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Author
Klems, J.H.

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Joseph H. Klems
Windows and Lighting Program
Center for Building Science
Applied Science Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

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ABSTRACT

U-value measurements made with the MoWiTT field test facility and at a commercial test laboratory for four commercial windows are compared with calculations made with the WINDOW program. Good agreement is found for three of the windows; for the fourth--a double-glazed window with a highly conductive frame--agreement is good between the calculations and the MoWiTT measurements, but agreement with the test laboratory is only marginal. Measurements of overall diurnal performance are presented, and it is shown that, even for a north-facing window, the uncertainties in thermal performance due to solar gain effects overshadow the effects of improved U-value. The author argues the need for better methods of accounting for solar gain effects in window performance comparisons, so that the net benefits of U-value improvements may be correctly assessed.

INTRODUCTION

There has been considerable development in the area of window U-value calculation procedures in recent years. Both in the U.S. and in Europe substantial agreement appears to be emerging that window U-values should be calculable from basic material properties and construction details, and methods for making these calculations have been proposed. However, to the extent that these calculations have so far been empirically tested, the data have been from laboratory tests. It would be desirable to have field data as well, both to check the calculations and to place the level of agreement between calculation and measurement in the context of the overall energy performance of fenestration.

In this paper we present measurements made in Reno, Nevada, using the MoWiTT (Mobile Window Thermal Test) facility during 1987. The MoWiTT, which has been described in detail elsewhere (Klems et al. 1982; Klems 1984), consists of two side-by-side room-sized, guarded calorimeters that measure net heat transfer through two window systems simultaneously exposed in the same orientation to ambient weather conditions. During 1987 earlier measurements on frameless sealed glazings (Klems and Keller 1987a; Klems and Keller 1987b) were extended to include the winter/spring performance of several commercial non-operable windows with frames.

NIGHTTIME U-VALUES

Single Glazing U-Values

During many of the MoWiTT tests, frameless single glazing is simultaneously measured in one of the calorimeters to provide a reference while the glazing of interest is mounted in the other calorimeter. As a result, we have accumulated measurements on frameless single glazing under a variety of conditions. The nighttime U-values derived for some of these measurements are shown in Table 1.

As can be seen from the table, the measured U-value is considerably lower than the 1.13 Btu/h·ft^2·°F expected for the ASHRAE standard condition of a 15 mph wind. This difference is not surprising in view of the fact that the actual wind speeds during the measurement were quite low. Low nighttime winter wind speeds are usual at the Reno test site. It is therefore necessary to pay some attention to the exterior film coefficient in order to interpret our measurements.

It is also true that the exterior radiant temperature frequently differs from that of the air. For the average U-value measurements presented below, this is about a 10% effect, i.e., our measured U-values may be up to 10% higher than the true, air-to-air U-values.

Exterior Film Coefficients

For the calorimeter chamber containing single glazing, we have instrumentation that detects the infrared radiation in a thermal infrared band emitted by a large circular area of the interior side of the window. It has been calibrated to give the true glass temperature of the central portion of the window, and, since there is no frame to induce temperature gradients at the edges, this is also the average glass temperature. From this we can derive the exterior film coefficient. In Figure 1 we plot the measured film coefficient against the measured wind speed at 10 m height on the test site. For comparison, we also plot the curves obtained using the suggested ASHRAE film coefficient algorithms (Lokmanhekim 1975). These are the formulas used by DOE-2, by WINDOW (version 2 or 3) (Arasteh et al. 1986; Rubin, 1982), and in ASHRAE Fundamentals.

Since nighttime wind speeds are typically low, it was necessary to select data to include a stormy night with abnormally high wind speeds. The data represented in the figure were collected from December 16 to 23, 1987. During most of the nights in that period, wind speeds were between 0 and 5 mph (the typical range), but were 10 - 20 mph on December 22 and 5 - 10 mph on December 23. Because the prevailing wind on those nights was from the west and the MoWiTT was facing east, there are no data for appreciable wind speeds in the windward hemisphere. Wind speed and direction were measured at a height of 10 m on the test site.

The data are systematically below the ASHRAE formula prediction--by 19% in the leeward hemisphere and 38% in the windward. The leeward data have a slope consistent with that of the ASHRAE formula. Both leeward and windward data are consistent with the value of 1.28 Btu/h·ft^2·°F at zero wind speed that follows from turbulent natural convection and radiation, using the measured glass, outdoor air, and radiant temperatures. Thus, the measured data present a physically reasonable picture. In contrast, the ASHRAE formulas reduce to different constant values for the two hemispheres when the wind speed becomes negligible, leading to the nonsensical conclusion that one can distinguish between windward and leeward in the absence of wind.

It is true that the experimental data (Ito and Kimura 1972) on which the ASHRAE formulas are based come from a set of conditions very different from the present ones. There, measurements were taken on the third and fourth floors of a building and compared to a weather tower on the roof, whereas here the film coefficient measurements were at about 6 ft above relatively open and flat terrain and referenced to wind measurements at a 10 m height. This difference in conditions might explain a different slope, but not a different intercept: When there is no wind, there is also no basis for a height dependence.

For all of these reasons we use in the following a simple linear form for the external film coefficient:

$$h_o = 1.28 + 0.56\,V_W \qquad \left[\frac{BTU}{hr\,ft^2\,F} \right] , \qquad (1)$$

where the average wind speed V_W is in mph. When this formula is used to correct the ASHRAE U-value for the experimental conditions listed in Table 1 it yields predicted U-values between 0.71 and 0.72 Btu/h·ft^2·°F, in excellent agreement with the measured values in Table 1. Note that none of the nighttime data that we will discuss have high wind speeds in the windward hemisphere, where this formula may not apply.

Glazings with Frames

During the winter and spring of 1987 we studied several types of windows common in residential applications: single glazing, double glazing in a wood frame, and double glazing in aluminum frames with and without a thermal break. Because winter testing time was limited, the double-glazed window with thermally broken aluminum frame was taken as a basis of comparison. Three tests were conducted, each with the comparison window mounted in one calorimeter and one of the remaining three windows mounted in the other, with the MoWitt facing east, west, or south. For completeness, data from a fourth test, with the comparison window facing north, are also included. The average nighttime U-values obtained with the MoWiTT, together with the measurement conditions, are shown in Table 2.

As indicated above, the two measurements in this table for each orientation were taken simultaneously. However, acceptability requirements placed on the data sometimes resulted in a difference in the average conditions for the two measurement results. The most serious of these cases occurred for the south-facing measurement, where an instrumentation problem in calorimeter B (the chamber with the double-glazed window with wood frame) caused some of the coldest nighttime data (which happened to have low wind speed) to be unusable, and for this reason the average wind speeds for the two measurements are quite different. However, if one restricts the data further so that the corresponding measurements are taken over identical time periods (by excluding the data for both calorimeters if those for either are unusable), the measured U-values are unchanged.

Comparison with Laboratory Measurements

Subsequent to the MoWiTT measurements, the U-value and air leakage rate of each window was measured at a commercial test laboratory. The AAMA-1503 procedure (AAMA 1979) was used for the U-value measurement. Since air infiltration was not a subject of this study, non-operable windows were used, and the laboratory air leakage tests confirmed that leakage rates were sufficiently small that heat transfer due to air infiltration was negligible. This conclusion was independently verified with tracer-gas measurements in the calorimenters during the MoWiTT tests. The U-values obtained by the test laboratory are shown in Table 3, together with the MoWiTT measurements.

Since the AAMA-1503 procedure is designed to reproduce the ASHRAE 15 mph wind speed condition on the exterior of the window, one would expect the MoWiTT U-value measurements, with the low wind speeds discussed above, to be systematically lower than the test laboratory measurements. Accordingly, we have also listed a column of adjusted test laboratory results, in which the exterior film coefficient has been corrected for our experimental conditions using Equation 1. In addition, the adjusted values have been corrected for the difference between the outdoor air and radiant temperatures during the MoWiTT tests. Unfortunately, use of the double-glazed window as a comparison standard precluded an accurate direct measurement of the film coefficient during these tests.

Examination of the table shows that for the single-glazed, double-glazed with thermally broken aluminum frame, and double-glazed with wood frame windows, the adjusted values are in excellent agreement with the MoWiTT measurements. For the double-glazed window with aluminum frame without thermal break, the adjusted test lab value and the MoWiTT measurement disagree by 2.2 standard deviations.

In summary, there is excellent agreement between the MoWiTT and the test laboratory measurements for all of the windows except the one with a frame significantly more conductive than the glazing unit.

Comparison with Calculations

We next consider how each set of measurements compares with U-value predictions from material properties, heat transfer theory, and environmental conditions. We use the computer program WINDOW (Arasteh et al. 1986) to make these predictions. This program currently exists in two versions: WINDOW 2.0 implements a calculation that computes the center-of-glazing U-value and uses a simple additive frame correction. WINDOW 3.0 makes a more detailed correction for the edge conductance in sealed-insulating-glass units and also uses somewhat higher numbers for the assumed additive thermal transmittance of the frame. The WINDOW 3.0 calculation has been proposed as the basis for the tables in the next edition of ASHRAE Fundamentals.

The frames of the windows we tested are unlike the WINDOW 3.0 default frames. We have therefore made an approximate calculation of the frame U-values, assuming one-dimensional heat conduction for the wood frames and in the thermal break material and assuming that all contiguous aluminum sections are isothermal. The values obtained are compared with the WINDOW 3.0 default values in Table 4; a substantial difference is obvious. These values were used in place of the default values in all WINDOW 3.0 calculations.

In Table 5 we compare the calculations with the test laboratory measurements. U-values were calculated using ASHRAE standard winter conditions. However, "ASHRAE standard winter conditions" can have two mutually inconsistent meanings: it can either refer to (1) the conditions of a 15 mph external wind with interior and exterior air temperatures of 70°F and 0°F, respectively, or (2) an exterior film coefficient of 6.0 Btu/h·ft^2·°F. Both WINDOW and VISION take the first definition, which corresponds to an exterior film coefficient of 5.07 Btu/h·ft^2·°F, while the AAMA 1503 standard uses the second definition. Accordingly, the WINDOW values listed in Table 5 have been corrected to an exterior film coefficient of 6.0 Btu/h·ft^2·°F. There is reasonable agreement between the measurements and the WINDOW 2.0 calculations for the double-glazed windows, but poor agreement for the single-glazed; for the WINDOW 3.0 calculations the agreement is good for both the single-glazed window and the double-glazed window with thermal break and worse for the double-glazed window with aluminum frame without thermal break. In these calculations the edge spacer effect is included, but it has a negligible effect on the calculated U-value. Comparison is of course obscured by the fact that commercial test laboratories do not report experimental errors; therefore, the uncertainty to be assigned to the test laboratory measurements is unknown.

In Table 6 a similar comparison is made for the MoWiTT measurements. Here the experimental data on film coefficients were inserted into the WINDOW program before doing the calculation, since, as has been shown above, the usual WINDOW film coefficient assumptions do not reflect our experimental conditions. Correction was also made for the outdoor radiant temperature. The differences between the WINDOW 2.0 and WINDOW 3.0 calculations are smaller here, due to the smaller exterior film coefficient. While the WINDOW 2.0 calculations are marginally consistent with the measurements, the agreement is significantly better for the WINDOW 3.0 calculations. Note that the calculated and measured values are in good agreement for the double-glazed window with aluminum frame without thermal break, in contrast to the situation in Table 5.

A comparison of the WINDOW calculations in the two tables indicates that the relative importance of frame effects on U-value depends on the exterior film coefficient, as one would expect from the physics of the heat transfer. It is difficult to understand the discrepancy between the WINDOW 3.0 calculation and the test laboratory measurement for the double-glazed window with aluminum frame without thermal break, given the good agreement for the double-glazed window with thermal break and the single-glazed window. The double-glazed window without thermal break has a sealed-insulating-glass unit essentially identical to the former combined with a frame identical to that of the latter. One might possibly explain a U-value larger than the calculated one as a result of two-dimensional heat transfer, but here the measured value is smaller. This circumstance, together with the good agreement between the calculation and the MoWiTT-measured result, raises the question of whether there may be systematic errors in the hotbox measurement when the frame has significantly higher conductance than the glazing.

In summary, there is excellent agreement between the WINDOW 3.0 calculation and the MoWiTT measurements for all windows, and between the WINDOW 3.0 calculation, the MoWiTT measurements, and the test laboratory measurements for all windows except one with a frame significantly more thermally conductive than the central glazing.

SOLAR HEAT GAIN

Nighttime U-values and their associated heat losses are only one factor in the energy performance of fenestration. The unique information produced by the MoWiTT is the continuous measurement of the heat flow through the fenestration as a function of time throughout the diurnal cycle. It is of interest to see how well this quantity fits our theoretical expectations.

The standard simplified model of window heat transfer is given by

$$W = U A_T [T_O - T_I] + F A_S I_V \quad (2)$$

where W is the net heat flow through the window (defined as positive for inward flow); A_T and A_S are the thermal and solar aperture areas, respectively; I_V is the incident solar intensity; U is the thermal transmittance; and F the solar heat gain coefficient. T_O and T_I are of course the indoor and outdoor air temperatures.

All of the quantities in this equation are measured in the MoWiTT as a function of time, with the exception of U and F. These can therefore be determined by fitting the equation to the data. The degree to which such a fit is possible is then a test of the accuracy of the model.

In Figure 2 we show the results of this fitting procedure for a north-facing test of the double-glazed window with thermally broken frame. In this fit F was assumed to be a constant and U was assumed to have different (constant) values during the nighttime and daytime. The nighttime U-value was fixed at the value obtained in the previous section, and the daytime U-value was determined by fitting the data, as was the value of F. Of course, the determination of the nighttime U-value in the previous section is equivalent to fitting the nighttime data. Different daytime and nighttime U-values were assumed because of the strong diurnal variation of wind speed, which may reasonably be expected to have an effect on the U-value.

Equation 2 reproduces the principal features of the data reasonably well, as can be seen from the figure. This level of agreement is typical of all of the window measurements. Similar fits to the data were done for each set of measurements. The values of the solar heat gain coefficients obtained from the fits are shown in Table 7, together with the corresponding WINDOW 2 prediction. The daytime U-values obtained from the fitting procedure were not physically meaningful.

As can be seen from Figure 2, there is some deviation between the prediction of Equation 2 and the data. Although the figure shows a few nights when there is a substantial deviation between the curve and the measured data points, this circumstance does not occur with comparable frequency on the plots of the other measurements. In most data runs, the principal contributor to the deviation is daytime energy flow.

We can obtain a quantitative measure of the uncertainty in energy flow that would arise from the use of Equation 2 as described above. In Table 8, the rms deviation between the measured points and the curve is listed for each set of measurements. The fact that deviations are principally associated with solar heat gain may be confirmed from the much smaller deviation for the north-facing orientation.

Daytime deviations arise from neglecting the angular dependence of F, the change in effective aperture with sun angle (due to self-shading by the frame), and the difference between window transmission, absorption, and aperture for beam and diffuse solar radiation. It is interesting to note the importance of these approximations relative to the uncertainties in specifying U-values. If we consider as an example the south-facing double-glazed window with thermally broken aluminum frame, the rms deviation is 230 Btu/h. By using the corresponding mean nighttime temperature difference from Table 2 and the sample area, we can see that an equal level of uncertainty in the overall net heat flow would be contributed if there were a U-value uncertainty of 0.57 Btu/h·ft^2·°F. Even if we consider the north-facing measurement, to equal the uncertainty of 82 Btu/h would require an uncertainty in U-value of 0.19 Btu/h·ft^2·°F. Clearly the daytime solar gain is the dominant effect.

OVERALL THERMAL PERFORMANCE

A unique feature of the MoWiTT data shown in Figure 2 is the ability to follow the net heat flowing through the window accurately over the full daily cycle. This enables one to distinguish between the different factors contributing to the average net thermal performance of the window. A key question is the effect of solar gain on overall thermal performance.

We approach this issue by considering several ways in which thermal performance might be estimated. First, there is the common degree-day calculation, which neglects solar effects entirely. A second approach might be to allow solar gain to reduce the heat loss due to the window in the daytime, but not to count any positive heating contributions (we are, of course, dealing only with winter performance). This approach might be taken, for example, by a conservative utility or code-setting body, assuming that windows would be shaded whenever there was direct sun, or that net solar heat gains could not significantly offset heating demand from other parts of the building. A third approach is to consider all of the solar heat gains as useful, so that net daily thermal performance is just the diurnal average of the window net heat flow.

Let us examine the effects of these three approaches on the thermal performance for two selected days in Reno. The first, February 4, 1987, is a cold, clear winter day when the window faces south. The second, March 20, 1987, is a cold, overcast day when the window faces north. In both cases the test window in question is the double-glazed window with thermally broken aluminum frame that was used as the reference for our tests.

Table 9 shows the net heat flow through the window on each of these days that would follow from the three approaches to calculating window performance. The degree-day calculation has been divided into two cases in order to illustrate the effect of using the MoWiTT measurement or the ASHRAE standard calculation for U-value. For these two cases the measured temperature profile has been used to evaluate the number of degree-hours in the 24-hour period. For the second approach (case 3), we calculated the 24-hour average net heat flow using the measured net heat flow so long as it was negative (heat flowing outward), but used zero whenever it was positive. The third approach (case 4) simply averages the measured net heat flow over a 24-hour period.

The south-facing sunny data show, not surprisingly, that when the solar gain is included the window shows a net energy gain. This is familiar from many studies in the passive solar field. More interestingly, even when the net energy gains are excluded (presumably by the use of shading), there is a 50% difference using the measured energy flow as compared with the degree-day calculation. This difference is much larger than the 13% difference that may arise from using the ASHRAE U-value or the field-measured one.

Still more interesting are the data for the north-facing window on an overcast day. This day was selected for low solar gain and low nighttime temperature. The maximum solar gain incident on the window was about 55 Btu/(h·ft^2) and the outdoor air temperature varied from a nighttime low of 20° F to a daytime high of 46° F. The radiant temperature was approximately equal to the air temperature during the day and some 10° F colder at night. The wind speed varied between 2 and 5 mph during the night and between 5 and 12 mph during the day. In short, while it does not represent peak winter conditions in the northern part of the country, this was a day that might occur during the winter over much of the U.S.

As can be seen from the table, solar gain is still a substantial effect. When solar heat gains are excluded, the actual net heat loss is still some 23% lower than one would conclude from a degree-day calculation, while if all solar gains are accepted (as would be reasonable for a north-facing window), the net heat loss is 42% less. In contrast, if instead of the measured U-value one used the value for ASHRAE standard conditions, one would find a heat loss only 6% higher.

But if window net heat losses are significantly affected by solar gain in a north-facing orientation where incident radiation is wholly diffuse, then it is reasonable to infer that solar effects will also be significant when windows are shaded, for example, by overhangs. From this one quickly sees that there are few, if any, cases where solar effects on winter thermal performance may be safely neglected.

CONCLUSIONS

In the first section of this paper we discuss discrepancies between U-value measurements and theoretical calculations. We concluded that the calculations, test laboratory measurements, and MoWiTT measurements were in good agreement when the frame conductance is similar to that of the glazing unit (and hence the frame correction is small). For the window with a frame substantially more conductive than the glazing there is good agreement between the calculations and MoWiTT measurements, both of which disagree with the test laboratory. This disagreement is only marginal in view of the measurement uncertainties. As a measurement of the discrepancies between the calculations, lab, and field tests, we may take the difference between the average MoWiTT measured U-value for the double-glazed window with thermally unbroken aluminum frame and the WINDOW 2.0 calculation for the same window under ASHRAE standard conditions. This yields a value of 0.06 $Btu/h{\cdot}ft^2{\cdot}{}^\circ F$.

The remainder of the paper provides some perspective on these discrepancies. In the second section we saw that using a simplified model for solar heat gain contributes uncertainties in the heat flow equivalent to having a U-value uncertainty of 0.2 to 0.5 $Btu/h{\cdot}ft^2{\cdot}{}^\circ F$, which is four to ten times greater than the discrepancies of the first section. In this case the measured incident vertical-surface solar flux is available. In the more usual case one would expect additional uncertainty to arise from estimating the incident vertical-surface solar flux from other data, such as horizontal solar intensity. In the third section we saw that even when the measured net energy flow is available, differences in assumptions about whether or how solar gain is to be included make a 20-40% difference, while U-value differences on the order of .06 $Btu/h{\cdot}ft^2{\cdot}{}^\circ F$ make a 5% difference in daily heat flow.

Without minimizing the importance of improvements in U-value and techniques for its measurement and calculation, it is clear that improved knowledge of U-value will not yield improved ability to predict fenestration energy use accurately unless there are substantial concomitant improvements in the ability to account for solar gain systematically. Specifically, we need agreed-upon procedures for determining useful and acceptable levels of solar gain. We also need better ability to account for the effect of shading. The dependence of solar heat gain coefficient on incident angle is also necessary for accurate predictions.

Without a methodology to treat thermal losses and solar gains even-handedly and systematically, fenestration energy calculations will remain uncertain, and any convincing demonstration of energy performance gains resulting from specific U-value improvements will be difficult.

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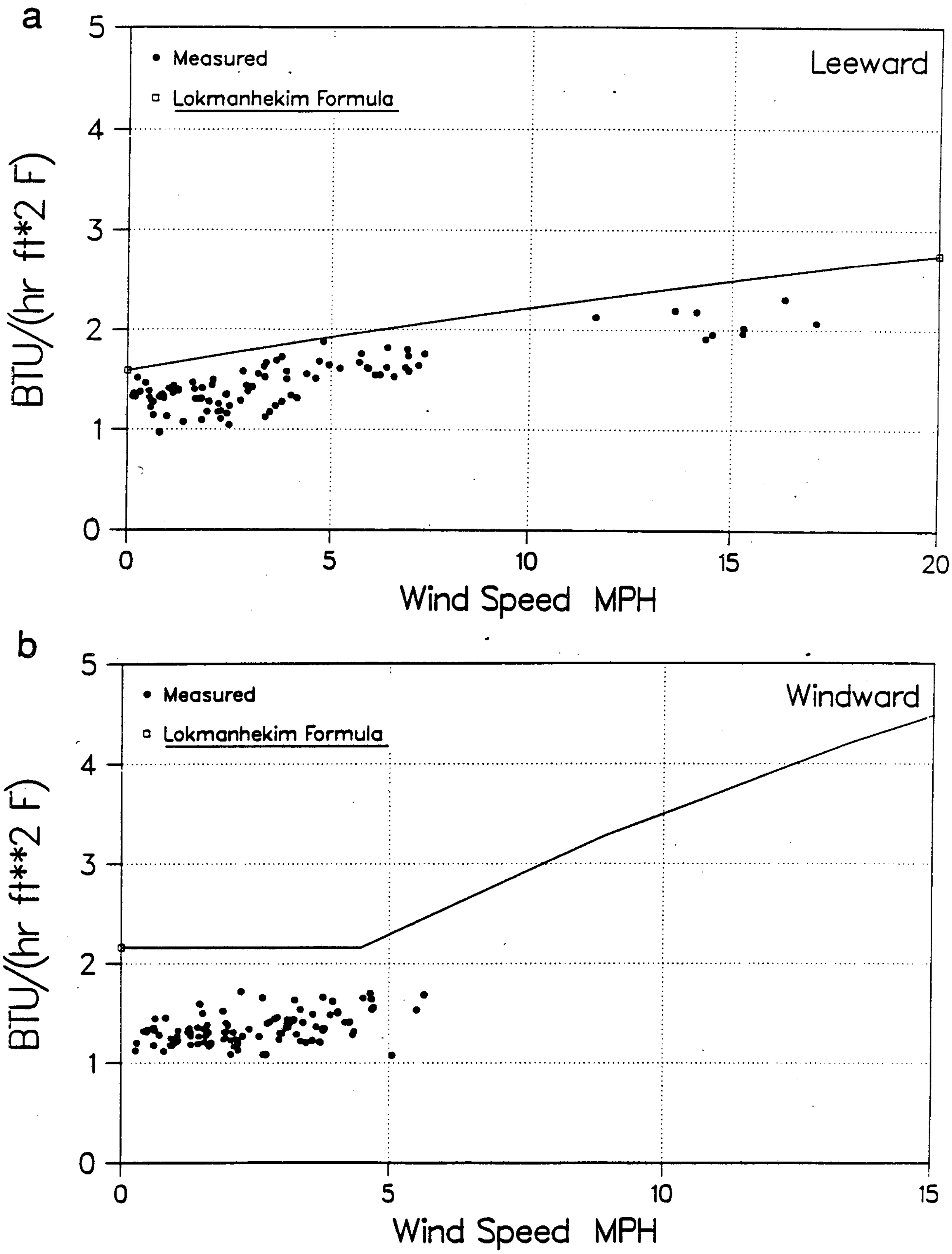

Figure 1. Measured exterior film heat transfer coefficient vs. wind speed (measured at 10-m height, on site): (a) leeward hemisphere, (b) windward hemisphere.

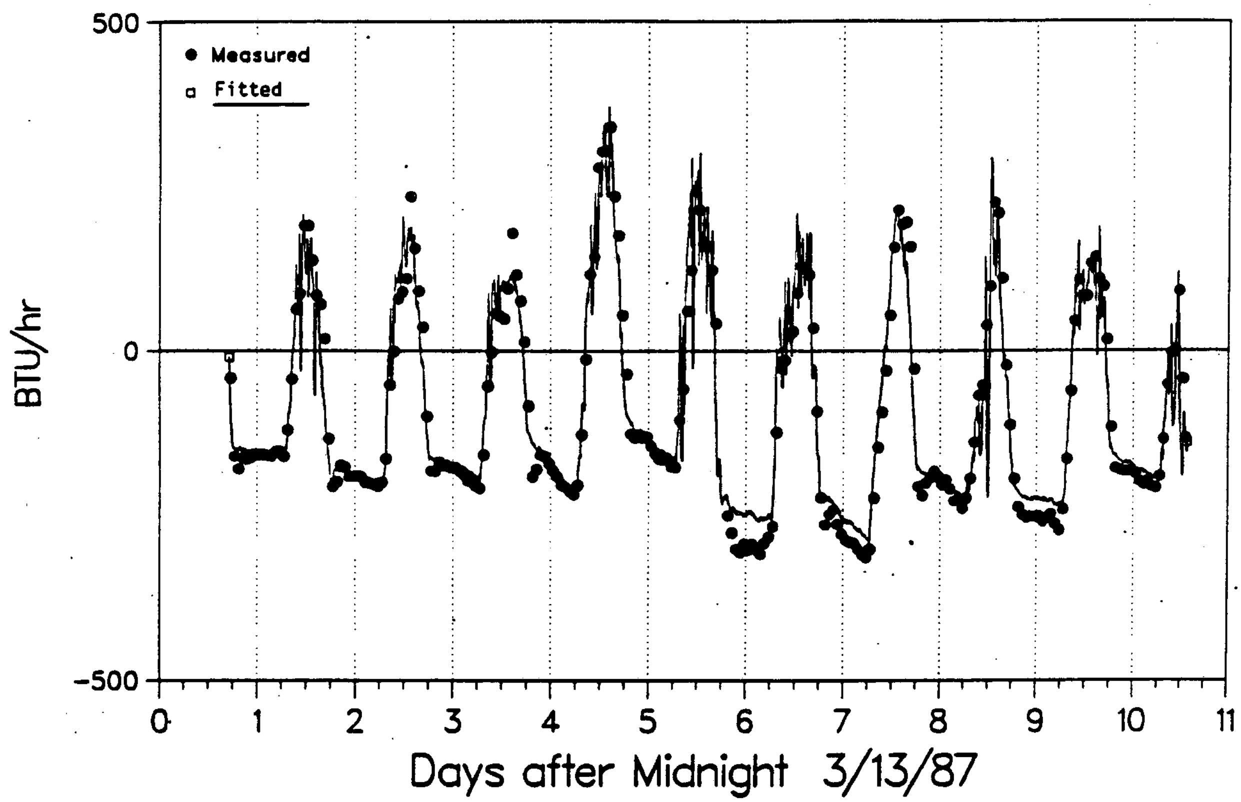

Figure 2. Comparison of measured net heat flow (solid circles) through a north-facing clear double-glazed window with thermally broken aluminum frame with calculated values (solid curve) obtained from Equation 2 with fitted U-value and solar heat gain coefficient.

TABLE 1
Measured Single Glazing Nighttime Winter U-Values
Together with Environmental Conditions

Date	Orientation	<V_{wind}> MPH	<T_{in} - T_{out}> Degrees °F	Measured U Btu/(hr·ft^2·°F)
1/3-9/87	South	3.2	40	0.72 ± .04
1/23-24/87	South	2.8	42	0.69 ± .09
2/16-26/87	North	2.8	26	0.67 ± .06
3/4-11/87	North	3.7	32	0.63 ± .08
12/14-20/87	East	3.2	41	0.79 ± .06

TABLE 2
Measured Nighttime U-Values and Average Conditions of the Measurement

Sample	Orientation	Air Temperatures Indoor °F	Air Temperatures Outdoor °F	Radiant Temperature °F	Wind Speed MPH	Measured U-Value Btu/(h·ft^2·°F)
Double, Al Frame with Thermal break	South	67.8	33.3	22.6	3.5	0.42 ± .04
	North	69.4	33.4	28.9	6.6	0.47 ± .04
	West	71.0	54.9	49.1	2.5	0.55 ± .10
	East	71.4	47.1	41.5	4.2	0.46 ± .08
Double, Wood Frame	South	67.8	38.1	27.5	4.8	0.46 ± .06
Double, Al Frame without Thermal Break	West	70.9	54.7	48.7	2.5	0.64 ± .06
Single, Al Frame without Thermal Break	East	71.8	47.1	41.5	4.3	0.87 ± .09

TABLE 3
Comparison of Test Laboratory and MoWiTT Measurements of U-Value

Sample	Orientation	Test Lab Measurement	Test Lab Adjusted	MoWiTT Measurement
		Btu/(h·ft^{2}·°F)	Btu/(h·ft^{2}·°F)	Btu/(h·ft^{2}·°F)
Double, Al Frame with Thermal Break	South	0.54	0.49	0.42 ± .04
	North	0.54	0.47	0.47 ±.04
	West	0.54	0.49	0.55 ± .10
	East	0.54	0.47	0.46 ± .08
	Average	0.54	0.43	0.45 ± .03
Double, Wood Frame	South	0.41	0.40	0.46 ± .06
Double, Al Frame without Thermal Break	West	0.57	0.51	0.64 ± .06
Single, Al Frame without Thermal Break	East	1.22	0.86	0.87 ± .09

TABLE 4
Comparison of Frame U-Values
Calculated for Test Windows with WINDOW 3.0 Default Values

Window	Calculated U-Value Btu/(h·ft^{2}·°F)	WINDOW 3.0 Default Value Btu/(h·ft^{2}·°F)
Double Glazed, Al Frame with Thermal Break	0.61	1.0
Double Glazed, Wood Frame	0.27	0.4
Double Glazed, Al Frame without Thermal Break	1.38	1.9
Single Glazed, Al Frame without Thermal Break	1.40	1.9

TABLE 5
Comparison of Calculated U-Values and Test Laboratory Measurements

Sample	WINDOW 2.0 Calculation Btu/(h·ft^{2}·°F)	WINDOW 3.0 Calculation Btu/(h·ft^{2}·°F)	Test Laboratory Measurement Btu/(h·ft^{2}·°F)
Double, Al Frame with thermal break	0.53	0.53	0.54
Double, wood frame	0.45	0.45	0.41
Double, Al Frame w/o thermal break	0.58	0.64	0.57
Single, Al frame w/o thermal break	1.15	1.20	1.22

TABLE 6
Comparison of Calculated U-Values and MoWiTT Measurements

Sample	Orientation	WINDOW 2.0 Calculation Btu/(h·ft^2·°F)	WINDOW 3.0 Calculation Btu/(h·ft^2·°F)	MoWiTT Measurement Btu/(h·ft^2·°F)
Double, Al frame with thermal break	South	0.49	0.48	0.42 ± .04
	North	0.47	0.46	0.47 ± .04
	West	0.50	0.50	0.55 ± .10
	East	0.48	0.48	0.46 ± .08
Double, wood frame	South	0.43	0.42	0.46 ± .06
Double, Al Frame w/o thermal break	West	0.56	0.65	0.64 ± .06
Single, Al frame w/o thermal break	East	0.84	0.93	0.87 ± .09

TABLE 7
Measured Solar Heat Gain Coefficients Compared with WINDOW 2 Calculations

Sample	Orientation	Measured F	WINDOW 2 Calculated F
Double, Al Frame with thermal break	South	0.81	0.76
	North	0.68	0.66
	West	0.72	0.76
	East	0.76	0.76
Double, wood frame	South	0.85	0.76
Double, Al frame without thermal break	West	0.76	0.76
Single, Al frame without themal break	East	0.92	0.85

TABLE 8
Root-Mean-Square Deviations of Measured Net Heat Flow from Calculated Values

Sample	Orientation	RMS Deviation Btu/h
Double, Al Frame with thermal break	South	236
	North	82
	West	198
	East	130
Double, wood frame	South	212
Double, Al frame without thermal break	West	225
Single, Al frame without thermal break	East	174

TABLE 9
Calculated Window Daily Net Energy Flow for Selected Days under Various Assumptions for a Double-Glazed Window with Thermally Improved Frame

Day	Assumptions	Net Energy Flow Btu (Losses are Negative)
Feb. 4, 1987, South-facing, High solar gain.	(1) Degree day calculation, U=0.45	-4404
	(2) Degree day calculation, U=0.52	-5090
	(3) Measured Heat Flows, exclude gain	-2393
	(4)Measured Heat Flows, net	10740
March 20, 1987, North-facing, Low solar gain.	(1) Degree day calculation, U=0.45	-4973
	(2) Degree day calculation, U=0.52	-5285
	(3) Measured Heat Flows, exclude gain	-3840
	(4)Measured Heat Flows, net	-2867