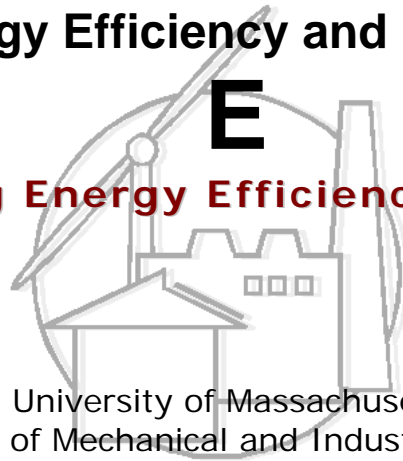


Center for Energy Efficiency and Renewable Energy

C E E R E

Building Energy Efficiency Program



University of Massachusetts
Department of Mechanical and Industrial Engineering
160 Governors Dr.
Amherst, MA 01003-9265

**Computer Modeling of Heat Transfer and Comparison for
PVC Casement Window – U-Factor and CR Simulations Using
THERM 2.1a and WINDOW 4.1**

Prepared by:

Yunhua Yang
Dr. D. Charlie Curcija
Dr. Mahabir Bhandari

June 2002

DESCRIPTION OF THE SPECIMEN

The product selected for simulation is a nominal 2'0" wide by 4'0" PVC casement window, manufactured by Anlin Industries. The specimen was tested by ATI from York, PA. The standardized tested U-factor, reported by ATI, is 0.31 Btu/h-ft²-F (see Appendix C).

Thermo physical properties of different frame material are given in Table 1 and schematic representation of the material locations for a jamb cross section is shown in Figure 1. AutoCAD drawings of the specimen is given in Appendix B.

The glazing was double-glazed, consisting of nominal 0.875" thick insulating glazing system fabricated from two 0.125" sheets of glass with a 0.036 emittance Low 'E' coating at surface 2, and 0.650" air space. The detailed reports from W4.1 are given in Appendix (A)

The spacer was a single seal Swiggle Strip spacer from True Seal company. The geometry and spacer details are given in Appendix D.

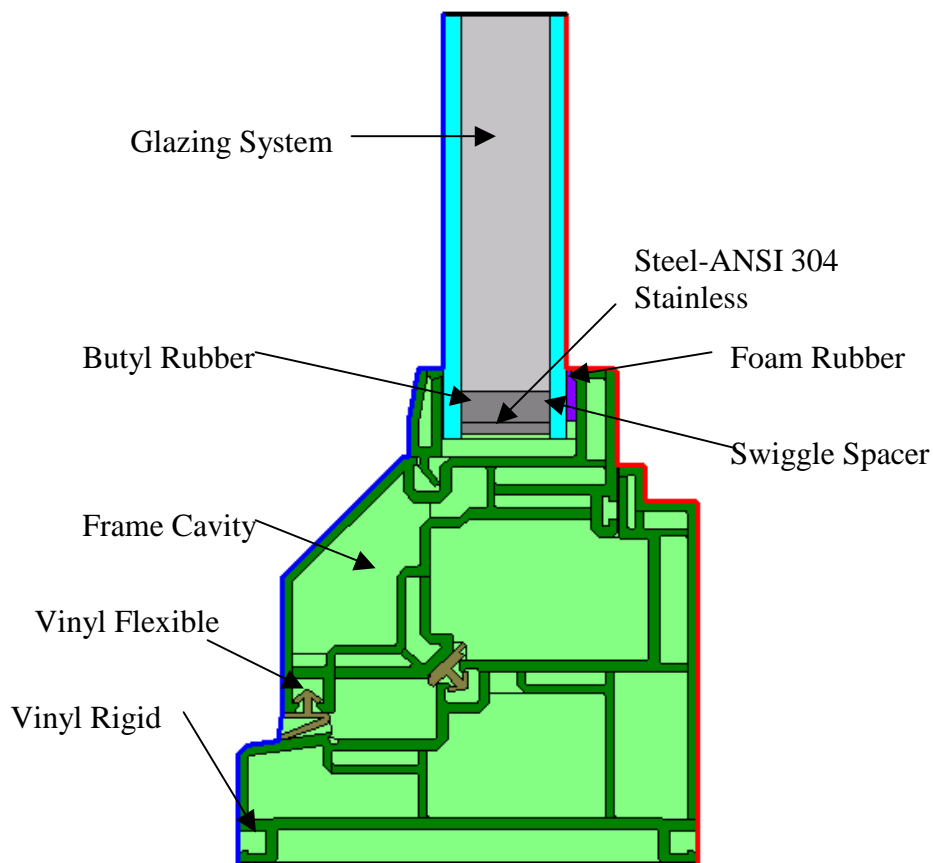


Figure 1: Schematic Representations Of Frame Materials In A Jamb Cross-Section Of Frame

Table 1: Material Thermo Physical Properties

Material	<i>k</i> (Btu/h-ft-F)	ϵ
PVC/Vinyl (Rigid)	0.0982	0.9
Foam Rubber	0.0173	0.9
Butyl Rubber	0.1387	0.9
Silica Gel (desiccant)	0.0173	0.9
Steel-ANSI 304 Stainless	8.2625	0.2
Vinyl (Flexible)	0.0693	0.9

The boundary conditions used in the calculations are listed in Table2.

Table 2: Boundary Conditions For Indoor And Outdoor Side Of Window System For U-Factor Calculation And CI Calculation

U-Factor Calculation:

<i>Boundary Conditions</i>		<i>Environmental Temperature (F)</i>	<i>Overall h (Btu/h-ft²-F)</i>
Outdoor Side	Glazing	0	5.112
	Frame		5.112
Indoor Side	Glazing	70	1.352
	Frame		1.340

CI Calculation:

<i>Boundary Conditions</i>		<i>Environmental Temperature (F)</i>	<i>h_c (Btu/h-ft²-F)</i>	<i>Overall h (Btu/h-ft²-F)</i>	ϵ
Outdoor Side	Glazing	0	N/A	5.112	0.84
	Frame		N/A	5.112	0.90
Indoor Side	Glazing	70	0.536	N/A	0.84
	Frame		0.44	N/A	0.90

The isotherms for different cross sections of the window system for U-factor calculations are shown in Figure 2.

The frame and edge cross-sections U-factors and overall U-factors for the window are given in Tables 3.

Table 3: Frame, Edge And Overall U-Factors

<i>Cross Section</i>	<i>Project Y of frame(inches)</i>	<i>U-factor of frame(Btu/h-ft²-F)</i>	<i>U-factor of edge-of-glass(Btu/h-ft²-F)</i>
Head	2.8130	0.3143	0.3579
Sill	2.8130	0.3141	0.3579
Jamb	3.5000	0.2912	0.3558
	<i>U-Factor</i> <i>(Btu/h-ft²-F)</i>	<i>SHGC</i>	<i>VT</i>
Center of glass	0.300	0.400	0.610
Window assembly	0.312	0.266	0.384

The isotherms for different cross sections of the window system for CR calculations are shown in Figure 3.

The results of CI calculation obtained are given in Table 4.

Table 4: CI Results Using Therm2+W4 Heat Transfer Coefficients

CI	Spreadsheet W4&Therm2
CI_f	70.74
CI_g	67.94
CI_e	59.13
CI	59

COMPARISON WITH TEST DATA:

Figure 4 and Figure 5 show the temperature variation along the inside surface for the window system. 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, or the left jamb section to the right jamb section. Temperature data obtained from the test are also plotted in the figures.

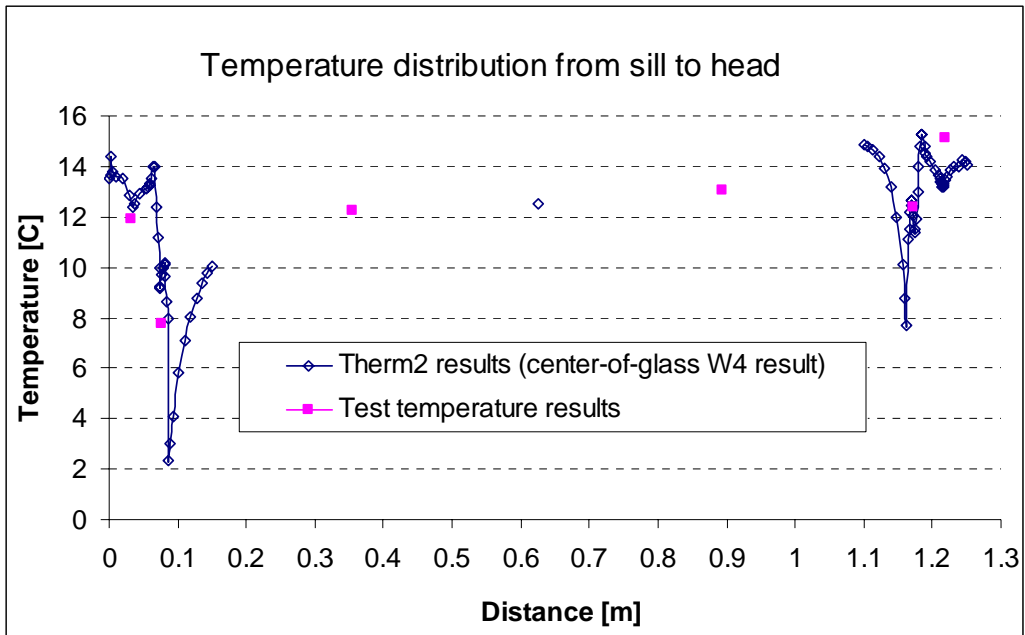


Figure 4. Temperature Distributions along Inside Surface (From Sill to Head)

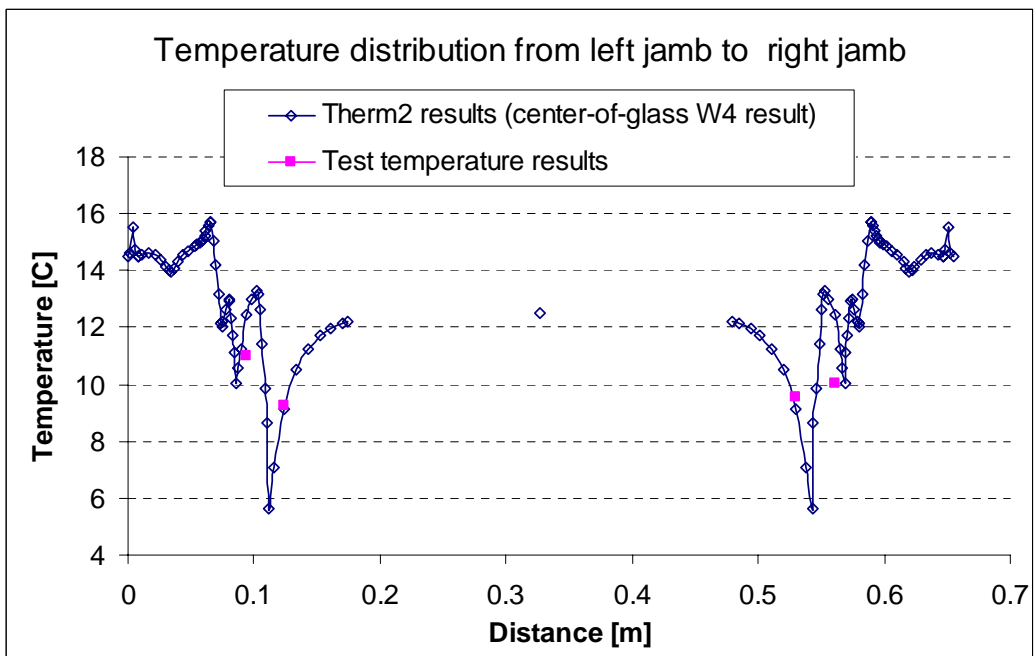


Figure 5. Temperature Distribution along Inside Surface (From Left Jamb to Right Jamb)

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	Esky (F)
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		Edge	GlzSys	GlzSys	Width	Abs
			Frame	Edge	Corr	Width	Uc	(PFD)	
			Btu/h- ft2-F	Btu/h- ft2-F		in	Btu/h- ft2-F	in	
8	CASEJAMB.T2W	FRAME Jamb	0.29	0.36	N/A	0.8750	0.300	3.500	0.50
7	CASEHEAD.T2W	FRAME Head	0.31	0.36	N/A	0.8750	0.300	2.813	0.50
9	CASESILL.T2W	FRAME Sill	0.31	0.36	N/A	0.8750	0.300	2.813	0.50

Divider Library Data

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

No Dividers for this Glazing System

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

Vtc : 0.614
 Rf : 0.286
 Rb : 0.236

Tsol : 0.350
 Rf : 0.401
 Rb : 0.408

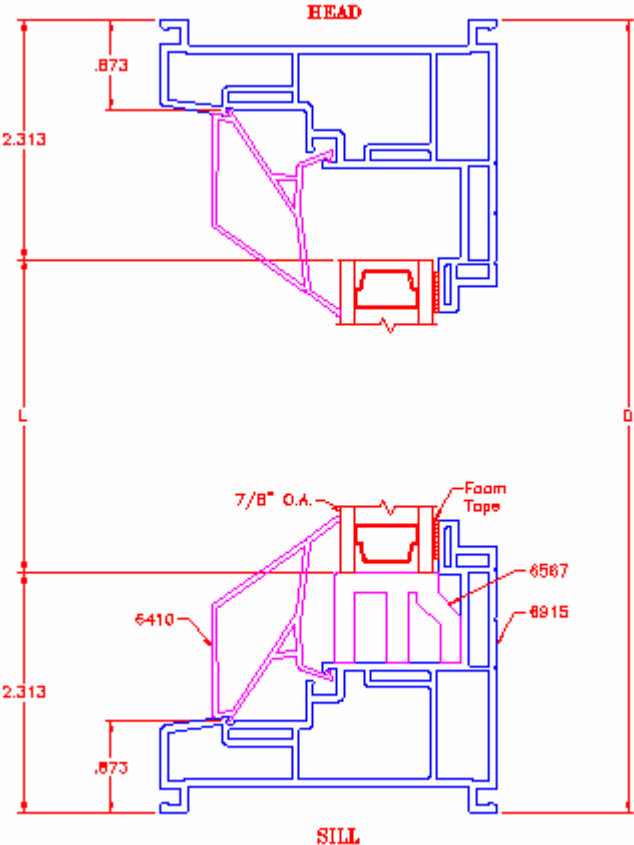
Abs 1: 0.211
 Abs 2: 0.039
 Abs 3:
 Abs 4:
 Abs 5:
 Abs 6:
 SHGCc: 0.395

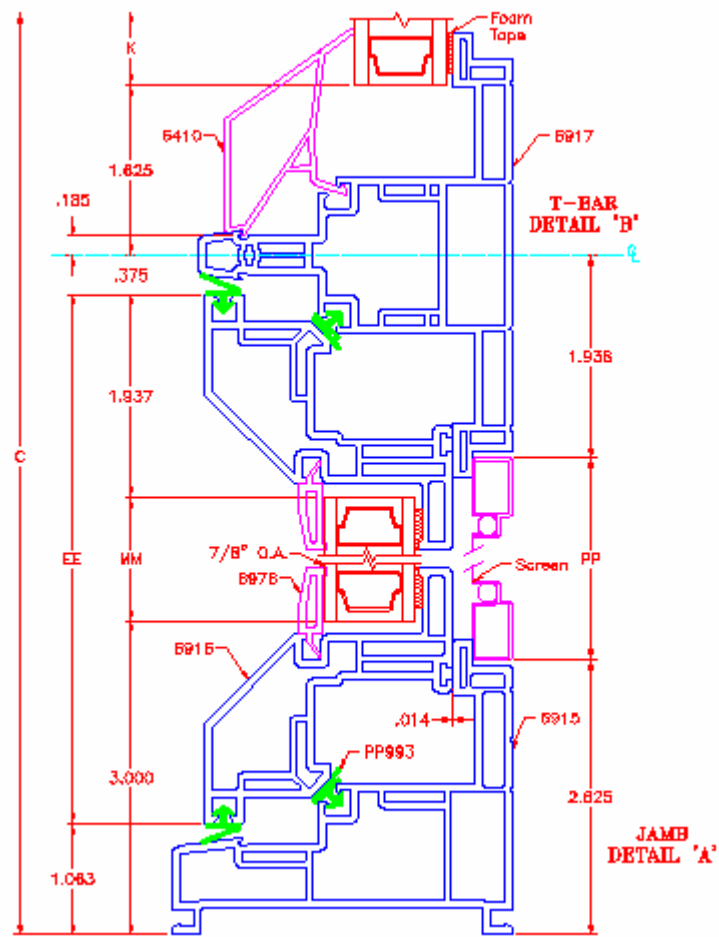
SCc: 0.46 Color Properties DomWL Purity L* a* b*
 Tdw: N/A Transmittance um %
 Tuv: N/A Reflectance um %

Temperature Distribution (degrees F) for '6 PVC'

Env. Conditions:		1 NFRC/ASHRAE	U-value	Condensation RH	Solar
	Outside Air		0.0		89.0
	Outer Surface		4.2	N/A	101.0
Layer 1	Center		4.4		101.4
	Inner Surface		4.6		101.4
	Outer Surface		54.1		85.9
Layer 2	Center		54.3		85.8
	Inner Surface		54.5	57.8%	85.7
	Inside Air		70.0		75.0

Appendix B -- Autocad drawing





Appendix C--Test Report

NFRC 100-97 THERMAL PERFORMANCE TEST REPORT

Rendered to:

ANLIN INDUSTRIES

SERIES/MODEL: "CORONADO"
TYPE: Vinyl (PVC) Casement Window

Report No: 03-31354.04
Report Date: 12-21-01
Expiration Date: 11-13-05

NFRC 100-97 THERMAL PERFORMANCE TEST REPORT

Rendered to:

Anlin Industries
1665 Tollhouse Road
Clovis, California 93611

Report No: 03-31354.04
Test Date: 11-13-01
Report Date: 12-21-01
Expiration Date: 11-13-05

Test Sample Identification:

Series/Model: "Coronado"

Type: Vinyl (PVC) Casement Window

Overall Size: 2' 0" wide by 4' 0" high

Representative Size: Residential

Test Procedure: U-factor tests were performed in a Guarded Hot Box in accordance with NFRC 100-97, *Procedure for Determining Fenestration Product Thermal Properties*.

Test Results Summary:

Standardized U-factor (U_{st}): 0.31 Btu/hr·ft²·F (CTS Equivalent Procedure)

Test Sample Description:**Construction:**

	Frame	Vent
Size	2' 0" x 4' 0"	1' 9-3/4" x 3' 9-7/8"
CORNERS	Mitered	Mitered
Fasteners	Welded	Welded
Sealant	None	None
MATERIAL	VY	VY
Color Exterior	White	White
Finish Exterior	Vinyl	Vinyl
Color Interior	White	White
Finish Interior	Vinyl	Vinyl
GLAZING METHOD	NA	Exterior glazed onto bed of silicone, held-in-place with vinyl glazing bead.

Glazing: (Sheet #1 is Exterior Sheet)

	Sheet #1	Gap #1	Sheet #2
THICKNESS	0.125"	0.625"	0.125"
COATING EMISSIVITY	0.036 *	NA	NA
COATING SURFACE	2	NA	NA
SPACER/SEALANT	NA	S5	NA
MATERIAL	Annealed glass	Air *	Annealed glass

Gas Filling Technique*: NA

* - Stated per Client/Manufacturer NA-Non Applicable See Appendix A for Description Codes

Test Sample Description: (Continued)

Components:

Type	Quantity	Location
WEATHERSTRIP		
Polypile with center fin	1 Row	Perimeter of vent
Single leaf gasket	1 Row	Perimeter of vent
HARDWARE		
Lock assembly	1	Lock stile
Roto-operator	1	Bottom rail
Multi-bar hinge assembly	2	Top and bottom rails
DRAINAGE		
0.375" x 0.100" weep hole	2	Each end of vent rail

Test Conditions:

t_{il} = Average weather side ambient temperature	0.06	F
t_i = Average room side ambient temperature	70.01	F
Metering room average relative humidity	7.72	%
<ul style="list-style-type: none"> • Nominal 15-mph dynamic wind applied perpendicular to the test specimen exterior. • Specimen was sealed during testing using clear tape. • The pressure created by the dynamic wind was offset to create a pressure difference across specimen to 0.00 ± 0.04" H₂O, using make-up air. 		

Test Data:

A_s = Projected specimen area	8.00	Ft ²
A_{sp} = Area of surround panel	28.20	Ft ²
A_{mb} = Metering box area	36.20	Ft ²
A_{bl} = Area of warm side baffle	32.13	Ft ²
Q = Total measured input to meter box	290.273	Btu/hr
Q_{sp} = Surround panel heat loss	94.508	Btu/hr
Q_{mb} = Metering box heat loss	12.827	Btu/hr
Q_{fl} = Flanking loss	10.174	Btu/hr
Q_s = Net specimen heat loss	172.764	Btu/hr
U_s = Thermal Transmittance of test specimen	0.309	Btu/hr·ft ² ·F
R_s = Thermal Resistance of the test specimen	3.239	Btu/hr·ft ² ·F
t_1 = Area-weighted warm side surface temperature	54.320	F
t_2 = Area-weighted cold side surface temperature	3.415	F
Equivalent warm side surface temperature	54.533	F
Equivalent cold side surface temperature	4.497	F
Area-weighted cold side frame surface temperature	1.570	F
Area-weighted warm side frame surface temperature	57.178	F
Area-weighted cold side edge-of-glass temperature	6.520	F
Area-weighted warm side edge-of-glass temperature	47.469	F

Area-weighted cold side center-of-glass temperature	3.618	F
Area-weighted warm side center-of-glass temperature	54.787	F
h_1 = Warm side surface conductance	1.395	Btu/hr·ft ² ·F
h_{11} = Cold side surface conductance	4.870	Btu/hr·ft ² ·F
C_s = Thermal conductance of specimen	0.432	Btu/hr·ft ² ·F
R_c = Surface-to-surface thermal resistance of specimen	2.317	hr·ft ² ·F/Btu
R_1 = Warm side surface resistance	0.717	hr·ft ² ·F/Btu
R_{11} = Weather side surface resistance	0.205	hr·ft ² ·F/Btu
R_u = Overall thermal resistance of specimen	3.252	hr·ft ² ·F/Btu
t_{b1} = Area-weighted baffle surface temperature	70.26	F
t_{sp1} = Surround panel warm side temperature	67.86	F
t_{sp2} = Surround panel cold side temperature	0.29	F
h_{st1} = Warm side standardized surface conductance	1.354	Btu/hr·ft ² ·F
h_{st11} = Cold side standardized surface conductance	5.100	Btu/hr·ft ² ·F
U_{st} = Standardized thermal transmittance of test specimen	0.308	Btu/hr·ft ² ·F

$$R_{st} = \frac{1}{h_{st1}} + \frac{1}{C_s} + \frac{1}{h_{st11}}$$

$$U_{st} = \frac{1}{R_{st}}$$

The reported standardized thermal transmittance (U_{st}) was determined using the CTS equivalent calculation procedure.

Glazing Deflection:

	Glazing
Glazing thickness at edge	0.875"
Center glazing thickness upon receipt of specimen in laboratory (after stabilization)	0.910"
Center glazing thickness at laboratory ambient conditions on day of testing	0.910"
Center glazing thickness at test conditions	0.890"

Attached to this report is an isometric drawing indicating thermocouple attachment locations and average surface temperature measurements.

The test sample was inspected for the formation of frost or condensation which may influence the surface temperature measurements. Any observed condensation/frost is indicated on the attached drawing if applicable.

A calibration of the Fresno, California, ATI "thermal test chamber" was conducted in November 2000.

"This test method does not include procedures to determine the heat flow due to either air movement through the specimen or solar radiation effects. As a consequence, the thermal transmittance results obtained do not reflect performances which may be expected from field installations due to not accounting for solar radiation, air leakage effects, and the thermal bridge effects that may occur due to the specific design and construction of the fenestration system opening. The latter can only be determined by on-site measurements. Therefore, it should be recognized that the thermal transmittance results obtained from this test method are for ideal laboratory conditions and should only be used for fenestration product comparisons and as input to thermal performance analyses which also include solar, air leakage and thermal bridge effects".

This report is reissued in the name of Anlin Industries through written authorization from Mikron Industries for whom testing was originally performed. The original Mikron Industries report number is 03-31354.01.

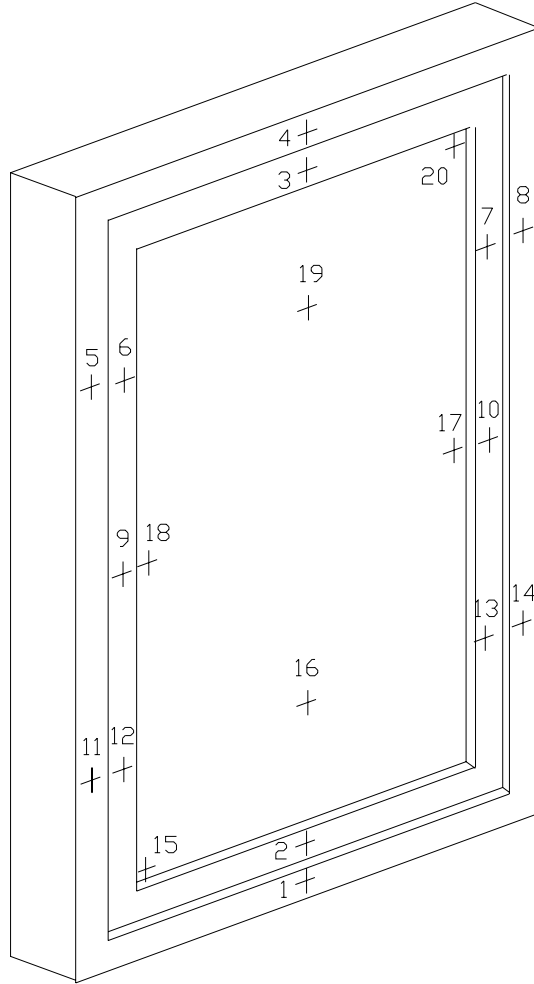
Detailed drawings, representative samples of the test specimen and a copy of this report will be retained by ATI for a period of four years. This report is the exclusive property of the client so named herein and is applicable to the sample tested. This report may not be reproduced, except in full, without the approval of the laboratory. ATI is an NFRC accredited test laboratory; all tests were conducted in compliance with NFRC approved procedures. Results obtained are tested values and do not constitute an opinion or endorsement by this laboratory. This report does not constitute certification of this product which may only be granted by an NFRC approved Independent Administrator.

For ARCHITECTURAL TESTING, INC.

Anthony Avalos
Technician

Leaton Kirk
Regional Manager

AA:lg



03-31354.04

Temperature (°F)

	<i>Interior</i>	<i>Exterior</i>
1	53.45	0.73
2	45.94	1.25
3	54.26	2.03
4	59.18	1.26
5	61.53	1.58
6	54.89	2.13
7	56.61	2.10
8	61.41	2.03
9	51.74	1.70
10	50.11	1.66
11	57.13	0.72
12	51.03	1.32
13	50.97	1.44
14	57.46	1.26
15	39.41	5.19
16	54.10	3.53

	17	49.18	5.38
<u>Thermocouple Location Diagram</u>			
Architectural Testing, Inc. 03-31354.04	18	48.64	5.96
Anlin Industries	19	55.47	3.70
Coronado, Vinyl casement window	20	52.65	9.55

Appendix A
Description of Table Abbreviations

COD	FRAME/PANEL MATERIAL	DEFINITION	
AI	Aluminum w/ vinyl inserts	Vinyl inserts employed in aluminum	
AL	Aluminum	No thermally broken frame/sash components	
AP	Aluminum w/ thermal breaks - partial	Some frame/panel members thermally broken	
AT	Aluminum w/ thermal breaks – all	All members contain thermal breaks	
AV	Aluminum/vinyl composite	Aluminum members combined with vinyl	
AW	Aluminum clad wood	Aluminum cladding covering primary wood	
FG	Fiberglass	Fiber reinforced frame/panel members	
OT	Other	Material not described in this lookup table	
PL	ABS Plastic	ABS plastic frame/sash members	
ST	Steel	Steel alloy members	
VA	Vinyl w/ reinforcing – all members	Some frame/panel members contain	
VC	Vinyl clad aluminum	Vinyl cladding covering primary aluminum	
VH	Vinyl w/ reinforcing – horizontal	Only horizontal panel members contain	
VI	Vinyl w/ reinforcing – interlock only	Only panel interlock members contain	
VP	Vinyl w/ reinforcing – partial	Only specific members contain reinforcing	
VV	Vinyl w/ reinforcing – vertical members	Only vertical panel members contain	
VW	Vinyl clad wood	Vinyl cladding covering primary wood	
VY	Vinyl	Vinyl members with no reinforcing	
WA	Aluminum / wood composite	Aluminum members combined with wood	
WD	Wood	All members are solid wood	
WV	Vinyl / wood composite	Vinyl members combined with wood	
COD E	INTERSPACE GAS FILL	COD E	THERMAL BREAK MATERIAL
AIR	Air	F	Foam
AR2	Argon / Krypton mixture	O	Other
AR3	Argon / Krypton / Air mixture	U	Urethane
ARG	Argon	V	Vinyl
CO2	Carbon Dioxide		
KRY	Krypton		
OT	Other		
SF6	Sulfur Hexafluoride		
COD E	SPACER TYPE	DEFINITION	
A1	Aluminum	Aluminum spacer system	
A2	Aluminum – thermally broken	Aluminum spacer with urethane thermal break	
A3	Aluminum – reinforced polymer	Polymer spacer with aluminum substrate	
A4	Aluminum / wood	Aluminum / wood composite	
A5	Aluminum reinforced butyl	Butyl spacer with aluminum substrate	
A6	Aluminum /foam/aluminum	Two aluminum spacers separated by foam	
A7	Aluminum U shaped	U shaped aluminum spacer embedded in sealant	
FG	Fiberglass	Fiberglass spacer system	
GL	Glass	Glass spacer system	
PU	Polyurethane foam	Polyurethane foam	
S1	Steel	Stainless steel spacer system	
S2	Steel – thermally broken	Stainless steel spacer with urethane thermal break	
S3	Steel / foam / steel	Two steel spacers separated by foam	
S4	Steel U shaped	U shaped stainless steel spacer system	

S5	Steel reinforced butyl	Butyl spacer with steel substrate
V1	Vinyl U shaped	U shaped spacer system embedded in sealant
WD	Wood	Wood spacer system
ZF	Silicone foam	Silicone foam spacer system

DOCUMENT CONTROL ADDENDUM #03-31354.04

Current Issue Date: December 21, 2001

Report No.: 03-31354.01

Requested by: Jeff Franson
Purpose: NFRC 100-97 Thermal Performance test report
Issued Date: November 23, 2001
Comments: First Issue

Report No.: 03-31354.02

Requested by: Jeff Franson
Purpose: Reissue report to Anlin Industries
Issued Date: December 7, 2001
Comments: Copies of report issued to ALI (Jim Hicks)

Report No.: 03-31354.03

Requested by: Jeff Franson
Purpose: Make correction on Glazing Method
Issued Date: December 21, 2001
Comments: Copy of report issued to client only

Report No.: 03-31354.04

Requested by: Jeff Franson
Purpose: Make correction on Glazing Method and reissue report to Anlin Industries
Issued Date: December 21, 2001
Comments: Copies of report issued to ALI (Jim Hicks)

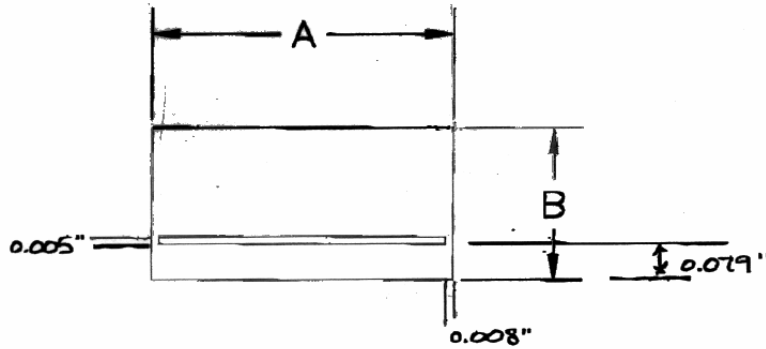
Appendix D: Spacer Geometry and Details

MAY. -29' 02 (WED) 15:43 ARCH. TESTING

TEL:1-717-764-4129

P. 002

Swiggle Spacer



Material: Stainless Steel
Width (A): 0.625"
Height (B): 0.292"