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ENERGY & ENVIRONMENT DIVISION

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August 1993

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PHASE I Results of the NFRC U-Value Procedure Validation Project

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ABSTRACT

The NFRC U-Value Procedure Validation Project was undertaken by a collaborative group of industry, public utility, trade associations, and government researchers in order to validate the testing and calculational methods of the NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values). This paper summarizes the validation project's goals and test methodology, the results of the data analysis, and the recommendations following completion of Phase I of the project. Simulations performed according to NFRC 100-91 are shown to agree with each other, to within the NFRC tolerance, in 100% of the cases. Window test results with perpendicular wind performed according to NFRC 100-91 are shown to agree with each other, to within the NFRC tolerance, in 84% of the cases. Simulations and perpendicular wind window test results are shown to agree with each other, to within the NFRC tolerance, in 80% of the cases. Testing of skylights was shown to be problematic under the procedure as written at the time. Agreement between tests and simulations will improve as a result of a strong NFRC education and accreditation program.

INTRODUCTION

The thermal performance of window systems has traditionally been determined using hot box test methods. Using this traditional method a hot box test would have to be done for each and every product in a product line in order for a manufacturer to obtain thermal performance rating and labeling for that product line. This would incur considerable time and undue expense to the manufacturer. The *NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values)* (NFRC 1991) was developed to address these concerns. The NFRC U-Value Procedure Validation Project was undertaken in order to validate the testing and calculational methods of the NFRC 100-91 procedure. This project compares the results of several simulation laboratories and compares the results of several thermal test laboratories, and then inter compares the simulation and test results so as to validate the NFRC 100-91 procedure for certification of window U-values. This procedure uses two-dimensional modeling of heat transfer through a window and frame system to determine total window U-values for each window in a product line. The simulation programs specified by NFRC 100-91 are WINDOW (LBL 1988) and FRAME (EE 1991). It then incorporates hot box thermal testing on the highest and lowest performing window that product line in order to verify that the modeling is an accurate representation of windows thermal performance. This paper summarizes the method, goals, analysis, results, and recommendations following Phase I of the NFRC U-Value Procedure Validation Project. Tests and simulations were performed in late 1991 and early 1992, before any test or simulation laboratories were accredited by the NFRC.

METHOD

A total of twelve windows from six different manufacturers' product lines, covering a range of operator, glazing and frame types, were selected as being representative of residential windows on the market today. Duplicate windows for two of these products were tested to asses product variability within a given product line, giving a total of sixteen windows which were physically tested. The windows from each product line were the "baseline products" as defined by NFRC 100-91: the two windows in each product line with the highest and lowest simulated U-values, respectively. Descriptions of the sixteen test windows are given in Table 1. These windows were tested for whole window U-values according to NFRC 100-91, Attachment A, at up to five different thermal test laboratory facilities. The windows were also modeled by up to six different simulation laboratories according to NFRC 100-91, and whole window U-values reported. Due to funding and time limitations, not all test laboratories and simulation laboratories were able to evaluate every window. In order to assure that all simulators were working from the same data, simulators were not allowed to communicate directly with the frame or glazing manufacturers. Simulations were based solely on technical drawings of the window profiles supplied by the manufacturers, with any questions regarding the simulations being directed to the projects' technical coordinator. The U-value data, test laboratory reports, and simulation laboratory reports were then compiled and analyzed by the Windows and Daylighting Group at Lawrence Berkeley Laboratory.

GOALS

In addition to the validation of the NFRC 100-91 procedure, the project's aim was to provide guidelines for improved calculational and test laboratory procedures. Specifically, the major goals of the project were to:

(1) ascertain the range of agreement of test laboratory results between the different laboratories for each of the windows physically tested,
(2) ascertain the range of agreement of simulation laboratory results between the different simulation laboratories for each of the windows simulated, and
(3) ascertain the range of agreement between the simulation laboratories and the thermal test laboratories for each of the windows considered.

Additional goals of the project were to:

(4) assess product variability by testing three identical units at one laboratory,
(5) assess test laboratory repeatability by testing one unit on three separate occasions at the same test laboratory, and
(6) assess any differences in U-values caused by physically testing a window with wind parallel to the test surface rather than perpendicular to the surface as in the NFRC test procedure.

ANALYSIS

Simulation and test points were first evaluated separately in order to determine which individual data points were valid, which points were not valid (due to miscommunication) and could be corrected, and which points were not valid (due to gross miscommunications or blatant errors) and could not be corrected due to time and/or cost constraints.

Checking simulation points for validity

To determine which simulation points were valid, the simulation reports were checked against the window technical drawings for the following:

- proper component dimensions
- correct glazing gap width, gas fill and glazing surface emissivity
- proper materials and material conductivities
- internal consistency of the report
- correct total product dimensions
- proper report labeling
- boundary conditions and location points.

For simulation points which were non-valid, an effort to correct the errors was made. Discrepancies in simulation results were generally not due to direct errors by the simulators, but were usually due to drawings with incomplete or inconsistent information. In cases where the error could be corrected by a simple modification to the original simulation file, such as a change in material conductivities and/or a change in glazing cavity properties, the modifications were made and the simulations rerun at Lawrence Berkeley Laboratory. The corrected U-value was then calculated according to the revised simulation results. In one such case, the thermal break material was not specified on the technical drawings. Two of the simulators assumed a urethane thermal break (K_{eff} = 2.149 Btu-in./h·ft^2·°F), as would be proper for a pour-and-debridged thermal break, while the third simulator was advised to use a much lower thermal conductivity polyurethane foam (K_{eff} = 0.208 Btu-in./h·ft^2·°F). For this case, the error was corrected by changing the material conductivity of the thermal break in the simulation file to reflect that of the window physically tested.

Modifications to simulation files involving changes in dimensions and/or component placement were not carried out at Lawrence Berkeley Laboratory, as modifications of this type are more complex than simply changing a material conductivity, and are best carried out by the original simulators. As an example of this type of case, window #11 had been simulated as being dual-glazed, yet the window tested was single-glazed. The simulations were not rerun, as the discrepancy required changes in the gap width dimension and glazing component placement. The two simulation points for window #11 were thus eliminated from the list of valid simulation results.

Of the 43 simulation points initially reported, 4 points were considered non-valid and eliminated and one point was added through modification to an existing simulation file, giving a total of 40 simulation points after corrections.

Checking test laboratory reports for validity

Data from the test laboratory reports were analyzed in order to identify any systematic trends within or between test laboratory results, and to identify any anomalous data and/or possible sources of disagreement between laboratories. To determine the validity of the test points, the test laboratory reports were checked in the following ways:

- Standardized U-values (U_{st}) were recalculated from the test report data according to NFRC 100-91, Attachment A, Section 7, and compared to the initially reported values.
- Heat transfer coefficients (h_I and h_{II}) were recalculated from the test report data according to NFRC 100-91, Attachment A, Section 7, and compared to the initially

reported values. Heat transfer coefficients for the specialty glazings (windows #5 and #6) were recalculated using the total surface area of the window per NFRC 100-91, Attachment A, rather than using the projected fenestration product area as reported by the test laboratories.

- The surface temperature differentials between both the warm and cold-side for the frame and glazing were compared between test laboratories and cross-correlated against U-values.
- The effect of glazing deflection on test results was estimated by calculating the change in glazing U-value expected from the deflection and running the revised center-of-glass U-value (Ucog) through the simulation program for that window to estimate the magnitude of the expected change in total window U-values.

On the basis of this analysis, all 47 tests run with a wind perpendicular to the cold-side surface and all 9 tests run with a wind parallel to the cold-side surface were deemed to be reasonable. The general results of the test report data analysis are as follows:

- The standardized U-values (U_{st}) reported by all test laboratories were in good agreement with the recalculated values.
- The heat transfer coefficients (h_l and h_{ll}) reported by all test laboratories were in good agreement with the recalculated values for all non-specialty glazings. However, heat transfer coefficients calculated using the total fenestration surface area of the specialty glazings (windows #5 and #6) ranged from 31% to 49% less than the reported values, with an increase in U-value ranging from 0.04 (Btu/h·ft^2·°F) to 0.14 (Btu/h·ft^2·°F).
- In general the surface temperatures and temperature differences correlated well with the total window U-values. A few anomalies were noted.
- Glazing deflection during the test was found to have negligible or no impact on whole window U-values for all but three tests. In those three cases, the effect of glazing deflection on total window U-values is estimated as a change of 0.02 (Btu/h·ft^2·°F) or less.

Issues identified in test laboratory accreditation

All of the tests were performed before the NFRC had accredited any test laboratories. The NFRC accreditation process identified numerous issues which would be expected to increase the accuracy of the reported results. These include the following:

1. Proper calibration of the test chamber.
2. All measurement equipment must have up-to-date independent calibration.
3. Proper characterization of mask wall thermal conductivity.
4. Proper construction of the Calibration Transfer Standard (CTS).
5. Proper edge sealing and uniform adhesion of the glass surfaces to foam surfaces within the CTS.
6. Ensure no heat transfer between the guard room and the metering box.
7. Monitoring of all individual surfaces (interior and exterior) of the metering box (ceiling, top half, bottom half, floor).
8. Better air mixing in the guard room to improve control of temperature differences in the metering box and on the baffle.

9. "Steady-state" conditions must be determined by monitoring both power input and temperature data.
10. Control the temperature of the metering box baffle.
11. Baffle temperature extremes should be monitored with individual sensors apart from the averaging thermocouples.
12. Proper treatment of thermocouples.
13. The tape used to mount thermocouples must be of the same emissivity as the surrounding surface.
14. Thermocouple wires must be oriented along (vertical) streamlines.
15. Better soldering of thermocouple leads.
16. Use proper techniques when sealing windows against infiltration prior to the test.
17. Maintain air pressure balance across each specimen during testing.

Initial comparison of test and simulation results

Valid and corrected simulation and test results were then compared to each other. If the results were not in general agreement, a physical analysis of the actual window tested was performed at Lawrence Berkeley Laboratory in order to explain the discrepancies between simulation and test results. Of the sixteen windows tested, four windows (windows #2, #6, #8, and #12) required physical analysis. Results for window #5 were also not in general agreement, but as this window was identical to window #6, except for size, it was not recalled for physical analysis. The analyses included:

- complete window disassembly
- component dimensions checked against simulation technical drawings
- materials properties checked against window technical specifications
- oxygen content of sealed IG unit checked to determine glazing gas fill concentration
- measurement of glazing surface emissivities.

Two of the windows that had been specified as argon-filled were found to be air-filled at the time of the analysis. For one of these glazings the low-E surface emittance was measured at 0.32, rather than 0.20 as originally specified. For the two windows constructed with thermally-broken aluminum frames (windows #2 and #12), thermal break dimensions were slightly less than had been specified on the simulation technical drawings. The use of urethane for all thermal breaks was verified. On the basis of these findings, the original simulation files for the windows were modified and the simulations rerun at Lawrence Berkeley Laboratory. The corrected U-value was then calculated according to the revised simulation results. As in the initial analysis, the re-simulations incorporated only simple modifications, such as changes in material conductivities and/or glazing cavity properties. Modifications involving changes in dimensions and/or component placement were not carried out for all files. However, the effect of the reduced thermal break dimension was analyzed for one set of files, with the result being that while there was a small change in overall U-value, it was not large enough to change the general agreement of the results.

The revised simulation brought windows #2 and #12 into general agreement with the test results. However, the revised simulations were unable to account for the discrepancies between tested and simulated results for window #6 (a skylight) and window #8 (a horizontal vinyl slider). The discrepancies encountered with window #6 are most likely associated with problems encountered when testing any type of specialty glazing, which are discussed in more detail in the next section. The discrepancies encountered with window #8 may be due to problems with accurately modeling convective heat transfer within hollow vinyl extrusion cavities, but the analysis is not conclusive on this point.

Problems encountered in testing and simulating specialty glazings

Windows #5 and #6, both of which were aluminum-clad wood-framed skylights, were simulated by two different simulators and tested at two test laboratories. Simulations and tests were not in general agreement for either window, and the test laboratory results for window #5 were not in agreement with each other. The following issues related to testing of skylights have been identified as possible sources of the discrepancies.

- Skylights were mounted different ways at different test laboratories.
- Two-dimensional heat flow will occur through the portion of the test wall exposed by the outside flush mount. This may not be accurately accounted for by the test lab heat flow measurements.
- Deep indent of skylights may disrupt natural convection. Warm-side convection coefficients as calculated by test lab may not be accurate. Warm-side convection coefficients used by the simulators may not be accurate.
- Disruption of natural convection may affect the air temperature gradient near the window surface. Current thermistor placement may not be correctly measuring the air temperatures. Warm-side air temperatures used by the simulators may not reflect actual test conditions, resulting in an inaccurate U-value simulation.
- Use of incorrect skylight surface area may result in errors in the calculation of the warm and cold-side heat transfer coefficients. This may lead to errors in the calculation of the total window U-value.

The following suggestions should help improve the accuracy and agreement of simulations and testing of specialty glazings such as the skylights used in this study.

- Simulators must be informed as to the method of mounting the skylight to the test wall and of the location of assumed adiabatic surfaces. Mounting should be uniform across all test laboratories.
- The test chamber calibration panel should be mounted in the same manner as the skylight will be mounted in order to account for two-dimensional heat flow through the test wall.
- Better characterization of the warm-side and cold-side film coefficients is important for accurate test and simulation results.
- Proper measurement of the warm and cold-side air temperatures of specialty glazings is necessary for accurate test and simulation results.
- The test laboratory must use the correct total surface area of the skylight (the surface area of all five exposed sides of the skylight) in the calculation of the warm and cold-side heat transfer coefficients. It should be noted that the interior surface area is not equal to the exterior surface area.

As there are many sources of uncertainty in the testing and simulation of the skylights which could not be corrected, windows #5 and #6 are eliminated from the following discussion.

RESULTS

Comparison between simulated data

After correcting for simulation discrepancies there were 40 valid simulation data points, yielding a total of 52 comparison points between simulation laboratories. The corrected simulation results agreed extremely well between all six simulators. The average difference between corrected simulation results was 0.01 Btu/h·ft^{2}·°F (an average difference of 1.6%), and the largest discrepancy between two simulated results for the same window was 0.03 Btu/h·ft^{2}·°F (a maximum difference of 8%).

Comparison between tested data

After review of the test laboratory reports, data were compared between test laboratories. This comparison is limited to windows which had test results from different test laboratories, applies only to the windows tested with wind perpendicular to the window surface, and excludes results for specialty glazings (window #5 and #6). Where one test laboratory re-tested the same identical window, results were averaged. This gives 32 test laboratory data points, and a total of 31 comparison points between test laboratories. An example of the data analysis carried out for each window follows. Window #8 was tested at four out of the five test laboratories, giving four data points and six possible comparisons between pairs of data points (#1 vs. #2, #1 vs. #3, #1 vs. #4, #2 vs. #3, #2 vs. #4, and #3 vs. #4).

Test Laboratory #1: U_T = 0.49 Btu/h·ft^{2}·°F
Test Laboratory #2: U_T = 0.49 Btu/h·ft^{2}·°F (average of 0.48, 0.48, and 0.52 Btu/h·ft^{2}·°F)
Test Laboratory #3: U_T = 0.43 Btu/h·ft^{2}·°F
Test Laboratory #4: U_T = 0.47 Btu/h·ft^{2}·°F

The comparison between data points was made by calculating the percentage difference between the points with respect to the mean of the test results for the window.

$$\% \text{ error} = \Delta U_T \times 100 = \frac{U_{Ti} - U_{Tj}}{\frac{1}{n}\sum_{i=1}^{n} U_{Ti}} \times 100 \qquad (1)$$

The results of the comparison for window #8 are given in Table 2. In this case, four of the comparisons agree within 10%, two do not (#1 vs. #3, #2 vs. #3).

Completing this analysis for all windows with more than one test laboratory involved shows that agreement between test laboratory results (for perpendicular winds) was reasonable, with 84% of test laboratory results being equivalent (within 10% or +/- 0.04 Btu/h·ft^{2}·°F) to other test laboratory results for the same window, and an average difference of 6.2 %.

Comparison between simulated and tested data

Simulation and test results were then compared with one another as they might be in the NFRC process to validate a matrix of product line comparisons. The comparison between simulation and test results was made in a manner similar to the comparisons of test laboratory results above. However, in this case the percentage error for each test was calculated relative to the simulation result for that window, as prescribed in NFRC 100-91. A total of 59 data points (34 corrected simulation data points and 25 test laboratory data points) were used in the data comparison, giving 100 comparison points. An example of the data analysis carried out for each window follows.

Window #1 had four simulation reports and two test laboratory results, giving six data points and eight possible comparisons between pairs of data points (S#1 vs. T#1, S#1 vs. T#2, S#2 vs. T#1, S#2 vs. T#2, etc.). (Note that Test Laboratory #3 is the average of two tests on the same window.)

Simulator #1: 0.56 Btu/h·ft^{2}·°F
Simulator #3: 0.56 Btu/h·ft^{2}·°F
Simulator #4: 0.55 Btu/h·ft^{2}·°F
Simulator #5: 0.56 Btu/h·ft^{2}·°F

Test Laboratory #1: 0.60 Btu/h·ft^{2}·°F
Test Laboratory #3: 0.53 Btu/h·ft^{2}·°F

The results of the comparison between simulated and tested data for window #1 are given in Table 3. In this case, all eight comparisons agree within 10%.

Completing this analysis for all the windows where there are both tests and simulations shows that 80% of the time, simulations were equivalent (within 10% or +/- 0.04 Btu/h·ft^{2}·°F) with tests. Out of the 100 comparison points, 15 of the points in non-agreement were from window #8. If window #8 is excluded from the data set, the agreement between test and simulation results rises to 94%. Table 4 gives the final total window U-values for all of the test windows from all test and simulation laboratories after corrections were made. These data are plotted in Figure 1.

Product variability

To assess product variability, three samples of the same model aluminum-framed single-glazed slider (Windows 11, 13, and 14) and three samples of the same model vinyl-clad wood-framed low-e argon-filled casement (Windows 4, 15, and 16) were tested at several laboratories. The differences between individual products were minimal and well within the definition of equivalence. However, this is an extremely small sample size. To properly address this issue, many other different types of windows should be tested at the same and different laboratories.

Test laboratory repeatability

To assess test laboratory repeatability, three of the four test laboratories took one or more windows and re-tested them from the start, using different operators. Test laboratory #1 tested Window #2 three times, with the same result each time. For test laboratory #2, one of the three tests produced a result 0.04 Btu/h·ft^{2}·°F (or 8%) different from the previous two. Several windows were tested at test laboratory #3, with agreement better than 5% in all cases. Here again, the sample size is small; however it can be noted that the discrepancies seen within a laboratory (up to 8%) on the same window are approximately half of those seen between all laboratories (up to 16%).

Parallel wind testing

To assess the differences between using parallel vs. perpendicular winds in a test, two laboratories performed both parallel and perpendicular tests on three windows. This again is a small sample size. Comparing parallel tests vs. perpendicular tests as above we see that only 65% of the comparisons indicate equivalence between parallel and perpendicular tests. All of the points not in agreement were less than 6% from the definition of equivalence. Note that the differences between 90 and 270 degree tests were minimal or nonexistent. Tests run with parallel winds always resulted in lower U-values than tests run with perpendicular winds. This may indicate that infiltration is more of an issue for testing with perpendicular winds than with parallel winds. The comparison between parallel and perpendicular winds can also be made by comparing parallel wind results to simulations. This comparison shows 100% agreement at the NFRC definition of equivalence.

CONCLUSIONS

This study has shown that the simulation and test procedure which form the basis of the NFRC 100-91 are a valid means to asses the thermal performance of fenestration products. However safeguards must be taken in order to ensure accuracy and unnecessary costs (from re-testing) to manufacturers. Specific conclusions can be summarized as follows:

1) Simulators must receive complete and accurate technical drawings, bills of materials, and glazing specifications. The NFRC should take steps to ensure that simulators review the technical drawings critically. If there are any doubts about the window specifications, the simulators must ask the manufacturer for clarification until they are sure that the simulation matches the window as accurately as possible. We recommend that cut cross-sections for all of the window components be supplied to the simulators along with the technical drawings.

2) To ensure proper simulations, NFRC must maintain a strong simulation education and accreditation program. The simulations in this study were undertaken prior to the accreditation of any simulators. It can only be assumed that the accreditation process helped to improve the simulators understanding of the information they require to properly complete a simulation. Now that accredited simulation laboratories exist, a repeat of this project would demonstrate the effectiveness of the NFRC accreditation program.

3) Agreement between test laboratories ranged from 0% to 16% difference, with equivalence (agreement within 10%) for 84% of the data points. Again, these tests were conducted before test laboratories were visited for accreditation. Two of the three commercial test laboratories that participated in this study have since requested accreditation and were found to have numerous (typically minor) deficiencies which had to be corrected before they were accredited. To date the third commercial laboratory has not applied for accreditation.

4) Agreement between test laboratories and simulation laboratories was found to be reasonable. While all participants believe that this agreement can only improve as a result of the accreditation process, the only way to ensure this would be to conduct a similar experiment using only accredited simulation and test laboratories. The project team highly recommends this for 1993.

5) The data on parallel vs. perpendicular wind testing is minimal. Parallel tests did not agree with perpendicular tests as well as either set of tests agreed with simulations. The trends in U-values between parallel versus perpendicular testing indicate that infiltration may not be adequately controlled in the perpendicular wind tests. However, since there are so few data points, the project team recommends further research in this area.

6) The testing and simulation protocol for specialty products, such as skylights, must be better defined. The project team recommends a more in-depth study of specialty product simulation and testing issues.

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Table 1: NFRC test window description				
NFRC #	frame description	glazing	size	actual size (w x h)
1	thermally broken aluminum, fixed	double-glazed, clear	AA	47.25" x 47.5"
2	thermally broken aluminum, fixed	double-glazed, argon, low-E	AA	47.25" x 47.5"
3	vinyl-clad wood, casement	double-glazed, clear	BB	28.25" x 60"
4	vinyl-clad wood, casement	double-glazed, argon, low-E	BB	28.25" x 60"
5	aluminum-clad wood, skylight	double-glazed, argon, low-E	AA	20" x 44.75"
6	aluminum-clad wood, skylight	double-glazed, argon, low-E	BB	44.75" x 44.75"
7	vinyl, horizontal slider	double-glazed, clear	AA	59.5" x 35.5"
8	vinyl, horizontal slider	double-glazed, argon, low-E	BB	71.5" x 47.5"
9	wood, double-hung	double-glazed, clear	BB	45.375" x 73"
10	wood, double-hung	double-glazed, argon, low-E	BB	45.375" x 73"
11	aluminum, horizontal slider	single-glazed, clear	AA	59" x 35"
12	thermally broken aluminum, horizontal slider	double-glazed, argon, low-E	BB	71.5" x 47.5"
13	aluminum, horizontal slider	single-glazed, clear	AA	59" x 35"
14	aluminum, horizontal slider	single-glazed, clear	AA	59" x 35"
15	vinyl-clad wood, casement	double-glazed, argon, low-E	BB	28.25" x 60"
16	vinyl-clad wood, casement	double-glazed, argon, low-E	BB	28.25" x 60"

Table 2: Test laboratory results for window #8						
	Window #8:	T1	T2	T3	T4	T5
	U-Value (Btu/h ft^2 F)	0.49	0.49	0.43	0.47	n/a
T1	0.49	x	0%	13%	4%	-
T2	0.49		x	13%	4%	-
T3	0.43			x	9%	-
T4	0.47				x	-
T5	n/a					x

Table 3: Test laboratory and simulation laboratory results for window #1						
	Window #1:	T1	T2	T3	T4	T5
	U-Value (Btu/h ft^2 F)	0.60	n/a	0.53	n/a	n/a
S1	0.56	7%	-	5%	-	-
S2	n/a	-	-	-	-	-
S3	0.56	7%	-	4%	-	-
S4	0.55	9%	-	5%	-	-
S5	0.56	7%	-	5%	-	-
S6	n/a	-	-	-	-	-

Table 4: Utotal after corrections (Btu/hr ft^2 F)

	S1	S2	S3	S4	S5	S6	Lab #1	Lab #2	Lab #3			Lab #4			Lab #5
									perp	par 90	par 270	perp	par 90	par 270	
1	0.56 (b)		0.56	0.56 (b)	0.54		0.60		0.52/ 0.54						
2	0.48 (b)		0.47 (b)	0.47 (b)	0.46 (e)		0.50/ 0.50/ 0.50		0.46						
3	0.48	0.49		0.48	0.48 (a)		0.51	0.54							0.50
4	(c)	0.29		0.29	0.29 (a)		0.31	0.32							
5	0.67 (d)			0.65 (d)			0.53		0.42						0.58
6	0.51 (d)			0.50 (d)			0.40		0.39/ 0.40/ 0.41						
7	0.50	0.51	0.50	0.50	0.51		0.53	0.52	0.49	0.48	0.48	0.50	0.46	0.46	0.54
8	0.42 (b)	0.42 (b)	0.41 (b)	0.42 (b)	0.42 (b)		0.49	0.48/ 0.48/ 0.52	0.43	0.41/ 0.41	0.42	0.47			
9	0.54 (a)			0.54		0.55 (a)	0.56								
10	0.38 (a)			0.39		0.41 (a)	0.41								0.40
11			(c)	(c)			1.09	1.11							
12	0.53 (b)	0.56 (b)	(c)	0.54 (b)			0.57	0.61	0.52			0.58			
13							1.09		1.02/ 1.02/ 1.03/ 1.05	1.03	1.05				
14							1.09								
15					0.29(a)		0.31								
16					0.29 (a)		0.32								

(a) U-values calculated for the model size (AA or BB) instead of the representative (tested) size A or B.
(b) Revised simulations based upon findings of the physical analysis.
(c) Data point found to be non-valid and eliminated.
(d) Revised simulation based upon skylight mounting configuration as tested.
(e) Data point added by modification to original simulation files.

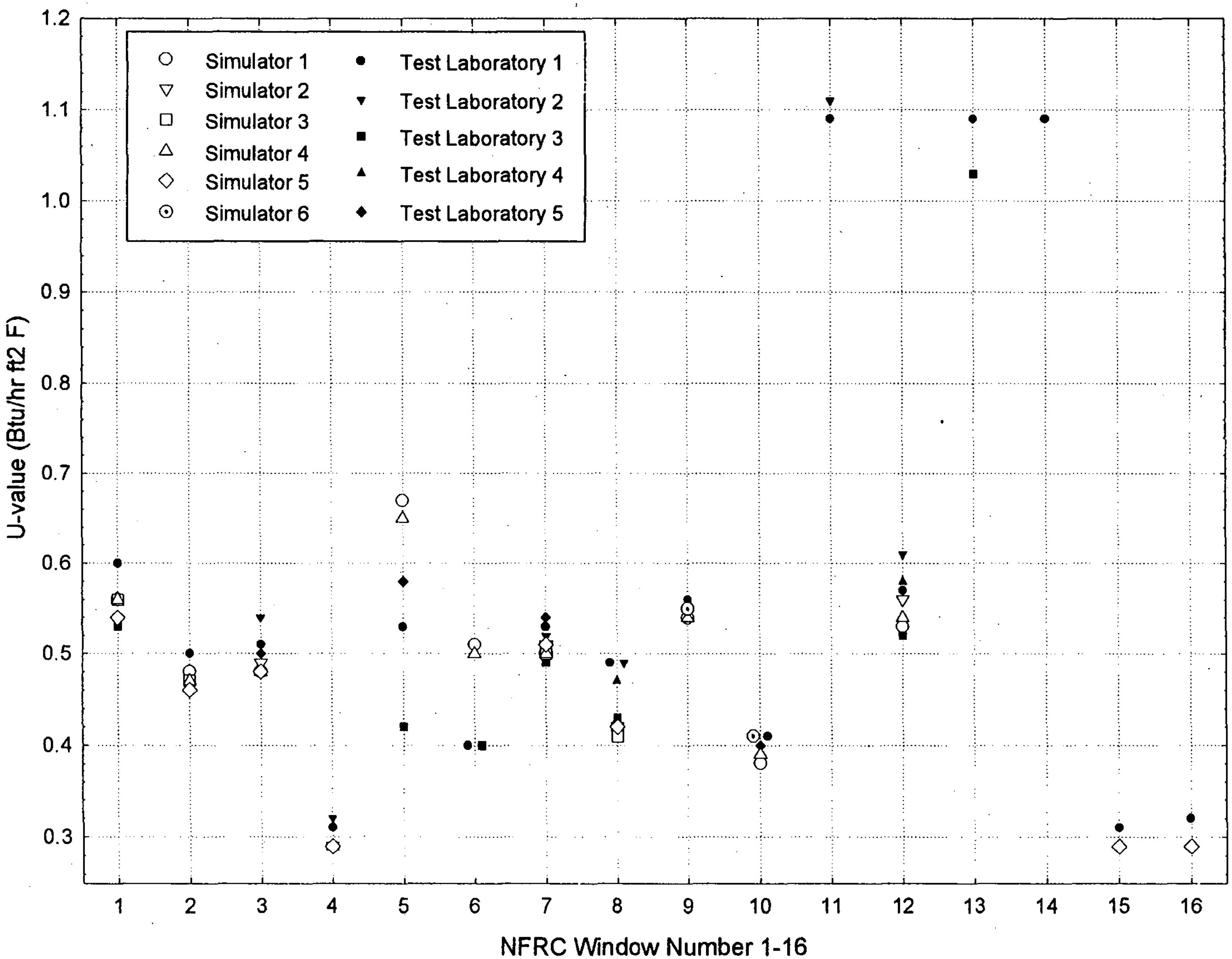

Figure 1: Plot of total window U-values from as measured by thermal testing and calculated by computer simulation for the NFRC Validation Project after corrections for errors had been made. Windows which were physically tested were shipped from laboratory to laboratory, then disassembled for inspection at Lawrence Berkeley Laboratory after all tests had been completed.

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