2004 Annual Interlaboratory Comparison of NFRC Accredited Testing Laboratories

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ABSTRACT

The National Fenestration Rating Council (NFRC) conducts annual Inter-Laboratory Comparisons (ILC) as part of its Laboratory Accreditation Program (LAP) for NFRC-accredited simulation and testing laboratories. This report presents the findings of the 2004 NFRC 102 Test Laboratory ILC of all seven NFRC-accredited testing laboratories.

Each participating laboratory conducted thermal performance tests on a 49 in. by 49 in. double pane skylight with a vinyl curb and aluminum retainer cap. The testing began in May and was completed in July of 2004. The thermal test data submissions from all the laboratories were reviewed, compared, and recalculated after errors were identified and corrected.

Although all seven participating laboratories were within the two standard deviation tolerance of the average standardized thermal transmittance, detailed analysis showed that one laboratory incorrectly determined the projected area of the test specimen. Upon recalculation of that laboratory's standardized thermal transmittance using the correct test specimen area, the results from that laboratory could be considered an outlier. If that laboratory's results are omitted from the recalculated analysis, the average standardized thermal transmittance from all of the laboratories is 0.44 Btu/(hr • Ft^2 • ºF) with a standard deviation of 0.013. This is identical to the standardized thermal transmittance that was derived from computer simulation by NFRC Staff using NFRC 100 [1].

BACKGROUND

The National Fenestration Rating Council (NFRC) has developed and is implementing a national rating system for the energy performance of fenestration products. The system currently uses *NFRC 100: Procedures for Determining Fenestration Product U-factors* (NFRC 100) for determining thermal transmittance (U-factor) ratings, and *NFRC 500: Procedure for Determining Fenestration Product Condensation Resistance Values* (NFRC 500) to calculate condensation resistance ratings. NFRC 100 employs a combination of computer simulation and physical testing to determine U-factor ratings, and NFRC 500 Condensation Resistance ratings are determined by testing or by computer simulation.

The NFRC Accreditation Policy Committee (NFRC APC) administers and oversees NFRC's Laboratory Accreditation Program. Under the *NFRC LAP: Laboratory Accreditation Program* (NFRC LAP), NFRC accredits independent testing and simulation laboratories to perform physical tests and computer simulations to issue fenestration product thermal performance ratings. All laboratories are required to participate in annual blind round robin evaluations as a condition of continued accreditation.

OBJECTIVE

The primary purpose of the 2004 NFRC Test Laboratory Inter-Laboratory Comparison (ILC) is to evaluate the technical competence of NFRC-accredited test laboratories by having

1. *THERM5.2 and WINDOW5.2 Inter-laboratory Round Robin Evaluation and Exam of NFRC Certified Simulators 2004*; Page 12

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each laboratory conduct the identical tests on the same test specimen and comparing the resultant data. This helps the NFRC APC evaluate the current level of consistency and reproducibility among the laboratories. This ILC was conducted in accordance with ASTM E 691, and ASTM E 177 provided guidance on how to report the results from the analysis.

Both NFRC 100 and NFRC 500 reference *NFRC 102: Test Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems* (NFRC 102). NFRC 102 was used to perform the thermal testing conducted in this round robin. NFRC 102 has significant references to ASTM C 1363, ASTM C 1199, and ASTM E 1423 to describe the test apparatus and procedure.

Test Specimen[2]

A 49 in. by 49 in. (1.2 m by 1.2 m)[3] double-glazed skylight with an aluminum glazing retainer and vinyl curb was selected as the test specimen. This is the first time that NFRC has selected a curb-mounted skylight for the NFRC ILC test specimen (See Figures 1 and 2).

The overall glazing system is 1 in. (25 mm) thick (nominal), which consists of an exterior light of nominal in. (3 mm) thick clear glass with a Low-E coating (PPG Solar-Ban 60; = 0.04) on the interior surface, and nominal ¼ in. (6 mm) thick laminated clear glass on the interior. The glazing cavity was filled with air, and surrounded by a ½ in. by 5/8 in. (12 mm by 16 mm) double seal aluminum spacer. The glazing system has a daylight opening of 46¼ in. by 46¼ in. (1175 mm by 1175 mm).

The hollow vinyl curb measures 1 in. by 3 in. (25 mm by 76 mm), and has an internal space that is split into two equal-dimension cavities by an integral wall. The curb is surrounded by a non-removable 2¾ in. (70 mm) wide vinyl nailing flange. A convoluted drip molding protrudes 1 in. (25 mm) from the interior surface of the curb with the interior edge of the drip molding 11/16 in. (17 mm) from the interior glass surface. This interior tip of the drip molding is considered to be the sight line. The hollow curb, nailing flange, and drip molding are all components of an integral PVC lineal extrusion with 1/16 in. (1.6 mm) thick walls.

The glazing system is directly sealed to the top of the vinyl curb with an EPDM foamed gasket between the glass and the curb. The glazing system is retained with an aluminum retainer cap that is sealed to the glazing with foam glazing tape, and attached to the hollow curb with #8 x in. Pan Head stainless steel screws. The exterior face of the glazing retainer cap protrudes 4 in. (105 mm) from the nailing flange, and has a projected width of 1½ in. (38 mm) when facing the glazing.

2. All dimensions in this section are determined from the working drawings of the test specimen and not actual measurements. These dimensions have been rounded to the nearest 1/16 in.

3. Since all measurements were reported by the laboratories in IP units, they are the primary units in this paper. Equivalent SI unit values have been presented in parenthesis and in separate tables.

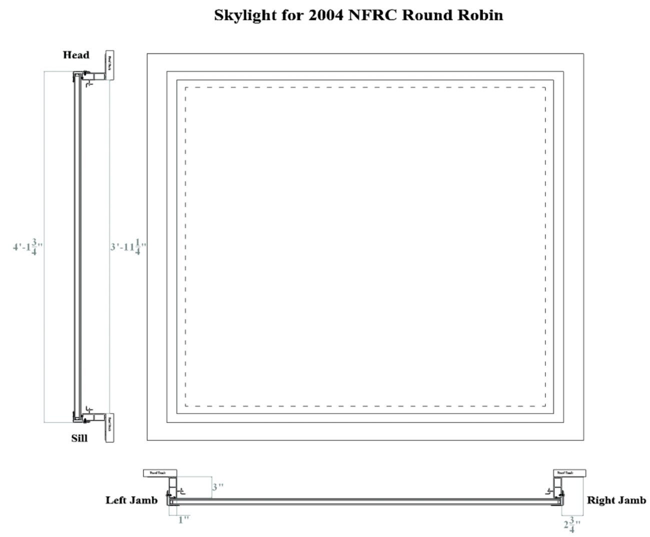

Figure 1 *NFRC 2004 round robin test specimen.*

Figure 2 *Installation of NFRC 2004 round robin test specimen in thermal chamber.*

Participating Laboratories

All seven of the 2004 NFRC-accredited test laboratories participated in the round robin testing. Although the following participating commercial test laboratories are listed in alphabetical order, that sequence has no relationship to the order in which the laboratories are identified in the data analysis:

- AIR-INS, Inc. – Varennes, Quebec, Canada
- Architectural Testing, Inc. – Fresno, California
- Architectural Testing, Inc. – Saint Paul, Minnesota
- Architectural Testing, Inc. – York, Pennsylvania

- E.T.C. Laboratories, Inc. – Rochester, New York
- National Certified Testing Laboratories, Inc. – York, Pennsylvania
- Quality Testing, Inc. – Everett, Washington

Instructions for Test Laboratories

Each NFRC-accredited testing laboratory was notified by letter on January 12, 2004 explaining the details of the 2004 NFRC ILC before testing commenced. This letter contained a set of identical product drawings and Bill of Materials. In addition, the package included blank forms requesting specific data that was to be completed by all participants and submitted to NFRC with the final test report.

Although NFRC 102 currently does not require surface temperature measurements of the test specimen, NFRC requested that 13 surface temperature sensors be used to measure the surface temperature of the warm side of the skylight glazing and frame, and to use this additional measured data to generate an NFRC 500 Condensation Resistance Test Report. Instructions and a diagram were provided to each laboratory by e-mail on February 26, 2004 (and again on March 4, 2004) identifying the placement of these additional temperature sensors (Figure 3). The second e-mail recommended that a specific brand of removable caulk be used to seal the test specimen so that the sealant can be easily removed. Although each laboratory measured and submitted the requested additional surface temperatures, only two laboratories submitted NFRC 500 reports with their round robin data, and one of those laboratories submitted their NFRC 500 report upon request after the deadline for the final reports. Partly for these reasons, the NFRC 500 Condensation Resistance ILC results are not included in this paper, but may be found in the full report submitted to the NFRC APC.

As this was considered to be a “blind” round robin, all participating testing laboratories were directed to keep all testing files, questions, correspondences and any other issue relating to the ILC confidential. Any and all correspondences were to be only directed to NFRC staff.

Schedule and Shipping

A test schedule was established prior to testing by contacting each laboratory and assigning a specified time period that was conducive to their thermal chamber test schedule. Each laboratory was given similar time periods to submit the initial data, and to issue the final report to NFRC. Although Table 1 lists the test laboratories in chronological order of testing, that sequence has no relationship to the order in which the laboratories are identified in the data analysis:

Each participating laboratory tested the same test specimen. Two identical spare units were constructed at the same time in case the original was damaged, but the spare units were not used. A custom-built wood shipping container was constructed with internal foam padding to protect the skylight as it was shipped between laboratories.[4] The skylight was shipped using a common carrier from one testing facility to another. Each laboratory was instructed to keep a record of the condition of the test specimen upon arrival at their facility and prior to shipment.

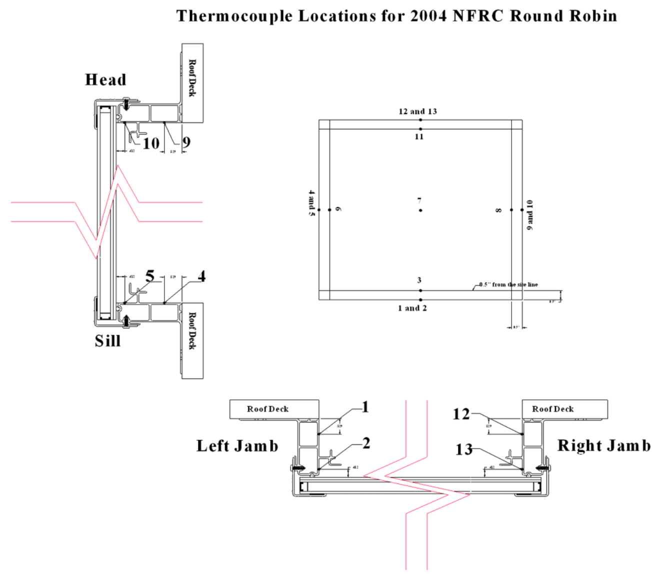

Figure 3 *Temperature sensor locations for NFRC 2004 round robin test specimen.*

Test Specimen Condition

The test specimen incurred minor damage as it was shipped between laboratories. At one point the wooden shipping crate was lost, but one of the participating laboratories constructed a new wooden shipping crate to protect the test specimen for the remainder of the tests. There is no evidence that the minor damage to the nailing flange, the retainer cap at the head and the glazing seal had any effect on the measurements or results generated by the laboratories. Table 2 identifies the reported condition of the test specimen as it was shipped from laboratory to laboratory. Photographs of the reported damage are shown in Figures 4, 5 and 6.

After interviewing the appropriate laboratories, it appears as though the initial wooden shipping crate was removed and replaced with a cardboard box by the trucking company. It also appears as though the most significant damage to the test specimen occurred at the same time while it was shipped between the first and second laboratories. All laboratories reported that the test specimen was sent out in the same condition that it was received.

Installation of Test Specimen

Curb-mounted skylights are installed in a thermal chamber differently than other fenestration products.[5] A typical

4. Shipping container constructed by Carli Inc., Amherst, Massachusetts.

5. NFRC 102; Section 6.2.1(A)

Table 1. 2004 NFRC ILC Testing Schedule

Laboratory	Initial Schedule				Raw Data	Actual
	Specimen In	Raw Data	Specimen Out	Report Due	Received	Report Date
A	March 12	March 19	March 22	March 26	March 26	March 30
B	April 13	April 22	April 23	April 29	April 21	April 21
C	April 26	May 5	May 5	May 12	April 29	May 11
D	May 5	May 7	May 11	May 14	May 12	May 20
E	May 19	May 28	May 28	June 4	May 27	May 26
F	June 1	June 11	June 11	June 18	June 17	June 17
G	June 15	June 25	June 25	July 2	July 15	July 15

Table 2. 2004 NFRC ILC Test Specimen Condition

Laboratory	Test Date	Reported Test Specimen Condition
A	March 24	No damage reported. Shipped out in wooden shipping crate provided.
B	April 17	Arrived in cardboard box. Nailing flange cracked, retainer cap bent at head.
C	April 27	Arrived in cardboard box. No damage reported. New wooden shipping crate built for shipping.
D	May 8	No damage reported.
E	May 26	Arrived with corner nail flange broken with piece missing. Left interior side of IG unsealed. EPDM foamed gasket replaced with wet glazing sealant.
F	June 10	Arrived with corner nail flange broken with piece missing. Another corner was cracked.
G	July 15	No damage reported.

Figure 4 *NFRC 2004 round robin test specimen: broken corner nail flange.*

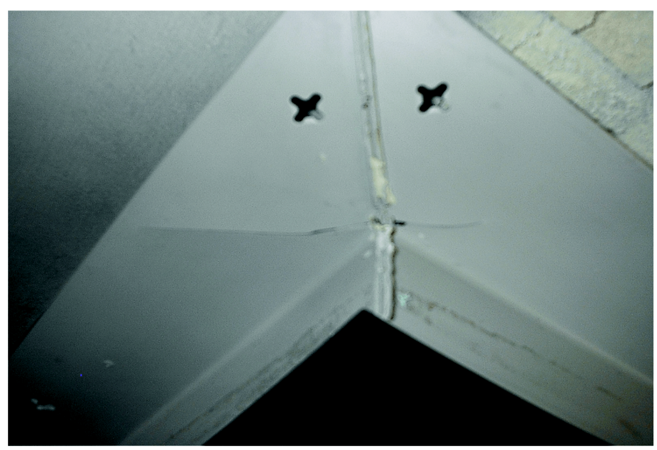

Figure 5 *NFRC 2004 round robin test specimen: other broken corner nail flange.*

window or door is installed within the aperture of a homogeneous foam panel (minimum 4 in. thick), called a surround panel. Curb-mounted skylights, which are designed to be installed on top of the rafters, are mounted over the hole in the surround panel such that the interior surface of the curb is flush with the edge of the surround panel aperture. In addition, fenestration products with non-removable nailing flanges are required to be installed so that the nailing flange is covered with a 1 by 4 fir trim.[6] Since a projecting skylight of this size is relatively heavy, some laboratories used external wooden braces under the overhanging curb on the cold side to help support the test specimen.

6. NFRC 100; Section 4.2.5(A)

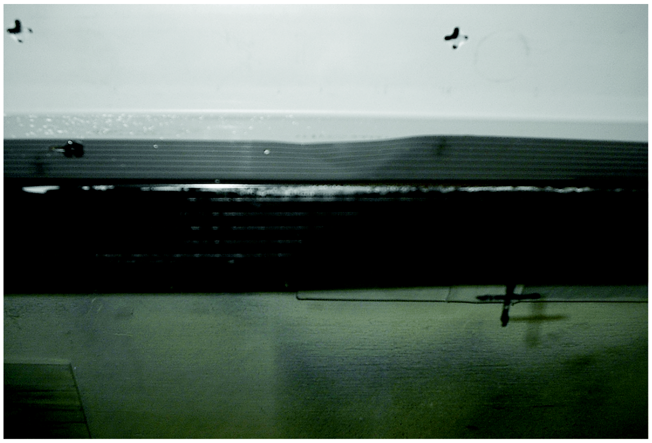

Figure 6 *NFRC 2004 round robin test specimen: dent in aluminum rail cup.*

Curb-mounted skylights protrude out into the cold chamber more that most test specimens, and therefore laboratories had to move their cold air temperature sensor array further away from the surround panel. At least one of these laboratories changed the location of their cold air temperature arrays using wooden braces between the face of the surround panel and the wires supporting the air temperature sensors.

All fenestration test specimens are required to be sealed to the surround panel, and sealed against air leakage.[7] Since the laboratories were not supposed to make any permanent modifications to the test specimen, they had to remove any tape or caulk that was used to seal the specimen before shipment to the next laboratory. Although NFRC recommended that a specific removable caulk be used to seal the skylight[8], most of the laboratories used tape instead.

Table 3 lists the methods that different laboratories used to seal and support the test specimen.

Glazing Deflection

When reporting the condition of the test specimen, many laboratories noted that the unit arrived at their laboratory with significant glazing deflection. With an overall thickness of nominal 1 in. (25 mm), the air-filled glazing cavity would be 0.625 in. (16 mm) thick without any glazing deflection. Three laboratories reported that they measured glazing deflections greater than 0.4 in. (10 mm), which would indicate that the glazing cavity was less than ¼ in. (6 mm) thick at the center of the glazing unit. Although most laboratories reported the glazing deflection (or gap width) measured just before and just after the test, one laboratory only reported the glazing deflection upon arrival at the laboratory, and another laboratory only reported the glazing deflection after the test.

7. NFRC 102; Section 5.1.5.A & ASTM E 1423; Section 7.1.3
8. Red Devil, ZIP-A-WAY® Removable Sealant

Although the relatively large glazing deflections appeared to decrease the overall thermal resistance of the skylight, there was not a strong correlation between gap width and the air-to-air thermal transmittance (R^2 = 0.2273), or the gap width and the standardized thermal transmittance (R^2 = 0.5581). In other words, the large glazing deflections of this test specimen measured by most of the laboratories may have had an affect on the average thermal transmittance reported by all the laboratories, but it did not seem to have a strong influence on the variability of reported results. Nevertheless, the lowest thermal transmittances were reported by those laboratories measuring the least glazing deflections. The correlation between gap width and thermal transmittance is viewed in Table 4. Since one of the laboratories did not report the glazing deflection measured after the test, that omitted value was replaced by the glazing deflection measured when the test specimen arrived at that laboratory for the purposes of performing the correlation analysis.

Data Collection

Laboratories submitted their data by overnight mail, facsimile and as attached files to e-mail. All of the data was submitted by the laboratories on the “Required Information for Thermal” forms in the instruction packets, and in the individual laboratory test reports.

Data Analysis

Data analysis was performed on the reported data, and in addition, raw calibration and test data was used to recalculate the results by the authors using spreadsheets containing identical calculation methodologies. The thermal transmittances were recalculated a second time using Calibration Transfer Standard (CTS) calibration test results that were recalculated by the authors based on the raw data from CTS tests from each laboratory. A spreadsheet developed by the authors was used to recalculate the CTS test results from each laboratory’s raw calibration data. The revised CTS test results are then used to recalculate the thermal transmittance results. In addition to correcting the typographical and unit conversion errors in these recalculated results, the projected area of the test specimen submitted by one of the laboratories was modified after a discussion with the laboratory identifying that they used the exterior dimension of the curb instead of the interior dimensions to determine the projected area.

Reported Data Analysis

The following observations were made when reviewing the data reported by the laboratories.

Missing Data. Some laboratories did not report all of the required data. Unless otherwise noted, missing data was excluded from the analysis.

Specimen Areas. Upon review of the Specimen Projected Areas, A_S, the area reported by one laboratory is significantly greater than the others. This issue was discussed with the

Table 3. Methods Used to Support and Seal the Test Specimen

Laboratory	Wood Supports Under Curb	Wood Over Nail Flange	Air Sensor Extensions on Surround Panel	Method to Seal Surround Panel	Method to Seal Specimen	Comments
A	One	Not reported	Not reported	Duct tape	Tape	
B	Two 2 × 4	Yes	Not reported	Not reported	Removable sealant	
C	Two	Not reported	Not reported	Duct tape	Not reported	
D	Two 1 × 4	0.75 in. × 2.5 in. (19 mm × 63 mm)	5.5 in. long on 3 in. × 3 in. base (140 mm long on 76 mm × 76 mm base)	Duct tape	Tape	Measured by NFRC staff during inspection
E	Two 2 × 4	Duct tape only	Not reported	Masking tape	Masking tape	
F	Two 2 × 4	Duct tape only	Not reported	Duct tape	Tape	
G	None, nail flange screwed to face of surround panel	Not reported	Not reported	Tape	Tape	

Table 4a. Glazing Deflection Vs. Thermal Transmittance (I-P)

	Laboratory							Statistical Data			
	1	2	3	4	5	6	7	Avg	Min	Max	R^2
Glazing Deflection											
Gap Width,[1] in.	0.200	0.210	0.300	0.185	0.412	0.386	0.565	0.323	0.185	0.565	
Thermal Transmittance											
Air-to-Air (U_S), Btu/(h·ft^2·°F)	0.47	0.45	0.47	0.48	0.46	0.46	0.45	0.463	0.446	0.480	0.2273
Standardized (U_{ST}), Btu/(h·ft^2·°F)	0.45	0.43	0.46	0.46	0.41	0.42	0.41	0.434	0.410	0.460	0.5581

[1]Measured after test except for Laboratory 5

Table 4b. Glazing Deflection Vs. Thermal Transmittance (SI)

	Laboratory							Statistical Data			
	1	2	3	4	5	6	7	Avg	Min	Max	R^2
Glazing Deflection											
Gap Width,[1] mm	5.08	5.33	7.62	4.70	10.46	9.80	14.35	8.20	4.70	14.35	
Thermal Transmittance											
Air-to-Air (U_S), W/(m^2·K)	2.67	2.53	2.67	2.73	2.63	2.61	2.56	2.63	2.53	2.73	0.2273
Standardized (U_{ST}), W/(m^2·K)	2.56	2.42	2.61	2.61	2.33	2.38	2.33	2.46	2.33	2.61	0.5581

[1]Measured after test except for Laboratory 5

laboratory after they submitted their report, and it was determined that they measured the exterior dimensions of the curb, not the interior dimensions. Although this laboratory claimed to install the test specimen properly, with the inside face of the curb flush with the edge of the aperture in the surround panel, they did not use the area of that aperture to calculate the thermal transmittance results. Minor changes in Specimen Projected Areas have a significant impact on the calculated thermal transmittances as demonstrated when the corrected area is used to generate new results.

The same laboratory did not measure the Specimen Cold Side 3-D Area, A_c, correctly. Although the authors understand the reasons for this error after discussion with the laboratory, the convoluted rationale used by the laboratory to determine this area is too difficult to briefly describe within the scope of this report. In addition, another laboratory did not report either the Specimen Cold Side 3-D Area, A_c, or the Specimen Warm Side 3-D Area, A_h, but since these areas are not used to calculate the thermal transmittance using NFRC 102, these errors and omissions did not affect the final results.

If the incorrectly measured value of the projected test specimen area previously mentioned is omitted from the statistical analysis, the average Specimen Projected Areas, A_S, for all the laboratories is 14.895 Ft^2 (1.384 m^2) with a standard deviation of 0.0647 (0.0060). It is refreshing that laboratories are able to reproduce similar dimension measurements once they are given proper instructions on what to measure.

Metering Room Air Temperature. NFRC 102 states that the warm side air temperature shall be 70 ± 0.5 ºF (21.1 ± 0.3 ºC), yet one laboratory's average Metering Room Air Temperature, t_h, was outside of those limits.[9] Since this laboratory's test was performed at almost the same average mean air temperature as the other laboratories, and the baffle temperatures were in tolerance, this small deviation between the measured warm side air temperature, and the desired warm side air temperature should not affect that laboratory's thermal transmittance results.

Metering Room Air-Baffle Temperature Difference. Unless a laboratory calculates the view factor for radiation heat transfer between the test specimen and the thermal chamber, the average surface temperature of the warm side baffle must be maintained within 2.0 ºF (1.0 ºC) of the warm side air temperature.[10] All of the laboratories reported average warm side baffle temperatures within this tolerance.

Relative Humidity. All participating laboratories reported that the measured Relative Humidity within their metering chambers were at or below the required 15% during the test.[11] The Relative Humidity reported by each laboratory ranged from a low of 3.5% to a high of 14.72%, with an average of 11.97%.

Static Pressure Difference. Although laboratories are required to seal a test specimen against air leakage before testing, it is also recommended that the pressured difference be monitored and maintained to minimize the pressure difference across the test specimen.[12] One laboratory did not measure the pressure difference across the test specimen, but stated that the measured air infiltration rate was zero after sealing the test specimen and surround panel before testing. Those laboratories that reported that they measured a pressure balance of zero identified that this measurement was only accurate to ±0.21 Lbf/Ft^2 (±10 Pa).

Surround Panel Heat Flow. Most laboratories used 4 in. (102 mm) thick (nominal) surround panels, except one laboratory used a 5 in. (127 mm) thick surround panel, and another used a 6 in. (152 mm) thick surround panel. One laboratory did not report the surface temperatures measured on each side of the surround panel, and another laboratory did not convert the surround panel conductance from metric units to I-P units correctly when reporting that value to NFRC. The authors verified the reported heat fluxes through the surround panels by recalculating the heat flows based on the reported surface temperature difference, area, and thermal conductance of each laboratory's surround panel. Although no significant discrepancies were identified, this verification was not conclusive as some laboratories did not report the thermal conductance of the surround panels to enough significant digits, or they assembled their surround panel from foam pieces with different thermal conductances and therefore the heat flux had to be area weighted. The significance of each laboratory's surround panel heat flow within the overall measurement of the test specimen heat flow is discussed in greater detail in the upcoming section titled, "Test Specimen Heat Loss."

Warm Side Specimen Surface Temperatures. All of the participating laboratories measured and reported the 13 warm side test specimen surface temperatures requested by NFRC. Only two laboratories provided the surface areas associated with each of those temperature measurements, which is needed to calculate the average area-weighted surface temperature of the test specimen. Upon closer inspection of the measurements submitted by all the laboratories, it is apparent that one laboratory may have switched the locations of the temperature sensors on the sill curb. After discussion with the laboratory, they could not confirm or deny that mistake. The same laboratory also reported the surface temperatures measured on the warm side of the interior glass surface placed ½ in. (12.7 mm) from the inside face of the curb and under the drip molding. It is interesting to note that the glazing surface temperatures measured under the drip molding are an average of 10 ºF (5.6 ºC) lower than the edge-of-glass glazing surface temperatures measured approximately 1 in. (25 mm) away. This large temperature gradient over such a short distance increases the uncertainty of the edge-of-glass surface temperature measurements, which are only measured with four thermocouples.

Cold Side Specimen Surface Temperatures. Three laboratories also reported the cold side surface temperatures that were measured at locations directly across the test specimen from the warm side surface temperature sensors. Only two laboratories provided the surface areas associated with each of those temperature measurements. Both of the laboratories that measured and reported the surface areas associated with each thermocouple on the warm and cold side of the test specimen, also calculated the average surface temperatures of both sides of the test specimen.

Metering Box Heat Flow. There were a number of anomalies with the reported Metering Box Heat Flow data. One laboratory reported that the sign of the metering box heat flow was a negative value, whereas the authors had to change the sign of that value to calculate the same Net Test Specimen Heat Loss, Q_S, as reported by the laboratory.

Another laboratory reported a Flanking Loss, Q_{fl}, which was more than 10% of the Net Test Specimen Heat Loss, Q_S.

9. NFRC 102; Section 4.2.A.1
10. ASTM C 1199; Section 5.2.4.7
11. NFRC 102; Section 4.2.A.3.
12. ASTM E 1423; Section 7.1.3

If one were to consider the surround panel flanking loss to be part of the metering box wall heat flow as it is currently determined using the recently published version of ASTM C 1363, then the large flanking loss heat flow reported by this laboratory would be outside of the recommended tolerance specified within ASTM C 1363.[13] Although this relatively large flanking loss heat flow may not affect the thermal transmittance measured by this laboratory, it increases the uncertainty of that measurement.

Finally, one laboratory forcefully ducted air from the climate chamber directly into the metering chamber to reduce the Relative Humidity of the air in their metering box. That laboratory attempted to measure the sensible heat transfer (cooling) associated with this exchange of air by measuring the airflow rate, temperature and relative humidity of the air entering the metering chamber, and reported that rate of heat transfer as -15.6 Btu/hr (-4.57 W). Since the estimated heat flux is relatively small compared to the test specimen heat flow, its affect on the measured thermal transmittance is probably minor. Nevertheless, the correction associated with this heat flux increases the uncertainty of their results.

Test Specimen Heat Loss. The measurement of the heat flow through a test specimen subjected to a consistently maintained temperature difference and environmental conditions is the primary measurement of an ASTM C 1363 Hot Box. Of all the parameters affecting the measurement of thermal transmittance, the accurate measurement of the heat flow through the test specimen is the most difficult to perform, and has the greatest significance on the final results. Since the test specimen heat flow, Q_S, is determined by subtracting the heat loss through the surround panel (including the flanking loss), and the metering box walls from the electrical energy supplied to the metering box by the heaters, fans and instrumentation, it is useful to analyze the measurement of the heat gain and the measurement of the heat loss of the metering box separately.

It is impossible to determine the accuracy of the equipment used by each laboratory to measure the power supplied by electrical components such as heaters, fans, and instrumentation in the metering chamber from the data provided by the laboratories for this round robin. The methodology and instrumentation used by each laboratory to perform these measurements are verified during the NFRC LAP Test Laboratory Inspection Assessments. The average Total Measured Heat Flow, Q_{Total}, is 666.37 Btu/hr (195.29 W) with a minimum of 592.39 Btu/hr (173.61 W), and a maximum of 714.99 Btu/hr (209.54 W). This large variation in the heat input into each laboratory's metering chamber is largely a function of the size and construction of each metering box, and therefore is not indicative of the accuracy of their measurements.

When analyzing the heat loss from the metering box, it helps to visualize the proportion of heat loss from each component of that thermal chamber. Consider an instrumented insulated box with six sides. The five sides of the metering box walls are surrounded by a guard chamber, which allows the laboratory to minimize the temperature difference across these five walls, and therefore minimize the heat flow through them. The sixth face of the metering box consists of a surround panel with the test specimen installed in (or over) an aperture at the center of the panel. Both the surround panel and the test specimen are exposed to a large temperature difference, which is intentionally created in part to generate enough heat flux through the test specimen to accurately measure. Finally, there is extraneous heat loss around the perimeter of the surround panel where it is in contact with the metering box walls, which is called flanking loss. Table 5 presents these heat flows from each laboratory.

Upon inspection of precentatges in Table 5, one can surmise that the uncertainty of the measured heat flux increases as the percentage of heat flow through the test specimen decreases. Therefore, it is desirable to minimize the heat flow through the metering box walls, the surround panel, and due to surround panel flanking loss. If an ideal hot box could be developed where all of the measured heat flow was confined to the test specimen, then the primary uncertainty in measuring the heat flux would solely be a function of the instrumentation and methodology used to measure the power supplied to the electrical equipment in the metering box.

There is significant variability in the percentage of surround panel heat flux reported by each laboratory (e.g., between 13.1% and 26.5%). This is more of a function of the size of the surround panel than its thermal resistance. Some laboratories use different sized metering boxes for different sized products, and therefore can choose the smallest metering box possible for a given size of test specimen. Not only does this minimize the surround panel area for smaller test specimens, but smaller metering boxes typically reach a state of thermal equilibrium faster, and therefore tests can be performed in shorter periods of time. A disincentive to using multiple metering boxes is that each one has to be calibrated separately.

The proportion of heat flux through the metering box walls and due to flanking loss is also significantly different between laboratories. It is interesting to note that within the recently published version of ASTM C 1363, the metering box wall and flanking losses are combined into the same parameter in which the component heat fluxes cannot be identified separately. By combining the percentage of heat fluxes through the metering box walls and flanking losses in Table 5, the proportions of those composite heat flows are much more similar between laboratories.

The average reported Net Specimen Heat Loss, Q_S, from all the laboratories is 491.76 Btu/hr (144.12 W) with a minimum of 465.67 Btu/hr (136.47 W) and a maximum of 535.38 Btu/hr (156.90 W). The maximum value was reported by the laboratory that did not measure the projected area of the skylight correctly, but even when the reported heat flux was corrected by using the proper area, that laboratory still generates the highest Net Specimen Heat Loss of 530.87 Btu/hr

13. ASTM C 1363; Section 6.5.3.2

Table 5a. Heat Flow Analysis (I-P)

	Laboratory							Statistical Data		
	1	2	3	4	5	6	7	Avg	Min	Max
Heat Flows, Btu/h										
Total Measured[1], (Q_{total})	614.9	592.4	675.2	672.7	691.8	715.0	702.6	666.37	592.39	714.99
Surround Panel Loss (Q_{sp})	80.4	82.0	140.4	115.1	149.4	114.5	186.5	124.02	80.40	186.49
Metering Box Wall Flux (Q_{mb})	39.9	26.9	20.1	27.2	20.7	6.5	31.1	24.63	6.47	39.94
Flanking Loss (Q_{fl})	5.9	17.8	20.3	28.4	36.6	58.7	8.6	25.18	5.88	58.66
Net Specimen Heat Loss (Q_s)	488.7	465.7	494.4	502.1	479.7	535.4	476.4	491.76	465.67	535.38
Percent of Total, %										
Surround Panel Loss (Q_{sp})	13.1	13.8	20.8	17.1	21.6	16.0	26.5	18.4	13.1	26.5
Metering Box Wall Flux (Q_{mb})	6.5	4.5	3.0	4.0	3.0	0.9	4.4	3.8	0.9	6.5
Flanking Loss (Q_{fl})	1.0	3.0	3.0	4.2	5.3	8.2	1.2	3.7	1.0	8.2
Net Specimen Heat Loss (Q_s)	79.5	78.6	73.2	74.6	69.3	74.9	67.8	74.0	67.8	79.5

[1]The Total Measured Heat Flow as reported by each laboratory. Some laboratories did not report all of the individual component heat flows, which would then have to be calculated by the authors based on the best available data. For this reason, there may be a slight discrepancy between the reported Total Measured Heat Flows and the summations of the individual component heat flows.

Table 5b. Heat Flow Analysis (SI)

	Laboratory							Statistical Data		
	1	2	3	4	5	6	7	Avg	Min	Max
Heat Flows, W										
Total Measured, (Q_{total}) [1]	180.2	173.6	197.9	197.1	202.7	209.5	205.9	195.29	173.61	209.54
Surround Panel Loss (Q_{sp})	23.6	24.0	41.1	33.7	43.8	33.5	54.7	36.35	23.56	54.65
Metering Box Wall Flux (Q_{mb})	11.7	7.9	5.9	8.0	6.1	1.9	9.1	4.94	5.89	11.71
Flanking Loss (Q_{fl})	1.7	5.2	5.9	8.3	10.7	17.2	2.5	7.38	1.72	17.19
Net Specimen Heat Loss (Q_s)	143.2	136.5	144.9	147.1	140.6	156.9	139.6	144.12	136.47	156.90
Percent of Total, %										
Surround Panel Loss (Q_{sp})	13.1	13.8	20.8	17.1	21.6	16.0	26.5	18.4	13.1	26.5
Metering Box Wall Flux (Q_{mb})	6.5	4.5	3.0	4.0	3.0	0.9	4.4	3.8	0.9	6.5
Flanking Loss (Q_{fl})	1.0	3.0	3.0	4.2	5.3	8.2	1.2	3.7	1.0	8.2
Net Specimen Heat Loss (Q_s)	79.5	78.6	73.2	74.6	69.3	74.9	67.8	74.0	67.8	79.5

[1]The Total Measured Heat Flow as reported by each laboratory. Some laboratories did not report all of the individual component heat flows, which would then have to be calculated by the authors based on the best available data. For this reason, there may be a slight discrepancy between the reported Total Measured Heat Flows and the summations of the individual component heat flows.

(155.58 W). Although the reported heat flow from this laboratory is not quite an outlier within a confidence level of 95% (i.e., two standard deviations), it is interesting to note that if the results from that laboratory are omitted from the statistical analysis, the average Net Specimen Heat Loss becomes 484.49 Btu/hr (141.99 W) and the standard deviation is reduced from 22.69 to 13.18 (6.65 to 3.86).

Methodology Used to Calculate Standardized Thermal Transmittance. Unlike wall or roof assemblies, the measurement of the thermal resistance of fenestration products is adjusted based on calibration test results from an appropriately sized Calibration Transfer Standard (CTS). Whereas unadjusted measurements of the thermal transmittance of fenestration products are typically referred to as the air-to-air thermal transmittance, U_S, the adjusted results are called the standardized thermal transmittance, U_{ST}. Since the heat flow through fenestration products is strongly dependent on the surface heat transfer coefficients on both sides of the test specimen, the process of standardizing the test results attempts to reduce the variability between different geometries and environmental conditions within different thermal chambers.

NFRC uses the standardized thermal transmittance to generate or validate U-factor ratings.

Actually, ASTM C 1199 permits two methods of calculating standardized thermal transmittance results. Laboratories are provided with criteria to determine whether the Area Weighting Method is to be used, or the CTS Method is used to calculate the final results. If the skylight used as the test specimen for this round robin was evaluated using ASTM C 1199 alone, the Area Weighting Method would be used to standardize the thermal transmittance results. Instead, the CTS Method has been used by all the laboratories participating in this round robin, as NFRC 102 has stipulated since 2002 that the CTS Method is the only methodology permitted.

Since the actual surface temperatures of the test specimen are not used to calculate the standardized thermal transmittance using the CTS method, the average surface temperatures on both sides of the test specimen are estimated assuming that the surface heat transfer coefficients on the test specimen are the same as measured on the CTS. These estimated surface temperatures are called the Equivalent Surface Temperatures. When evaluating the affect of standardization on the measurement of thermal transmittance, it is useful to compare the surface temperatures and surface heat transfer coefficients that were actually measured, to the temperatures and surface heat transfer coefficients generated by the standardization processes. Keep in mind that the temperatures and surface heat transfer coefficients measured on a flat CTS may be significantly different from those generated on a curb-mounted skylight that projects out into the climate chamber.

Calibration Transfer Standard Calibration Test Results. Some perceive that the CTS Method is easier to use because laboratories do not have to place temperature sensors on the test specimen to measure the average surface temperature of both sides. Instead, the CTS Method assumes that the surface heat transfer coefficient on the cold side, h_c, and the convection component of the surface heat transfer coefficient on the warm side of the test specimen, K, are the same as measured on a similar-sized CTS. These surface heat transfer coefficients are generated in a separate calibration test of the CTS. In addition, the surface heat transfer coefficients measured on the CTS during this calibration test are used to adjust and set the fan or blower speeds in both the metering box and the climate chamber. The intent is to generate the same air velocities on the CTS as the test specimen would experience during a test. Understandably, the calculation of the standardized thermal transmittance using the CTS Method is strongly dependent on the surface heat transfer coefficients generated during those CTS calibration tests.

Note that some of the data that is about to be presented from the CTS calibration tests were provided after the final submission of the round robin data. Not all the laboratories submitted round robin reports containing the raw data and results from the CTS tests, which were used to generate the surface heat transfer coefficients that were then used to calculate the standardized thermal transmittance of the round robin test specimen. The authors requested the missing calibration reports at a later date. Therefore the possibility exists that three laboratories inadvertently sent the wrong report or made a typographical error as their cold side surface heat transfer coefficients reported to have been used to calculate the thermal transmittance of the test specimen were different than those reported in their CTS calibration test results.

Warm Side Surface Heat Transfer Coefficients Measured on the CTS. The Convection Coefficients, K, reported by all the laboratories varied between 0.27 and 0.37 Btu/(hr • Ft^2 • ºF)$^{1.25}$ (1.53 and 2.10 W/(m^2 • K)$^{1.25}$) with an average coefficient of 0.31 Btu/(hr • Ft^2 • ºF)$^{1.25}$ (1.76 W/(m^2 • K)$^{1.25}$). This Convection Coefficient is measured on the warm side of the CTS, and is used to estimate the warm side surface temperature and heat transfer coefficient on the test specimen during a test.

The Warm Side Surface Heat Transfer Coefficients, h_h, generated during the CTS calibration tests are only used to adjust the fan speed, and therefore the air velocity in the metering chamber. All of the warm side surface heat transfer coefficients measured on the CTS had to be retrieved from the actual calibration test results provided separately. To meet the tolerance specified in NFRC 102, the surface heat transfer coefficients on the warm side of the CTS must not vary more than ± 5.0% from the standard value of 1.35 Btu/(hr • Ft^2 • ºF) (7.67 W/(m^2 • K)).[14] This allows surface heat transfer coefficients between 1.28 and 1.42 Btu/(hr • Ft^2 • ºF) (7.27 and 8.06 W/(m^2 • K)). All the laboratories were within tolerance as they reported warm side surface heat transfer coefficients between 1.29 and 1.39 Btu/(hr • Ft^2 • ºF) (7.32 and 7.89 W/[m^2 • K]) with an average equaling the standard value of 1.35 Btu/(hr • Ft^2 • ºF) (7.67 W/(m^2 • K)).

Standardized Warm Side Surface Heat Transfer Coefficients. The previous presentation of actual measurements of the warm side surface heat transfer coefficients on the CTS provides an opportunity to discuss a current anomaly within NFRC 102. The 2002 edition of NFRC 102 added a complex equation to define the standardized warm side surface heat transfer coefficient[15] that contradicts with the test conditions mandated in a previous section.[16] All of NFRC 102 laboratories must now calculate and report this warm side surface heat transfer coefficient, h_{STh}, for every NFRC 102 test, which for the first time, requires that the height of the test specimen be included in their calculations. Not only does this equation generate surface heat transfer coefficients that are lower than many test laboratory operators believe credible, the results from this equation vary between test specimens which is contrary to normalization process typical when standardizing results.

As previously mentioned, the air velocities and distribution on both sides of the thermal chamber are generated to

14. NFRC 102; Section 4.2.A.4
15. NFRC 102; Section 8.2.9.1.A
16. NFRC 102; Section 4.2.A.4

produce surface heat transfer coefficients on a CTS within a specified tolerance of standard warm and cold side surface heat transfer coefficients. Logically, these standard surface heat transfer coefficients are constants, regardless of the height or size of the CTS. Although the standardized warm side surface heat transfer coefficient value has a strong influence on the environmental conditions experienced by the test specimen, it is not a component of the iterative calculation used to estimate the temperatures (i.e., Equivalent Temperatures) and warm side surface heat transfer coefficients for determining the standardized thermal transmittance using the CTS Method. Instead, the CTS Method uses the Convection Coefficient, K, as measured on the warm side of the CTS as a means to estimate the surface heat transfer coefficient on the warm side of an actual test specimen. As the title implies, the Convection Coefficient is very sensitive to the airflow conditions generated in the metering box, and is unique to each thermal chamber, surround panel thickness, CTS size, and fan speed settings.

The results generated by the standard warm side surface heat transfer coefficient equation in Section 8 of NFRC 102 are consistently lower than the actual warm side surface heat transfer coefficients measured by a CTS or on a test specimen. Calibration Transfer Standards are designed, assembled and characterized to serve as sensitive instruments to measure the heat flux, surface temperatures and therefore the surface heat transfer coefficients generated on their flat glass outer surfaces. Provided with the raw data from each laboratory's CTS Calibration Tests, the authors recalculated the standard warm side surface heat transfer coefficients using the equation in Section 8 of NFRC 102 based on the CTS height, the CTS surface temperature and militance, and the ambient air temperature in the metering chamber. These Standard Warm Side Surface Heat Transfer Coefficients, h_{STh}, calculated from each laboratory's CTS test results vary between 1.19 and 1.24 Btu/(hr • Ft^2 • ºF) (6.76 and 7.04 W/(m^2 • K)), with a mean value of 1.21 Btu/(hr • Ft^2 • ºF) (6.87 W/(m^2 • K)). As mentioned in the previous section, the standard warm side surface heat transfer coefficient measured on the CTS is 1.35 Btu/(hr • Ft^2 • ºF) (7.67 W/(m^2 • K)), and it is not even permitted to be lower than 1.28 Btu/(hr • Ft^2 • ºF) (7.27 W/(m^2 • K)). Similar discrepancies are apparent when reviewing the warm side surface heat transfer coefficients reported for the round robin test specimen. Under theoretically ideal conditions, it might be possible to produce surface heat transfer coefficients predicted by this equation, but it would be difficult to generate such low coefficients on a CTS mounted in the recess of a surround panel even with the metering chamber fans turned off.

Cold Side Surface Heat Transfer Coefficients Measured on the CTS. The Cold Side Surface Heat Transfer Coefficients, h_c, measured on the CTS are not only used to establish the speed of the blower or fan in the climate chamber, but it is also used in the calculation of the temperatures and surface heat transfer coefficients on the test specimen using the CTS Method. The standard cold side surface heat transfer coefficient is 5.28 Btu/(hr • Ft^2 • ºF) (30.0 W/(m^2 • K)). With a tolerance of ± 10%, the permitted range is between 4.75 and 5.81 Btu/(hr • Ft^2 • ºF) (27.0 and 33.0 W/(m^2 • K)). The CTS Method assumes that the cold side surface heat transfer coefficient measured on the CTS and test specimen are identical, but some laboratories reported different Cold Side Surface Heat Transfer Coefficients in their round robin test report, than reported in the separately submitted CTS Calibration Test Results. One laboratory reported a cold side surface heat transfer coefficient of 8.96 Btu/(hr • Ft^2 • ºF) (50.9 W/(m^2 • K)) in the round robin report, but should have used the value of 4.99 Btu/(hr • Ft^2 • ºF) (28.3 W/(m^2 • K)) reported in their CTS calibration test report. If this one error is corrected, the laboratories reported cold side surface heat transfer coefficient ranging between 4.89 and 5.64 Btu/(hr • Ft^2 • ºF) (27.7 and 32.0 W/(m^2 • K)) with an average of 5.29 Btu/(hr • Ft^2 • ºF) (30.0 W/(m^2 • K)).

Calibration Transfer Standard Size. Ideally, the CTS and test specimen size should be similar if the surface heat transfer coefficients measured on the CTS are going to be used to estimate the surface heat transfer coefficients on a test specimen. Three laboratories used a 2 Ft by 4 Ft CTS (8 Ft^2) (0.6 m by 1.2 m (0.74 m^2)), three laboratories used a 4 Ft by 6 Ft CTS (24 Ft^2) (1.2 m by 1.8 m (2.2 m^2)), and the remaining laboratory used a 2½ Ft by 5 Ft CTS (12½ Ft^2) (0.8 m by 1.5 m (1.2 m^2)). This singular laboratory used a CTS that was closest to the test specimen size of 4 Ft by 4 Ft (15 Ft^2) (1.2 m by 1.2 m (1.5 m^2)).

Thermal Transmittance (U-Factor). As previously mentioned in the discussion of the net heat flow of the test specimen, the measurement of the Thermal Transmittance, U_S, is the primary measurement of ASTM C 1363. The thermal transmittance of the test specimen is simply a function of measurements of the area, air temperature difference, and heat flow through the test specimen. The thermal transmittance results are presented in Table 6, Figures 7 and 8. Initial review of the thermal transmittance values reported by all the laboratories is favorable, with a minimum value of 0.45 Btu/(hr • Ft^2 • ºF) (2.56 W/(m^2 • K)), a maximum value of 0.48 Btu/(hr • Ft^2 • ºF) (2.73 W/(m^2 • K)) and an average of 0.46 Btu/(hr • Ft^2 • ºF) (2.63 W/(m^2 • K)). With a standard deviation of 0.011 (0.063), the relative differences in the air-to-air U-factors reported by all of the laboratories are comparable to the variability found in previously performed NFRC Test Laboratory Round Robins.

But remember that we previously identified that one laboratory did not measure the projected area of the test specimen correctly, and the same laboratory measured a Net Specimen Heat Flow that was significantly higher than the other laboratories. Since the thermal transmittance reported by the laboratory in question equals the average thermal transmittance reported by all of the laboratories, the errors associated with the incorrectly measured area and relatively high test specimen heat flow are not immediately apparent. It is not until an attempt is made to recalculate this laboratory's results with

Table 6a. Reported Thermal Transmittance Test Results (I-P)

	Laboratory										Statistical Data		
	1	2	3	4	5	6	7	Avg	Min	Max	Standard Deviation	*R*, 95%	*R*, 95%/Avg
Air-to-Air (U_s), Btu/(h·ft^2·°F)	0.47	0.45	0.47	0.48	0.46	0.46	0.45	0.46	0.45	0.48	0.011	0.031	6.73%
Difference from Average, %	1.5	–2.8	1.5	3.7	–0.6	–0.6	–2.8	0.0	–2.8	3.7	2.4		
Standardized (U_{st}), Btu/(h·ft^2·°F)	0.45	0.43	0.46	0.46	0.41	0.42	0.41	0.43	0.41	0.46	0.022	0.062	14.35%
Difference from Average, %	3.6	–1.0	5.9	5.9	–5.6	–3.3	–5.6	0.0	–5.6	5.9	5.1		

Table 6b. Reported Thermal Transmittance Test Results (SI)

	Laboratory										Statistical Data		
	1	2	3	4	5	6	7	Avg	Min	Max	Standard Deviation	*R*, 95%	*R*, 95%/Avg
Air-to-Air (U_s), W/(m^2·K)	2.67	2.56	2.67	2.73	2.61	2.61	2.56	2.63	2.56	2.73	0.063	0.177	6.73%
Difference from Average, %	1.5	–2.8	1.5	3.7	–0.6	–0.6	–2.8	0.0	–2.8	3.7	2.4		
Standardized (U_{st}), W/(m^2·K)	2.56	2.44	2.61	2.61	2.33	2.38	2.33	2.47	2.33	2.61	0.126	0.354	14.35%
Difference from Average, %	3.6	–1.0	5.9	5.9	–5.6	–3.3	–5.6	0.0	–5.6	5.9	5.1		

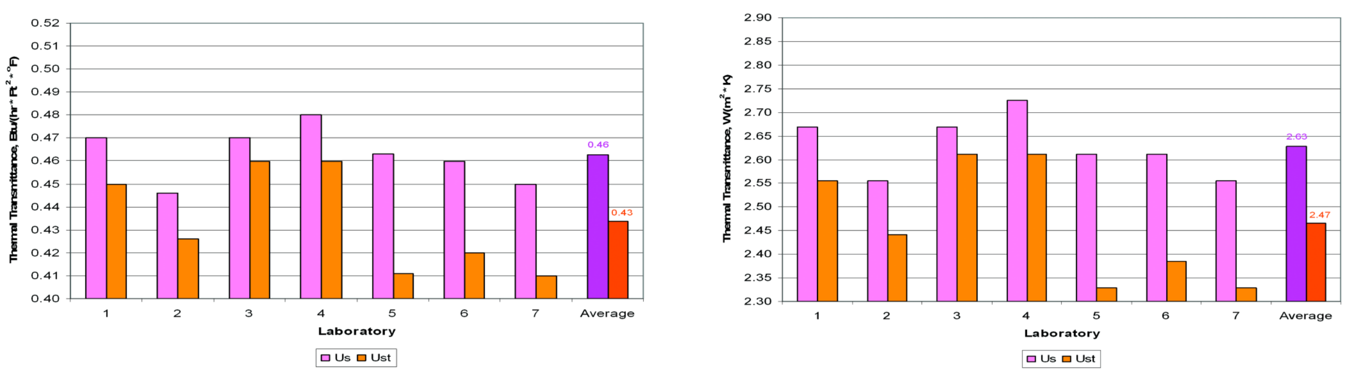

Figure 7 *NFRC 2004 test round robin reported results: I-P (left) and SI (right).*

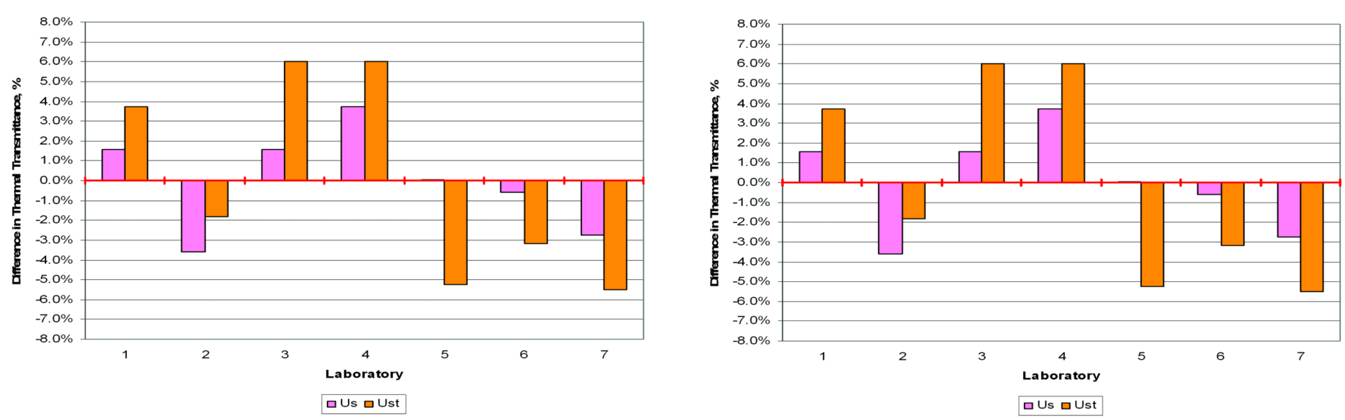

Figure 8 *NFRC 2004 test ILC reported results: I-P (left) and SI (right).*

these errors corrected do the thermal transmittance values from this laboratory deviate from the others.

Standardized Thermal Transmittance. The variability of the standardized thermal transmittance, U_{ST}, reported by all the laboratories is a little more disconcerting. As summarized in Table 6, the average standardized thermal transmittance is 0.43 Btu/(hr • Ft^2 • ºF) (2.47 W/(m^2 • K)) with a range of 0.41 to 0.46 Btu/(hr • Ft^2 • ºF) (2.33 to 2.61 W/(m^2 • K)). With deviations between reported U-factors as high as ± 6% represented by a standard deviation of 0.022 (0.126), the variability between the reported standardized thermal transmittance of the skylight chosen for this round robin is greater than previous NFRC Test Laboratory Round Robins, and is contrary to the objectives of the standardization process. As previously mentioned, the intent of standardizing the raw thermal transmittance results from fenestration products measured in an ASTM C 1363 thermal chamber is to minimize the variability between different geometries and environmental conditions within each laboratory's thermal chamber. Instead, the standardized results from all of the laboratories showed much greater variability than the direct measurement of thermal transmittance.

Recalculated Data Analysis

Given the errors identified in the previous section and the large variability in the reported Standardized Thermal Transmittance, U_{ST}, one might question if deviations within the calculation methodology used by each laboratory to determine standardized thermal transmittances might account for these discrepancies. One way to verify discrepancies within the calculation procedures used by each laboratory is to recalculate their results using their raw data, and a common spreadsheet. The authors used a modified version of the spreadsheets used in the 2004 NFRC LAP Test Laboratory Inspections to verify each laboratory's test reports.

The test results from each laboratory are recalculated twice. The first recalculation intends to recalculate standardized thermal transmittances using the input data intended by the laboratory, or in other words, only correcting the typographical errors associated with their data submittal to NFRC. This initial recalculation hopes to identify errors and discrepancies solely within the calculation procedures used by each laboratory. The second recalculation is an attempt to correct all the known errors with the submitted data, and to use recalculated CTS test results to recalculate new standardized thermal transmittance values.

Keep in mind that the process of recalculating results generates minor errors associated with rounding the raw data entries. Many laboratories input raw data directly from their data acquisition systems into their own spreadsheets, which likely records each measurement as an 8 or 16 digit number. When the laboratories report this raw data to NFRC on a paper data entry form, it may be rounded to a 3 or 4 digit number. This rounding error is further compounded by converting the reported value from metric to I-P units for two laboratories. Whenever possible, data values were directly copied from electronic spreadsheets provided by the laboratories into the spreadsheets used for this report, but only two laboratories provided their results in Microsoft EXCEL spreadsheets to facilitate that process.

In addition, the different components of heat loss out of the metering box (i.e., flanking loss, metering box wall heat loss, etc.) could not be accurately verified for every laboratory, and the authors had to make slight adjustments or assumptions about the input data to generate component heat flows as close as possible to those reported by the laboratory.

The following observations were made when reviewing the recalculated results.

Correct Typographical Errors. Four typographical errors were identified. A list of these corrections follows:

- *Change thermal conductance of surround panel.* One laboratory did not convert the thermal conductance of their surround panel from metric into I-P units correctly when reporting that value to NFRC. When the authors performed this unit conversion using the metric value found in the printout of the laboratory's spreadsheet, more reasonable results were generated that were verified by the calculation of similar surround panel heat flows.
- *Switch location of warm surface temperatures on sill frame*. When compared with the accompanying data from all the other laboratories, one laboratory reported temperatures in two cells that appear to have been measured at the other cell's location. Although these temperatures were not used to calculate the standardized thermal transmittance, swapping these values improves the statistical evaluation of the array of temperature measurements.
- *Change sign of metering box heat flux.* To calculate the same Net Specimen Heat Flow, the sign of the metering box wall heat flux reported by one laboratory had to be reversed in the authors' spreadsheets.
- *Use net specimen heat flux reported by laboratory.* The spreadsheets developed by the authors could not be used to calculate the same Net Specimen Heat Flow, Q_S, reported by one laboratory without significant modification. This laboratory used a surround panel consisting of foam pieces with different thermal conductances, and therefore the heat flux had to be area weighted. In addition this laboratory forcefully ducted air between their climate chamber and metering box, and the methodology that would be used to correct for the sensible heat exchange associated with this heat transfer is not included in the authors' spreadsheets.

Equivalent Surface Temperatures. One of the first differences to stand out when reviewing the recalculated data is the change in the calculated value of the Equivalent Surface Temperatures, especially on the warm side. The average warm side equivalent surface temperature is reduced more than a 1.5 ºF (0.83 ºC) from 48.74 ºF to 47.12 ºF (9.30 ºC to 8.40 ºC), but more importantly, the standard deviation between the temperatures calculated for each laboratory is reduced from 2.543 to 1.161 (1.413 to 0.645). The average cold side equivalent surface temperature is slightly reduced after recalculation from 5.72 ºF to 5.65 ºF (-14.60 ºC to 14.64 ºC), but when reviewing the cold side surface temperatures calculated for all of the laboratories, one low value of 3.71 ºF (-15.72 ºC) stands out. Remember that this laboratory used a cold side surface heat transfer coefficient, h_c, of 8.96 Btu/(hr • Ft^2 • ºF) (50.9 W/(m^2 • K)), yet they reported that this coefficient was 4.99 Btu/(hr • Ft^2 • ºF) (28.3 W/(m^2 • K)) in their CTS calibration test results. This would explain the significant difference in the equivalent cold surface temperature calculated for this laboratory compared to the temperatures generated from other laboratories' raw data.

Warm Side Surface Heat Transfer Coefficients. With such a large change in the warm side surface temperatures upon recalculation of the standardized thermal transmittance, it is not surprising that the warm side surface heat transfer coefficients, h_h, also change. The average coefficient reported by all of the laboratories is 1.55 Btu/(hr • Ft^2 • ºF) (8.80 W/(m^2 • K)) with a standard deviation of 0.151 (0.875). Upon recalculating all of the laboratories' results, the average warm side surface heat transfer coefficient is lower with a value of 1.43 Btu/(hr • Ft^2 • ºF) (8.12 W/(m^2 • K)), and a significantly lower standard deviation of 0.066 (0.375).

Standardized Thermal Transmittance. Table 7, contains a statistical review of the recalculated thermal transmittance results and Figures 9 and 10 show bar charts presenting the results and differences between results. The previous discussion provides hope that the reduction in the variability of the calculation of temperatures and surface heat transfer coefficients will lead to a decrease in the discrepancy between the calculations of the standardized thermal transmittances, U_{ST}, between all of the laboratories. As might be expected, the average standardized thermal transmittance reported by all the laboratories of 0.43 Btu/(hr • Ft^2 • ºF) (2.47 W/(m^2 • K)) has increased upon recalculation to 0.44 Btu/(hr • Ft^2 • ºF) (2.51 W/(m^2 • K)). More importantly, the standard deviation between the thermal transmittance results from all of the laboratories has decreased from 0.022 to 0.013 (0.126 to 0.073), which is almost identical to the standard deviation for the thermal transmittance values alone.

Although the recalculated standardized thermal transmittance is higher, and therefore closer to the thermal transmittance, no claims can be made as to whether the reported values are more accurate than the recalculated values. Other than the comparison of results between laboratories, there is no way to know the actual thermal transmittance of the test specimen. The one conclusion that can be made with certainty is that differences between standardized thermal transmittance measurements are reduced if all of the laboratories perform the calculations in the same way. The intent of the standardization process is to reduce the variability of results generated in different thermal chambers.

Corrected and Recalculated Data Analysis

As previously identified, there are two obvious errors when reviewing the data used by the laboratories in their calculations. Since one of these errors consisted of the improper use of calibration test data, there is a need to understand the possibility of variability in the standardized thermal transmittance associated with the variability in each laboratory's calculation of the surface heat transfer coefficients on the CTS during calibration tests.

The raw data from each laboratory's CTS Calibration Tests were compiled and input into spreadsheets developed by the authors. These identical spreadsheets were used by the NFRC Inspectors to validate the calibration test results reviewed during the 2004 NFRC LAP Test Laboratory Inspections.

The following observations were made when reviewing the corrected and recalculated data.

Projected Test Specimen Area Correction. One laboratory reported a Projected Test Specimen Area, A_S, that was much greater than the areas reported by all the other laboratories. Conversations with that laboratory identified that the laboratory used the exterior dimensions of the curb instead of the interior dimensions of the curb to calculate the projected area of the skylight. For this recalculation, the incorrect area reported by the laboratory of 16.76 Ft^2 (1.56 m^2) is replaced with the average area of 14.89 Ft^2 (1.38 m^2) as calculated from all of the other laboratories' reported data.

A decrease in the size of the test specimen would correspond to a proportional increase in the area of the surround panel since the metering box area does not change. Likewise, the Net Specimen Heat Flow decreases, Q_S, from 535.39 to 530.87 Btu/hr (156.91 to 155.58 W), and the Surround Panel Heat Flow, Q_{SP}, increases from 114.47 to 118.99 Btu/hr (33.55 to 34.87 W).

Convection Coefficient. There were large changes in the Convection Coefficient, K, upon recalculation. Although the average value of 0.31 Btu/(hr • Ft^2 • ºF)$^{1.25}$ (1.76 W/(m^2 • K)$^{1.25}$) does not change, the standard deviation between the laboratories' Convection Coefficient drops from 0.037 to 0.026 (0.210 to 0.148). All the laboratories' coefficients appear to change upon recalculation. Before recalculating the CTS results, the laboratories reported Convection Coefficients between 0.27 and 0.37 Btu/(hr • Ft^2 • ºF)$^{1.25}$ (1.53 and 2.10 W/(m^2 • K)$^{1.25}$), whereas after recalculation, the Convection Coefficient varied between 0.28 and 0.35 Btu/(hr • Ft^2 • ºF)$^{1.25}$ (1.59 and 1.987 W/(m^2 • K)$^{1.25}$).

Cold Side Surface Heat Transfer Coefficient. Recall the other previously identified error where one laboratory reported a Cold Side Surface Heat Transfer Coefficient, h_c, measured on the CTS that was out of tolerance, and much higher than reported in that laboratory's CTS Calibration Test report. Using that laboratory's erroneous cold side surface heat transfer coefficient value of 8.96 Btu/(hr • Ft^2 • ºF) (50.9 W/(m^2 • K)) generates the standardized thermal transmittance

Table 7a. Recalculated Thermal Transmittance Test Results (I-P)

	Laboratory							Statistical Data					
	1	2	3	4	5	6	7	Avg	Min	Max	Standard Deviation	*R*, 95%	*R*, 95%/Ave
Air-to-Air (U_s), Btu/(h·ft^2·°F)	0.470	0.446	0.473	0.484	0.463	0.456	0.456	0.464	0.446	0.484	0.013	0.036	7.72%
Difference from Average, %	1.3	–3.9	1.9	4.3	–0.2	–1.7	–1.8	0.0	–3.9	4.3	2.8		
Standardized (U_{st}), Btu/(h·ft^2·°F)	0.455	0.427	0.459	0.453	0.429	0.442	0.435	0.443	0.427	0.459	0.013	0.036	8.09%
Difference from Average, %	2.7	–3.5	3.6	2.2	–3.1	–0.1	–1.8	0.0	–3.5	3.6	2.9		

Table 7b. Recalculated Thermal Transmittance Test Results (SI)

	Laboratory							Statistical Data					
	1	2	3	4	5	6	7	Avg	Min	Max	Stdandard Deviation	*R*, 95%	*R*, 95%/Avg
Air-to-Air (U_s), W/(m^2·K)	2.67	2.53	2.69	2.75	2.63	2.59	2.59	2.63	2.53	2.75	0.073	0.203	7.72%
Difference from Average, %	1.3	–3.9	1.9	4.3	–0.2	–1.7	–1.8	0.0	–3.9	4.3	2.8		
Standardized (U_{st}), W/(m^2·K)	2.58	2.43	2.60	2.57	2.44	2.51	2.47	2.51	2.43	2.60	0.073	0.203	8.09%
Difference from Average, %	2.7	–3.5	3.6	2.2	–3.1	–0.1	–1.8	0.0	–3.5	3.6	2.9		

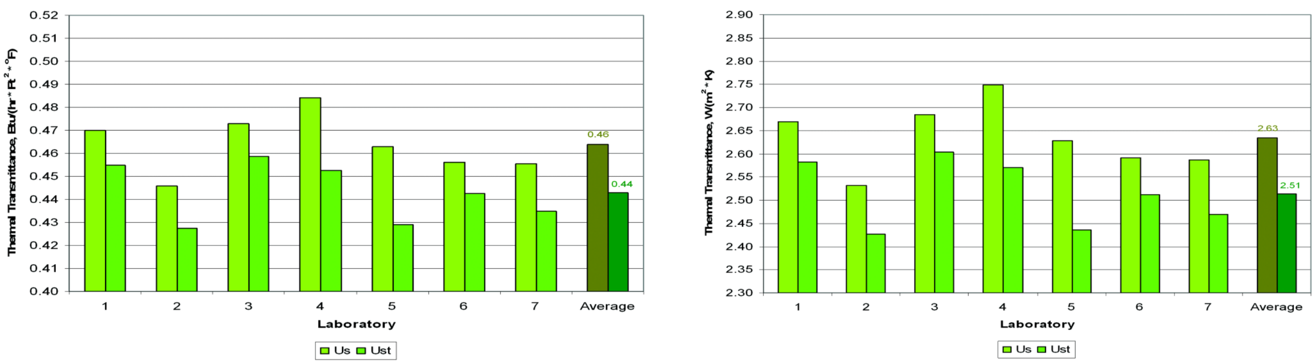

Figure 9 *NFRC 2004 test round robin recalculated results: I-P (left) and SI (right).*

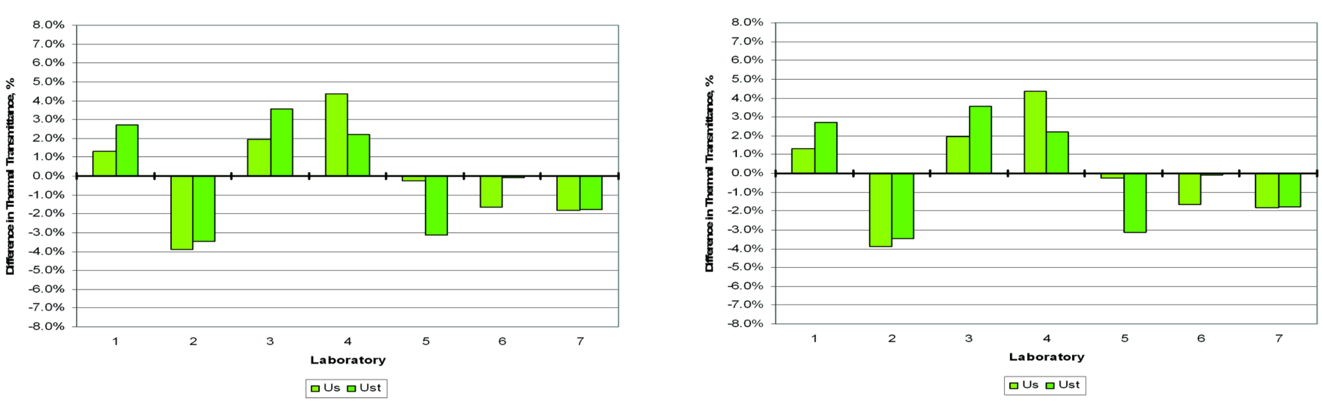

Figure 10 *NFRC 2004 test ILC recalculated results: I-P (left) and SI (right).*

of 0.43 Btu/(hr • Ft^2 • ºF) (2.44 W/(m^2 • K)). If the results are generated using the cold side surface heat transfer coefficient of 4.99 Btu/(hr • Ft^2 • ºF) (28.3 W/(m^2 • K)) from that laboratory's CTS calibration test report, the standardized thermal transmittance is 0.45 Btu/(hr • Ft^2 • ºF) (2.56 W/(m^2 • K)).

But remember that all of the cold side surface heat transfer coefficients are being recalculated for this recalculation, so this error will not affect the results from this set of recalculations. New Convection Coefficients, K, and cold side surface heat transfer coefficients, h_c, are generated by this recalculation from the raw data from each laboratory's CTS calibration test reports.

All of the recalculated cold side surface heat transfer coefficients, h_c, are within the tolerance specified by NFRC 102. With a tolerance of ± 10%, the permitted range is between 4.75 and 5.81 Btu/(hr • Ft^2 • ºF) (27.0 and 33.0 W/(m^2 • K)). After recalculation, the average cold side surface heat transfer coefficient is 5.29 Btu/(hr • Ft^2 • ºF) (30.0 W/(m^2 • K)) with a minimum of 4.80 Btu/(hr • Ft^2 • ºF) (27.3 W/(m^2 • K)), and a maximum of 5.71 Btu/(hr • Ft^2 • ºF) (32.4 W/(m^2 • K)). All but two of the coefficients changed upon recalculation, and except for the improperly reported value discussed in the previous paragraphs, the changes in the recalculated cold side surface heat transfer coefficients are minor.

Standardized Thermal Transmittance (CTS Method). Table 8, contain statistical reviews of the recalculated thermal transmittance results and Figures 11 and 12 show bar charts presenting the results and differences between results. Once again, the reduction in the variability of the calibration test results after recalculation provides hope that the deviations between the standard thermal transmittances using these recalculated CTS coefficients will be reduced. Instead, we find that the disagreements between the standardized thermal transmittances in this recalculation increase with a standard deviation of 0.019 (0.107) compared with the standard deviation of 0.013 (0.073) from the previous recalculation. The standard deviation of the thermal transmittance results from all the laboratories also increased dramatically to 0.021 (0.117).

Upon closer inspection, notice that the standardized thermal transmittances results for three laboratories incurred no change, the standardized thermal transmittances increased 0.01 Btu/(hr • Ft^2 • ºF) (0.06 W/(m^2 • K)) for three laboratories, and one laboratory incurred a significant increase of 0.05 Btu/(hr • Ft^2 • ºF) (0.28 W/(m^2 • K)). Low and behold, the laboratory with the corrected test specimen area now reports significantly higher thermal transmittance results of 0.509 Btu/(hr • Ft^2 • ºF) (2.89 W/(m^2 • K)), and significantly higher standardized thermal transmittance results of 0.485 Btu/(hr • Ft^2 • ºF) (2.75 W/(m^2 • K)). Even with the recalculated reduction in the Net Specimen Heat Flow from 535.39 to 530.87 Btu/hr (156.91 to 155.58 W), the decrease in the projected surface area from 16.76 to 14.89 Ft^2 (1.56 to 1.38 m^2) generates a new thermal transmittance of 0.509 Btu/(hr • Ft^2 • ºF) (2.89 W/(m^2 • K)), which is teetering on the line of being an outlier at 95% confidence limits (e.g., maximum limit at two standard deviations is 0.5128 Btu/(hr • Ft^2 • ºF)) (2.912 W/(m^2 • K)).

This warrants a review of the recalculated results from all of the laboratories without the one in question. The statistical analysis data is recalculated using the thermal transmittance results from only six laboratories, omitting the results from the laboratory reporting the highest net specimen heat loss. Mercifully, the standard deviation of 0.013 (0.075) between the standardized thermal transmittances from the six laboratories is much less, with an average standardized thermal transmittance of 0.45 Btu/(hr • Ft^2 • ºF) (2.53 W/(m^2 • K)) that ranges from 0.427 to 0.465 Btu/(hr • Ft^2 • ºF) (2.42 to 2.64 W/(m^2 • K)). Although this represents a slightly greater deviation than previously recalculated, it is difficult to make conclusions as to the affect of recalculating each laboratory's CTS test results on recalculating the standardized thermal transmittance. This is partly due to the round-off errors associated with recalculation that were previously discussed. In addition, the discrepancies between the cold side surface heat transfer coefficients used for the round robin, and those reported on three separate CTS test results, could indicate that the wrong CTS raw data was used for the authors' recalculations.

CONCLUSIONS

Although ASTM E 691 provides guidance on how to conduct this ILC, it is ASTM E 177 that specifies methods of expressing precision and bias in this report. The NFRC ILC intends to determine the reproducibility of the test method, as the repeatability cannot be determined without performing much more testing. Given the specifications and tolerances in NFRC 102, ASTM C 1199, ASTM E 1423 and ASTM C 1363, and given the environmental conditions stipulated in NFRC 102, the test method can be assumed to be in a state of statistical control, and therefore variations in measurements are the result of chance causes. Since the actual thermal transmittance of the skylight used as a test specimen in this ILC is not known, the bias cannot be established.

With an average of 0.46 Btu/(hr • Ft^2 • ºF) (2.63 W/(m^2 • K)), the 95% reproducibility limit (between laboratories) for thermal transmittance, U_S, is 0.031 Btu/(hr • Ft^2 • ºF) (0.177 W/(m^2 • K)), or 6.73% of the measurement. The reproducibility limit for the standardized thermal transmittance, U_{ST}, is much higher at 0.062 Btu/(hr • Ft^2 • ºF) (0.354 W/(m^2 • K)), which is 14.35% of the average value of 0.43 Btu/(hr • Ft^2 • ºF) (2.47 W/(m^2 • K)). The variance of the thermal transmittance reported for the 2004 NFRC ILC is similar to the standard deviations reported from previous NFRC Round Robins, whereas the discrepancy reported between the standardized thermal transmittance results are the worst experienced in recent years.

Upon recalculation of the raw data submitted by the laboratories, the reproducibility limit for the standardized thermal transmittance is reduced to 0.036 Btu/(hr • Ft^2 • ºF) (0.203 W/

Table 8a. Corrected and Recalculated Thermal Transmittance Test Results (I-P)

	Laboratory							Statistical Data					
	1	2	3	4	5	6	7	Avg	Min	Max	Standard Deviation	*R*, 95%	*R*, 95%/Ave
Air-to-Air (U_s), Btu/(h·ft^2·°F)	0.470	0.446	0.473	0.484	0.463	0.509	0.456	0.472	0.446	0.509	0.021	0.058	12.28%
Difference from Average, %	–0.3	–5.4	0.3	2.7	–1.8	8.0	–3.4	0.0	–5.4	8.0	4.4		
Standardized (U_{st}), Btu/(h·ft^2·°F)	0.448	0.427	0.455	0.465	0.443	0.485	0.439	0.452	0.427	0.485	0.019	0.053	11.71%
Difference from Average, %	–0.9	–5.5	0.7	2.8	–1.9	7.4	–2.8	0.0	–5.5	7.4	4.2		

Table 8b. Corrected and Recalculated Thermal Transmittance Test Results (SI)

	Laboratory							Statistical Data					
	1	2	3	4	5	6	7	Avg	Min	Max	Standard Deviation	*R*, 95%	*R*, 95%/Ave
Air-to-Air (U_s), W/(m^2·K)	2.67	2.53	2.69	2.75	2.63	2.89	2.59	2.68	2.53	2.89	0.117	0.329	12.28%
Difference from Average, %	–0.3	–5.4	0.3	2.7	–1.8	8.0	–3.4	0.0	–5.4	8.0	4.4		
Standardized (U_{st}), W/(m^2·K)	2.54	2.42	2.58	2.64	2.52	2.75	2.49	2.57	2.42	2.75	0.107	0.300	11.71%
Difference from Average, %	–0.9	–5.5	0.7	2.8	–1.9	7.4	–2.8	0.0	–5.5	7.4	4.2		

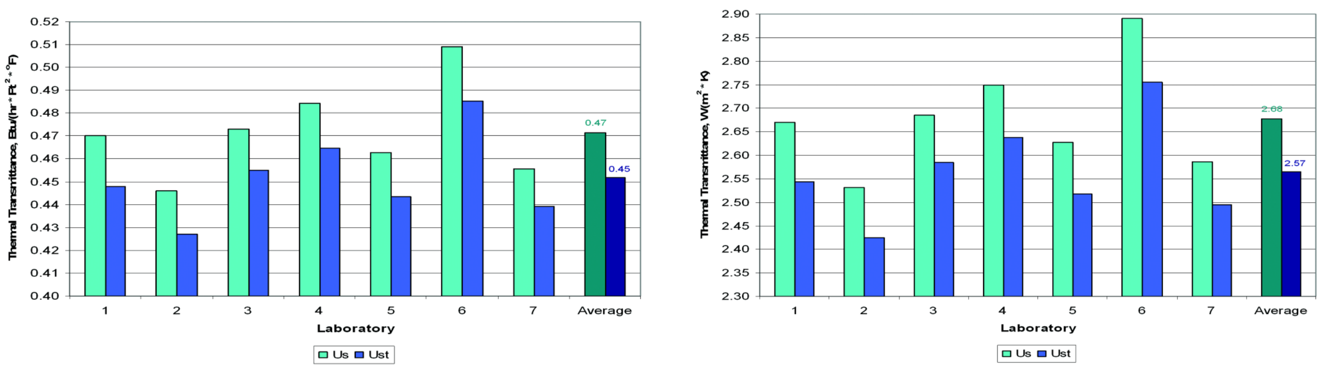

Figure 11 NFRC 2004 test round robin recalculated (CTS) results: I-P (left) and SI (right).

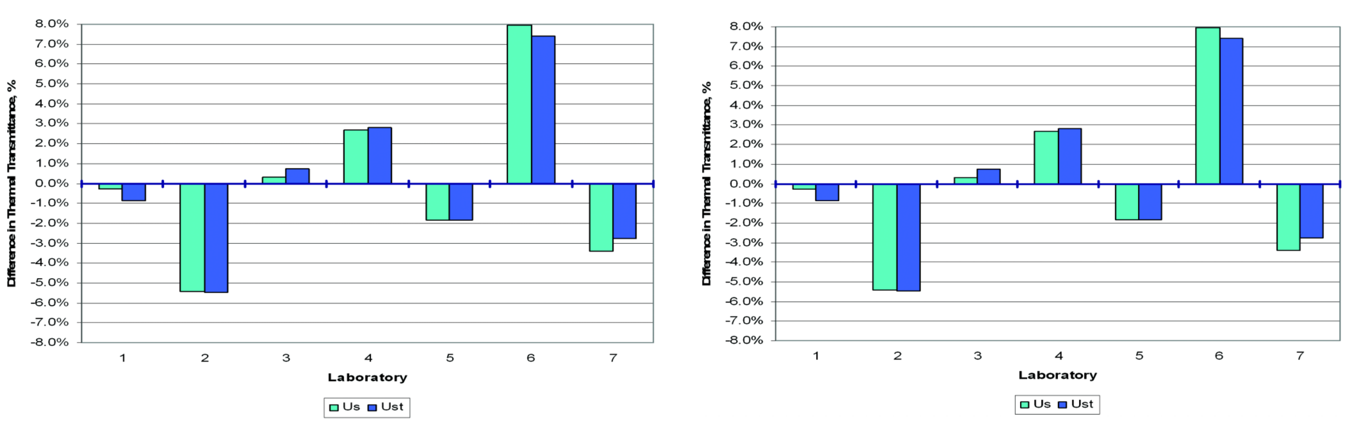

Figure 12 NFRC 2004 test ILC recalculated (CTS) results: I-P (left) and SI (right).

($m^2 \cdot K$)), which is 8.09% of the average recalculated standardized thermal transmittance of 0.44 Btu/(hr • Ft^2 • ºF) (2.51 W/($m^2 \cdot K$)). This reduction in variance suggests that variation in the calculation methodology used by each laboratory to determine standardized thermal transmittance strongly affects the variability of NFRC 102 results. In defense of the test laboratories, the test methods have experienced significant revisions on at least two occasions in the last five years, and commercial test laboratory operators have to implement these revisions in such a way that they do not seriously jeopardize their previously established test, calibration, and inspection schedules. In addition, the test methods may not provide adequate descriptions of the equations or calculation methodology, which would warrant a review of the appropriate test method in context with the issues identified in this report. Of all the items inspected by an accreditation inspection agency, the calculation methodology used by each laboratory is one of the easiest to verify. Although time consuming, the NFRC Inspectors have the opportunity to accurately verify the calculation methodologies used by each laboratory to perform different measurements from the calibration tests used to characterize the instrumentation and thermal chamber to the tests of actual fenestration products. Considering the variability of the standardized thermal transmittance results generated by this ILC, this should continue to be a priority of future inspections performed in accordance with the NFRC LAP.

Recalculation of each laboratory's CTS calibration results generated different surface heat transfer coefficients for most of the laboratories. Although these new coefficients were used to recalculate the standardized thermal transmittance results, any variability in those surface heat transfer coefficients did not appear to significantly affect the final results from all of the laboratories. This issue is compounded by uncertainties with the relevance of CTS Calibration Test reports submitted sometime after the round robin was conducted, and therefore these reports should be requested in the initial instructions to the laboratories.

The process of recalculating the standardized thermal transmittance for each laboratory helped identity a potential outlier. The results from this laboratory were not conspicuous during the initial review of this round robin as their reported thermal transmittance and standardized thermal transmittance results were so close to the average values from all of the laboratories. Once it was uncovered that this laboratory incorrectly determined the projected area of the test specimen, the recalculated thermal transmittance and standardized thermal transmittance values were significantly higher than initially reported. Upon closer inspection, the high thermal transmittance values generated by recalculation were attributed to the fact that this laboratory reported the highest net specimen heat loss.

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