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Contact Resistance in a Steel-Framed Wall

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ABSTRACT: This paper sets out to answer, experimentally, the question "how much influence does the contact tightness between steel frame and facings have on the overall thermal resistance of a wall panel ?" The contact tightness has been equated to the mean contact gap between those two items. Accurate methods for both control and measurement of this gap have been utilised for this task. The experiment was devised so that precision adjustments to the contact gap could be made externally, and the wall panel was repeatedly adjusted and its thermal resistance measured, with no disturbance to any other part of the wall.

The results showed that the mean contact gap could be adjusted between a minimum of 0.5 mm and a chosen maximum of 3 mm. Variations solely in the tightness of fit between frame and facing (equated here to the mean contact gap) were found to produce up to ~ 30% variation (16% per face), from 1.30 to 1.51 m^2 °C/W, in the rated R-Values of the test panels studied. The effect was moderately linear.

KEY WORDS: Thermal resistance, contact gap, wall panels.

1. INTRODUCTION

Lightweight steel-framed construction for buildings is becoming increasingly important, but the prediction of thermal performance of wall panels built with steel frames has been uncertain. The thermal conductivity of mild steel (30 - 60 W/m.°C) is very high, over 300 times that of timber and 1000 times that of thermal insulants, and the overall effect on the structure has been difficult to predict by simple methods.

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Previous work [1 - 3] has suggested that the contact resistance between the steel frame and the facing materials is an important issue. Although the contact resistance is very small (typically ~ 0.03 m^2 °C/W) it is large compared with that of the ~ 75mm depth of steel (typically ~ 0.0015 m^2 °C/W). The contact resistance arises mainly from the fact that the frames are not completely flat, and pressure from the fixings can distort the frames as well. In previous tests with the same frame as used in this test series, mean gaps typically ranged from 0.75 mm to 1.5 mm on different occasions.

The purpose of this project was to demonstrate the magnitude of contact resistance effects on the overall R-Value, for a typical steel frame.

2. DESCRIPTION OF PROJECT

This was essentially a laboratory measurement project based on guarded hotbox measurements of R-Values of a steel-framed wall panel, to establish

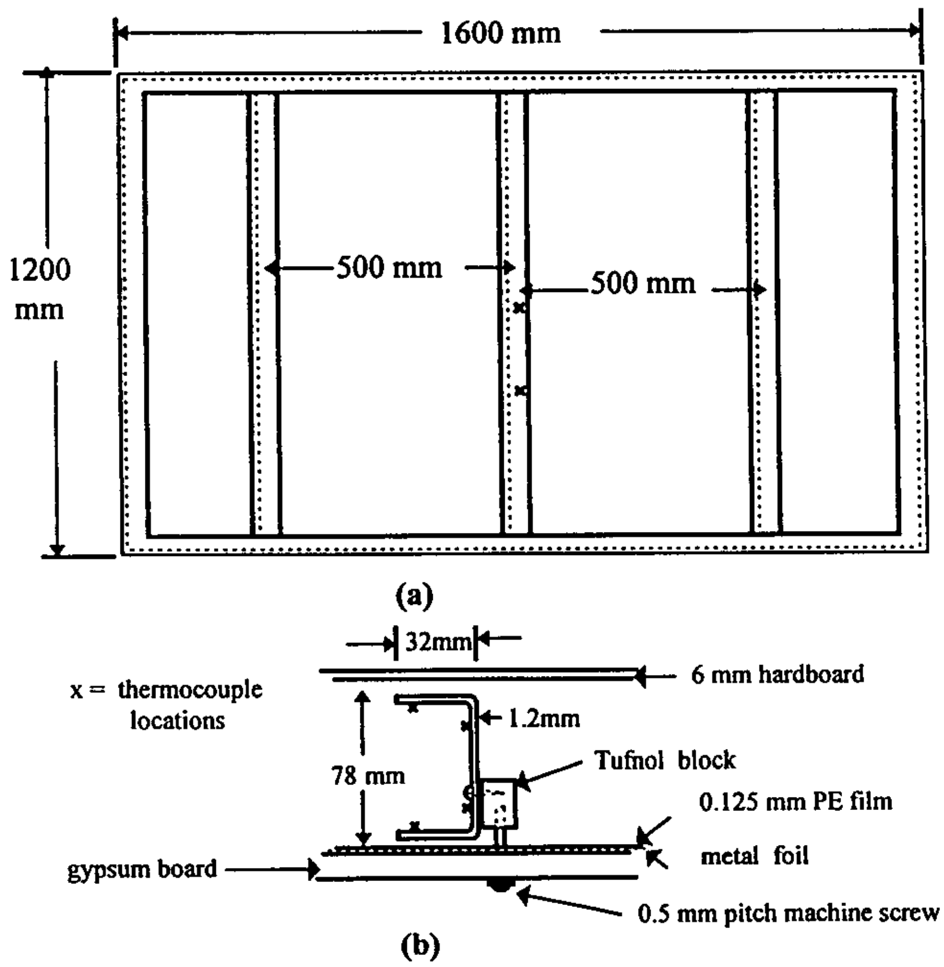

FIGURE 1. Layout of steel test frame.

the overall R-Value for the 1.6m x 1.2m panel as a function of the mean contact gap, when no other variations are made. Two different cavity insulations were used in two series of measurements using the same frame, to show any sensitivity to conductivity. All thermal measurements were made using a 1m x 1m metering box, by the Guarded Hotbox method, to ASTM C236 [4].

A single lightweight steel-framed panel, Figure 1, was clad with sheet facings on both faces, and insulated with one of the two fibrous insulants described below. Provision was made for precise variation of the contact tightness. The tightness of fixing of one facing was then varied, without any other change to the panel assembly, and the R-Value was measured at each value of tightness. Precise methods of measurement of the mean contact gap width (described later) were used to indicate the fixing tightness of the facing. The contact gaps achieved ranged from 0.48 mm (the tightest obtainable) to 3.0 mm (chosen arbitrarily as a very poor fit). The "normal" gap was about 0.75mm. Temperatures in the steel frame were also monitored, to indicate approximate heat flows in the steel frame members.

The contact tightness was varied only on the warm face. The cold face was left constant throughout the tests at a "normal" fixing tightness. This limitation was necessary because rear access could not be obtained without disturbing the panel. This restriction avoided any need to disturb the panel between tests except as intended.

To compare the ability of simple calculation methods to forecast these effects, the measured R-Values were compared to calculation by the simplified methods of "Isothermal Planes" and "Parallel Flow", as described in the ASHRAE Handbook of Fundamentals [2].

3. TEST PANEL

The lightweight steel frame used in these tests is detailed in Figure 1. The galvanised steel members, 1.2 mm thick, were standard commercial rolled steel, spot welded at intervals to form a frame. The frame facings were assessed as flat within 3 mm before fixing the facings.

The cold side facing was of 6 mm thick hardboard, screwed to the frame using No. 6 self-tapping screws (3.5 mm) at a spacing of ~ 300 mm. This is consistent with local building practice, and provides adequate racking strength [5]. These fixings were touched again only once, to change the insulant between the two test series.

The warm side facing was made of paper faced gypsum plasterboard. This had aluminium foil bonded to the frame side of the board, and the foil was in turn covered with clear 0.125 mm polyethylene film to provide electrical insulation from the frame (see section 4). This gypsum board facing (see Figure 1b) was attached to the steel frame via "Tufnol" resin-bonded fibre blocks at 300 mm centres, which were tapped for M3 machine screws (3 mm dia.) of 0.50 mm pitch. This mounting was designed so that the gap between facing and frame was electrically insulated, and could be precisely controlled from outside the panel.

Two grades of blanket insulation were used in this panel, in two separate series of tests. One was fibreglass batts of thickness 79 mm, density 8.0 kg/m^3, and R 1.74 m^2 °C/W, the other was sheepwool batts of thickness 78 - 80 mm, density 11.6 kg/m^3, and R 1.38 m^2 °C/W, as measured by guarded hotbox to ASTM C236 [4]. In both cases the insulant was installed to fill the entire cavity space, including the space within the steel stud and edge members, and was placed uniformly with no visible edge gaps, folds, creases, or other discontinuities.

4. MEASUREMENT OF THE CONTACT GAP

The main method for both setting and monitoring the contact gap spacing, was by a screw turn count method. This method was first calibrated against feeler gauge survey of the gap. During testing, an electrical capacitance method as below was used also, mainly to confirm that no errors in the turn count had occurred. That method is reported because it seems to have excellent potential for any other work of this type. All these methods are discussed below.

Feeler Gauge Survey: The gap mean value and distribution were found by survey, using finely tapered wedge gauges, and by automotive feeler gauges where the gap was small. For each survey 108 measurements were made, from both edges of all stud flanges.

Feeler gauges are routinely used in metal working industries to resolve gaps to a few microns. In our panels individual measurements are considered to be within ± 0.01 mm, on the grounds that this is the difference between a feeler gauge that was clearly "slack", and one that would not enter the gap. A total of 108 measurements on each panel (viz, @ ~ 150 mm spacing over the whole frame), were made for each condition. From these the standard deviation was typically 0.8 mm, and the standard error on the mean was therefore typically 0.08 mm. These variations were clearly dominated by actual variance in the gap width, rather than by error of individual measurements.

Screw Turn Count: The main method used for making changes to mean gap width, and also to track spacing changes, was to simply count the number of turns of the (0.5 mm pitch) machine screws which attached the gypsum board to the steel frame, from the known starting position.

The use of machine screws ensured that the thread pitch was of high precision. The screw slot orientation was used for counting the turns, and was judged by eye.

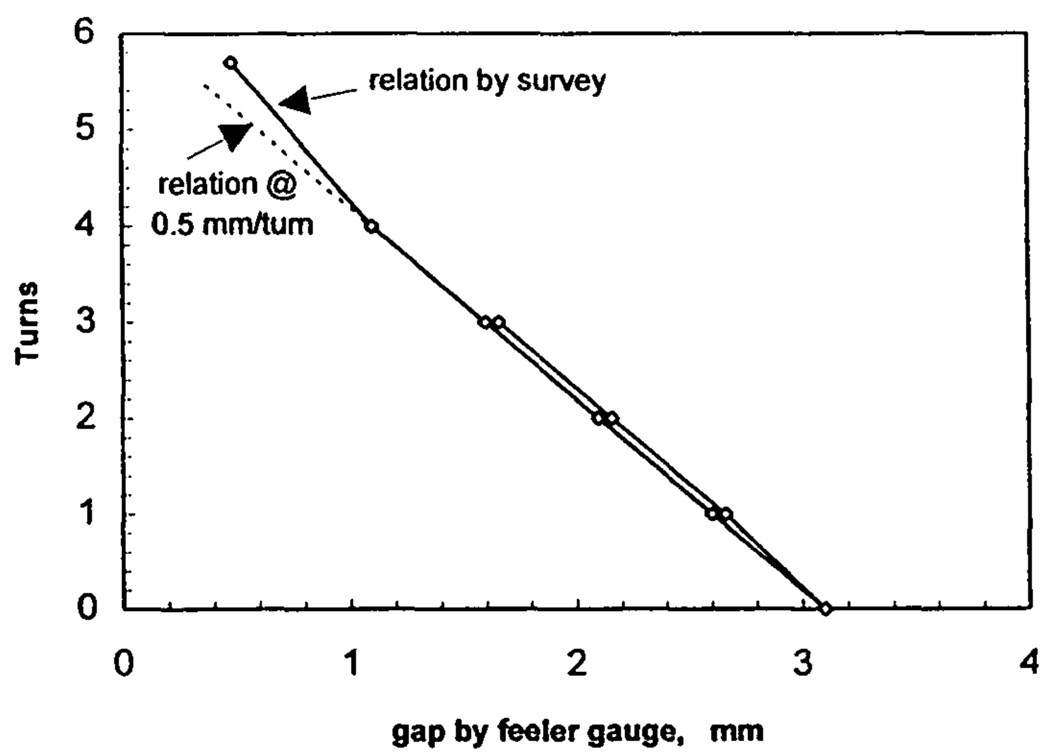

FIGURE 2. Calibration of screw turn control v thickness by survey.

It is easy to judge this orientation to 1/16 turn. This indicates a resolution of this method within 0.03 mm. By comparing with feeler gauge measurements, as in Figure 2 with one facing attached, this method agrees with feeler gauge values within 0.005 mm, except for the tightest 0.5 mm where distortion up to ~ 0.2 mm occurred.

Electrical capacitance method: A third method was to measure the electrical capacitance between the steel frame and the aluminium foil bonded to the gypsum plaster board. The frame and foil were electrically insulated from each other by the clear 0.125 mm polyethylene film. This film together with the air space forms the dielectric of the capacitor formed by these two elements. The capacitance was measured at a series of mean gap settings from 0.5mm (the tightest obtainable) to 3mm as found by survey as above, and the result of this calibration is shown in Figure 3.

The accuracy of the capacitive method was found by calibrating it against the two direct mechanical methods. The method is described and assessed below.

The electrical capacitance between the steel frame and a layer of conducting foil on the back of the lining board is in the order of a few thousand picofarad. The capacitance of a parallel plate arrangement is given in Equation (1)

$$C = \frac{\varepsilon . A}{b} \qquad (1)$$

where

C = capacitance, farad
ε = permittivity farad/m ($8.85.10^{-12}$ for dry air)
A = area , m^2
b = mean spacing, m

The permittivity of air varies with temperature and relative humidity, but the amount of variation is too small to be of interest for this project. The permittivity of dry air relative to vacuum [7] is 1.00054 , and for air at a dewpoint of 11°C is 1.00066. The laboratory space was continuously monitored, and remained within 35 % to 45 % through the tests. Thus changes in capacitance from RH variations would have been less than 0.01 %.

If there is an electrical insulating layer of relative permittivity S, and thickness $b2$ (leaving a residual air space of thickness $b1$), then this can be treated as two series plate capacitors, and the apparent space B between the plates is :

$$B = \left(b1 + \frac{b2}{S}\right) \qquad (2)$$

The capacitances were measured with a Thorn B183 L-C-R meter, having resolution of 0.1 pF to 1 pF in this range. Lead capacitance was always less than 10 pF, equivalent to less than 0.001 mm change in contact gap.

The results of calibrating this method for the wall panel are shown in Figure 3. Two sets of results are given, for "before" and "after" attachment of the cold side facing.

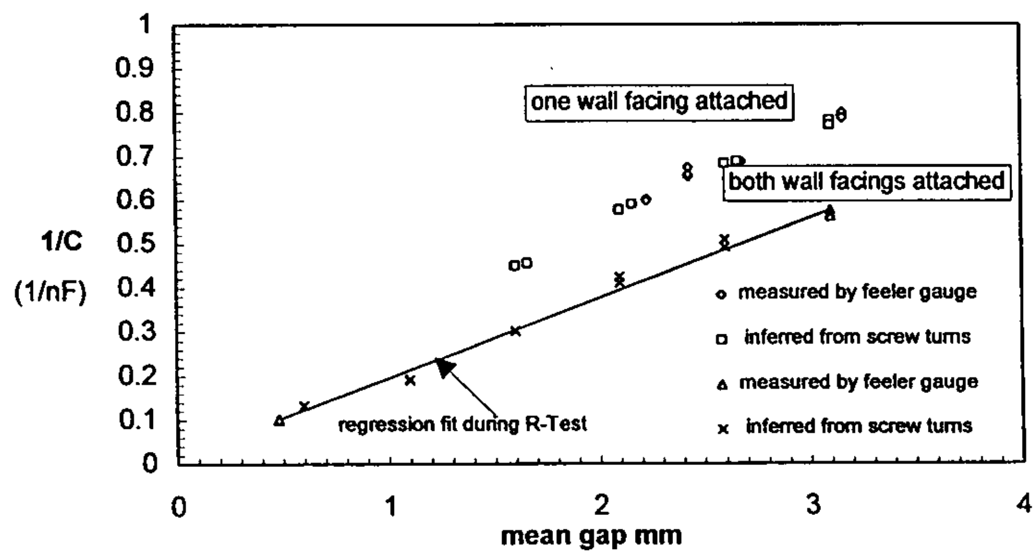

FIGURE 3. Electrical capacitance v mean gap (one face).

The "before" calibration was established against feeler gauge survey values as in Figure 2 and Figure 3. The gap was reset to 3.1 mm, and then the coldside facing was attached. The capacitance increased from 1.3 nF to 1.7 nF at that time. Initially this was attributed to distortion of the frame by pressure of the fixings, but was later found to be due to additional stray capacitance provided by the cold side facing material. This was confirmed by monitoring the capacitance whilst the cold side fixing screws were first slackened and then removed. The capacitance did not change until the board itself was removed, and thus distortion could not have been a factor. The relation between capacitance and the screw turn count was then determined as in Figure 3. Regression shows that the mean contact gap g mm for the complete panel can be inferred from the capacitance C nF, according to Equation (3)

$$g = 5.509/C - 0.078 \text{ mm} \qquad \pm 0.05 \text{ mm} \qquad (3)$$

Equation (3) is estimated as within ~ 0.05 mm at 95% confidence. Thus the method is satisfactory within that tolerance, and was used to confirm that no errors had occurred in the turn count.

5. PROCEDURE

Guarded hotbox measurements of the thermal resistance of the whole 1.6m x 1.2m panel were made by the Guarded Hotbox method, ASTM C236. The initial mean gap between frame and warm side facing was set at 3.1 mm, based on feeler gauge data. The thermal resistance of the panel was then measured repeatedly for a succession of mean gap widths, by progressively tightening the machine screws in 0.5mm steps (ie, 1 turn), until the tightest fit obtainable (0.48 mm) was reached. During this entire process no other disturbance to the panel was allowed: no other part of the panel was moved, nor was the panel disturbed or dismounted from the hotbox rig. On the completion of these measurements, the panel was removed and opened, and the insulant changed from fibreglass to sheepwool. The mean gap was then resurveyed by feeler gauge, and the procedure for the first series was repeated in reverse. During the second series, the steel frame temperatures were also recorded (these were recorded in the first series, but records were accidentally destroyed).

Surface thermocouples were attached at four points in two locations along expected isotherms on the flanges and webs of the central steel stud. The thermocouple leads were dressed neatly along these expected isotherms of the studs, firmly attached to the steel with adhesive tape for a distance of >100mm. Corresponding thermocouples were also attached to the cavity side of the warm side facing.

Both outside surfaces of the panel were fitted with an array of 5 pairs of differential surface-air thermocouples, and the overall air-air temperature differences were recorded from a set of 4 pairs of differential thermocouples. All thermocouples were fitted as for standard commercial R-Value tests to ASTM C236 in this laboratory.

6. RESULTS

The measured thermal resistances v the mean contact gap during the test, for both insulants, are given in Table 1 and also illustrated in Figure 4. Both series show clearly that the overall R-Value of this panel varied in response to the mean contact gap, over a range of some 16 % for variations of contact gap on just one side.

The temperature gradient across the steel frame was ~ 3.0 °C, about 22 - 29 °C/m along the web of the stud. This was some 20% of the overall temperature difference across the panel. From this the heat flux in the steel of 1100 - 1400 W/m^2 or 1.3 - 1.7 W/m run was inferred, using an assumed conductivity of 50 W/m.°C [8] for the steel.

7. DISCUSSION

The two mechanical methods used for mean gap measurement between the steel frame and the facing have been shown to have an accuracy within 0.02 mm and 0.03 mm respectively. The electrical capacitance method has an accuracy within 0.05 mm, as illustrated in Figure 3. All gap measurements appeared to agree, within the confidence figures assessed above. There can thus be confidence in the measured gap values within the level required for this project.

Table 1. Measured R-Values v mean gap for two insulants

Insulant R = 1.74 m^2°C/W		Insulant R = 1.38 m^2°C/W	
Mean Gap mm	Measured R-Value, m^2°C/W	Mean Gap mm	Measured R-Value, m^2°C/W
3.1	1.52		
2.6	1.483		
2.1	1.445		
1.6	1.414	1.5	1.25
1.1	1.357	1.0	1.17
0.6	1.322		
0.48	1.302	0.48	1.15

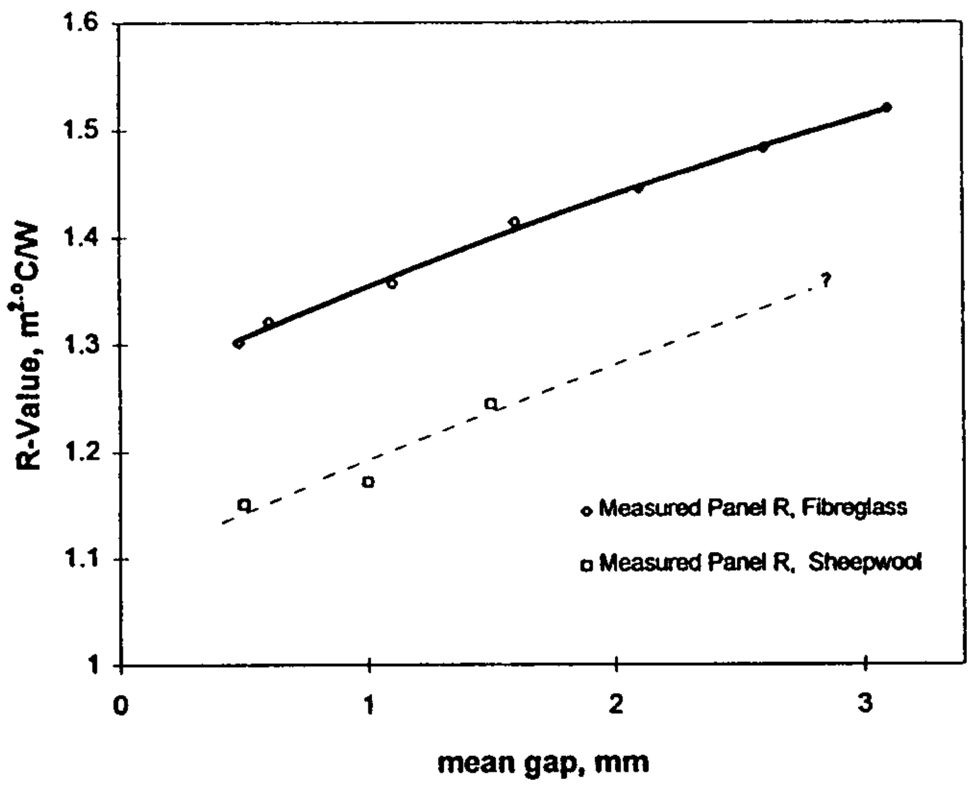

FIGURE 4. Measured R-Values at various mean contact gap (one face varied).

The results in Table 1 and Figure 4 show that there is a substantial and consistent change of R-Value as the fixing tightness of the facing is changed. One might expect this to be true when large gaps of 2 or 3 mm are present, but Figure 4 shows that the effect continues to be significant down to the smallest gaps obtainable. In a "normal" wall panel the changes would be double those measured here, as the gaps on both sides would vary, rather than on just one.

These results offer a mechanism to account for previous testing in which the R-Value of a panel had been able to vary, sometimes up to 30%, after merely dissassembling and reassembling precisely the same parts in what had previously been thought to be the same way.

It is clearly of interest to try to quantify the typical ranges of fit for different frames and facings. In this frame we were not able to tighten the mean gap to less than 0.48 mm, equivalent to a contact resistance of ~ 0.02 m^2 °C/W, because the steel frame was not flat enough. This itself might cause some surprise, as the frame did appear to be flat. A standard default value of 0.03 m^2 °C/W for contact resistance in "normal" light steel-framed panels has become adopted in our laboratory [2] on empirical grounds, and this is equivalent to a mean gap of about 0.75mm. There was no indication that there was anything unusual about the assembly, which appeared to be tight, and followed normal screw spacing and sizes.

Table 2. Comparison of measured and calculated values by isothermal planes and parallel flow methods

Mean Contact Gap, mm	Estimated Contact Resistance m²°C/W	R-Value by Parallel Flow Method, m²°C/W	R-Value by Isothermal Planes Method m²°C/W	R-Value by Measurement m²°C/W
0.0	0.0	1.42	0.98	-
0.5	0.02	1.47	1.16	1.30
1.0	0.04	1.50	1.19	1.35
1.5	0.045	1.53	1.25	1.40
2.0	0.055	1.56	1.31	1.45
2.5	0.065	1.59	1.36	1.47
3.0	0.085	1.61	1.41	1.51

Neither the relative temperature gradients across the steel frame, nor the temperature pattern over the facing along the stud line, showed significant differences between the vicinity of the screw fixings and elsewhere. When the steel screws on the cold side facing were replaced by nylon screws of the same diameter, there was zero change in thermal resistance, and thus conductance along the screws must have had only minor influence on overall heat flow.

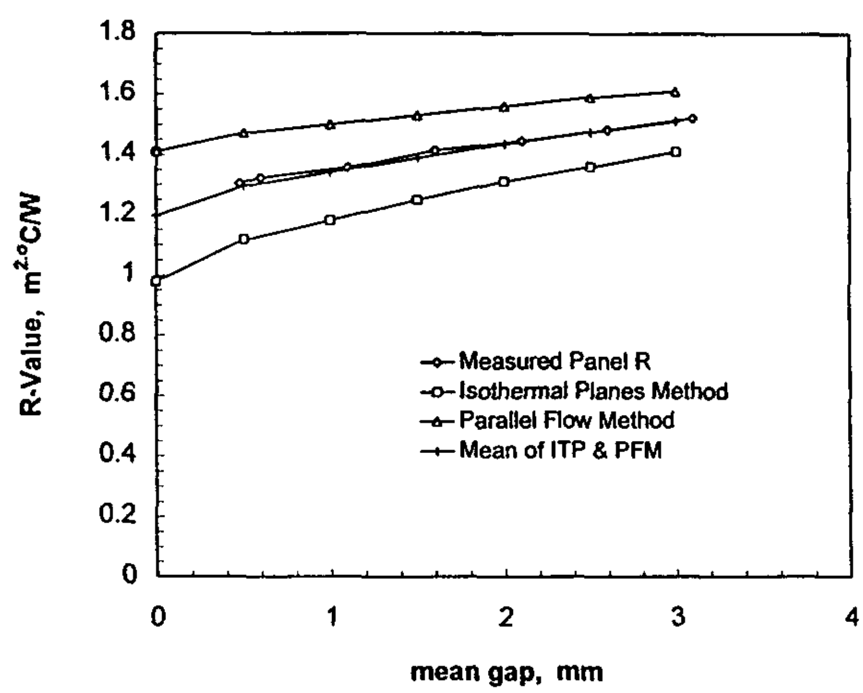

FIGURE 5. Comparison of calculated R-Values, fibreglass insulation (one face varied).

The measured results for the fibreglass-insulated case were compared with calculated values from the Isothermal Planes and Parallel Flow methods [1, 6]. The Isothermal Planes calculations were carried out according to the rules described in [6], and for very small gaps ≤ 1 mm, the resistance of the contact gap was taken as (0.04∗t) m^{2}°C/W, with 't' being the mean gap width in mm. These contact resistances were also included in the Parallel Flow calculations (this would not normally be done), where they produce over half of the variation in Table 2 and Figure 5. This shows that the Parallel Flow method gives an over-optimistic forecast, whilst the Isothermal Planes method is conservative. The average of the two is in this case close to the measured values.

8. CONCLUSIONS

The contact between metal frames of wall panels and the (warm side) facing attached to them has been shown to affect the observed R-Value of the panel by some 16% when the mean gap between stud and facings was varied over 0.5 to 3.0mm. This was found to apply for two insulation levels, under conditions controlled so that the only change during the test series was to the tightness of the fixing.

A method using electrical capacitance was used as one way to measure the mean contact gap in a single measurement, and appears to have been very successful. The smallest mean gap obtainable in this panel was 0.48 mm under the tightest possible screw pressure, and a typical range has been observed to be 0.75 - 1.5 mm.

The contact thermal resistance of these gaps was about 0.02 m^2°C/W for 0.5 mm, to 0.1 m^2°C/W for 3mm. This variation of 0.08 m^2°C/W produced a change of 0.21 m^2 °C/W, or some 16 % in the overall R-Value.

The Isothermal Planes method of predicting the thermal resistances was found to respond to the changes due to contact quality, but the Parallel Flow method responded inadequately to those changes, even when boosted by the (unusual) inclusion of contact resistances

Variations solely in the tightness of fit between frame and facing (equated here to the mean contact gap) were found to produce about 30% variation (16% per face) in the rated R-Values of the test panels studied.

ACKNOWLEDGEMENTS

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