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R-VALUES THAT ARE MADE-TO-MEASURE

H.A. Trethowen

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R-Values That Are Made-to-Measure

H.A. Trethowen
ASHRAE Member

ABSTRACT

Calculated R-values for a variety of timber-framed, concrete masonry, and panel constructions have been compared to measured values, using results from 10 years of laboratory testing for industry and from field surveys of nearly 100 occupied houses. From this data it is concluded that R-values can be realistically predicted by simple formulae with care and sound judgment.

The principal factors causing R-values to vary from ideal are argued to be the well-known and widely ignored trio of thermal bridging, gaps in insulant, and moisture (moisture effects are not examined here). Thermal bridging is shown to reduce realized R-values by up to 50% in common cases, even with timber framing, and the reduction becomes even more severe with increasing R-value. In many cases this loss can be largely avoided by using thermal breaks.

A recent trend towards wider acceptance of "zero lateral conductance" calculations is deprecated, and the alternative "infinite lateral conductance" is instead advocated for engineering purposes.

INTRODUCTION

Designers are sometimes required to recommend construction details to achieve a particular R-value, especially where the item is being designed down to a price but needs to meet a specification or regulation requirment.

The R-values of building structures have been found in some cases to vary widely from the "expected" value. These variations can usually be accounted for by complex analysis. Testing can be used and should always be the final arbiter, but calculation of some kind is still needed.

The reasons for R-values falling below "expected" values are usually one or more of the well-known trio of thermal bridging, gaps in insulation, and moisture. Except for one issue, moisture is not considered here. Gaps in insulation are considered to be a form of thermal bridging. Hence, this paper deals principally with thermal bridging and also with several details of heat transfer behavior.

Designers have a need for methods of calculation that are both reliable and simple, although the behavior of heat transfer is variable and complex. This paper intends to show that there is a good compromise, in which a degree of engineering skill plays a part. Where simple methods of calculating R-values are required for structures with thermal bridging, the procedure advocated is that of assuming infinite lateral conductance adjacent to the bridged zone (method 2 below). There has been in recent years a swing towards the wider use of the zero lateral conductance model (method 1 below), which is not compatible with either laboratory or field experiences summarized here.

H.A. Trethowen. Head of Components Research, Building Research Association of New Zealand, Private Bag, Porirua, New Zealand.

TYPES OF THERMAL BRIDGES

The most common types of thermal bridges are illustrated in Figure 1, and can be referred to as:

1. Structural bridge,	- where structural elements form a heat conducting path bypassing the insulation.
2. Insulation gap,	- where defects in workmanship, settling, or shrinkage of insulation, create gaps in the insulation.
3. Air circulation bridge,	- where the presence of gaps allows circulating convective air currents.

The best-known type of thermal bridge results from the presence of structural elements. However, the other types can be at least as important.

In both structural bridges and insulating gaps, heat flowing in to the warm side of the structure flows laterally along some conducting layer to an easier crossing point. Thus the final effect may depend on the conductivity of the facing materials. The air circulation bridge does not rely on lateral conduction in the facing materials and can operate equally well with high or low conductive facings.

THE EFFECTS OF THERMAL BRIDGING

It is not hard to imagine metal bridges having considerable effect, but it is less obvious that structural bridges of timber can be almost as important. This arises partly because of the large difference in thickness between (say) a steel stud of 1 mm thickness and a timber one 50 mm thick, but also because of the ability of the facing material to deliver heat to the bridge from nearby zones.

In the case of high conductivity materials such as concrete in high density concrete masonry, the ability of the concrete face and webs to conduct heat is sufficiently large that attempts to insulate the cores have only limited effect.

CALCULATION METHODS

Only the simplest methods of calculation are considered here. They are based on three alternate assumptions:

1. Method 0 - thermal bridges are ignored
2. Method 1 - lateral heat conductance is zero
3. Method 2 - lateral heat conductance is infinite.

The details of how to carry out these calculations has been given in various references [1,2,3]. They have been particularly clearly described by Valore[3] . The formula for methods 1 and 2 is the same, but the sequence of calculation differs. Figure 2, reproduced from Valore[3] illustrates the difference. For method 1 the conductances through the entire structure are area weighted, while in method 2 the conductances that are area-weighted are those through just the bridged portion, to which are then added the resistances of the outer layers. The procedure can be carried out without undue difficulty for more complicated structures, such as cavities with timber members crossing at right angles, or even for concrete masonry. How successful these calculations are is discussed later.

Figure 3 shows a complete sample calculation for one case (case 10 of Table 1). This illustrates the procedures used throughout this paper.

The sequence in method 1 carries an implicit assumption that there is no lateral heat flow. The sequence in method 2 carries an implicit assumption that there is unimpeded lateral heat redistribution of heat flow in the layers immediately outside the zone where the thermal bridge calculation is made. Although the term "infinite lateral conductance" is used, this should not be misunderstood. Firstly, it is the conductance and not the heat flow that is unlimited. Secondly, the lateral conductance does not need to be infinite, only large enough to allow heat redistribution. Figure 4 suggests that this condition is commonly approached.

It is not hard to find cases where any one of the methods 0, 1, or 2 may fit measured data more closely than the others. Table 1 and Figure 4 attempt to show that method 2 is more likely to be reliable than the others.

COMPARISONS OF MEASURED AND CALCULATED RESULTS

The results introduced here have been selected from more than 10 years of routine laboratory and development testing, with recent additions from field surveys incorporating about 100 houses. "Measured" results for laboratory data were obtained from a 1 m square guarded hotbox equipment to ASTM C236, for conditions in the vicinity of 20°C, 50% rh and 5°C, 80% rh. "Measured" results for field data were obtained using interior surface mounted heat flux meters, 600 x 450, over a three to four-day period.[8] The field measurements were reported to be accurate within ± 10%.

The material properties listed are approximations only and are considered to be within ±5%. Because of the source of the results, individual thermal conductivities were not always obtained. Further, the insulants involved were of domestic grade and not entirely uniform.

Panel and Timber-Framed Structures - Laboratory measurements

Fifteen results from panel and timber-framed structures are presented in Table 1, and illustrated in Figure 4 together with results from references 4 and 5. The Table 1 results have been selected from some 200 cases of routine product development testing in the author's laboratory and are intended to reflect the typical nature of results and not to represent extremes.

Three things are apparent. Firstly, the degree of agreement between the three different methods of calculation ranges from excellent to poor. In the worst cases, there is some 2:1 difference between the three predictions. Secondly, where agreement between the methods is good, the measured value is also in close agreement with that calculated. Thirdly, where there are differences between the three methods, the result from method 2 is always close to the measured value, and method 1 and 0 are not always close to that measured.

There are four basic types of construction included in Table 1: timber-framed wall panels, metal-framed wall panels, insulated timber plank walls, and timber-framed roof panels. All four types exhibit the common pattern described above. In certain cases, possible variations are explored, such as the contact resistance (cases 4, 9) or the observed insulation edge gaps (case 10). These factors are discussed further in a later section.

Also shown in Figure 4 for comparison are previously published data from two USA studies [4,5] on insulation defects. The first [4] describes a timber-framed wall panel in which additional insulation gaps were cut. Four cases are shown, corresponding to insulation gaps of 0, 5%, 10%, and 15%. The form of this data suggests that when gaps are large (10% or more) method 1 fits better, but for more realistic workmanship with 5% or less gap, method 2 fits better. These figures represent substantial gaps - a 10% gap was 120 mm (nearly 5in). The second [5] describes not a made-up structure but insulating material in which gaps were formed. The cases illustrated here are those where gaps were cut through the entire 90 mm thickness of insulant, and method 2 appears once again to fit reasonably. Other cases were cited [5] in which gaps were cut in only upper or lower halves of the insulant. Those results (not illustrated here) differ appreciably from all three methods and have the unusual feature of not having appreciably higher resistance than those where gaps penetrated the entire thickness.

Concrete Masonry - Laboratory Results

Eighteen results for concrete masonry walls are presented in Table 2 and illustrated in Figure 5. They were obtained in routine product development testing in the author's laboratory. There is an immediate problem with concrete masonry over whether the prediction is to be based on the block or the wall. As will be shown, there can be very substantial differences between these two. For the moment the calculated resistance for the block will be used, as has been common in the literature, but the measured values refer to whole wall performance. For brevity the block dimensions are omitted, and results are not sensitive to the exact concrete dimensions.

The principal implication of Figure 5 is that there appears to be a limit to the R-value of about 0.7 m^2C/W, which only two cases have bettered. This limitation is considered to be real and to result from the thermal bridging that occurs in the mortar and from air circulation bridges, which form in the mortar gap when insulated blocks are assembled into walls.

The two cases that better this limit were both deliberately designed to have no mortar gap. In cases 11 and 12, which showed R-values of 1.0 m^2C/W, mortar rebates were formed at the block corners so that mortar could neither bridge the insulating layer in the block nor form a gap between blocks. The same block design previously erected into a wall with traditional mortaring (case 8) produced an R-value of only 0.60 m^2C/W, even when care was taken to avoid mortar spill. In case 15 a wall erected from blocks with no mortar at all showed the blocks to have an R-value of 1.56, but when traditionally mortared, the wall could reach only 0.77 even when great care was taken to avoid mortar spill.

Figure 5 also shows the calculated relationship between the R-value of a wall and that of the blocks, using method 2. This should be compared with the points for the cases just discussed. While an exact agreement is not to be expected, there is a realism about the correlation between these predicted results and the measured ones.

Field Survey Data

In 1982-83, a field survey of R-values in occupied houses[8] was conducted in New Zealand, based on heat flux sensor measurements. Including both the pilot survey and main survey, about 100 houses were measured. The purpose of this survey was to establish how well the building industry at large was coping with insulation regulations produced in 1978. The survey used nondestructive methods, and, therefore, the details of construction were not always available. The heat flux sensors were large enough (600 x 450mm) to ensure they would span timber-frame members and, thus, not be very sensitive to positioning. Prescreening with hand-held radiometers was used to avoid placement of sensors at atypical points.

Therefore, the measured performances described in this section are not compared with individual predictions but with generic predictions based on overall descriptions. The source of these generic predictions was a set of illustrated tables[9] for quick reference selection of R-values by builders and inspectors. These tables were prepared for local use, reflecting local building practices, and include allowance for thermal bridging. They were based primarily on calculation by method 2.

The results of this comparison are illustrated in Figures 6 and 7. The agreement for walls is good, with nearly all results falling within ± 20% of the prediction just described. The agreement is rather less good for roofs, where perhaps one fourth of the results are little better than half that predicted, especially in the intermediate range of values. In the report[8] on this survey, there is some discussion on the reasons for this, with thermal bridging by structural timber, air gaps around poorly fitted insulation, and short measure of insulation all being cited as contributors. No need was suggested to invoke factors beyond these three to account for the differences.

DISCUSSION

The discussion below centers on several details of heat transfer behavior that are significant in arriving at these results. The degree of correlation between measured and calculated values in Figures 4 and 5 probably represent the best that can be done with simple methods. In many cases, the use of normal handbook data and methods alone would have produced far greater discrepancies than are apparent in Figures 4 and 5.

Contact Resistance

There is always some contact resistance between conducting layers, and it is usually of no significance. An exception is for very highly conducting thermal bridges such as metal framing in a panel. Contact resistance varies widely according to surface roughness and contact pressure, though not to emittance. Typical building values range around 0.01-0.03 m^2C/W, corresponding to an average gap of less than 1mm.

Cases 4 and 9 of Table 1 illustrate the effect. In case 4, three different values of contact resistance were used as trial values, since the true value was not known with much accuracy. Methods 0 and 1 do not indicate that any difference should be expected as a result, but method 2 shows great sensitivity to contact resistance. It is evident that the contact resistance should have a marked effect, since its value, in the order 2 x 0 .03 m^2C/W, is some 20 times that of the aluminium extrusion, about 0.003 m^2C/W. In case 9, the addition of a thermal break with an R-value of 0.3 m^2C/W to what is otherwise the same panel largely remove the difference between methods. This step gives a result that is a smooth extrapolation of the case 4 results. There is a need for more data on contact resistances to be collated and made readily available in reference handbooks.

Mortar Bridging. The mortar applied in traditional assembly of concrete masonry walls spreads very widely and frequently may bridge across any insulation system built into the blocks. This effect may be seen in cases 13 and 14, of Table 2 where more careful rebuilding of the same blocks lead to an improvement of about 17% in the R-value. However, even with this particular care taken, bridging of the insulant was not entirely prevented.

Air Circulation Bridging

Many of the concrete masonry results in Table 2 are believed to be limited by air circulation bridging, in addition to their internal structural bridging.

In cases 4-7, the concrete blocks were made with one or more sets of slots in which inserts of aluminium foil were placed. These were intended to each create a double reflective cavity, with hoped-for R-values of 1 to 2 m^2C/W. It was initially thought that thermal bridging by concrete webs was preventing this performance, but a series of development tests involving conduction breaks in these walls did not support this view. Instead, it was found that the foil inserts did not remain straight, and in addition there were gaps between the inserts at the mortar joints - this allowed air circulation within the masonry cavities, between the supposedly separate reflective cavities. Air circulation bridging has not been highlighted in literature, and yet appears to be an important process.

Air circulation bridging can clearly occur with some other insulated block designs. It is suggested that this mechanism is the main reason for the failure to find any masonry walls exceeding R-0.8 when mortared in the traditional way.

There is no readily available data on the effects of air circulation bridges, and this should be remedied. Based on a crude engineering calculation, a provisional rule is suggested that an air circulation bridge will approximately halve the R-value between the limits of the air circulation zone. This rule has been used in calculations presented here, apparently successfully.

Emittance

The radiative contribution to heat transfer is easily miscalculated. One of the most important factors is moisture. It takes only the slightest deposit of dew on metal foil to make the surface practically non-reflective. Following Bassett and Trethowen[10] it is clear that if there is enough condensate to be visible at all, the mean emittance of aluminium foil is probably over 0.2 or 0.3. Thus, if foil is used in other than an ideal position from the moisture control point of view, it will probably not come up to expectation on insulation value - this is believed to be the reason for case 6, Table 1, falling short of prediction.

On the other hand, it may be noted that bright galvanized steel often has emittance of about 0.2 and may contribute a little to insulation value. Glass, ice, water, and clear lacquer, however, are all opaque and near-black to long wave radiation, as are most nonmetallic finishes of all colors.

Heat Transfer across Cavities

Engineers sometimes ignore the fact that heat transfer coefficients vary widely according to the direction of heat flow and even the aspect ratio of a cavity, as well as with boundary emittance. Data on these are readily available.[1]

Real construction details often include odd gaps and cavities, and they have to be properly allowed for if realism is not be lost. Examples are the triangulated cavities behind bevelled weatherboards or narrow cavities between underlays and cladding. From routine industry tests, we have observed a contribution of about 0.15-0.17 from the gaps behind bevelled weatherboard, equivalent to an average gap of some 12 mm. Figure 8 gives resistances for very narrow gaps, derived from Robinson et al.[6] Although those data were verified only for cavity thickness down to 15 mm, this extension has been found to be consistent with laboratory observation in routine tests.

In Situ Thermal Conductivity

The thermal conductivity of materials in situ sometimes varies from the manufacturer's rating, and dimensions may also differ. This should be anticipated by the designer where it is likely to occur. The conductivity of low density insulants can vary sharply with density. Insulants may settle or sag or shrink, often in ways that can be anticipated, and their apparent insulating value can then be anticipated with some realism. The values predicted in Table 1 have been based on the observed installed density of compressible insulants rather than solely on manufacturer's data.

The thermal conductivity of materials usually increases with temperature. The variation is typically 0.5%/°C. This can lead to significant changes in effective R-values. However, this effect has been given less emphasis here in favor of other effects that can be much larger.

CONCLUSIONS

Four conclusions are drawn from the data presented here:

1. Simple area-weighted thermal bridging calculations can be satisfactory for engineering applications where 10% error or so is acceptable, even for multiway bridging, but only if they are:

   a) based on method 2 (infinite lateral conductance);
   b) based on wider knowledge of heat transfer (contact resistance, air circulation bridging, in situ emittance, and conductivity values, etc.);
   c) executed with a certain input of skill, knowledge, and experience.

2. There is a need for more available data on contact resistance and air circulation bridging.

3. The most common reason for R-values to be lower than predicted appears to be one or other form of thermal bridging. (However, most of the cases discussed here have not been exposed to the effects of dynamic moisture movement, and this must be still considered.)

4. Insulated single-skin high-density masonry is limited to R-values of about 0.7 m^2C/W unless the method of mortaring is redesigned.

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TABLE 1
Measured vs Calculated R-Values for Timber Framed and Panel Constructions in order of increasing measured R-Value

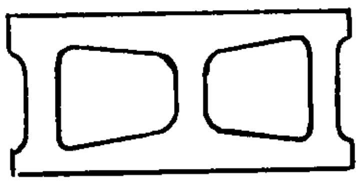
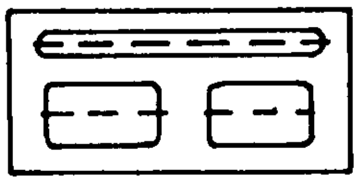
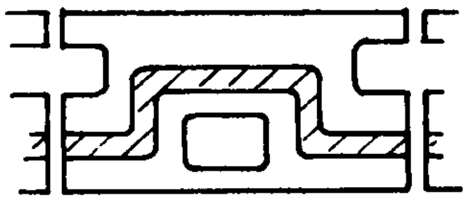
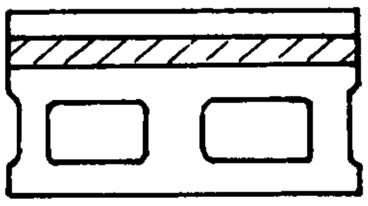
Case	Calculated Method 0	 Method 1	 Method 2	Measured	Description
	R Value m^{2}C/W				
1	0.41	0.45	0.43	0.37	Timber framed wall. Studs 97x47 @500, nogs 97x47 @1000. Clad interior 10mm gypsum board. Clad exterior with 265x7.5 cement fibre planks lapped 30mm. No sheathing
2	0.99	0.90	0.90	0.75	Insulated timber plank wall, 180mm pitch. Planks 43mm timber+19mm EPS 150mm wide.
3	0.85	0.87	0.87	0.85	Timber framed wall. Studs 97x47 @500, nogs 97x47 @1000. Clad interior with foil-backed 10mm gypsum board, exterior with 265x7.5 cement fibre planks lapped 30mm. Paper sheathing.
4				0.90	RHS (50x25,2.5 thick) aluminium frame panel, 800x1200. Cavity filled with 50mm EPS (R=1.43). Clad interior 10mm gypsum board, exterior 6mm cement fibre board.
	1.65	1.22	0.60		assumed contact resistance=2x0.015 (between RHS and claddings)
	1.65	1.27	0.82		assumed contact resistance=2x0.030
	1.66	1.30	0.97		assumed contact resistance=2x0.045
5	1.52	1.21	1.02	1.00	Insulated timber plank wall, 130mm pitch. Planks 23mm EPS core (R=0.66) in two 45mm wide segments, with 10mm and 35mm timber facings.
6				1.03	Roof panel. Joists 97x47 @500, nogs 97x47 @1000. Clad interior 10mm gypsum board. Clad exterior GMS tiles on 50x50 purlins, over double sided foil underlay.
	1.13	1.14	1.15		- assuming foil underlay totally dry
	0.99	1.0	1.01		- assuming foil underlay has just-visible condensate (1 g/m^2)[10]
7	0.88	0.91	0.91	1.05	Timber framed wall. Studs 97x47 @500, nogs 97x47 @1000. Clad interior foil-backed 10mm gypsum board. Clad exterior 150x25mm Redwood planks, lapped 30mm. Paper sheathing.
8	1.52	1.30	1.23	1.1	Timber framed wall. Studs 45x45 @400. No nogs. Clad interior 3mm ply, exterior 240x10mm wood fibre planks lapped 30mm. Sheathing 8mm foil-faced ply. Cavity insulated with 50mm fibreglass batts (R=1.0).
9	1.65	1.47	1.41	1.4	As case 4, with addition of a complete sheathing layer of 12mm EPS as thermal break. (note that 12mm EPS has R=0.34, but increase in R-value is 0.5, due to suppression of thermal bridging)
10				1.4	Timber Framed wall. Studs 97x47 @500, nogs 97x47 @1000. Clad interior 10mm gypsum board. Clad exterior lapped Redwood planks. Building paper sheathing. Cavity insulated fibreglass batts R=1.3 (65mm).
	1.99	1.74	1.62		- including insulation edge gaps 10mm.
	1.99	1.84	1.81		- ignoring insulation edge gaps 10mm.
11	1.79	1.63	1.61	1.55	Timber framed wall. Studs 97x47 @500, nogs 97x47 @1000. Clad interior 10mm gypsum. Clad exterior 265x7.5 cement fibre planks, lapped 30mm. Building paper sheathing. Cavity insulated fibreglass batts R=1.3 (65mm).
12	1.89	1.76	1.61	1.55	Insulated timber plank wall, 175mm pitch. Planks on full 27mm core of EPU with 35 and 38mm timber facings tied through core by 6mm ply fillets @ 100 centres.
13	2.36	2.07	2.01	1.8	Timber framed wall. Studs 97x47 @400, nogs 97x47 @600. Clad interior 10mm foil-backed gypsum board. Clad exterior 235x6 cement fibre planks lapped 40mm. Paper sheathing. Cavity insulated with fibreglass batts R=1.5 (79mm).
14	2.42	2.23	2.19	2.3	Timber framed roof. Joists 97x47 @600, no nogs. Clad interior 8mm ply + 5mm wood fibre board. Clad exterior long-run GMS over 7.5 ply sarking. Cavity insulated with fibreglass batts R=1.9 (97mm).
15	3.5	3.3	3.2	3.1	Roof panel. Joists 140x47 @1000, nogs 47x69 @1000. Joists overlaid by 47x69 purlins @600. Clad interior 10mm gypsum board. Clad exterior corrugated GMS over building paper. Cavity insulated fibreglass blanket R=3.2 (160mm) compressed over nogs, bulged elsewhere.

Notes;-

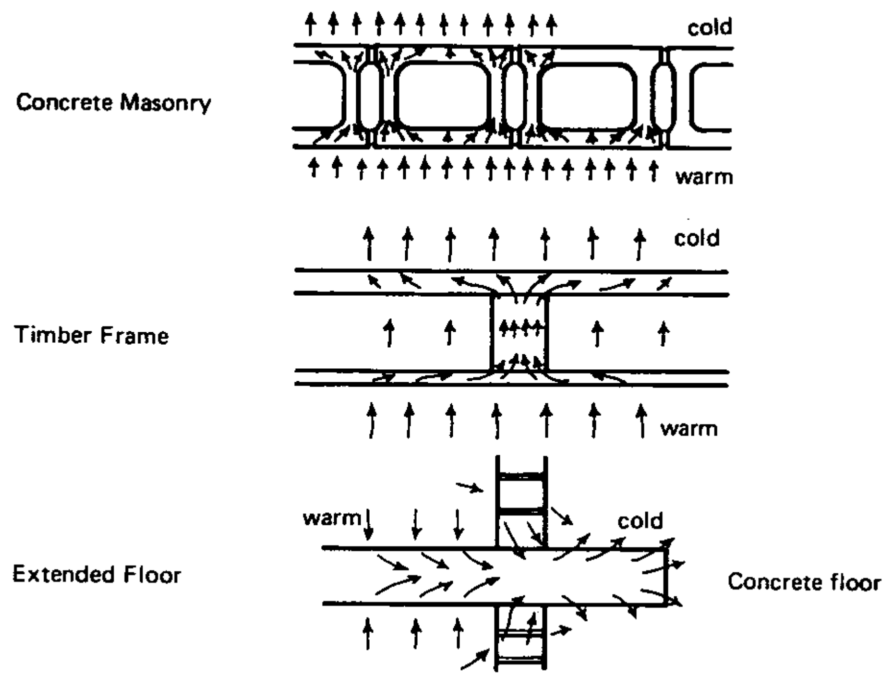
all dimensions in mm
EPS= Expanded Poly-Styrene
EPU= Expanded Poly-Urethane
GMS= Galvanised Mild Steel
RHS= Rectangular Hollow Section

"Nog" - see Fig 3
"Stud" see Fig 3
Measured R-Values were obtained at 20°C/5°C
Insulant properties are best estimates only and are understood to be within ±5%.

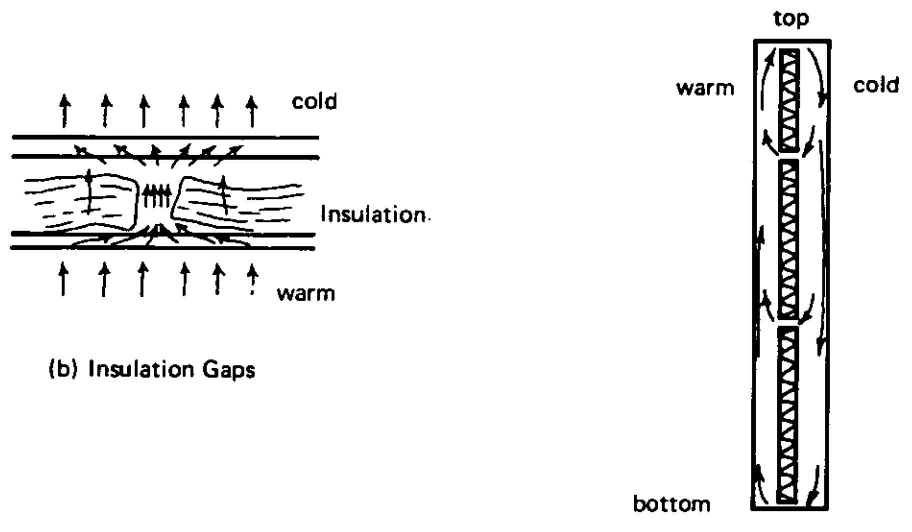
TABLE 2
Summary of Measured Thermal Resistance of Concrete Masonry Walls, by Guarded Hot Box

		Proportion of Cores grouted					
		Nil	1:5	2:5	1:2	1:1	Remarks
Standard block 				R Value m^{2}C/W			
	150 mm High density 2400 kg/m^3	0.28		0.27			Case 0 Ungrouted cores empty
				0.31			ungrouted cores filled polystyrene beads
	200 mm high density 2400 kg/m^3	0.30					Case 1 Ungrouted cores empty
	200 mm low density 1600 kg/m^3	0.5					Case 2 Ungrouted cores empty.
	"	0.73					Case 3 Ungrouted cores filled polystyrene beads
Foil Insulated 	High density Standard	0.45					Case 4
	2 foils		0.63	0.49			Case 5,6
	2 centred foils	0.50					Case 7
Roman Key 	High density 2400 kg/m^3			0.60			Case 8 20 mm PU foam
	"			0.72			Case 9 30 mm PU foam
	2100 kg/m^3 low density (pumice concrete)			0.73			Case 10
	High density, with mortar rebate	1.0				1.0	20 mm PU foam Case 11, 12
Parallel faced 	High density 2400 kg/m^3	0.65					Case 13 mortar bridging 50% 27mm PU foam
	"	0.77					Case 14 mortar bridging 10%
	"	1.56					Case 15 No mortar

Notes:
1. Densities are approximate
2. PU = Polyurethane foam,Expected conductivity 0.02 W/mC



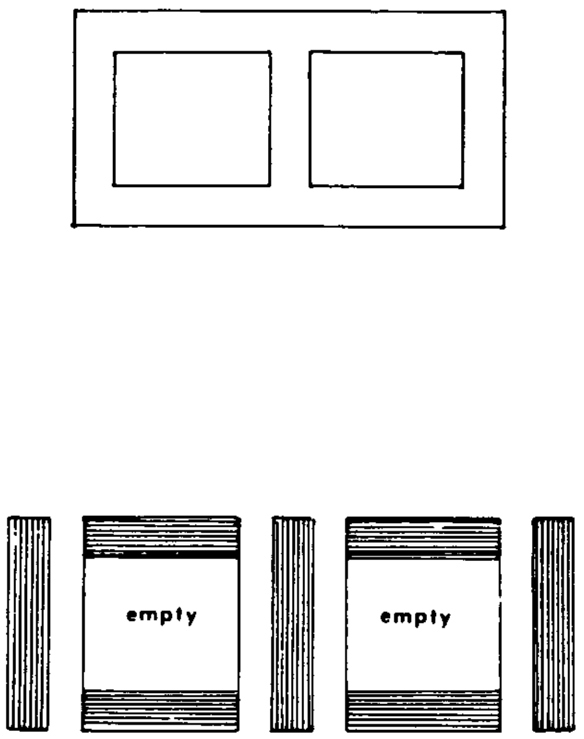
(a) Structural Bridges



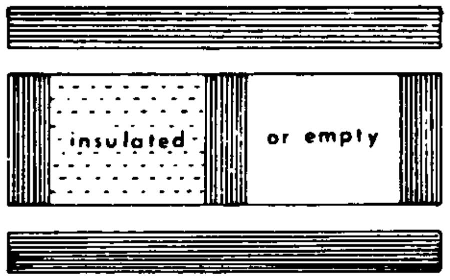
(b) Insulation Gaps

(c) Air Circulation Bridge

Figure 1. Illustrating three types of thermal bridge

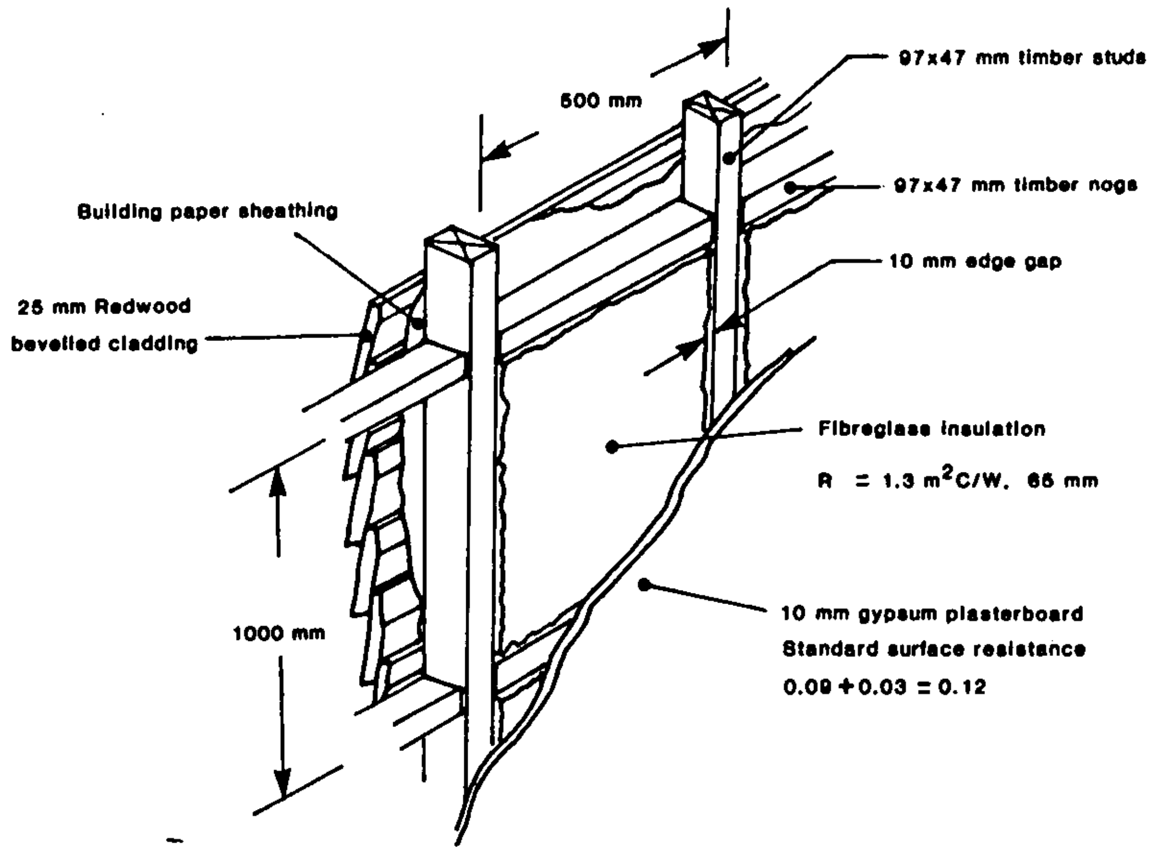


METHOD 1



METHOD 2

Figure 2. Schematic representation of methods one and two for calculating thermal insulation (acknowledgment to Valore Contrete International)



DETAILS OF EXAMPLE CASE

1. The region between gypsum plasterboard and the air cavity at exterior side of the fibreglass is the region considered to be thermally bridged.

2. DATA;-

Area ratios;-			
	framing	$\frac{(500+1000).47}{500.1000}$	= 0.141
	insulation edge gap	$\frac{(500+1000).10}{500.1000}$	= 0.03
	insulation	1- 0.141 - 0.03	= 0.829
Thermal resistances;-			
	framing	= 0.097/0.13	= 0.75
	insulation edge gap		= 0.19
	insulation	= 1.3 + 0.17	= 1.47
	gypsum	= 0.01/0.17	= 0.06
	Redwood cladding	= 0.025/0.13	= 0.19
	partial cavity between cladding and sheathing		= 0.15
	internal + exterior surfaces		= 0.12

3. CALCULATION;-

Method 2 mean resistance Rb across bridged section;-

1/Rb = 0.141/0.75 + 0.03/0.19 + 0.829/1.47 = 0.91

Rb = 1.10

sum of other resistances = 0.06 + 0.19 + 0.15 + 0.12 = 0.52

TOTAL RESISTANCE = 1.62m^2 C/W

Method 1 resistances across each section are;-

frame - 0.75 + 0.06 + 0.19 + 0.15 + 0.12 = 1.27

edge gap - 0.19 + 0.06 + 0.19 + 0.15 + 0.12 = 0.71

insulation - 1.47 + 0.06 + 0.19 + 0.15 + 0.12 = 1.99

1/Rt = 0.141/1.27 + 0.03/0.71 + 0.829/1.99 = 0.57

TOTAL RESISTANCE = 1.74m^2 C/W

Method 0

Rt = 1.47 + 0.06 + 0.19 + 0.15 + 0.12

TOTAL RESISTANCE = 1.99m^2 C/W

Figure 3. Example calculation of the three methods of calculation (using case 10 of Table 1)

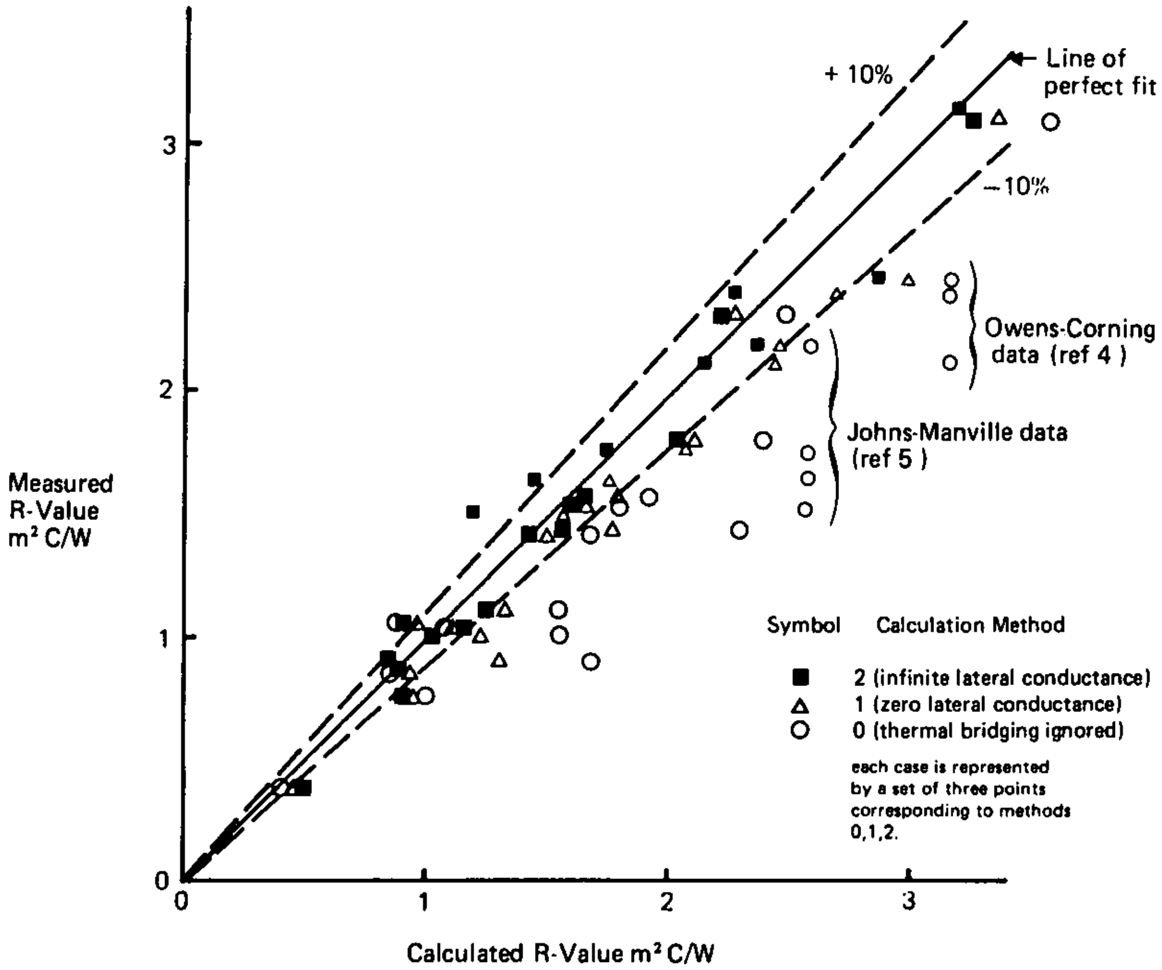


Figure 4. A comparison of measured and calculated R-values for panel and timber framed structures (from Table 1 and Johns-Manville Sales Corporation Research and Development Center, 1980; and Lewis, 1979)

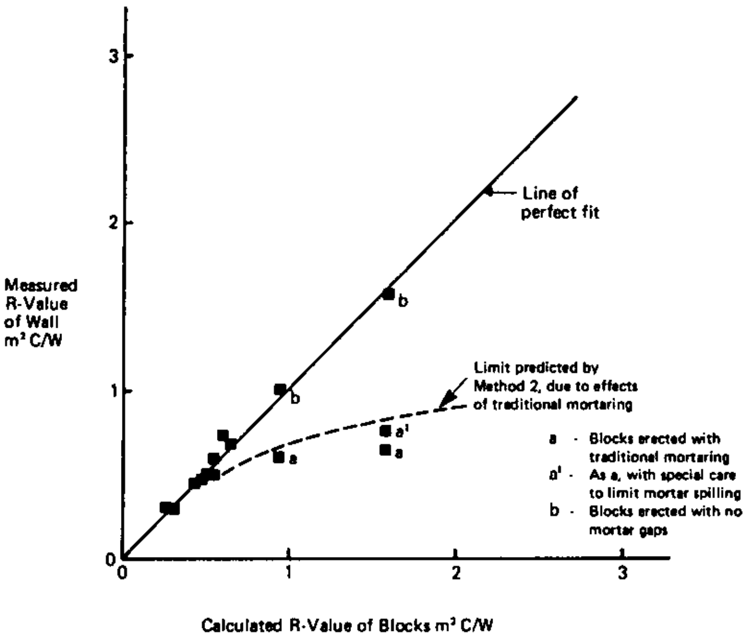


Figure 5. A comparison of measured and calculated R-values for concrete masonry (from Table 2)

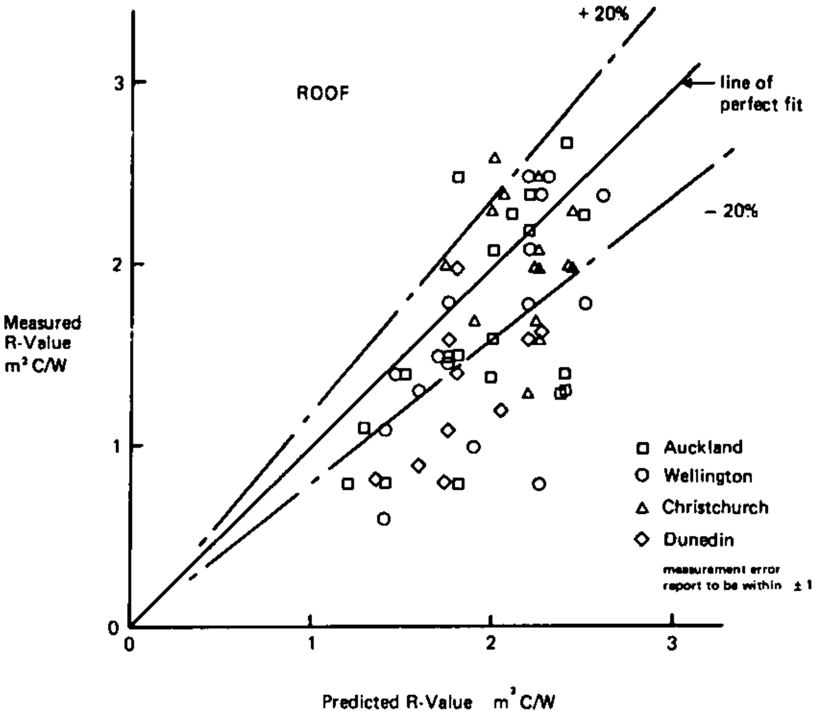


Figure 6. Comparison of field-measured and type-calculated R-values for 63 houses (New Zealand survey, 1983)

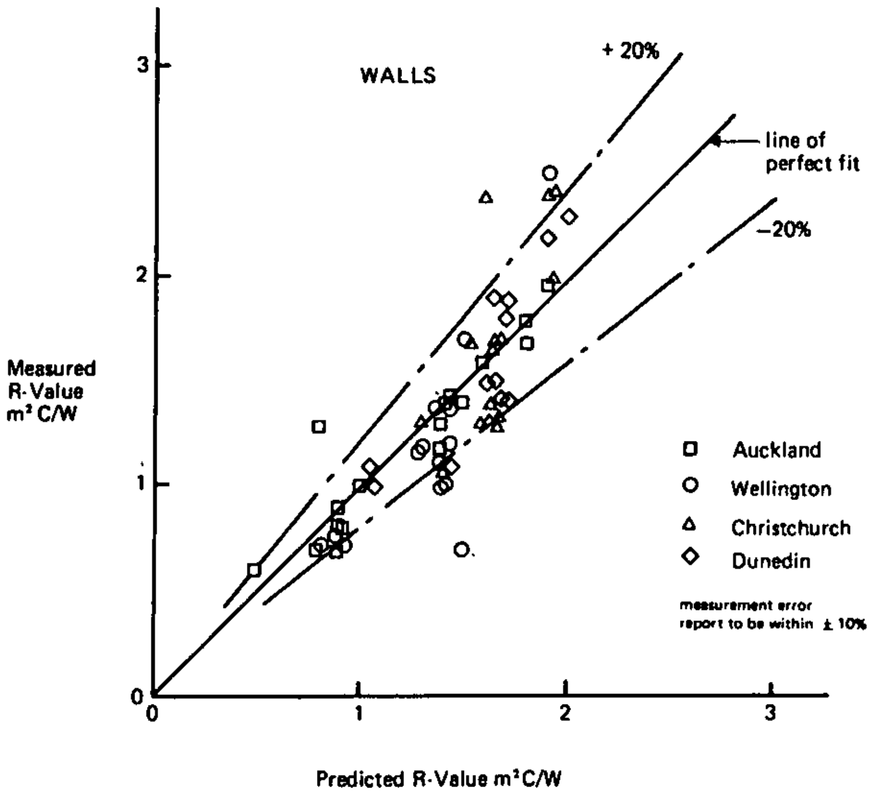


Figure 7. Comparison of field-measured and type-calculated R-values for 63 houses (New Zealand survey, 1983)

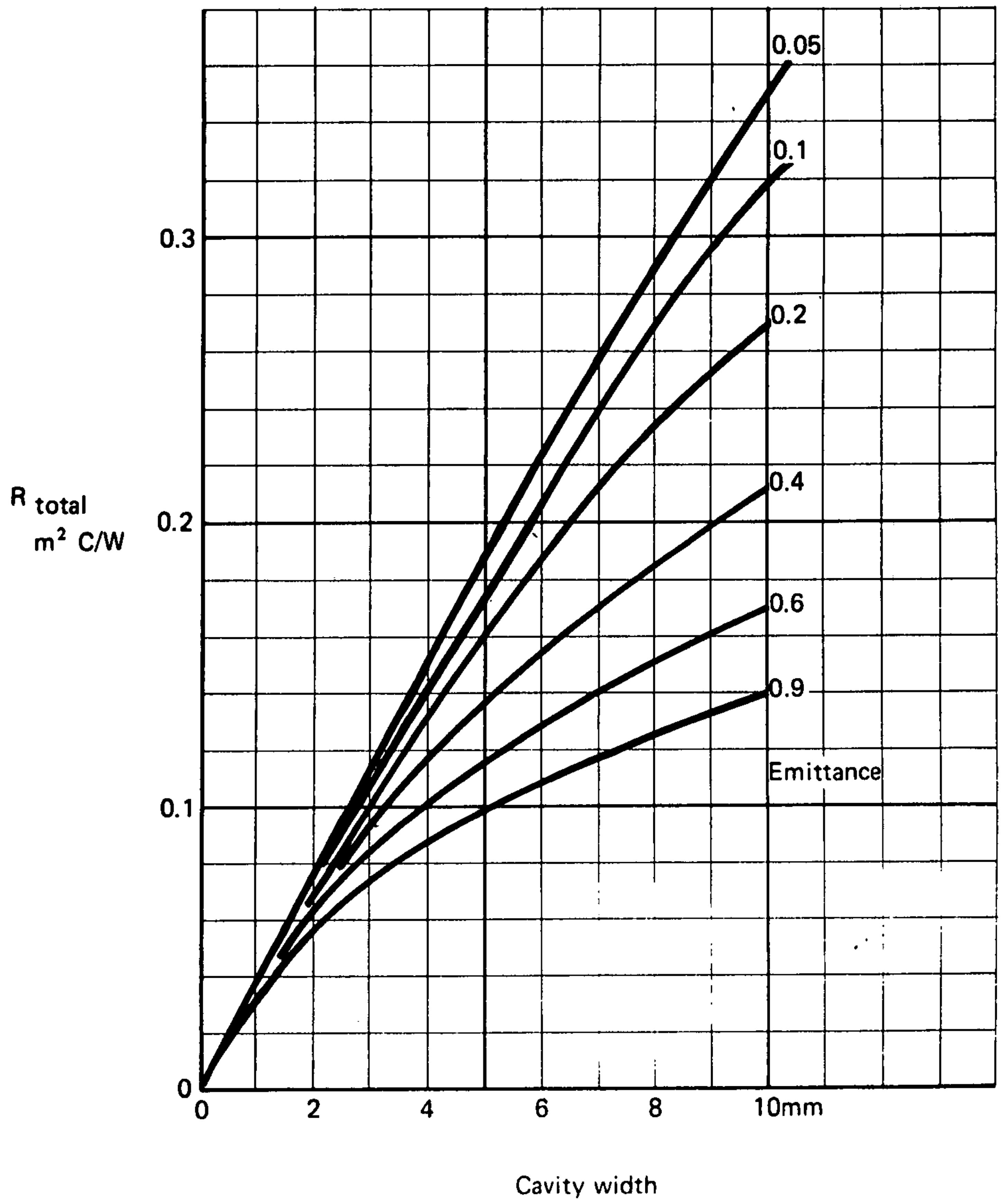


Figure 8. Thermal resistance across small cavities - all orientations

Discussion

R.M. COHEN, McDonnel Douglas Technical Services, Rockville, MD: Considering this paper and the previous paper (M. Van Geem), would you comment on the relative impact of block wall cavity fill material as a reducer of wall internal air circulation as opposed to the added resistance of the fill material?

TRETHOWEN: The possibility of internal air circulation becomes important only when the thermal resistance is increased, to greater than about $0.5m^2C/W$ in the data here. This can be reached with low density blocks of Standard design, but not with high density blocks.

B. HOWARD, NCMA, Herndon, VA: Explain why you feel the different dimensions of block were ignored, since Van Geem's work shows there is variation.

TRETHOWEN: Block dimensions always have an influence, but the effect is small with high density blocks. This paper discussed major influences only in (principally) high density blockwork, Van Geem was concerned mainly with heat flow in medium or low density blockwork.

HOWARD: Have you investigated steel framing systems? Did you identify construction types that had better or worse agreement between field measurements and calculations? Owens-Corning insulation tests have shown a steel stud wall to have only measured R7.3 versus R11.2 calculated by ASHRAE methods, for example.

TRETHOWEN: Yes, steel-stud frame examples are included in the paper. A major purpose of the paper was to show that exlusive use of the isothermal planes method (Method 2) coupled with specific extra heat transfer data (eg., contact resistance in the case of metal frames) tended to give rise to a fairly uniform quality of agreement.

J. HOGAN, Seattle Dept. of Construction and Land Use, WA: I work in the Seattle Building Department. Your presentation indicates either that heat loss does not follow expected paths or that the calculations are difficult to do at best. What are the implications of your research on calculations submitted for energy code compliance?

TRETHOWEN: This paper argues that adequate calculations can be done without undue difficulty. But marginal cases will arise, and calculation practices can slip over a long period. The implication for code compliance is that back-up verification by measurements should be available.

HOGAN: Are tested panel R-values available? Where? Is this the direction that ASHRAE and the building industry should be moving toward in lieu of calculated U-values?

TRETHOWEN: Some tested panel R-values have been reported in this paper. For code compliance purposes in New Zealand we have published a booklet of illustrated look-up tables of R-values for all the common construction forms. These take into account the normal trade practices, listing any particular warnings. This has proved to be a very efficient process.

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