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ABSTRACT

The need for fenestration performance measurements under realistic conditions is noted, and the Mobile Window Thermal Test facility (MoWiTT), newly constructed at LBL to make these measurements, is described. A key feature of the MoWiTT is the direct measurement of instantaneous net energy flow in the presence of sunlight. Ongoing calibration to establish the accuracy of this facility is described, and calibration data so far obtained are presented. Estimates from these data indicate that the facility will have sufficient accuracy for most fenestration measurements of interest.

Keywords: Fenestration thermal performance, field measurement, calorimeter, fenestration U-value, and shading coefficient.

INTRODUCTION

Fenestration systems are unique among building envelope components in that they experience instantaneous net heat flows which (a) may be directed inward under winter conditions, and (b) may change by 100% or more over a short time period, due to changes in sky or wind conditions. The impact of these heat flows on building energy consumption is a long-term average of the net energy flow. Accurate calculation of the average value of a rapidly varying quantity requires very good knowledge of that quantity's behavior; however, numerous authors (e.g., Yellott, Schuyler, and Timmons, 1979; Fracastoro, Masoero, and Cali, 1983) have suggested ways in which fenestration systems under realistic conditions may be expected to depart from the assumptions generally made in calculating their performance and have pointed to the need for realistic performance measurements (Klems and Selkowitz, 1981).

A FENESTRATION PERFORMANCE MEASUREMENT FACILITY

In Klems, Selkowitz, and Horowitz (1982) it was shown that a surprisingly high degree of measurement accuracy is necessary for determining fenestration performance moderately well. The reference then described a facility designed to have the necessary accuracy, the Mobile Window Thermal Test facility (MoWiTT), on which work was underway at Lawrence Berkeley Laboratory. The MoWiTT, one module of which has now been completed, is shown in Fig. 1. Realistic measurement conditions are achieved by using roomlike interior chamber dimensions, especially height (2.4 m), and by exposing the fenestration systems (which may include skylights) to actual weather; commensurability of results is achieved by simultaneous, side-by-side comparison of a given system with a simple reference system (such as unshaded single glazing), the behavior of which is relatively predictable. The air inside the calorimeters may be either electrically heated or cooled by a liquid-to-air heat exchanger. Extracted heat is determined by temperature and flow measurements on the fluid; electrical inputs (including fans) are monitored using accurate watt-hour meters. The interior air temperature may be either tightly controlled or allowed to "float" within a set range.

The key measurement made by the MoWiTT facility is the direct, calorimetric determination of the net heat-flow rate through the fenestration, including solar gain if any, as a function of time and with a short time constant. This is accomplished by almost completely covering (approximately 90%) the interior surfaces of each calorimeter with large-area heat-flow sensors [see Fig. 1(c)] of a type developed especially for this application (Klems and DiBartolomeo, 1982; Klems, 1983). These, together with measurement of the heat added to or extracted from the air, allow the fenestration net heat transfer to be inferred from the net heat balance of the air in the calorimeter. The dominant time constants will be (1) that of the heat-flow sensors (approximately 3 minutes) and (2) that associated with the distribution by convection of heat within the air. Both of these are much shorter than

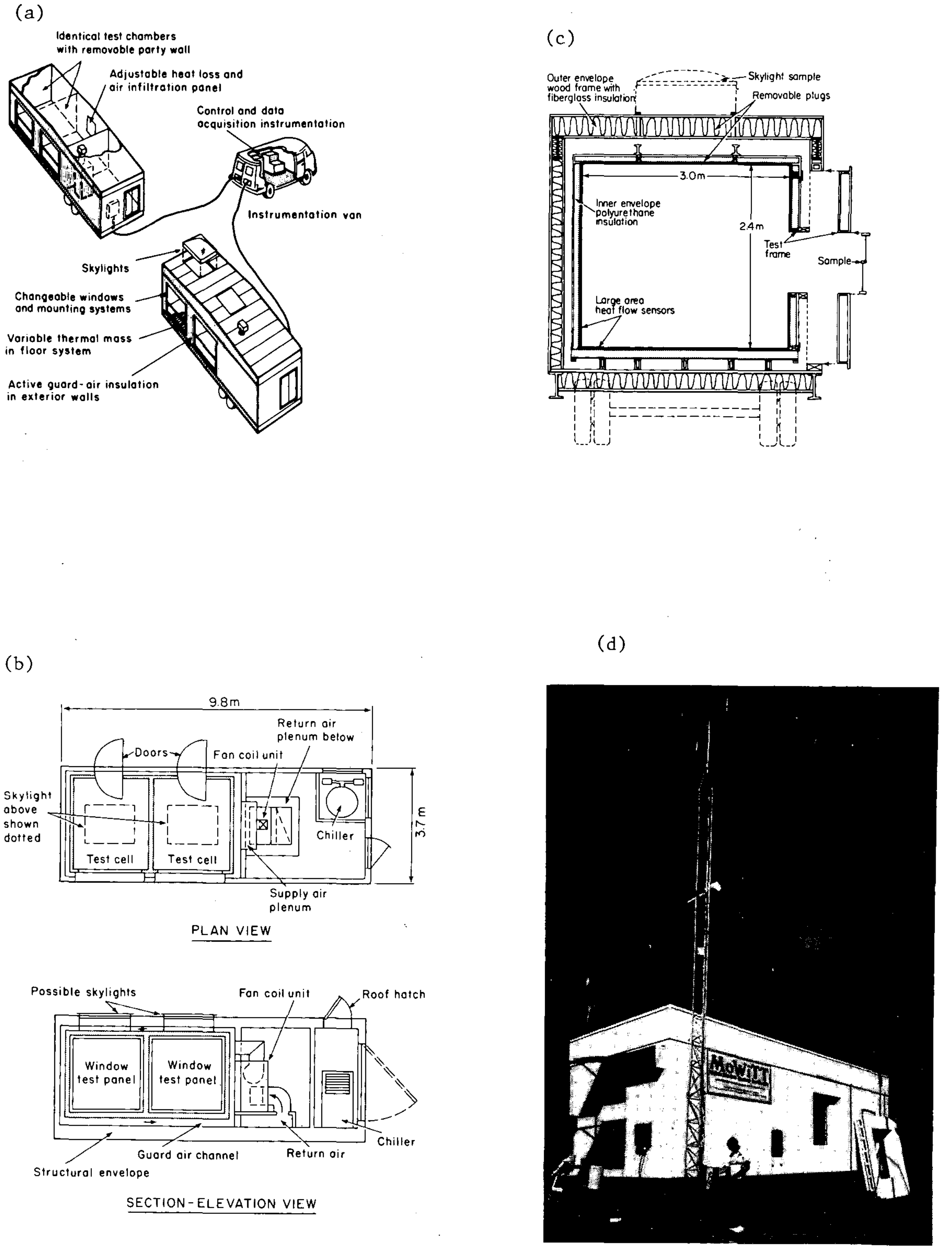

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Figure 1. The Mobile Window Thermal Test facility (MoWiTT). (a) Planned field configuration, showing two mobile test modules, each containing a pair of room-sized, air-guarded calorimeters. (b) Layout of a test module, showing the controlled-temperature guard plenum surrounding the calorimeters, together with its air-handling system. The guard air temperature, which plays no direct part in the net heat balance, is normally at the same temperature as the calorimeter air, but can be varied for specific experiments. (c) Cross section through the center of a test chamber, showing mounting of various window or skylight systems. (d) The first test module during calibration at Lawrence Berkeley Laboratory.

the time constant of any real building, so the net heat-flow measurement is effectively instantaneous.

In addition to the basic net heat-flow measurement, the MoWiTT facility records weather data such as wind speed and direction, barometric pressure, ambient temperature, humidity, and direct and diffuse solar intensity. Up to 200 channels of additional data may be recorded per chamber in order to provide sufficient physical information to explain the net heat-flow measurement.

MOWITT CALIBRATION

Klems, Selkowitz, and Horowitz (1982) demonstrated that not only is it possible for the fenestration heat flow to be obliterated by random experimental errors, but it is also possible to make systematic errors much larger than one would expect based on the quoted accuracy of the instruments used. Accordingly, it is important to establish the accuracy of the MoWiTT by direct measurement.

Each subsystem entering into the net heat balance measurement has been calibrated individually. The results of the calibrations for two critical subsystems are shown in Fig. 2. In each case the calibration measurements are consistent with the expected result, represented by a straight line. From the scatter of the points about the line we can estimate the reproducability of the measurement system, provided we make the pessimistic assumption that all the scatter is due to intrinsic errors. (In fact, most of the scatter is due to known sources of uncertainty in the calibration experiments; however, this procedure fairly represents the limits of our current knowledge about the system accuracy.) By this method we derive an RMS error of 10 W for the cooling system, and 0.13 W/m^2 for the heat-flow sensor. The latter figure implies an overall error of 5 W in the envelope heat flow.

In a similar manner, accuracy estimates have been made from measurements on each subsystem of the first calorimeter chamber. Similar measurements will be made on the second chamber when its instrumentation is completed. The results for the first calorimeter chamber are shown in Table 1.

The next step in the calibration will be a system-level test of the assembly. The wall holding a window [shown in Fig. 1(c)] will be replaced by a blank double wall covered with heat-flow sensors; guard air will flow between the parts of the double wall just as it does on the other surfaces of the calorimeter (except the common wall between the two chambers). This "closed-box" test will provide a redundant measurement of changes in the air heat content, and thus a check on the accuracy of the complete measurement system. Response of the heat-flow sensors to inhomogeneous radiative fluxes will be checked by using a light source inside the closed chamber.

The estimates in Table 1 allow us to explore the limitations of the facility. If we wished to measure a 1 m^2 window having 7 times the thermal resistance of single glazing, achieving 20% accuracy would require an inside/outside temperature difference of about 30 °C. A north-facing 1 m^2 window would admit approximately 100 W of diffuse solar energy during most parts of the year and during most daylight hours. If we neglect thermal losses, the cooling system uncertainty would imply that one could achieve 20% accuracy when measuring a system having a 0.5 shading coefficient. This is adequate resolution for spring, summer, and fall measurements on systems of moderate thermal resistance; better resolution may be desirable for high-thermal-resistance, north-facing systems during winter, when thermal losses and solar gains offset one another.

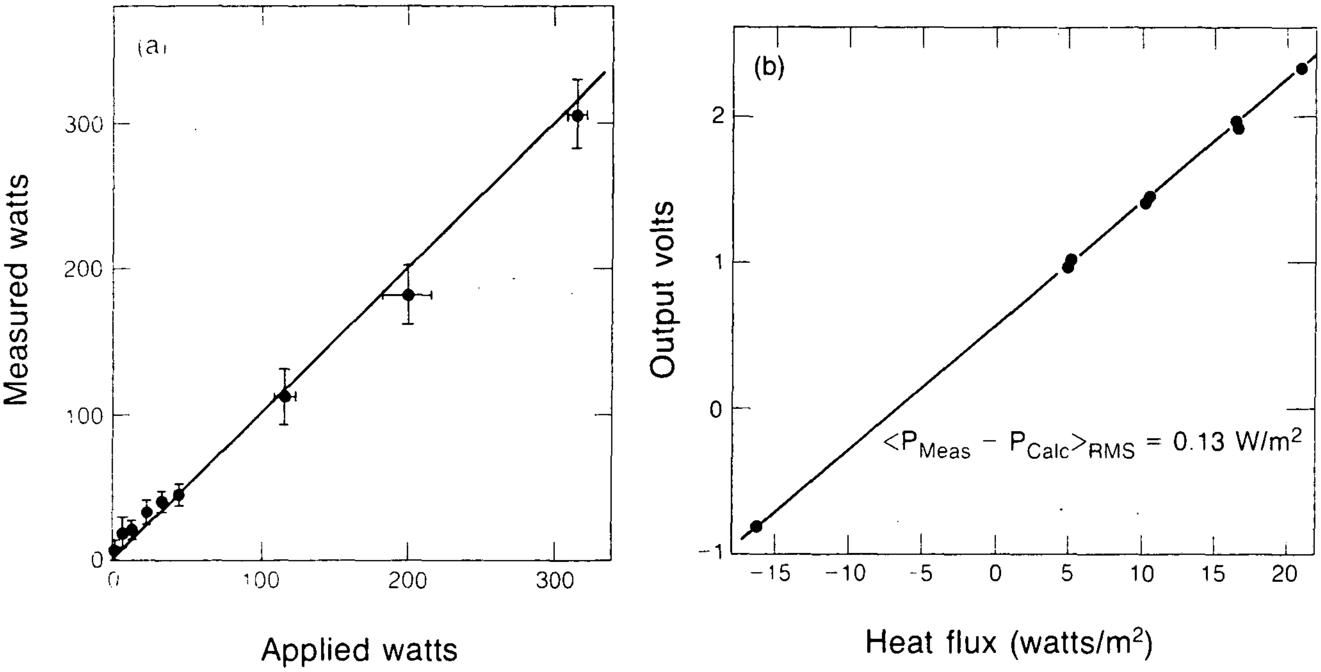

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Figure 2. Calibration of two critical measurement subsystems in the MoWiTT. (a) Calibration of system measuring the energy extracted by the cooling system, using an electric heater to inject a known wattage into the heat-transfer fluid. (b) Guarded hotplate calibration of one of the large heat-flow sensors (0.55 m x 1.10 m) lining the calorimeter interior.

Table 1. Error sources in MoWiTT determination of fenestration net energy flows.

Source	Magnitude (Watts)
Heat Added to Air	0.1
Heat Removed from Air	10
Envelope Heat Flow	5
Air Infiltration	<1
Air Heat Capacity	<2

CONCLUSIONS

A mobile facility for measuring fenestration performance under realistic conditions has been constructed, and calibration, still in progress, has demonstrated that the facility provides high measurement accuracy. This accuracy is both necessary and adequate for measuring most fenestration systems of current interest. However, for very high-thermal-resistance fenestration systems (7 to 10 times the resistance of single glazing), especially in north-facing orientations, accuracy may have to be improved.

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