ces calculs que la mesure de l'énergie sur l'eau
présente plusieurs particularités :
u type de compteur d'énergie est importante si l'on
s extrêmes (mauvais choix du matériel),
nérale, les erreurs commises restent inférieures à 5%
peuvent varier sensiblement suivant l'emplacement des
, le temps de réponse à la montée en température des sondes
sure "chaude", les caractéristiques dynamiques du compteur
testé et bien sûr suivant le profil de soutirage réel.

5. Conclusion générale

tir de ces essais et des simulations complémentaires que nous
menées, nous avons la possibilité d'établir un certain nombre
gles d'utilisation de ces appareils en régime transitoire.
s amples précisions sont disponibles en /4/.
vient de prendre garde à l'utilisation de ces appareils pour
trôle des installations à forte dynamique.

l'erreur due à l'inertie des sondes ou à la réponse du
eur d'eau est-elle prépondérante pour la mesure de la
mmation en eau chaude sanitaire. De même dans les applications
s déphasage et à dynamique moyenne (capteur solaire,
ière) l'emplacement des sondes ainsi que la symétrie de leur
se peut être plus importante que leur inertie propre. Dans
les cas le bon calibrage du débitmètre est également un
r important, ceux-ci ayant généralement de très mauvaises
rmances en régime dynamique en deça de 10% de la pleine
le.

Remerciements

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ies qui ont bien voulu collaborer à ces travaux.

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#6679

FIELD MEASUREMENT OF HEAT FLOW THROUGH WINDOWS

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1. Introduction

Estimation of the performance of such fenestration products as windows, glass patio doors, and skylights, particularly as they affect energy use in buildings, commonly involves the calculation of the rate of heat transfer using heat transfer data such as thermal transmittance (U-value). Manufacturers have usually tested their products in the laboratory at standard winter design conditions by one of the following hot box techniques: the AAMA test method (1), the ASTM C236 Guarded Hot Box method (2), or the ASTM C976 Calibrated Hot Box method (3). The differences and the similarities between each of these test methods have been described by Goss (4).

Laboratory test results have shown the thermal performance of windows to have greater sensitivity to climatic variables such as air temperature and wind velocity then anticipated (5). Therefore, window manufacturers' performance data based on testing done at winter design conditions may not be directly applicable for estimating energy performance over a heating and/or cooling season. These concerns suggest that an alternative method for evaluating thermal performance of competing window designs is by long-term, side-by-side testing in the field, with controlled interior temperatures.

In measuring the thermal performance of alternative fenestration products in the field, it is important that each product be tested under identical conditions, due to the sensitivity of the performance to prevalent climatic conditions. For windows, this implies side-by-side testing of the same size windows located on the same building wall at the same elevation and exposed to the same environments of solar and long-wave radiation, temperature, and wind. Another consideration in comparative field testing of windows is the measurement of air leakage, since it is desired to determine the performance difference between different glazing units, independent of air leakage effects.

2. Description of test specimens and test apparatus

The upper and lower sash and glazing units of the existing north-facing double-hung windows in a National Bureau of Standards (NBS) test building were replaced with new sash and glazing units, which were similar in construction to the original units, except that one of the windows, was manufactured with a low-emittance coating and the other window was uncoated. The insulating glass units were filled with dry air and were constructed of clear sealed glass, 3 mm thick with an 11 mm air space. The clear low-emittance coating was applied by the glass manufacturer to the outward facing surface of the inner pane of glass using a vacuum deposition technique. The nominal window dimensions, based on the interior opening, were 914 mm wide by 1150 mm high, with each glazing unit having a transparent area 825 mm wide by 508 mm high, giving a glass fraction of 80.0%.

The window manufacturer provided copies of laboratory test reports for both the low-E window and the control window, which were from the same product line as those tested by NBS, with, however, slightly larger dimensions. The laboratory testing had been performed using the ASTM C236 method with essentially zero air velocity on either side, 20°C inside air and -8°C outside air temperatures, and the measured U-values were 1.76 $W/m^2 \cdot K$ and 2.33 $W/m^2 \cdot K$, respectively, for the low-E and control windows.

Portable calorimeters were constructed for measuring the thermal performance of each window. The calorimeter is a five-sided insulated metering box with an open side that is sealed against the interior side of the building element under test. Figure 1 shows the calorimeter installation in the window opening.

Type-T thermocouples fitted with radiation shields were used to measure calorimeter air and outdoor air temperature. One calorimeter, designated Calorimeter A, was fitted with minimal instrumentation consisting of a single shielded interior thermocouple located in the air space approximately 51 mm in from the window glazing surface on the center line at about mid-height. The second calorimeter, designated Calorimeter B, was fitted with additional sensors in order to provide data to assist in interpretation of the test results. Figure 2 schematically shows the instrumentation installed for Calorimeter B, which for most of the test period was used for measuring the low-E window. Sensors were also installed to measure outdoor air velocity, solar irradiance, and infrared irradiance at approximately mid-height using a hot wire anemometer, a pyranometer, and a pyrgeometer, respectively. The velocity sensor was located approximately 50 mm from the outer sash of the center of the window and the radiation sensors were mounted flush to the wall adjacent to the window.

Air-leakage measurements were made using Calorimeter B and the test apparatus described elsewhere (6), which conformed to the ASTM E783-84 method for field measurement of air leakage through windows and doors.

3. Test results

Evaluation of the calorimetric test results will focus on two objectives. First is determining the comparative thermal performance of the two windows under essentially identical ambient conditions. The second objective is an assessment of the use of portable calorimeters for field measuring nighttime U-values of windows. The additional sensors installed with Calorimeter B permit computation of an overall energy balance on the calorimeter/window system and provide some insight into the heat transfer mechanisms that occur within the calorimeter and at the outside of the window.

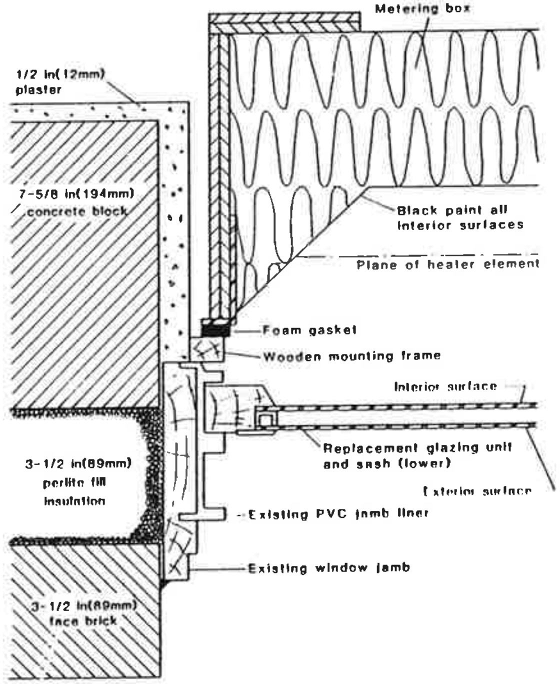

Figure 1. Calorimeter installation in test window aperture.

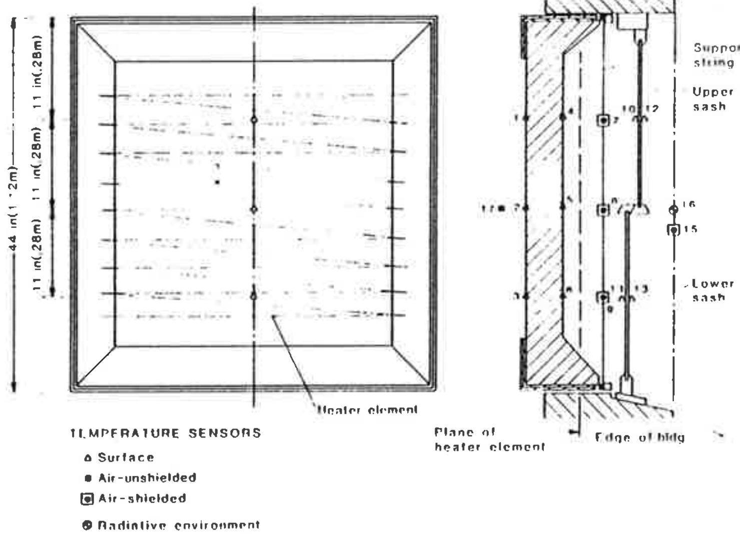

Figure 2. Sensor locations in Calorimeter B.

3.1 Comparative performance of windows:

The underlying assumptions for the calorimetric test method are that the energy input to the metering box is transferred through the window, and, therefore, the measured nighttime values of heater energy and temperature difference between calorimeter air and outside air are sufficient to measure thermal performance differences between alternative glazing systems. The selected time interval for each data point is one hour and is comprised of cumulative heater energy and average air-to-air temperature differences derived from data scans taken every 60 seconds.

Figure 3 shows the comparative performance between the low emittance window and the uncoated window. A linear relationship between the measured heater power per unit of window area and the air-to-air temperature difference is determined by a least-squares fit of the data, assuming:

$$Q_{HTR}/A = B + U(T_{CAL} - T_{AMB}) \qquad (1)$$

where
A = window inside area
B = intercept
U = slope (U-value)
T_{CAL} = calorimeter air temperature
T_{AMB} = ambient air temperature.

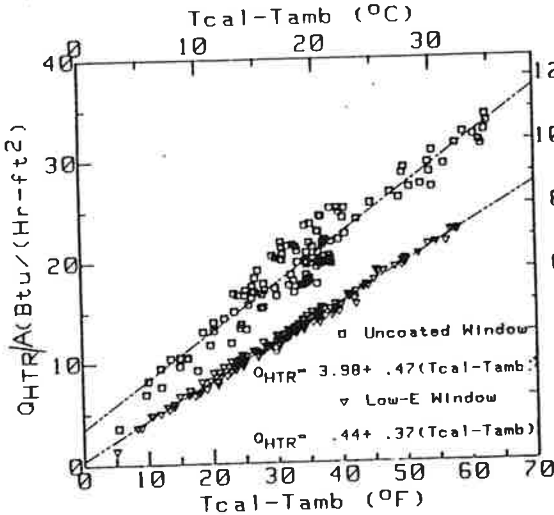

Figure 3. Measured electrical power vs. air-to-air temperature difference for low-E window and uncoated window.

Table 1 shows the results from the least squares data fits for both windows, including the mean values for the intercept, B, the mean values and standard deviations for the slope, U, and the correlation coefficients. The measured U-values (slopes) of the NBS test results are also compared with the previously described laboratory test results.

Examination of these data shows an excellant correlation for the low-E window and a very good correlation for the uncoated window for the linear data fit of Equation 1, based on the standard deviations for the slope (U-value) and the correlation coefficients. Comparison with the laboratory test results for both windows shows the average U-values from the field test data to be 13% to 16% greater than the laboratory U-values.

3.2 Calorimeter/window energy balance:

The additional sensors provided with Calorimeter B permit more detailed evaluation of the system energy balance than possible with Calorimeter A. Four potential sources of error in the use of the portable calorimeter for measuring the absolute U-value of field-installed windows were considered: metering box heat conduction to the room, metering box leakage from the outside air, interior air temperature gradients, and exterior surface radiative heat transfer. The first two sources of error test the assumption that all the electrical energy dissipated in the metering box is transferred through the test window. The last two sources of error test the assumption that the effective temperature difference for heat transfer is given by the difference between the single indoor and outdoor air temperatures. It was concluded (6), that only the last potential error source was significant for the particular application and test period.

3.2.1 Error due to radiation effects:

A potential source of error occurs when ambient air temperature is used to compute U-value because of radiative heat transfer between the exterior surfaces of the window and the outdoor surfaces and sky, whenever their temperatures are different from the air temperature. Consider the nighttime energy balance at the exterior surface of the window given by:

$$Q_{HTR}/A = h_c(T_G - T_{AMB}) + \epsilon_g \sigma (T_G^4 - T_{RAD}^4) \qquad (2)$$

where
Q_{HTR}/A = window heat loss rate, per unit area, (W/m^2)
T_G = absolute window average surface temperature, (K)
T_{AMB} = absolute air temperature, (K)
T_{RAD} = effective blackbody temperature of outdoor radiant sources, (K)
h_c = surface convection coefficient, ($W/m^2 K$),
ϵ_g = surface emittance = 0.84
σ = Stefan-Boltzmann constant = 5.6697×10^{-8} $W/m^2 K^4$

It is desired to account for radiative effects by relating the measured rate of heat loss to an effective air temperature, T_{EFF}, based on the convective heat transfer coefficient, h_c as:

$$Q_{HTR}/A = h_c(T_G - T_{EFF}) \tag{3}$$

Combining Equations 2 and 3 gives:

$$T_{EFF} = T_{AMB} - \frac{\epsilon_g \sigma}{h_c}(T_G^4 - T_{RAD}^4) \tag{4}$$

Examination of this equation shows that as the convective
coefficient, h_c, increases due to air motion induced by wind, the
significance of the radiative contribution decreases and the effective
temperature approaches that of the ambient air temperature. For the
climatic conditions experienced during the test period, wind speed was
frequently less than .9 m/s, suggesting that the surface coefficient was
either in the free convection or mixed convection regions; therefore,
published correlations for free convection might not be accurate due to
a significant forced-convection component. The approach taken to obtain
values for h_c needed to evaluate T_{EFF} in Equation 4 was to use the
relationship given in Equation 2 based on long-term measured values of
all the variables to compute an average value for h_c.

Figure 4 shows a plot of nighttime hourly measured heat transfer by
convection (assumed equal to electrical heat dissipation minus radiated
heat) versus $(T_G - T_{AMB})$ for the low-E window. The slope of the least
squares line is 5.72 $w/m^2 \cdot K$. Similar data plotting was performed for
other time periods providing average convective coefficients of 10.53
$W/m^2 \cdot K$ and 5.58 $W/m^2 \cdot K$. Effective temperature, T_{EFF}, calculated in this
manner was used in place of ambient air temperature, T_{AMB}, in Equation 1
to provide revised least squares data fits with the results shown in
Table 2 for the low-E window.

Examination of these results shows the very significant effect that
the radiative heat loss has on determining U-values under the prevailing
environmental conditions during the testing period. In fact, the U-
value of 1.65 $w/m^2 \cdot K$, based on the field test with revised values of
inside and ambient temperature, is seen to correlate with the laboratory
measured U-value of 1.76 $w/m^2 \cdot K$ in which the radiative environment in
the hot box is presumed to be much closer in temperature to the ambient
air.

4. Conclusions and Recommendation

The use of portable calorimeters for thermal performance testing of
windows appears to provide a relatively simple method for field testing
of alternative glazing systems. However, it is important that the
instruments used for power and temperature measurements be calibrated
and that air leakage effects are quantified by measuring outside-to-
inside pressure differences. The portable calorimeter was seen to have
potential for absolute measurement of nighttime U-values for windows,
provided the effects of radiative heat exchange with the night sky and
the outdoor surfaces are properly evaluated, since these radiant heat
sources are usually at a lower temperature than the outdoor air. This
is particularly important at times when the air is clear and the wind

velocity is low. An effective outdoor temperature, involving both the convective and radiative components of the exterior surface heat balance, was shown to provide a better correlation between the field and laboratory test results than a correlation based only on outdoor air temperature.

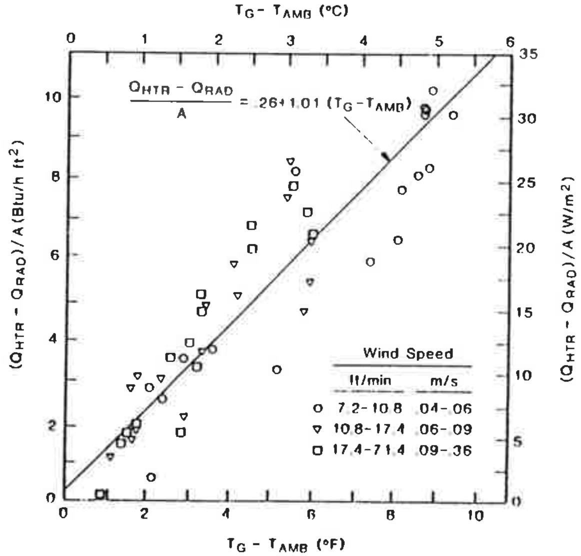

Figure 4. Convective heat loss from low-E window during time period from 3/21/86 to 3/26/86.

The placement of a metering box on the interior of a window results in air temperature stratification and, consequently, an uneven distribution in heat loss from the upper and lower windows. The effect of this stratification and the resulting convective and radiative heat balance on the inside surface of the window was not determined; therefore, additional research is necessary to quantify the significance of the thermal environment produced by the metering box. In addition, it appears that the exterior surface of a window can operate in a mixed-convection regime in which both the free and forced-convection mechanisms are significant. Evaluation of the exterior surface convective heat transfer coefficient under those conditions is important in establishing an effective temperature used in the U-value measurement.

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Table 1

Field Test and Laboratory Test U-Values of Windows

Window Glazing	Field Test Results: Mean Intercept B W/m^2	Mean Slope W/m^2K	Std Dev.	Correlation Coefficient R	Laboratory Test Results: U_{lab} W/m^2K	Percent Difference: $\frac{U-U_{lab}}{U} \times 100$
low-E	1.32	2.10	.017	.995	1.76	16.2
Uncoated	12.55	2.67	.127	.853	2.33	12.8

Table 2

Revised U-Value Estimate for Low-E Window
Based on Effective Air Temperature

No. Sensors for inside air Temperature	Basis for Ambient Temperature	Mean Intercept $W/m^2 \cdot K$	Mean Slope U $W/m^2.K$	Std Deviation	Correlation Coefficient R
1	air	1.32	2.10	0.17	.995
3	air	1.20	2.16	0.17	.995
1	effective	0.35	1.65	0.23	.989
3	effective	0.09	1.65	0.23	.989