0000	0.481	2.637	0.50

Divider Library Data

ID	Name	Source	U-value Div Btu/h-ft2-F	U-value Edge Btu/h-ft2-F	Edge Corr	GlzSys Width in	GlzSys Uc Btu/h-ft2-F	Width (PFD) in	Abs

No Dividers for this Glazing System

Optical Properties for Glazing System '7 glass103new'

Angle	0	10	20	30	40	50	60	70	80	90	Hemis

Vtc : 0.784
Rf : 0.143
Rb : 0.143

Tsol : 0.596
Rf : 0.112
Rb : 0.112

Abs 1: 0.168
Abs 2: 0.124
Abs 3:
Abs 4:
Abs 5:
Abs 6:
SHGCc: 0.694

		DomWL	Purity	L*	a*	b*
SCc: 0.81	Color Properties					
Tdw: N/A	Transmittance	um	%			
Tuv: N/A	Reflectance	um	%			

Temperature Distribution (degrees F) for '7 glass103new'

Env. Conditions:	1 NFRC/ASHRAE	U-value	Condensation RH	Solar
	Outside Air	0.0		89.0
	Outer Surface	6.7	N/A	99.0
Layer 1	Center	7.3		99.7
	Inner Surface	7.9		99.6
	Outer Surface	44.6		97.6
Layer 2	Center	45.2		97.5
	Inner Surface	45.8	41.9%	96.9
	Inside Air	70.0		75.0

Appendix 3—Procedure for calculation effective conductivities thermal debridge

1. K

	Name of Material	W/mk
K_1	Air Cavity	0.0283
K_2	Aluminum Aloy	160
K_3	Vinyl	0.12
K_4	Air Cavity	0.0283

2. d

	m
d_1	0.00535
d_2	0.00318
d_3	0.00556
d_4	0.01905

3. R=d/k (W/m^2k)

	(W/m^2k)
R_1	0.189
R_2	0.00001988
R_3	0.0463
R_4	0.6731

4. $R_t=R_1+R_2+R3+R_4=0.9084$ (W/m^2k)

$D_{1=}\ d_1+d_2+d_3+d_4=0.03314$ (m)

5.$K_n=Dt/Rt=0.03648$ (W/mk)

$K_b=14.3$ (W/mk)

6. $W_b=12.446$ mm

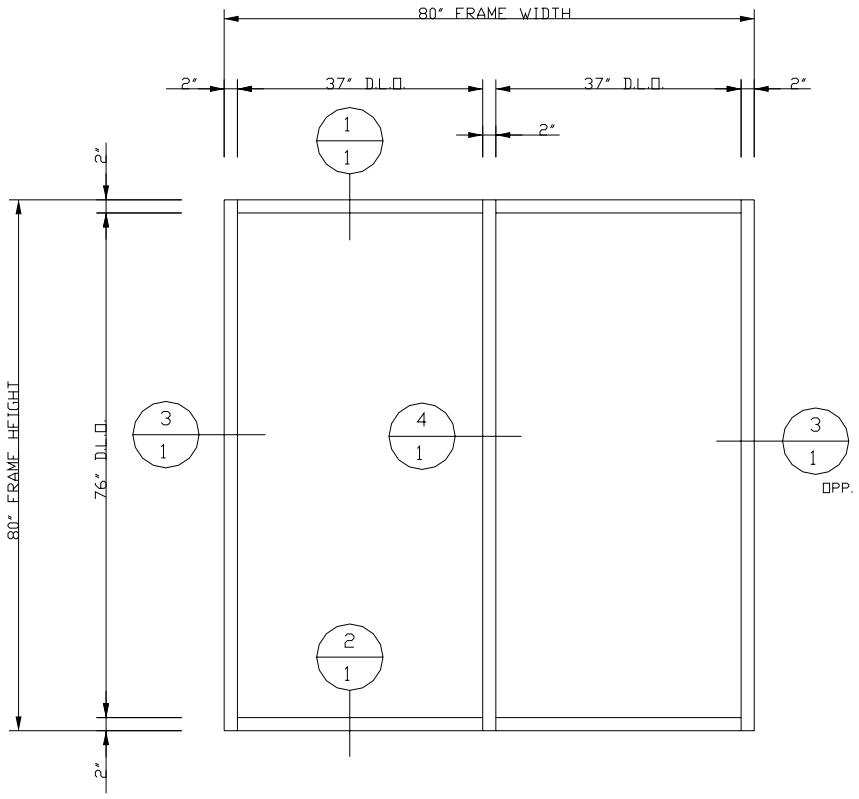
$S_b=228.6$ mm

$F_b=W_b/S_b=5.44\%$

$F_n=1-F_b=94.56\%$

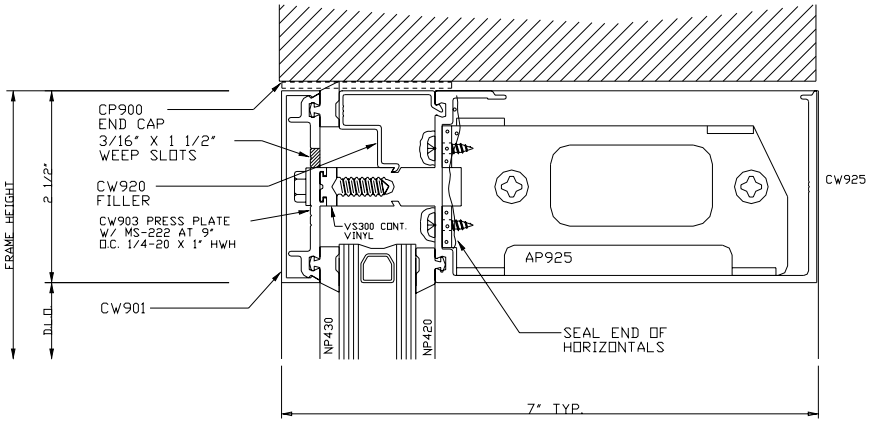
7.Keff= F_b*** K_b**+ F_n* $K_n=0.8124$ (W/mk)=0.47 (Btu/hr-ft-F)

Appendix 4—AutoCAD drawings

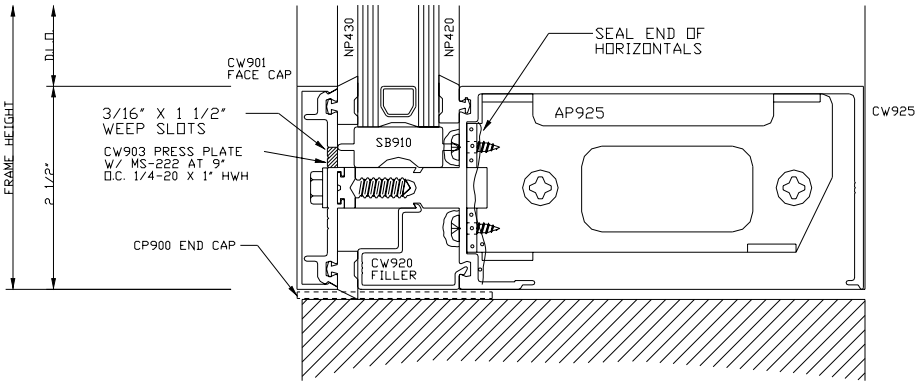


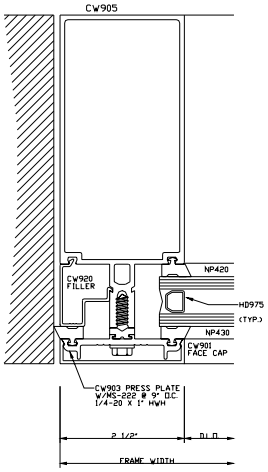
ELEVATION

1

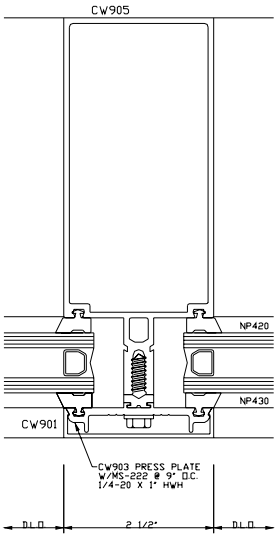

CP900
END CAP
3/16" X 1 1/2"
WEEP SLOTS
CW920
FILLER
CW903 PRESS PLATE
W/ MS-222 AT 9"
O.C. 1/4-20 X 1" HWH
VS300 CONT.
VINYL
CW901
FRAME HEIGHT
2 1/2"
D.L.O.
NP430
NP420
AP925
CW925
SEAL END OF
HORIZONTALS
7" TYP.

2


D.L.O.
CW901
FACE CAP
3/16" X 1 1/2"
WEEP SLOTS
CW903 PRESS PLATE
W/ MS-222 AT 9"
O.C. 1/4-20 X 1" HWH
CP900 END CAP
FRAME HEIGHT
2 1/2"
NP430
NP420
SB910
CW920
FILLER
SEAL END OF
HORIZONTALS
AP925
CW925


CW905
CW920
FILLER
NP420
HD975
(TYP.)
NP430
CW901
FACE CAP
CW903 PRESS PLATE
W/MS-222 @ 9" O.C.
1/4-20 X 1" HWH
2 1/2"
FRAME WIDTH

3


CW905
NP420
NP430
CW901
CW903 PRESS PLATE
W/MS-222 @ 9" O.C.
1/4-20 X 1" HWH
2 1/2"

4