INSULATION MATERIALS

Testing and Applications

3rd Volume

Ronald S. Graves
Robert R. Zarr
Editors

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Insulation Materials: Testing and Applications, Third Volume

Ronald S. Graves and Robert R. Zarr, editors

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Foreword

This publication, *Insulation Materials: Testing and Applications, Third Volume,* contains papers presented at The Third Symposium on Insulation Materials: Testing and Applications, held in Quebec City, Quebec, Canada on 15-17 May 1997. The sponsor of the event was ASTM Committee C-16 on Thermal Insulation.

The symposium co-chairmen were Ronald S. Graves, R & D Services, Inc., Lenoir City, TN, and Robert R. Zarr, NIST, Gaitherburg, MD. They also served as editors of this publication.

Overview

After several decades of development, the testing and applications of thermal insulation materials may be considered, by some, a mature technology. Yet, new insulation materials, systems, and test methods for the measurement of thermal properties continue to emerge and evolve. In advancing the state of the art, ASTM Committee C-16 on Thermal Insulation has periodically published the latest up-to-date information on thermal insulation materials, systems, and measurement technology based on symposia sponsored by the committee. This Special Technical Publication continues this tradition of communicating state-of-the-art technology to those engaged in this field of endeavor.

In many ways, developments in the thermal insulation community reflect society's technological interests and needs. For example, during the 1960s the insulation community turned its attention to the space program. Later, in the 1970s and the 1980s, public awareness of rising energy costs focused attention on effective energy conservation programs using thermal insulation. More recently, the community has been involved with mitigation of the effects that the production and consumption of energy have on the environment. This publication presents the thermal insulation community with the latest information on developments in residential, commercial, and industrial applications.

Currently, there are several areas of interest and the papers in this volume have been organized in six categories. These categories are fenestration testing, system testing, materials testing and properties, models and materials, test methods, and performance. The papers and presentations for this publication were truly international in scope, with participation from 13 countries: Austria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Israel, Italy, Sweden, the United Kingdom, the United States, and the West Indies.

The editors of this Special Technical Publication gratefully acknowledge the contributions of the authors, technical reviewers, steering committee, and session chairpersons. The steering committee, session chairpersons, and technical reviewers are identified on the following page.

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William C. duPont[1]

COMPARISON OF METHODS TO STANDARDIZE ASTM C 1199 THERMAL TRANSMITTANCE RESULTS.

REFERENCE: duPont, William C., "**Comparison of Methods to Standardize ASTM C 1199 Thermal Transmittance Results,**" Insulation Materials: Testing and Applications: Third Volume, ASTM STP 1320, R.S. Graves and R.R. Zarr, Eds., American Society for Testing and Materials, 1997.

ABSTRACT: ASTM C 1199-91 requires that the measured air-to-air U-factor, U_S, is standardized to the U-factor that the test specimen would have if it was tested with standardized surface conductance coefficients on both sides. This produces the standardized thermal transmittance, U_{ST}, which is typically a smaller value than the thermal transmittance (the air-to-air U-factor), U_S. ASTM C 1199-91 currently allows for two methods of determining standardized thermal transmittance, and this paper proposes a variation of one of those methods. In addition this paper compares the results from all three methods of standardization using actual test results from five NFRC accredited testing laboratories. By standardizing the measured thermal transmittance, the results from different laboratories that may have different wind machines and thermal chamber configurations can be directly compared. In addition, the test results can be directly compared with computer simulation results that have also been determined using standardized surface heat transfer coefficients. This latter point is critical to the National Fenestration Rating Council's certified product validation program. This paper recommends that the proposed method of determining the standardized thermal transmittance replace one of the existing methods, and that there be a criteria established that clearly identifies which of the two methods of calculating the standardized thermal transmittance is to be used when testing different fenestration products.

KEYWORDS: thermal transmittance measurements, fenestration U-factor testing, laboratory hot box, surface heat transfer coefficients, standardized surface heat transfer coefficients, surface temperature measurements.

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INTRODUCTION:

Before the development of ASTM Standard Test Method for Measuring the Steady State Thermal Transmittance of Fenestration Systems Using Hot Box Methods (C 1199) in 1990, the thermal transmittance (U-value or U-factor) of fenestration products in North America was typically measured using the procedures outlined in ASTM Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box (C 236: Annex A1), ASTM Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box (C 976: Annex A2) or AAMA Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections (1503.1-88). All three of these procedures require that the "air-to-air" thermal transmittance (U-factor) be reported. Although ASTM C 236 and ASTM C 976 were originally developed with the intent of testing test flat, homogeneous wall sections, this "air-to-air" U-factor, U_S, has been used for years to rate the thermal performance of fenestration products that are not flat or homogeneous. The thermal transmittance is described by the following simple equation [1, 2]:

$$U_S = \frac{Q_S}{A_S \cdot (t_I - t_{II})} \tag{1}$$

where:

	U_S	=	thermal transmittance, W/(m^2 · K)
	Q_S	=	heat flow through the test specimen, W
	A_S	=	the projected area of the test specimen (the area of the aperture in the surround panel), m^2
	t_I	=	warm side air temperature, K
	t_{II}	=	cold side air temperature, K.

This thermal transmittance is considered to be a primary measurement because all the variables on the right side of the equation can be directly measured by the test laboratory, and the uncertainty of each measurement can be determined. Basically, the measured heat flow through the test specimen is divided by the product of the area of the test specimen times the air temperature difference on both sides of the test specimen.

The development of ASTM C 1199 not only introduced the necessary modifications and extra calibrations associated with testing fenestration products smaller than the metering area of a typical ASTM C 236 thermal chamber, but it also presented two methods of standardizing the warm side and cold side surface conductance (heat transfer) coefficients on each side of the test specimen to produce a new final result called the standardized thermal transmittance, U_{ST}. This standardized thermal transmittance is represented by the following equation in ASTM C 1199-91 [3].

$$U_{ST} = \frac{1}{\frac{1}{h_{STI}} + \frac{1}{C_S} + \frac{1}{h_{STII}}} \quad \mathbf{(2)}$$

where:

U_{ST} = standardized thermal transmittance, $W/(m^2 \cdot K)$

h_{STI} = warm side standardized surface heat transfer coefficient, $W/(m^2 \cdot K)$

C_S = thermal conductance of the test specimen (surface-to-surface), $W/(m^2 \cdot K)$

h_{STII} = cold side standardized surface heat transfer coefficient, $W/(m^2 \cdot K)$.

Although the standardized thermal transmittance is not considered to be a primary measurement due to the uncertainties in measuring the surface heat transfer coefficients, h_I and h_{II}, and the "surface-to-surface" conductance, C_S, it provides many advantages over not standardizing the results.

The primary benefit is that results from different laboratories, with significantly different air flow delivery systems, and thermal chamber configurations can be directly compared with confidence. Results from the 1994 NFRC Test Laboratory Accreditation Program[(2)] round robin [4] on identical test specimens show that there is greater agreement between the standardized thermal transmittance, U_{ST}, as compared to the thermal transmittance, U_S. Two of the laboratories in that round robin had cold side air flow delivery systems that delivered the air parallel to the plane of the test specimen, and the remainder of the laboratories had cold side air flow systems that directed the air directly at the test specimen normal to its plane of installation. This method of blowing the cold side air perpendicular to the test specimen seems to be unique to North America because the International fenestration thermal transmittance test procedures [5] only reference parallel air flow on the cold side. The large number of perpendicular cold side air flow thermal chambers in the United States and Canada is historically due to the AAMA 1503 test procedure which requires perpendicular air flow on the cold side of the test specimen.

Another advantage of standardizing the surface heat transfer coefficients on each side of the test specimen is that the test results can be directly compared with computer simulation results that use the same standardized surface heat transfer coefficients. This capability has been a cornerstone to the success of the NFRC Procedure for Determining Fenestration Product Thermal Properties (100-91) U-factor rating system because it allows manufacturers to inexpensively derive accurate U-factor ratings for a vast variety

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2 References to the NFRC accredited test and simulation laboratories and the procedures that those laboratories use are frequently relied on throughout this paper because the NFRC is the most active user of ASTM C 1199.

of different product configurations with computer modeling, and directly verify those computer generated results with a relatively small number of thermal tests. Currently, NFRC 100-91 [6] specifies that the U-factor of a fenestration product can be determined by the WINDOW 4.1 [7] and FRAME 4.0 [8] computer programs for certified rating purposes, and tests from ASTM C 1199 are used to validate those results(3).

One disadvantage of the standardization process, as it is currently described in ASTM C 1199, is that it allows two methods of calculating the standardized thermal transmittance, and the test laboratory is permitted to choose which result they want to report. Although each of these two methods have advantages and disadvantages that will be discussed later in this report, the fact that the test laboratory has the opportunity to choose which result they want to report is problematic. Currently there is no criteria in ASTM C 1199 to guide laboratories in making that decision.

DESCRIPTION OF STANDARDIZATION METHODS

ASTM C 1199 currently allows for the following two methods of determining the standardized thermal transmittance, and the third method presented has been proposed as a modification to the first method. This modified method has been used by NFRC accredited testing laboratories since June, 1993.

Projected Area Weighting Method

One of these methods, which is often called the "area weighting method," (Section 7.1.7 and 7.1.8 of ASTM C 1199) relies on measuring 20 surface temperatures on each side of the test specimen with temperature sensors (such as thermocouples), and using those surface temperatures to determine the surface heat transfer coefficients on both sides of the test specimen during the test using the following equations:

$$h_I = \frac{Q_S}{A_S \cdot (t_I - t_1)} \quad (3)$$

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3 NFRC has its own version of ASTM C 1199 called NFRC 100-91 Attachment A: Interim Standard Test Method for Measuring the Steady-State Thermal Transmittance of Fenestration Systems Using Hot Box Methods. NFRC 100-91 Attachment A was published before ASTM C 1199. Although the NFRC Technical Committee voted to replace NFRC 100-91 Attachment A with ASTM C 1199 in January, 1992 (Anaheim, CA), the fact that Draft 10 of ASTM C 1199 was published instead of Draft 11 caused NFRC accredited test laboratories to continue to use NFRC 100-91 Attachment A. Also see footnote (5).

where: h_I = warm side surface heat transfer coefficient, W/(m²· K)
t_I = warm side test specimen surface temperature, K

and,

$$h_{II} = \frac{Q_S}{A_S \cdot (t_2 - t_{II})} \qquad (4)$$

where: h_{II} = cold side surface heat transfer coefficient, W/(m²· K)
t_{II} = cold side air temperature, K

The calculated warm and cold side surface heat transfer coefficients are used to determine the test specimen thermal conductance, C_S, using the following equation:

$$C_S = \frac{1}{\frac{1}{U_S} - \frac{1}{h_I} - \frac{1}{h_{II}}} \qquad (5)$$

The thermal transmittance of the test specimen is determined from Equation 1, and the surface heat transfer coefficients are determined from Equations 3 and 4. The thermal conductance of the test specimen calculated using Equation 5 is then combined with the standardized surface heat transfer coefficients to determine the standardized thermal transmittance using Equation 2. The cold side standardized surface heat transfer coefficient is considered to be a constant, 28.98 W/m² · K[4]. The warm side standardized surface heat transfer coefficient is also considered to be a constant, 8.3 W/m² · K[5], in ASTM C 1199-91, but is calculated using Equation 37 of NFRC 100-91 Attachment A [9] by the NFRC accredited test laboratories, by the computer program WINDOW 4.1, and in the analysis performed in this paper.

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4 Actually, ASTM C 1199-91 (and ASTM E 1423-91) lists the cold side standardized surface heat transfer coefficient as "30.0 W/(m² · K) (5.1 Btu/(h · ft² · °F))". If one converts 5.1 Btu/(h · ft² · °F) into metric units the result is 28.89 W/(m² · K). The results in this paper were calculated using a cold side standardized surface heat transfer coefficient of 28.89 W/(m² · K) because that is the value that the NFRC accredited test laboratories and the computer programs WINDOW 4.1 and FRAME 3.1 were using.

5 The differences between ASTM C 1199-91 and NFRC 100-91: Attachment A can be summarized by the differences between Draft 10 and Draft 11 of the original submission for ASTM C 1199. Somehow Draft 10 of ASTM C 1199 was printed as the final document, when Draft 11 was considered to be the final draft. NFRC printed Draft 11 as NFRC 100-91 Attachment A, which has been used since by the NFRC accredited test laboratories.

Calibration Transfer Standard Method

The other method of standardizing the thermal transmittance which is called the "CTS method," relies on first measuring the surface temperatures on both sides of a unique Calibration Transfer Standard(CTS) [10] in one set of tests, and using those temperatures to calculate the heat transfer coefficients (Section 5.2 of ASTM C 1199) on the CTS. The test on the actual test specimen is performed in a separate test using the same thermal chamber without changing the wind velocities, wind directions, and thermal chamber configuration. The test specimen surface temperatures are then calculated by iteratively solving the heat balance equation assuming that the heat transfer coefficients on each side of the test specimen are the same as was measured on the CTS, but based on the measured heat flow, Q_s , through the test specimen. The CTS method does not require that the surface temperatures of the test specimen be measured (no need for surface temperature thermocouples) because the "equivalent" surface temperature is calculated using this method.

Actually, on the cold side, the combined radiative and convective surface heat transfer coefficient from the CTS, h_{II}, is used to determine the "equivalent" cold side surface temperature of the test specimen, whereas on the warm side, only a convective surface heat transfer coefficient, K, is used. For this purpose, the cold side surface heat transfer coefficient can be expressed in an equation much like Equation 4, but separating the radiative and convective components[6]:

$$h_{II} = \frac{(q_{r2} + q_{c2})}{(t_{II} - t_2)} \qquad \textbf{(6)}$$

where: q_{r2} = net radiative heat flux from the cold side, W/m^2

q_{c2} = net convective heat flux from the cold side, W/m^2

6 Measuring the average surface temperature of the baffle next to the cold side of the test specimen in a parallel air flow cold chamber is not too difficult of a task, but in a perpendicular air flow cold chamber, such as those used by most of the NFRC accredited test laboratories, this measurement is much more problematic. In a perpendicular air flow cold chamber the test specimen usually faces the fan, the fan exit plenum, and the air flow deflection louvers or screens placed in the exit plenum. Measuring the surface temperatures and view factors of all those surfaces (including the spinning fan blades and fan motor) is not practical for most commercial laboratories, and is therefore not always performed by the perpendicular air flow laboratories that participated in this study. Instead, most of them used Equation 4 to determine the cold side surface heat transfer coefficient, h_{II}, on the CTS.