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PROPOSED METHOD FOR MEASURING THE THERMAL PROPERTIES OF WINDOWS IN THE NEW BRANZ GUARDED HOTBOX

Ian Cox-Smith

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Proposed method for measuring the thermal properties of windows in the new BRANZ guarded hotbox

Ian Cox-Smith, Building Physicist
Building Research Association of New Zealand

Abstract

The existing hotbox rig at BRANZ has been used extensively to measure the thermal resistance of most types of insulation as well as built-up panels. These measurements have been made using the ASTM standard C236 (Standard test method for steady-state thermal performance of building assemblies by means of a guarded hotbox). Manufacturers of windows have requested thermal resistance measurements and ratings on their products be done to a recognisable standard. The need for such a capability in New Zealand has increased to a point where the new guarded hotbox currently being developed at BRANZ will be provided with the ability to make thermal resistance measurements on fenestration products such as windows and doors. This paper describes the basis of the testing procedure.

Introduction

The existing building code requirements for insulation in residential buildings, "H1 Energy Efficiency" does not require double glazing in any climatic zones in New Zealand. Double glazing will however contribute to the building thermal performance index of a building and allow insulation levels in walls, roofs or floors to be relaxed so long as they do not fall below minimum values for indoor moisture control.

The New Zealand building code section H1 and associated compliance standards are in revision at the time of writing this paper. Homes in cooler climatic areas require higher overall levels of insulation in the draft revisions. Double glazing is clearly emphasised and encouraged because single glazing is an obvious weak link in the thermal envelope. Heat loses through single glazed windows typically contribute half of the total conduction and infiltration heat loss from houses. Double glazing has the potential to make a 20-30% improvement in overall building thermal performance.

Thermal testing support for window manufacturers is being developed at BRANZ to foreshadow improvements to building thermal performance demanded by the building code and by the house buying public.

Current test method

The existing hotbox at BRANZ is equipped with a heat-metering box of dimensions 1.0m x 1.0m, which is sufficient for testing homogenous specimens of insulation as well as sections of non-homogenous specimens such as building construction assemblies. The test temperatures are fixed at about 20°C on the warm side and 6°C on the cold side, or a mean temperature of 13°C. Those temperatures are typical of temperatures where insulation is important in most regions of New Zealand, although the results of thermal resistance measurements are usually adjusted by calculation to a mean temperature of 15°C.

The test method used in the past for windows is illustrated in Figure 1. The incompatibility between window finish and the necessary heat metering box is dealt with by forcing a "still air zone" on the warm side of the window. This relies on the fact that the heat-metering box is thermally transparent, because it is operated by forcing both faces to have the same temperature. The window is installed in the guarded hotbox rig with the face of the window which is normally facing outward, facing inward into the hotbox maintained at 6°C. The reveal of the window is thus facing outward into the laboratory space at 20°C. A 4 mm sheet of medium density fibreboard (MDF) is placed over the inside face of the reveal, creating a cavity between the MDF sheet and the glazing, and the heat metering box is centred over the MDF sheet.

The window rating is determined from the observed resistance by deducting the known resistance of the air cavity and MDF sheet, and adjusting to standard surface resistances. The rating illustrated is typical of the thermal performance of double glazed windows currently being developed in New Zealand. The standard surface resistances have a combined thermal resistance which is about half that of the double glazed window system itself. The cold side surface resistance is calculated by measuring the temperature difference between the cold side surface of the window and the adjacent air stream. The warm side resistance on the other hand is in fact the resistance for the warm side surface of the MDF panel and again is measured by measuring the temperature difference between the surface and the air stream. The original BRANZ hotbox is unable to measure the thermal resistance of single glazed windows since the thermal resistance of the glazing unit is a small fraction of the overall thermal resistance, which is dominated by the surface resistances.

ASTM C236-89 (1)

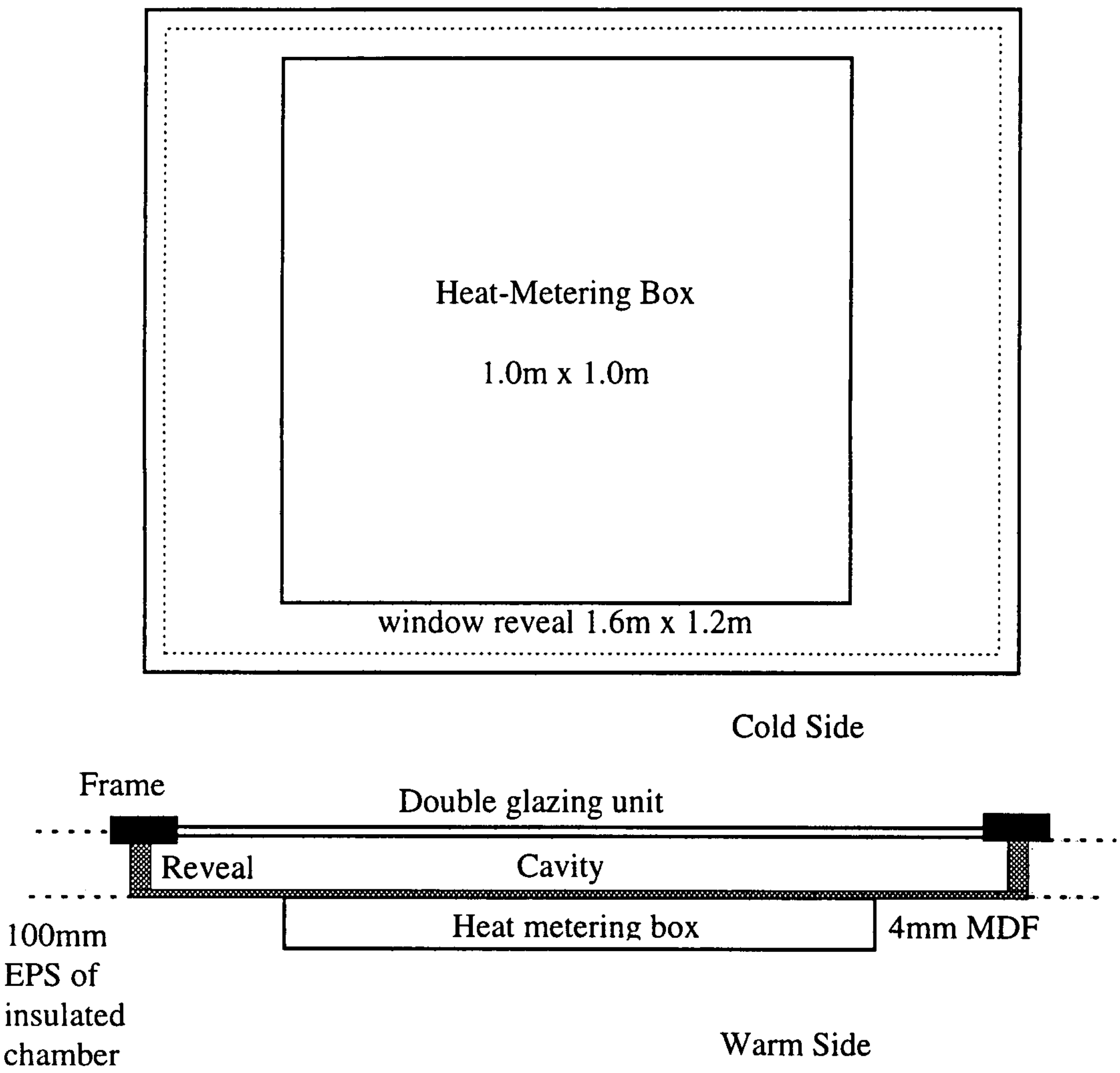
ASTM C236 section 5.2 states:

> "For vertical specimens with air spaces that significantly affect thermal performance, the metering box height should ideally match the construction height. If this is not possible, horizontal convection barriers must be installed to prevent air exchange between meter and guard areas, unless it can be shown that the omission of such barriers does not significantly affect results."

and section 5.3:

> "For all specimens it is necessary to maintain a near zero lateral heat flow between the guard area and the meter area of the specimen..."

In the case of building construction assemblies containing such cavities, there are a number of cases where such assemblies have been tested in the BRANZ rig, both with and without convection barriers. In those cases the barriers appeared to have no effect, but in the case of windows, placing such barriers in the cavity between the MDF panel and the window could circumvent the measurement since it will isolate parts of the perimeter frame from the centre of glass area. The BRANZ test method for windows relies on the air in the cavity being well mixed so that there is no lateral variation in heatflow.



In a typical case:

Total air-to-air thermal resistance			0.50 m$^{2\circ}$C/W
-	coldside surface resistance	0.06	
-	warmside surface resistance	0.07	
-	4mm MDF thermal resistance	0.04	
-	thermal resistance of cavity	0.18	

=	thermal resistance of glass unit		0.15
+	standard surface resistances		0.15

=	Thermal Resistance Rating		0.30 m$^{2\circ}$C/W

Figure 1. Mounting condition and typical results for a double glazed window

Section 5.4 states:

"Since this test method determines the total flow of heat through the test area demarcated by the metering box, it is possible to determine the heat flow through a building element smaller than the test area, such as a window or representative area of a panel unit, if the parallel heat flow through the remaining surrounding area or mask is determined." (Annex A1 explains a method for doing this).

This adjustment is not possible with the BRANZ rig since the size of the heat-metering box unreasonably restricts the size of windows which could be tested. The height of guard area of the side of the hotbox prevents the heat-metering box from being any taller. In addition, in ASTM C236 section 6.2.1 the comment is made that: "....for panels incorporating air spaces or stud spaces, the metering area, preferably, should exactly span an integral number of spaces." It goes on to state that the height of the metering box should be not less than the width.

It is of importance to note that the standard does not explicitly exclude the use of a guard area of zero width or equivalently a sample size the same as the heat-metering box. For typical double glazed window types used in New Zealand the heatflow through the window will be so high that the lateral heatflow into a relatively high thermal resistance surround panel will be minimal compared to the window.

Section 6.2.3 describes a method for using fans to approximate natural convection type airflow in the heat-metering box. The BRANZ window test method achieves natural convective heatflow on the warm face of the window by creating a cavity against the window. One problem is that for low thermal resistance windows (high heatflow), there will by necessity be large temperature gradients in the cavity. This places a lower limit on the R-value of windows that the BRANZ equipment can be used for when making thermal measurements.

Section 6.4.4 discusses air circulation in the cold box and starts: "High air velocities are permissible when their effect upon heat flow is to be determined. This may be accomplished by directing the airflow either parallel or perpendicular to the specimen cold surface." It goes on to declare that parallel velocities help to obtain uniform specimen surface temperatures and they simulate the effect of cross winds. Another important comment in that section is: "Velocities commonly used to simulate crosswind conditions are 3.35 m/s for summer conditions and 6.70 m/s for winter conditions." These velocities seem rather high when compared with measured values for New Zealand houses.

Temperature measurement equipment is described in section 6.5 and in particular in section 6.5.1.3, it says that when surface temperatures are very non-uniform, (as may be the case for windows) enough temperature sensors must be used and located to give a reliable weighted mean temperature.

Standards for measuring the thermal transmittance of fenestration systems

Standards specifically for measuring the thermal performance of windows have existed since about 1988 when the American Aluminium Manufacturers Association introduced voluntary test standards AAMA 1503-88 (2) and AAMA 1504-88 (3), which were widely adopted in the US by laboratories doing regular tests on window systems. Other organisations such as the National Bureau of Standards also introduced similar test standard NBSIR 87-356 (4) at about the same time, but they were not as widely adopted as the AAMA standards.

In 1991 ASTM introduced two new standards which add additional information to ASTM C236 (1) and ASTM C976 (5) but which is specific to fenestration systems. ASTM E1423 (6) describes a standard practice for measuring thermal transmittance while ASTM C1199 (7) describes the test method. They have very quickly taken over from the AAMA standards. Also in 1991, the National Fenestration Rating Council introduced an interim standard incorporating ASTM E1423 and ASTM C1199 as a measurement method into an attachment (9) to NFRC Document 100-91 (8) which is a procedure which describes how to extend the measurements of thermal transmission using computer based simulation methods. By making measurements on a representative sample of sizes of windows of the same type, the whole size range of the particular window type can be simulated. The NFRC is still undertaking a procedure validation project of both the measurement and calculation parts of the standard. The project involves an inter-laboratory comparison of experimental results and computer simulations for the steady state thermal transmittance of fenestration systems. It is the intention of ASTM to incorporate both window standards ASTM E1423 and ASTM C1199 into revised versions of the more general thermal properties standards, ASTM C236 and ASTM C976.

The International Standards Organisation has recently introduced their own standard ISO 8990:1994 (10), which combines ASTM standards C236 for guarded hotboxes, and C976 for calibrated hotboxes, into one document for the determination of steady state thermal transmission properties.

The ASTM standards ASTM E1423 and ASTM C1199 are the most obvious choice to follow when developing a method for testing window systems in the new BRANZ guarded hotbox and so it is the expected intention to follow those two standards as closely as is practical.

The new BRANZ guarded hotbox

The major difference between the ASTM standards specific to the thermal performance of windows and the earlier more general thermal performance standards is the requirement to calibrate the test set-up to determine the surface conductances on both the warm and cold faces. To some extent this nullifies the benefits of using a guarded hotbox over a calibrated hotbox. In fact neither ASTM E1423 nor ASTM C1199 makes mention of any difference between the two types of hotbox when it comes to testing fenestration products.

ASTM C1199-91

This test method specifies the necessary measurements to be made using measurement systems conforming to either test method ASTM C236 or ASTM C976 for determination of fenestration system thermal transmittance. Essentially it adds a calibration process, a modified testing procedure and additional temperature instrumentation.

Section 3.1.2 defines the test specimen thermal conductance, but in Note 3 the comment is made that the test specimen thermal conductance is an approximate value that is calculated from the measured thermal transmittance and the two surface conductances.

"For non-homogeneous test specimens such as windows, only the thermal transmittance can be defined and measured since it is essentially impossible to accurately measure the area weighted temperature difference between the surface of a window and the adjacent airstream. It is therefore essential to test with surface conductances as close as possible to the conventionally accepted values for building design."

Section 4.2 states that the use of recommended temperature and surface air film conditions will assist in reducing confusion caused by comparing results of tests performed under dissimilar conditions. It goes on to comment that this procedure can be used with other conditions for research purposes or product development.

Section 5 covers calibration. (Figures 2 & 3) The essential elements of the section are:

1. The projected area of the calibration transfer standard shall be the same as the test specimen size.
2. It is desirable to have a relatively high-resistance surround panel to minimise thermal shorting
3. The test facility is calibrated using a heat flux transducer calibration transfer standard as described in Annex A1. The core material has known characteristics traceable to primary standards such as the guarded hot plate of a national standard laboratory.
4. A surround panel of a stable homogeneous material with a thermal conductivity less than 0.04 W/(m.K) and low gas permeance. The width of the core shall be at least the maximum width of the test specimen and not less than 100mm. The maximum width is 25mm greater than the maximum width of the test specimen. A recommended material is EPS with density greater than 20 kg/m^3 which has been aged for at least 90 days. It is recommended that the thermal conductivity is measured in a guarded hotbox at a minimum of three temperatures. It is also recommended that the thermal conductivity is measured before cutting the mounting hole.
5. In addition to the air and surface area weighted temperature measurements specified in ASTM C236, the following temperature measurements are required:
   The temperature of all surfaces exchanging radiation heat transfer with the test specimen using area weighting.
   The roomside and weather side air streams at the same horizontal plane as the surface temperature sensors.
   All potential air leakage sites must be sealed. The tape used for the sealing must be less than 13mm in width. As an additional precaution to minimise the potential for leakage of air through and around the sealed test specimen, means may be provided to measure and equalise the pressure difference across the test specimen.

The second part of section 5. covers the procedure for the calibration. The equations to be used are given but the important features are contained in the margin notes.
In note 10. of section 5. the following is mentioned:

"If the view factor between the test specimen surface and the baffle surface is not equal to 1.0 or if the baffle is not isothermal to within 0.5°C, then the radiative heat transfer calculation procedure in Annex A2 is required. Hot box operators should recognise that the radiative calculation procedure in Annex A2 adds to the complexity of the tests being conducted."

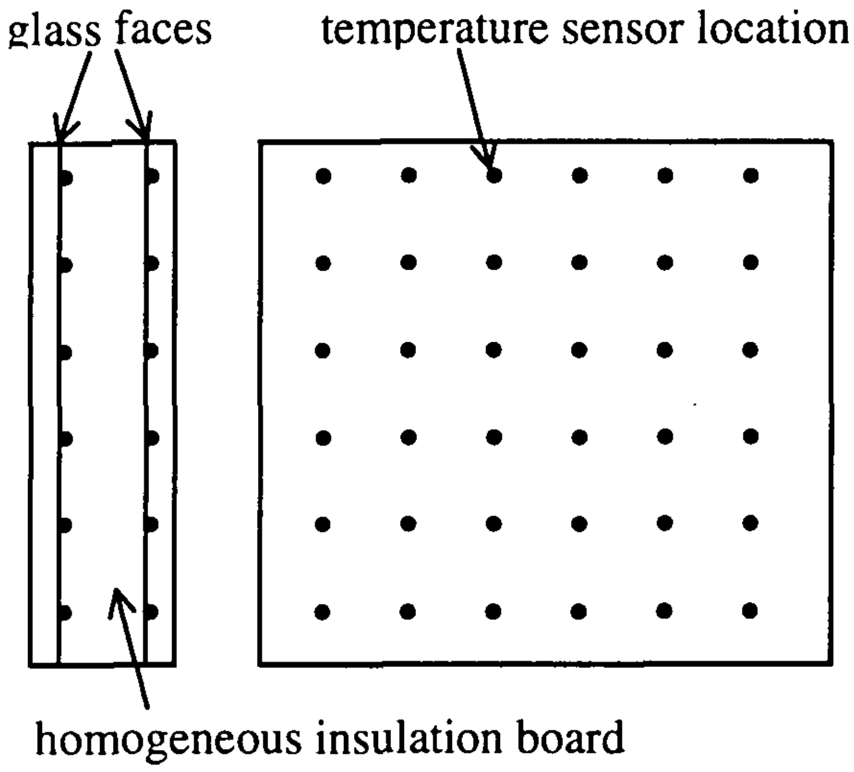


Figure 2. Calibration transfer standard

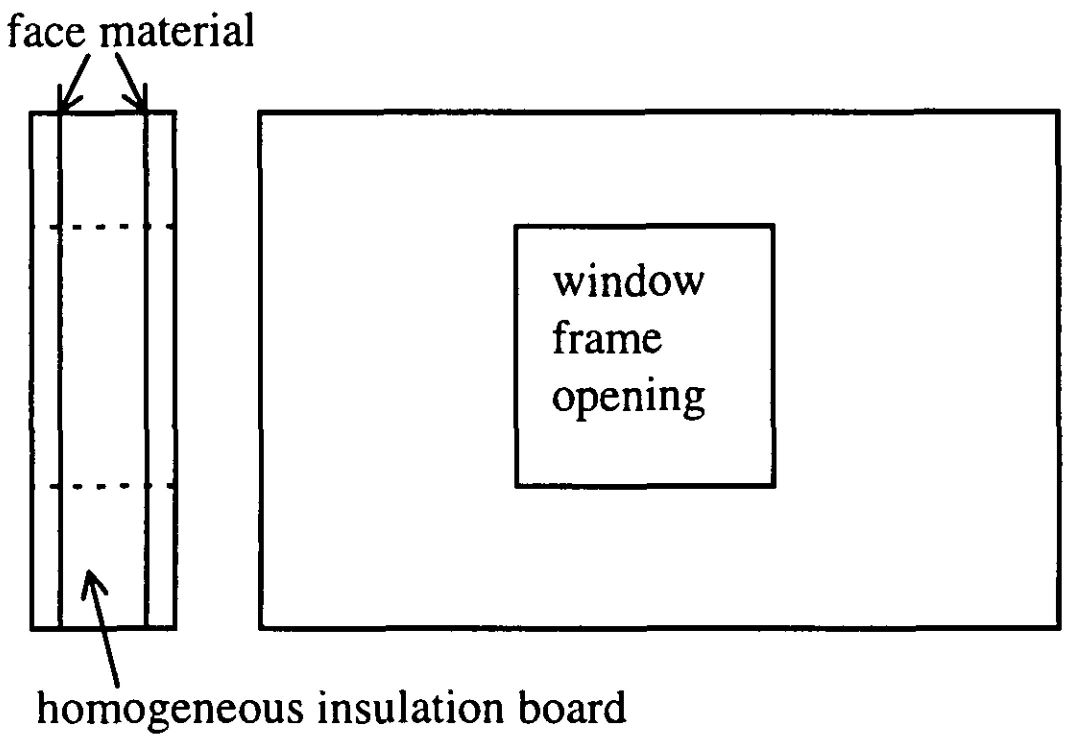


Figure 3. Surround panel

Note 11. of section 5. refers to the calculation of the room side convective heat transfer and the calculation of the convective constant K. The convective heat transfer calculation assumes natural convection on the room side of the calibration transfer standard.

> "To ensure that a single convection coefficient, K, can be used for fenestration system tests, its behaviour should be investigated, using the calibration transfer standard, over the range of heat flows expected."

Section 6 covers the general test procedures:

Section 6.1.1 includes the comments that the technique of direct area weighted surface and air temperature measurements may be applicable when the frame and glazing conductances are similar and the surface geometry is not too complicated. "If this is not the case, excessive use of temperature sensors may cause the surface conductances to differ from calibration tests."

Section 6.1.2 reiterates that the temperature of all surfaces exchanging radiative heat transfer with the fenestration system must be measured.

Section 6.2 recommends that the weather side wind speed be measured at a minimum distance of 75mm out from the test specimen center point. "Periodic traversing of the air flow field to determine the air velocity distribution is advisable. On the room side, it is also advisable to have a sensor so that natural convection conditions can be verified."

Section 6.3 is concerned with glazing deflection. An estimation of the gap spacing between the glass sheets of the sealed glass units is required before and after the test.

Results of the NRFC procedure validation project

As well as showing good agreement between testing laboratories, between simulation laboratories, and between testing and simulation, the NRFC project showed there was not good agreement between tests with parallel, and tests with perpendicular wind on the weather side. Parallel wind tests agreed 100% with simulations. The conclusion of the comparison of parallel and perpendicular wind was thus: (11,12)

> "Parallel tests did not agree with perpendicular tests as well as either set of tests agreed with simulations. The trends in U-values between parallel versus perpendicular testing indicate that infiltration may not be adequately controlled in the perpendicular wind test. However, since there are so few data points, the project team recommends further research in this area."

ASTM E1423-91

> "This practice specifies standard test specimen sizes and test conditions, as well as the calculation and presentation of the thermal transmittance and conductance data measured in accordance with Test Method C1199. The standard sizes and conditions are to be used for fenestration product comparison purposes. The specifier may choose other sizes and conditions for product development or research purposes."

In section 6 dealing with test conditions, section 6.2 discusses wind direction.

> "The thermal conductance of the specimen is essentially independent of the wind direction relative to the fenestration glazing surface. For this reason, either a perpendicular or parallel weather-side wind direction may be used. However, it is recommended that a perpendicular weather-side wind direction be used due to the effect of the geometry of the fenestration systems, which can have a smaller effect on the surface conductance when using perpendicular wind patterns."

Section 6.3 defines the test temperatures and airflow rates to be used for comparison purposes.
On the room side 21°C and air velocity, for natural convection, less than 0.3 m/s.
On the weather side -18°C and wind speed 6.7 m/s.

Proposed BRANZ test method for windows

The first heat-metering box has been built for the new rig. It has dimensions 1.2m x 1.2m and meets or exceeds all the requirements of ASTM C236. If window sizes are restricted to 1.2m x 1.2m and to a range in maximum thickness of 125mm, then only one surround panel is required and its thermal resistance will not have to be measured. If the test conditions are also restricted to one set of temperatures and one set of air velocities, then only one calibration of a transfer calibration panel will need to be made.

Using parallel airflow on the cold side and using the ASHRAE summer airflow condition of 3.4 m/s (conductivity 23 $W/m^2/K$) will mean the fan can be smaller than would be required for perpendicular airflow, and there is not the same problem with leaks through the windows. The cold-side chamber has an air exchange rate of nearly 0.5 m^3/s which could be directed across the window face to further reduce the size of any additional fan required. If the air temperature sensors in the airstream adjacent to the window face are to be in keeping with the standards then the spacing between the window face and the baffle channelling the airstream, must be at least 100mm. This corresponds to an airflow of 0.4 m^3/s.

The method for construction of the calibration transfer standard requires the use of glass on both faces, but this could be substituted with something which has a smooth flat surface such as hardboard. Eventually a larger heat-metering box will be constructed and larger windows will be able to be tested.

Conclusion

Once commissioned, the new equipment will be able to test windows to the ASTM E1423 and ASTM C1199 combination with the test conditions of 21°C and 1 m/s air velocity on the indoor face, and a parallel airflow of 3.4 m/s and -10°C to 10°C on the outdoor face. This will meet the needs of the New Zealand window manufacturers by providing intercomparison between locally maufacturered windows and at the same time provide a basis for comparison with tests results from other countries.

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Moonshine Road, Judgeford
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REGIONAL ADVISORY OFFICES

AUCKLAND
Telephone - (09) 526 4880
FAX - (09) 526 4881
419 Church Street. Penrose
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