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A ROUND-ROBIN COMPARISON OF AUSTRALASIAN THERMAL LABORATORIES

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ABSTRACT: This paper describes a comparison of seven laboratories in Australia and New Zealand, and one US laboratory, involved in testing thermal properties of materials. The primary objective of this Round Robin was to establish or confirm what degree of confidence can be placed in measurements by the various laboratories in this region. It was carried out using two industrial insulant products which were premeasured. Three samples were sent to each participant, who each conducted four thermal resistance measurements.

Results were typically within ±6% of the mean value, with a worst-case difference of -15.5% from the mean value.

KEYWORDS: Confidence, interlaboratory comparison, measurement, Round-Robin, R-Values, standardisation, survey, thermal insulants.

INTRODUCTION

This paper describes a comparison of laboratories in Australia and New Zealand, and one US laboratory, involved in testing thermal properties of materials. At the time this work was planned there were about 10 Australasian laboratories involved in work of this type, about half as independent laboratories and half testing mainly their own products. Seven of these eventually participated, giving a total of eight laboratories.

The primary objective of this Round-Robin was to establish or confirm what degree of confidence can be placed in measurements by the various laboratories in this region. The willingness of a US

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laboratory to join in this Round-Robin also allows comparison with one other important region. No attempt is included to probe any deficiencies in standard or actual procedures - indeed this survey includes laboratories using four different procedures. Part of the desired confidence-establishing goal includes the question of whether the choice of method need concern laboratory clients.

DESCRIPTION OF SURVEY

The survey involved each participant measuring three sample pieces of two insulant board materials in four measurements. The thermal resistances ranged from about 0.2 $m^2 °C/W$ to 3.0 $m^2 °C/W$. In a preliminary series, the coordinating laboratory (Building Research Association of New Zealand, Laboratory Z) measured the thermal resistance of every board. Individual samples were then cut, arbitrarily from various boards, to sizes to suit each participant. Participants received one low resistance sample of 14mm high density mineral fibre board, and two nominally identical samples of 50mm medium density glass fibre board. They were asked to measure the R-value of each of these separately, and then of the two glass fibre samples together with no septa. No results were revealed to any participant until all participant results were received for each board type.

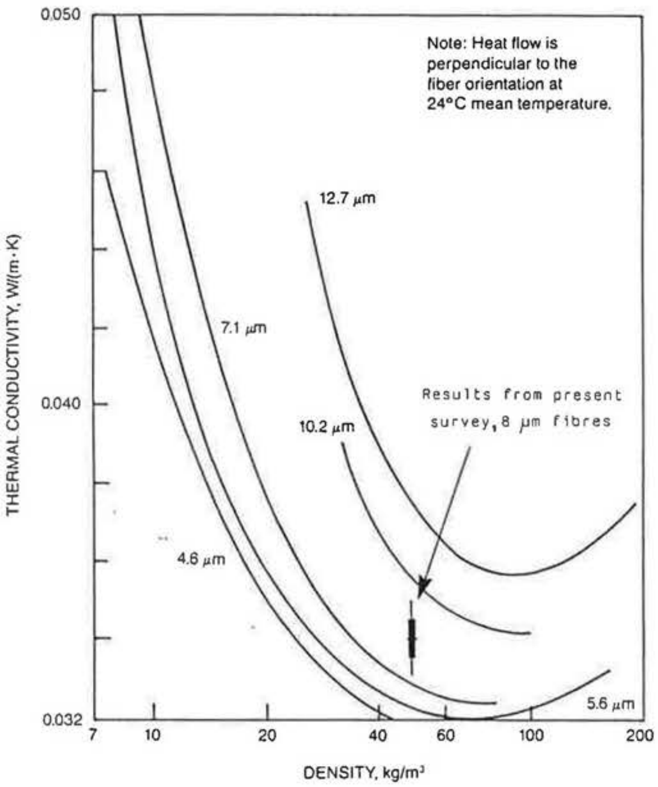
The two test materials were chosen from regular industrial products. The mineral fibre board was 14-15mm thick, density 421 kg/m^3. The fibre diameter was estimated as 4 - 6 micron. The surface was nominally flat one side, and dimpled 0.7mm on the other, and this surface condition was left in place. The glass fibre board was 50mm thick, density 50 kg/m^3, with fibre diameter 8-9 micron. The surface was nominally flat both sides. These materials were chosen partly for availability, partly because they were expected to have relatively small variation in conductivity with density variation.

Figure 1 shows typical previously published values from ASHRAE [1] for the thermal conductivity of glass fibre. Values for mineral fibre board are less well reported, ASHRAE reports about 0.06 W/m°C in this density range.

The test conditions were left open to the participating laboratories. This was decided in order not to exclude any of the candidate participants, some of whom have (different) restrictions on the temperatures at which they can test. Instead, it was planned to normalise all results to a mean temperature of 24°C. This, after all, is the likely approach for typical routine commercial test work which these laboratories might undertake. Many of the laboratories did in fact test close to 24°C mean temperature, though at different surface temperatures, but one laboratory (Z) is restricted to around 20°C and 6°C surface temperatures, mean 13°C.

A survey like this expects to encounter variance in result due to a number of factors including:-

- inter-sample variance
- within-lab variance
- between-lab variance
- between-method variance
- temperature effects



Apparent Thermal Conductivity of Glass Fibers (Lotz 1969)

(Reproduced with permission from ASHRAE from Fig.2, Ch 20, Handbook of Fundamentals 1989 This corrected version supplied by ASHRAE)

FIGURE 1, TYPICAL THERMAL CONDUCTIVITY, FIBRE GLASS

Any of these variations may be different at different insulation resistances. In this survey the first two items were expected to be indistinguishable. The initial pretesting in which the coordinating laboratory (Z) measured all boards, was expected to provide information on the combined inter-sample and its own in-house variability. For the survey to be useful, this combined variability has to be sufficiently small. The between-lab variance and between-method variances would also be likely not to be separable, unless one of the variances was dominant, as each laboratory used only one method. To determine this combined between-laboratory and between-method variance was in fact an object of this survey. Finally, the effects of test temperature were expected to be present but not intended to be part of the survey.

PARTICIPATING LABORATORIES

Table 1 lists the eight participating laboratories. There were three New Zealand laboratories including the coordinating laboratory, four Australian, and one United States of America. One New Zealand and three of the Australian laboratories operate principally to support their own insulation products, the remainder are independent.

TABLE 1 -- SUMMARY OF PARTICIPATING LABORATORIES AND EQUIPMENT

(a) - Schedule of Participants, in alphabetic order	
LABORATORY	
Australian Consolidated Industries	Dandenong, Melbourne, Australia
Building Research Association of New Zealand	Judgeford, New Zealand
Bradford Insulation	Nunawading, Melbourne, Australia
Commonwealth Scientific & Industrial Research Organisation	Highett, Melbourne, Australia
Concord Research & Development Centre	Concord West, Sydney, Australia
Holometrix Inc	Cambridge, Mass, United States of America
New Zealand Fibre Glass	Penrose, Auckland, New Zealand
Wool Research Organisation of New Zealand	Lincoln, Christchurch, New Zealand

(b) Schedule of Equipment and Laboratory Code Names

Laboratory Code Reference (Randomized)	Equipment Type	Metered Area (mm)	Max Sample Size (mm)	Equipment Origin	Equipment Temperature Limits	
					Warm Side (max)	Cold Side (min)
Z	Guarded hot box ASTM C236 type (with mounting frame)	1000 x 1000	1600 x 1200 x 100	Custom made	+20°C	+6°C
A	Series Comparator, BS 5335	1000 x 600 or 300 x 300	2000 x 1500 x 170	Custom made	+36°C	+19°C
B	Heat flow meter	100 x 100	305 x 305 x 100	Proprietary "B"	+70°C	+10°C
C	Heat flow meter ASTM C518	250 x 250	610 x 610 x 200	Proprietary "A"	+37°C	+13°C
D	Heat flow meter ASTM C518	250 x 250	610 x 610 x 200	Proprietary "A"	+45°C	+5°C
E	Heat flow meter ASTM C518	460 x 460	1000 x 1000 x 200	Custom made	+45°C	+5°C
F	Heat flow meter ASTM C518	250 x 250	610 x 610 x 200	Proprietary "A"	+45°C	+0°C
G	Heat flow meter ASTM C518	250 x 250	610 x 610 x 150	Proprietary "A"	+220°C	-180°C

Five laboratories used commercial guarded hot-plate insulation testing equipment. One used custom-made heat-flux meter equipment to ASTM C518-85 [2] with 460mm x 460mm metering area. Another laboratory used custom-made comparative equipment to BS 5335 [3] intended for use on quilting fabrics. The temperature drop is measured relative to that across an adjacent reference sample (of R ~ 1.4 m²°C/W). The equipment is periodically checked against a sample of reference material known as NBS 1450b, supplied by National Bureau of Standards. Finally, laboratory Z used a guarded hot box normally operated as in ASTM C236 [4], with a special holding frame to generate one-dimensional heat flow in a single-layer sample of insulant at the required thickness. This is prewired with a set of differential thermocouples which indicate the surface-to-surface temperature difference across the insulant sample.

RESULTS

Laboratory Z Pre-measurements

The properties of the five 1600 x 1200 sheets of mineral fibre board, and the eight 1200 x 1200 sheets of medium density fibre glass, as measured by Laboratory Z, are shown in Table 2 and Figures 2 and 3.

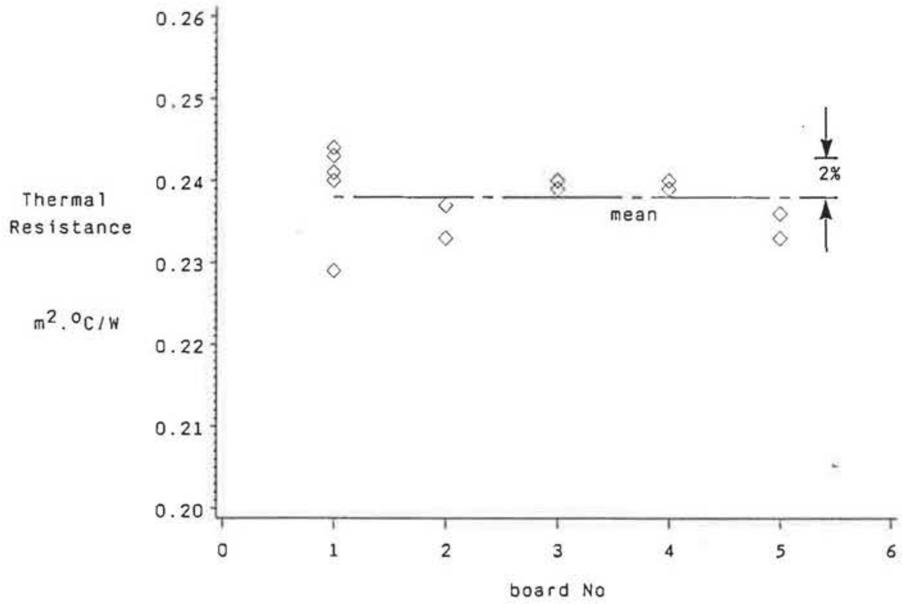


FIGURE 2, Laboratory Z results - 14mm Mineral Fibre Board adjusted to 24°C

These results were corrected from the mean test temperatures listed in Table 2 to 24.0°C using linear temperature coefficients of 0.38%/°C for the mineral fibre board, and 0.34%/°C for the glass fibre. eg. (resistance at 24°C) = (resistance at 13°C)/(1 + 11 x 0.38/100). These coefficients were found as follows: Data in ASHRAE [1] Handbook of Fundamentals (Chapter 22) group mineral fibre and glass fibre together, and at a density of 48kg/m³ over the 10-30°C range, indicates a temperature coefficient of 0.38%/°C. Measurements by laboratory E indicated a temperature coefficient of 0.34%/°C for the glass fibre material used in this series, over the range 20°-30°C. Lack of time prevented similar measurements for the mineral fibre board.

The mineral fibre board thickness varied from 14 to 15mm. The surface was dimpled on one side, and the thickness variations occurred on both small scale (a few mm) and large scale (over the whole board). The board density was determined as 421 ± 7 kg/m³.

The thermal resistance of the five boards averaged 0.247 m²°C/W when measured at a mean temperature of 13°C, with a standard deviation[a] of 0.0023 m²°C/W (0.9%). When corrected at the assumed temperature coefficient of 0.38% per °C, to a mean temperature of 24°C, this translates to a mean of 0.237 m²°C/W. See Figure 2.

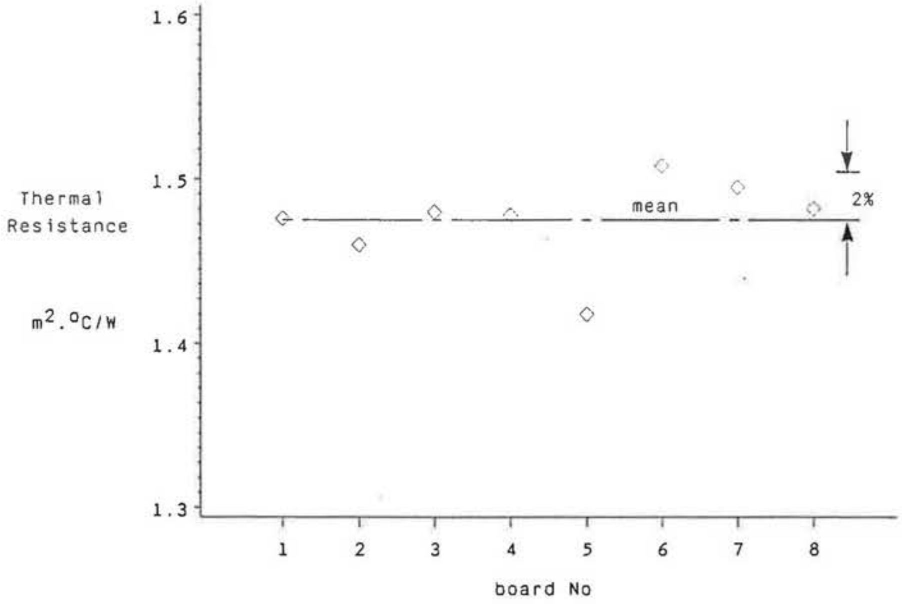


FIGURE 3, Laboratory Z Results - FibreGlass Board adjusted to 24°C

The fibre glass boards were found to average 49.7mm thickness, with a standard deviation of 0.49mm (±1% of mean) on the board averages. The extreme thickness ranged at any point from 47.5mm to 52.0mm. The density of these boards was determined as 50 ± 3 kg/m³ (±6% of mean).

The thermal resistance of these eight boards averaged 1.532 m²°C/W, with standard deviation 0.026 (±1.7% of mean) at a mean temperature of 13°C. When corrected to 24°C mean using the temperature coefficient of 0.34°C the average resistance becomes 1.475 m²°C/W. See Figure 3.

[a] throughout this paper standard deviations apply to the sample, not to an assumed parent population: they do not contain "Bessels correction".

Results from all Participants

The results of measurements from all laboratories are summarised in Tables 3 and 4, with the mean temperatures at which those results were obtained. These values are then converted to a mean temperature of 24°C, using the same temperature coefficients as above.

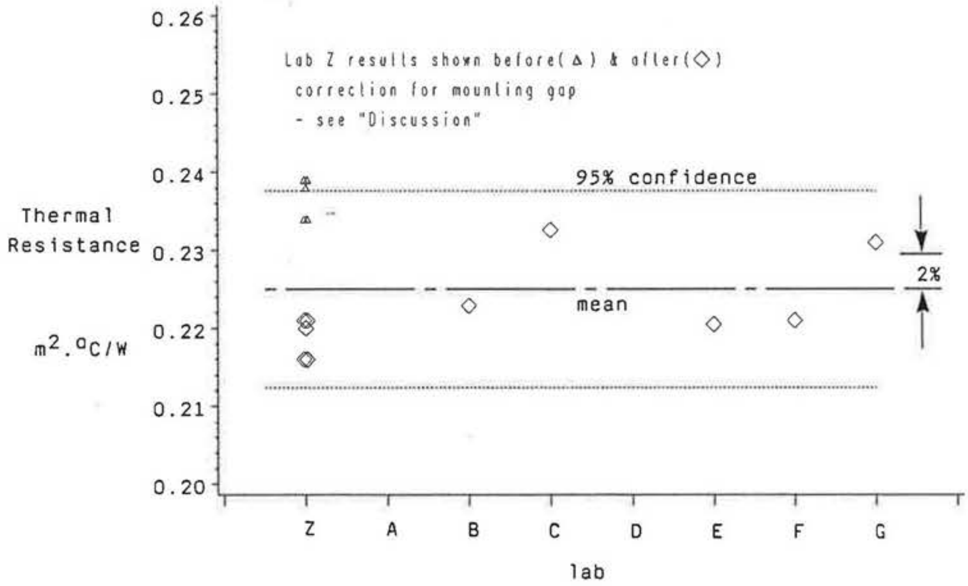


FIGURE 4. COMPARISON OF ALL RESULTS - Mineral Fibre Board

14mm Boards - adjusted to 24 °C
(no result received from Laboratories A & D)

14mm Samples: Table 3 indicates the mean resistance reported for the 14mm mineral fibre boards, before temperature correction, as 0.229 $m^2°C/W$, with standard deviation 0.007 $m^2°C/W$ (3.1%). After adjustment to 24°C, this became 0.228 $m^2°C/W$, with standard deviation of 0.006 (2.6%). The thickness reported for these samples ranged from 13mm to 15mm (±7%), three laboratories of six reporting to the nearest whole mm. No individual result differed from the mean by more than 1.3 times the standard deviation, whilst the mean result from proprietary equipment "A" differed from those of custom-made by only 0.6 of the common standard deviation. Figure 4 illustrates these results.

50mm Samples: Table 4 shows the mean resistance reported for 50mm and 100mm glass fibre board. The mean as-measured value for 50mm boards was 1.488 $m^2°C/W$, with standard deviation of 0.050 $m^2°C/W$ (3.4%). After adjustment to 24°C, the mean becomes 1.487 $m^2°C/W$, with standard deviation 0.049 $m^2°C/W$ (3.3%). The reported thickness ranged from 47.4mm to 52.3mm. The highest and least individual results differ from the mean by +1.3 and -1.5 standard deviations respectively.

The mean of results from proprietary equipment "A" differed from that of custom-made by only 0.32 of the standard deviation. Figure 5 illustrates these results.

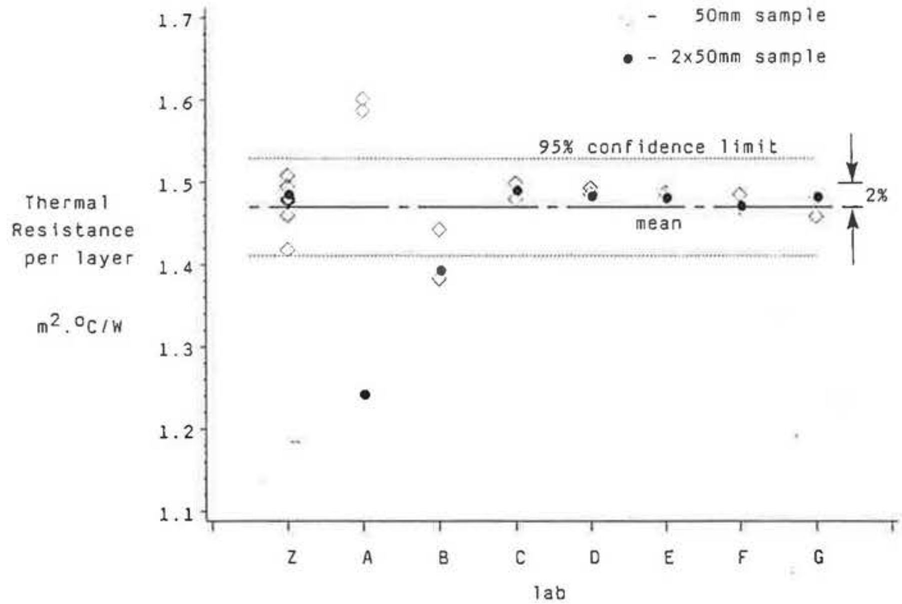


FIGURE 5. COMPARISON OF ALL RESULTS - FIBRE GLASS
50mm & 2x50mm Boards - adjusted to 24°C

<u>100mm Samples:</u> The mean as-measured resistance for 100mm boards was 2.883 $m^2{}^\circ C/W$ with standard deviation of 0.173 $m^2{}^\circ C/W$ (6.0%). After adjustment to 24°C the mean becomes 2.882 $m^2{}^\circ C/W$ with standard deviation of 0.161 $m^2{}^\circ C/W$ (5.6%). The highest and lowest individual results differ from the mean by +0.6 and -2.5 standard deviations respectively. The individual 100mm results differ from the sum of the two contributing 50mm results by extremes of +0.8% and -28.4%, or -1.1% excluding laboratory A.

DISCUSSION

The results of this survey indicate inter-laboratory differences of 0% -6% with guarded hotbox (GHB) and heatflow meter (HFM) facilities. The largest individual difference was -15.5%. Previous surveys reported (e.g. Bales, [5]) have shown a similar variation. Table 5 lists some basic comparisons between the various results, for reader convenience.

The thermal resistance values have been taken as the primary parameter in this study. In practice all laboratories used procedures that determine resistance, from which the thermal conductivity is derived. This conductivity is in all cases an apparent conductivity. In the typical industrial samples used here, the thickness varies over the sample on both small and large distance scales. There is an uncertainty as to the "true" thickness, but the choice of plate spacing is an important one. Insufficient plate spacing will tend to increase the observed resistance pro-rata with thickness, ie, about 7% per mm for the 15mm sample, 2% per mm and 1% per mm for the 50mm and 100mm

TABLE 2 -- Summary of Pretesting by Laboratory Z

	BOARD NO						
	1	2	3	4	5	MEAN	SD
thickness mm	14.5	14.5	14.5	14.5	14.5		
R m²°C/W } @	0.248	0.244	0.249	0.249	0.244	0.247	0.0023
k W/m°C } 13°C	0.0585	0.0594	0.0582	0.0582	0.0594	0.0587	0.0006
R m²°C/W } @	0.238	0.234	0.239	0.239	0.234	0.237	0.0022
k W/m°C } 24°C	0.0609	0.0620	0.0607	0.0607	0.0620	0.0613	0.0006

(a) Laboratory Z tests on all boards, 14 mm mineral fibre board, 420 kg/m³

	BOARD NO									
	1	2	3	4	5	6	7	8	MEAN	SD
thickness mm	49.25	49.34	49.13	49.46	49.50	49.87	50.15	50.67	49.7	0.49
R m²°C/W }	1.533	1.517	1.538	1.535	1.473	1.567	1.553	1.540	1.532	0.026
k W/m°C } 13°C	0.0321	0.0325	0.0319	0.0322	0.0336	0.0318	0.0323	0.0329	0.0324	0.0005
R m²°C/W }	1.476	1.460	1.480	1.478	1.418	1.508	1.495	1.482	1.475	0.025
k W/m°C } 24°C	0.0334	0.0338	0.0332	0.0335	0.0349	0.0331	0.0335	0.0342	0.0336	0.0006

(b) Laboratory Z Tests on all boards, 50 mm glass fibre

TABLE 3 -- Results from all laboratories, 14 mm mineral fibre board, 420 kg/m³

	LABORATORY									
	Z	A	B	C	D	E	F	G	MEAN	SD
thickness	14.5	...	15	14	...	14.35	13	14.35	14.2	0.61
Temp °C	13	...	23.85	23.55	...	26.95	25.1	24.35		
R m²C/W	0.247	...	0.223	0.235	...	0.218	0.220	0.231	0.229	0.007
k W/m °C	0.0587	...	0.0673	0.0596	...	0.0658	0.0591	0.0621	0.0621	0.003
R m²C/W } at 24°C	0.237	...	0.223	0.235	...	0.220	0.221	0.231	0.228	0.006
k W/m °C }	0.0610	...	0.0673	0.0596	...	0.0651	0.0588	0.0621	0.0623	0.002

TABLE 4 -- Results from all laboratories, 50 mm and 100 mm glass fibre, 50 kg/m³

	LABORATORY									
	Z	A	B	C	D	E	F	G	Mean	SD
Sample ID	1	5	7.3	7.1	8.1	4	1.3	1.1		
Thickness mm	49.3	50.0	48.0	50.0	51.7	47.4	49.9	50.3		
Temp °C	13.0	27.13	25.2	25.73	26.35	25.1	24.84	24.05		
R m²C/W	1.533	1.57	1.377	1.471	1.474	1.481	1.481	1.481		
k W/m°C	0.0321	0.0318	0.0349	0.0340	0.0351	0.0320	0.0337	0.0339		
R m²C/W } at 24°C	1.476	1.587	1.383	1.480	1.486	1.487	1.485	1.481		
k W/m °C }	0.0334	0.0315	0.0347	0.0338	0.0348	0.0319	0.0336	0.0340		
Sample ID	8	6	7.4	7.2	8.2	3	1.4	1.2		
Thickness mm	50.7	49.5	49.0	50.0	52.3	48.9	50.0	50.0	49.8	1.16
Temp	13.0	26.08	25.2	26.09	25.55	25.1	24.88	24.05		
R m²C/W	1.540	1.59	1.429	1.488	1.485	1.476	1.466	1.459	1.488	0.050
k W/m°C	0.0329	0.0311	0.0341	0.0336	0.0352	0.0332	0.0341	0.0343	0.0335	0.0012
R m²C/W } at 24°C	1.482	1.601	1.434	1.499	1.493	1.482	1.470	1.459	1.487	0.048
k W/m °C }	0.0342	0.0309	0.0340	0.0334	0.0350	0.0330	0.0340	0.0343	0.0335	0.0012
Sample ID	1+8	5+6	7.3 + 7.4	7.1 + 7.2	8.1 + 8.2	3 + 4	1.3 + 1.4	1.1 + 1.2		
Thickness mm	99.9	99.5	97.0	100.0	104.0	97.8	99.2	100.3	99.7	1.95
Temp	14.25	25.72	25.2	26.14	25.9	25.1	24.96	24.05		
R m²C/W	3.07	2.47	2.775	2.959	2.946	2.950	2.932	2.963	2.883	0.173
k W/m°C	0.0325	0.0403	0.0349	0.0338	0.0353	0.0331	0.0338	0.0339	0.0347	0.0023
R m²C/W } at 24°C	2.968	2.484	2.786	2.981	2.965	2.961	2.942	2.964	2.882	0.161
k W/m °C }	0.0336	0.0400	0.0348	0.0336	0.0351	0.0330	0.0337	0.0338	0.0347	0.0021

samples. Excess plate spacing of up to 2-3mm will tend to add linearly to the observed resistance, about 18% per mm for the 15mm sample, 2.7% per mm and 1.3% per mm for the 50mm and 100mm samples. The decision on plate spacing is therefore crucial especially in thin samples. Only one laboratory (E) made any distinction between sample thickness and plate spacing.

The resistance for the 14mm boards was consistently higher in the Laboratory Z results than in others. The mean difference was 0.012 $m^2 °C/W$, about 5.1%. Applying Students 't' test to this result showed the difference to be "highly significant". It is attributed to an imperfection in the sample holding frame, the two faces of which can slightly warp differentially. The effect in these tests was to add a small cavity averaging 0.46mm wide. For cavities less than ~10mm convection is suppressed and at less than 3-4mm even radiation is swamped by gas conduction. Thus provided that the cavity is also large compared with mean free path, the heat transfer is dominated by gas conductivity of some 0.025 W/m.°C. Thus a 0.46mm cavity is expected to add a resistance of about 0.018 $m^2 °C/W$ to the observed result, see Figure 4.

The resistance for these 14mm boards is estimated as 0.255 ± 0.003 $m^2 °C/W$. This estimate is the mean of the 5 participant results plus the average Laboratory Z result corrected as above.

Results for 50mm and 100mm boards can be investigated together. The 100mm board resistances should be almost equal to the sum of the two 50mm boards included, different only by the "thickness effect". From Pelanne [6] and Hollingsworth [7] we should expect the combined 100mm samples to have some 0.01 $m^2 °C/W$ (0.3%) less resistance than the two 50mm pieces. In this survey we found the deficit to average 0.00236 $m^2 °C/W$ but the standard deviation on this was 0.013 $m^2 °C/W$. Thus this survey is not able to contribute usefully to "thickness effect" data, which at 0.3% has been ignored.

A comparison of the glass fibre board results in Figure 5, shows overall mean and 90% confidence limits for the set, and the individual results from each laboratory. Laboratory A reported a systematic problem, obtaining high results for low-R samples and vice-versa.

The inter-board variance is quite small. The Laboratory Z -pre-measurements - see Figure 3 - show the maximum deviation from the mean to be little over 2%, includi-ng the laboratory variability. Inspection of Table 4 and Figure 4 does not suggest much variation with board, most of the variation being associated with the laboratory.

The mean thermal resistance for the 50mm glass fibre boards is estimated as 1.470 ± 0.006 $m^2 °C/W$. This estimate is the average of the 21 results (50mm and 100mm) reported by the seven laboratories with smallest variability. The effect of laboratory exclusion is shown below:-

	Mean	Standard Error of the Mean
All laboratories included	1.472	0.014
Most variable laboratory excluded	1.470	0.006
Two most variable laboratories excluded	1.481	0.002

Table 5 -- Comparison from individual boards

	BOARD						
Source	1	2	3	4	5	6	best estimate [b] of mean value
	Measured R Value, m²°C/W						
Laboratory Z - as reported	0.238	0.234	0.239	0.239	0.234	...	
- corrected for mounting gap	0.220	0.216	0.221	0.221	0.216	...	
Other Participants	...	...	0.223 0.221	0.220	0.233	0.231	0.225
	% difference from mean						
Laboratory Z	-2.2	-4.0%	-1.8%	-1.8%	-4.0%	...	
Others	... -1.8%	...	-0.9%	-2.2%	+3.6%	+2.7%	

(a) Mineral fibre board

	BOARD								
Source	1	2	3	4	5	6	7	8	best estimate [b] of mean value
	Measured R-value m²° C/W								
Laboratory Z	1.476	1.460	1.480	1.478	1.418	1.508	1.495	1.482	
Other Participants	1.485 1.470 1.481 1.459	...	1.482	1.487	1.587	1.601	1.480 1.499 1.383 1.433	1.481 1.459	1.470
	% difference from mean								
Laboratory Z	+0.4%	-0.7%	+0.7%	+0.5%	-3.5%	+2.6%	+1.7%	+0.8	
Others	+1.0% 0.0% +0.7% -0.7%	...	+0.8%	+1.2%	+8.0%	+8.9%	+0.7% +2.0% -5.9% -2.5%	0.7% -0.7%	

(b) Glass Fibre Board

[b] see "Discussion"

The mean thermal conductivity for this material is therefore 0.0340 ± 0.0002 W/m°C. The "typical" data of ASHRAE [1] Fundamentals Chapter 20, shows the conductivity of fibre glass of 8-9 micron diameter, at 24°C and 50 kg/m³ density, as 0.0345 W/m°C - only 1.45% different. (The ASHRAE data was based on 25mm samples, and a small further "thickness effect" correction applies). See Figure 1.

This survey can be subdivided into laboratories using proprietary equipment "A", and custom-made equipment. Comparing these two sets does not show either statistically significant or apparent differences.

If the results from each custom-made equipment is individually compared with the average for proprietary equipment results, it differs in the worst case by less than 1.4 standard deviations and in all other cases by less than 0.75 standard deviations. The standard deviations amongst the results from custom-made equipment were slightly smaller than the proprietary results.

CONCLUSIONS

A Round-Robin comparison of thermal laboratories has been conducted using typical industrial board insulants 14-100mm thick, thermal resistance 0.22 - 3.0 $m^2{}^\circ C/W$. Eight laboratories using four measurement methods were included; three from New Zealand, four from Australia, one from United States of America.

Each laboratory measured different samples, but the intersample standard deviation was small - about 2% for the combined sample and laboratory deviation in the coordinating laboratory measurements.

Results from one laboratory using a comparative procedure to BS 5335 had more variation than other laboratories, with individual results reaching a maximum 15% from the mean.

Results from the seven laboratories using GHB and HFM methods were all individually within 5.9% of the best estimate of mean value for each material. Excluding the seventh ranked laboratory would leave all results within 4.0% for the mineral board samples, and 2.0% of the mean for fibre glass samples.

The mean thermal resistance for fibre glass found in this survey was within 1.5% of the "typical" data in the ASHRAE Handbook of Fundamentals for the same conditions.

Results for 100mm samples from the seven laboratories using GHB and HFM methods were individually within 1.5% of the sum of their respective 50mm measurements. The mean difference was consistent with previous data on "thickness effect" difference, but not of sufficient certainty to confirm or modify it.

No significant differences could be established between different methods (except BS 5335), between Australasian and United States laboratories, or between users of proprietary equipment and custom-made equipment types.

ACKNOWLEDGEMENTS

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REFERENCES

[1] "Thermal insulation and Water Vapor Retarders," in ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, Georgia, 1989, pp. 20.1-20.20.

[2] ASTM C518, Test Method for Steady-State heat flux measurement and thermal transmission properties by means of the Heat flow meter apparatus, American Society for Testing and Materials, Philadelphia, 1985.

[3] BS 5335, British Standard Specification for Continental Quilts, British Standards Institution, London, 1984.

[4] ASTM C236, Standard Test Method for Steady State therma performance of Building Assemblies by means of a guarded hot box, American Society for Testing and Materials, Philadelphia, 1987.

[5] Bales, E.R., "ASTM/DOE Hot Box Round Robin," presented at the ASTM/BTECC Workshop for Hot Box operators, Colorado Springs, Mar 1985; available as ORNL/Sub/84-97 333/2, Oak Ridge National Laboratory.

[6] Pelanne, C. M., "Discussion on Experiments to Separate the "Effect of Thickness" from systematic Equipment Errors in Thermal Transmission Measurements," in Thermal Insulation Performance, ASTM STP 718, American Society for Testing and Materials, 1980, pp. 255-271.

[7] Hollingsworth, M., "Experimental determination of the thickness effect in glass fibre building insulation," in Thermal Insulation Performance, ASTM STP 718, American Society for Testing and Materials, 1980, pp. 255-271.