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Comparative Testing of Thermal Conductivity for Thermal Insulation Products: The European Keymark Experience for More Than 50 Equipment at 25 Test Institutes

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ABSTRACT

This article describes comparative testing of thermal conductivity on a range of thermal insulation products used in the construction of buildings. This testing was arranged by the CEN Keymark scheme for voluntary certification of insulation within Europe, and measurements have been performed using over 50 instruments in more than 25 registered laboratories.

The uniformity of the material and a unique thermal conductivity value for each set of test specimens that were used in the comparison have been established according to the Keymark scheme rules, which were developed by experts from the most respected European laboratories. These experts include most of the laboratories responsible for characterizing the European certified reference material (IRMM 440) for thermal conductivity measurements on thermal insulation products (Quin, Venuti, De Ponte, & Lamberty, 2000).

The sets of test specimens that have been characterized by the expert group were circulated and measured by the laboratories registered within the Keymark scheme, and the results are presented in this article and compared to the results of the first comparative testing in the Keymark scheme carried out up to August 2003 and presented at ITCC 27 (Rasmussen & ITCC 27 Paper, 2003).

The voluntary Keymark scheme works alongside the mandatory CE conformity mark (CE mark) used within the European Union and includes rigorous auditing and assessment of measurement capability, which provides a high level of confidence in measured thermal conductivity values produced by registered laboratories. Information on this Keymark scheme can be found on the website: www.insulation-keymark.org.

Keywords: thermal conductivity, thermal insulation products, Keymark, comparative testing, laboratories.

1. INTRODUCTION

Uniformity of quality in product testing became essential both for manufacturers and testing institutes when conformity marking was introduced as a legal requirement for thermal insulation products in the European Economic Area in June 2002. All manufacturers of thermal insulation products were then obliged to declare their product's thermal performance based on measurements verified by an independent laboratory. Within the CE conformity marking requirements the manufacturers are allowed to choose any officially notified laboratory from anywhere in Europe, not just their nationally approved laboratory as had been the rule earlier. This situation encouraged the development of a Keymark scheme for registering independent laboratories to ensure uniformity and high standards of quality in testing and calibration.

Another European quality mark (VDI-Keymark) for thermal insulation products for low and high temperature applications has been also been implemented to address the EN product standards (EN standards) for industrial insulation that were published during mid-2009. An important feature of the VDI-Keymark for industrial insulation products has been to ensure coordination of testing in Europe with the highest priority on the measurement uncertainty. Procedures similar to the Keymark rules for building

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insulation have been developed to approve and monitor laboratories registered within the scheme and this has been described in other papers presented at this conference (CEN/VDI Keymark Scheme Rules Appendix B, 2011).

Both the building and industrial insulation Keymark schemes include the use of regular comparisons between laboratories to ensure that measurement capability is being adequately maintained and that there is uniformity of measured values produced by registered laboratories across the scheme. This is achieved by circulating sets of test specimens that have been characterized by the scheme's Expert Group.

2. UNIFORMITY OF MATERIALS USED FOR COMPARATIVE TESTING

So far, three types of material in two thicknesses have been prepared and used within the Keymark scheme for building thermal insulation. These are:

- 50 and 100 mm thick Fiberglass boards (mineral wool, MW) with a density of ~30 kg/m^3 for 50 mm and 25 kg/m^3 for 100 mm;
- 50 and 100 mm thick expanded polystyrene boards (EPS) with a density of ~21 kg/m^3;
- 40 and 80 mm (Neopor™ or "black EPS") with a density of ~29 kg/m^3.

These materials, kindly supplied by Isover Saint-Gobain: France and BASF: Germany, were selected for this purpose to optimize the homogeneity of their thermal performance.

From each of the products, there were test specimens cut with lateral dimensions of 800 × 800 mm and 610 × 610 mm, being the standard sizes most common for thermal conductivity testing equipment in Europe. The test specimens were weighed and the thickness measured to the nearest 0.1 mm. The mineral wool (M) products were produced with some "over-thickness" and the thickness for testing was fixed at 50.0 and 100.0 mm, whereas the rigid expanded polystyrene (E) and Neopor (N) specimens were tested at their actual thickness. The thermal conductivity of all the individual test specimens was measured at 10°C mean temperature (with a temperature difference of 20K) using two different Heat Flow Meter (HFM) instruments. Based on these measurements, the test specimens were paired as uniformly as possible based on their thermal performance. The sets of test specimens were marked on the edge, e.g., M01-12A and E01-23B or N04-02A, identifying the material, year of preparation, and an identification number for the individual test specimen, see Figure 1.

Figure 1. Examples of Keymark test specimens (only half a pair of each).

3. THE EXPERT GROUP ESTABLISHING THE KEYMARK VALUES

The procedures followed by the Keymark scheme's Expert Group and the rules for approving laboratories to become registered are described in the scheme rules Appendix B (Keymark Scheme Rules Appendix B, 2005) and were presented at the ITCC 27 conference together with the results of the first comparative testing (Rasmussen & ITCC 27 Paper, 2003).

The main activities of the Expert Group are to coordinate comparative testing, carry out audits at laboratories, and develop guidance papers aimed at improving the general knowledge of thermal conductivity testing in Europe. These guidance papers are available on the Keymark Internet site for use by the official laboratories and also by manufacturers that are undertaking thermal conductivity testing.

Several members of the Expert Group are from those laboratories that prepared the latest European certified reference material for thermal conductivity testing of insulation products (IRMM 440). There are a few additional laboratories with long-term experience in thermal conductivity testing that were chosen to give a good geographical spread of laboratories across Europe.

KEYMARK

Flightcase No. 19

ID No.	
Dimension	600 x 600 mm
Weight	973 g
Thickness for λ-measurement	100.0 mm
ID No.	M01 - 06B
Dimension	600 x 600 mm
Weight	971 g
Thickness for λ-measurement	100.0 mm

From RI Nov 2011

Figure 2. (a) Example of metal box. (b) Example of note accompanying the test specimens in the metal box.

The tasks for the Expert Group related to comparative testing are:

- planning and conducting comparative tests within the Expert Group;
- preparing of test specimens for the candidate and the registered laboratories.

The Keymark test specimens sent to each laboratory participating in the comparative testing were shipped in metal boxes with a note as shown in Figure 2 to ensure a uniform approach to thickness and to keep track of specimen stability.

3.1 First comparative testing (the expert group)

The first comparative testing was carried out between the eight Expert Group laboratories using their chosen highest-capability equipment with metering areas of 300 × 300 mm. Two sets of test specimens were measured by these laboratories in 2001 with the aim of ensuring that the laboratories measured to the same level and in line with the European certified reference material IRMM 440. This was confirmed and is shown in Table 1.

The two sets of test specimens (each composed of two pieces) were a 50-mm thick expanded polystyrene and a 100-mm thick mineral wool, both having dimensions of 800 × 800 mm. These test specimens were first measured by laboratories with instruments having plates of 800 × 800 mm, then the test specimens were cut to 750 × 750 mm, 610 × 610 mm, and finally 600 × 600 mm successively for laboratories with instruments having smaller plate dimensions. The central part of the specimens was left undisturbed during the cutting process.

The laboratories also reported the test results from measurements of their own IRMM 440 reference material.

Table 1. Comparison of test results.

Test specimens, thickness	Max./min. deviation from IRMM 440 – EU κ_{10}-level	Standard deviation
IRMM 440, 35 mm	+0.4% –0.9%	0.45%
EPS, 50 mm	+1.0% –0.8%	0.59%
MW, 100 mm	+1.3% –1.2%	0.73%

Notes: IRMM; EPS, expanded polystyrene board; MW IRMM 440; EPS, expanded polystyrene board; MW, fibreglass board.

The results show that all the measured values are within ±1.3% for three different types of test specimens, and that there were no systematic differences between the test laboratories. Therefore. the agreement between laboratories is better than the ±1.5% target initially specified for the Keymark scheme and in addition, the aim of defining the European $\lambda 10$ level as the mean of these test laboratories has been successfully achieved.

3.2 Second comparative testing (Expert Group) – defining the keymark value for all sets of test specimens

The individual sets of Keymark test specimens are measured by two Expert Group laboratories to determine their thermal conductivity value, which is referred to within the scheme as the "Keymark value". The laboratories are paired at random to avoid any systematic difference. This work is an ongoing process and the results so far are shown in Table 2.

The mean difference between two Expert Group measurements on the same set of test specimens is typically ~0.2 mW/m·K. This difference is 0.5% of the measured thermal conductivity value with a standard deviation of only 0.2%–0.3%. The level of agreement between the Expert Group laboratories is of a similar order for both the comparative testing on specimens with 40–50 mm thickness and for specimens with 80–100 mm thickness. The Keymark value is defined within the scheme as the mean of the test results from two different Expert Group laboratories.

These Experts Group measurements are thus deviating typically 0.1 mW/m·K from the Keymark value and are considered to be providing sufficient confidence for their use in evaluating the calibration level of laboratory equipment in combination with the IRMM 440 reference material.

4. COMPARATIVE TESTING (CANDIDATE) REGISTERED LABORATORIES

The Keymark scheme rules require comparative testing that shall be performed for each individual test instrument used by a registered laboratory, including the Expert Group laboratories that have more than one instrument. Each instrument shall be within a ±1.5% limit for any of the Keymark value of materials sent to

Table 2. Keymark value – Difference between Expert equipment.

Test result difference between expert equipment – 2001 to 2013						
Number	Type and thickness (mW/m·K)					
	EPS		MW		Neopor™	
	50 mm	100 mm	50 mm	100 mm	40 mm	80 mm
1	0.11	0.04	0.09	0.20	0.28	0.04
2	0.19	0.01	0.27	0.48	0.05	0.01
3	0.29	0.24	0.72	0.13	0.10	0.09
4	0.07	0.16	0.41	0.24	0.15	0.11
5	0.06	0.51	0.32	0.34	0.23	0.03
6	0.07	0.52	0.16	0.06	0.24	0.14
7	0.30	0.03	0.40	0.10	0.09	0.11
8	0.06	0.05	0.15	0.09	0.20	0.15
9	0.30	0.14	0.12	0.48	0.07	0.09
10	0.20	0.10	0.28	0.20	0.06	0.02
11	0.13	0.02	0.36	0.10	0.17	
12	0.12	0.00	0.43	0.30		
13	0.05	0.06	0.50	0.09		
14	0.33			0.27		
15	0.21			0.21		
16	0.17			0.08		
17				0.25		
18				0.14		
Mean	**0.17**	**0.14**	**0.29 (0.32)**	**0.21**	**0.15**	**0.08**
Mean in %	**0.49**	**0.43**	**0.92 (1.02)**	**0.65**	**0.50**	**0.26**
St. dev.	**0.10**	**0.17**	**0.14 (0.18)**	**0.13**	**0.08**	**0.05**
N	16	13	12 (13)	18	11	10

Notes: EPS, expanded polystyrene board; MW, fibreglass board; St. dev., standard deviation.

the registered laboratory as part of the comparative testing (50- and 100-mm thick MW and EPS as well as 40 and 80 mm Neopor).

The comparative testing is performed every 3–5 years by having the scheme secretariat distributing two sets of test specimens (with two different thicknesses covering the largest range appropriate for the equipment) for all registered laboratories. Test specimens are circulated to groups of laboratories having test equipment requiring the same size of test specimens. Different sizes are needed for some laboratories with more than one instrument and they may therefore be part of more than one group of laboratories. For the most common sizes (600, 610, and 800 mm), more groups of a few laboratories are defined at random to finish the ongoing comparative testing campaign within a reasonable time.

The laboratories are informed about the test specimen's identification, weight, lateral dimensions, and thickness to be used for the testing, but the Keymark value is withheld. See Figure 3 for example of a test specimen cut to fit different sizes equipment.

The laboratories are required to report the test results to the Keymark secretariat on a standard form and are also asked to report their latest measurement on an IRMM 440 certified reference sample. The laboratories are then informed whether their results are within the required ±1.5% limit. If not, then further investigations are agreed to find a resolution.

New laboratories applying for registration are also subject to the same comparative testing in addition to auditing of their laboratory by an expert and evaluation of their equipment performance documentation.

A list of registered laboratories is made available to insulation product certification bodies and includes information on individual test equipment and for which insulation products the laboratories have testing experience.

Figure 3. Example of test specimens cut down to 400 × 400 mm.

The latest comparative testing campaign has lasted from 2011 to 2013, and the results are shown in Figures 4 and 5 and summarized in Table 3.

The first comparative testing processed in 2001–2004 had the following results as shown in Figures 6 and 7 and summarized in Table 3. The details of this testing was reported during the ITCC 27 (Rasmussen & ITCC 27 Paper, 2003).

The second comparative testing between the European laboratories was done between 2005 and 2010.

The results are shown in Figure 8 and summarized in Table 3.

Each identification number (in the left hand column in Table 3) represents a set of tests in a particular instrument within one of the three comparative testing periods. In a few cases, two sets of tests were carried out using the same instrument within a period and therefore, two numbers are associated with one instrument. Numbers within the three periods are chosen at random and therefore the same number in

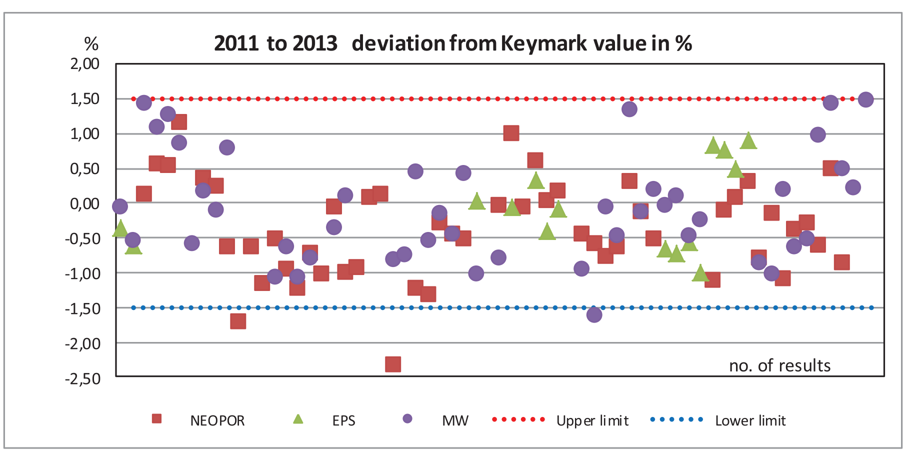

Figure 4. 2011–2013 comparative testing "unknown test specimens".

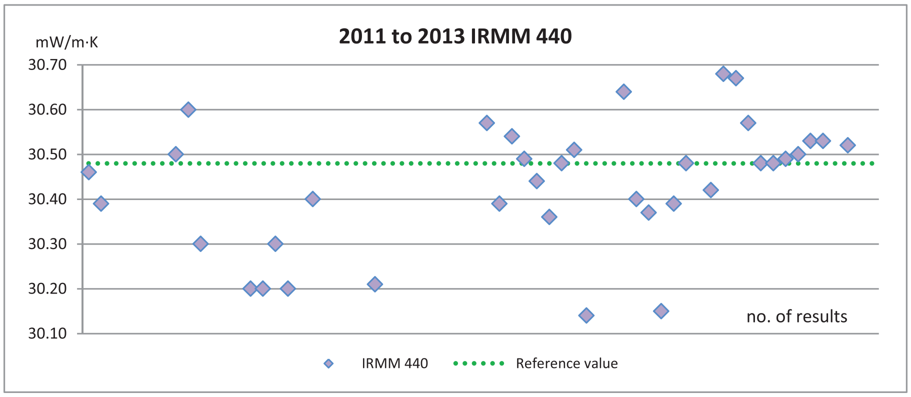

Figure 5. 2011–2013 comparative testing 35 mm IRMM reference material.

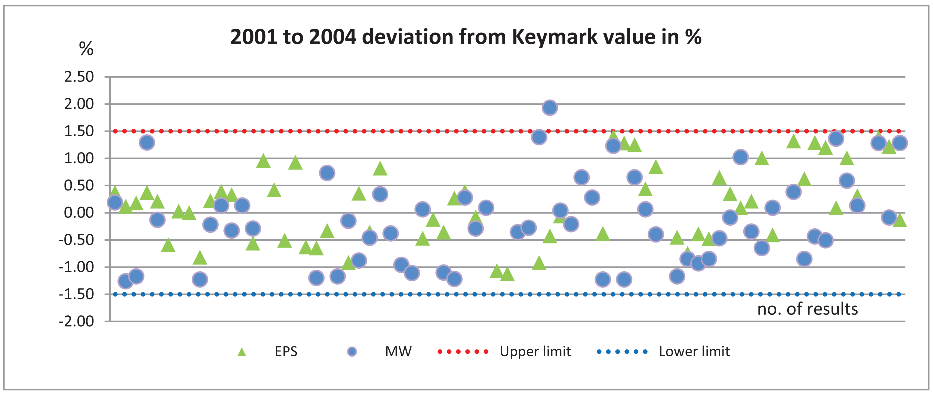

Figure 6. 2001–2004 comparative testing “unknown test specimens”.

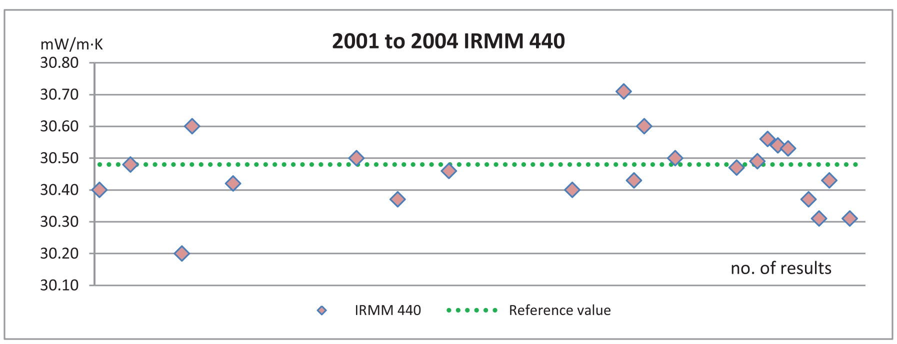

Figure 7. 2001–2004 comparative testing 35 mm IRMM reference material.

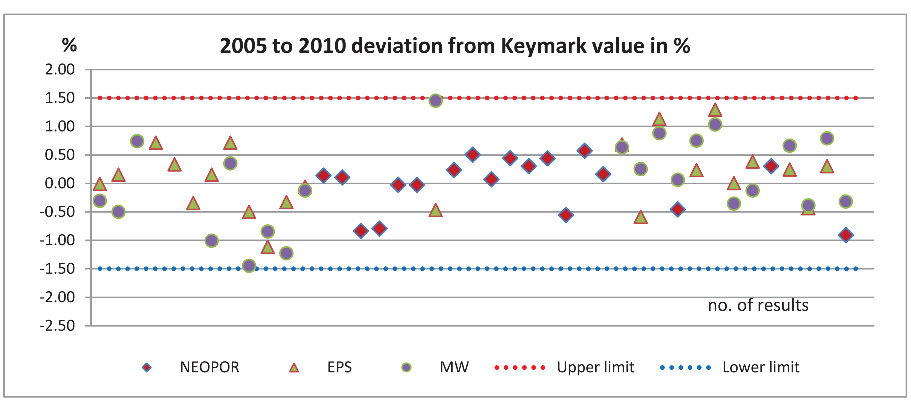

Figure 8. 2005–2010 comparative testing “unknown test specimens”.

Table 3. Comparative testing summary – All results.

No.	2001–2004			2005–2010			2011–2013			
	IRMM 440	EPS	MW	Neopor	EPS	MW	IRMM 440	Neopor	EPS	MW
	mW/m·K	% Deviation		% Deviation			mW/m•K	% Deviation		
1	30.40	0.37	0.19		–0.01	–0.31	30.46		–0.37	–0.06
2		0.12	–1.26		0.15	–0.50	30.39		–0.62	–0.54
3		0.18	–1.17			0.74		0.13		1.43
4	30.48	0.37	1.29		0.71			0.56		1.09
5		0.21	–0.13		0.33			0.53		1.27
6		–0.59			–0.35			1.16		0.85
7		0.03			0.15	–1.01				–0.60
8		0.00			0.71	0.35	30.50	0.36		0.16
9	30.20	–0.82	–1.23		–0.50	–1.45	30.60	0.23		–0.11
10	30.60	0.22	–0.22		–1.12	–0.85	30.30	–0.63		0.79
11		0.39	0.13		–0.33	–1.23		–1.72		
12		0.33	–0.33		–0.06	–0.13		–0.63		
13			0.13	0.13				–1.16		
14	30.42	–0.56	–0.29	0.10			30.20	–0.53		–1.08
15		0.96		–0.84			30.20	–0.96		–0.63
16		0.42		–0.80			30.30	–1.22		–1.08
17		–0.51		–0.03			30.20	–0.73		–0.79
18		0.93		–0.03				–1.02		
19		–0.63			–0.47	1.45	30.40	–0.07		–0.35
20		–0.65	–1.20	0.23				–1.00		0.09
21		–0.33	0.73	0.50				–0.93		
22			–1.17	0.07				0.07		
23		–0.92	–0.15	0.44				0.13		
24		0.36	–0.88	0.30			30.21	–2.34		–0.82
25		–0.36	–0.46	0.44						–0.76
26	30.50	0.82	0.34	–0.56				–1.23		0.45
27			–0.38	0.57				–1.33		–0.54
28			–0.96	0.16				–0.30		–0.16
29			–1.11		0.68	0.63		–0.45		–0.45
30	30.37	–0.47	0.06		–0.59	0.25		–0.51		0.43
31		–0.12			1.13	0.88			0.03	–1.02
32		–0.36	–1.10	–0.46		0.06				
33		0.27	–1.22		0.23	0.75	30.57	–0.03		–0.79
34		0.39	0.28		1.29	1.03	30.39	1.00	–0.06	
35	30.46	–0.08	–0.29		0.00	–0.36	30.54	–0.07		
36			0.09		0.38	–0.13	30.49	0.60	0.33	
37		–1.07		0.3			30.44	0.03	–0.41	
38		–1.12			0.24	0.66	30.36	0.17	–0.09	
39			–0.36		–0.44	–0.39	30.48			
40			–0.28		0.30	0.79	30.51	–0.46		–0.95
41		–0.92	1.39	–0.91		–0.32	30.14	–0.60		–1.62
42		–0.43	1.93					–0.78		–0.06
43		–0.06	0.04					–0.64		–0.48
44			–0.21				30.64	0.30		1.34

(Continued)

Table 3. (*Continued*)

No.	2001–2004			2005–2010			2011–2013			
	IRMM 440	EPS	MW	Neopor	EPS	MW	IRMM 440	Neopor	EPS	MW
	mW/m·K	% Deviation		% Deviation			mW/m•K	% Deviation		
45			0.65				30.40	–0.13		–0.13
46			0.28				30.37	–0.53		0.19
47	30.40	–0.38	–1.23				30.15		–0.65	–0.03
48		1.40	1.23				30.39		–0.72	0.11
49		1.28	–1.23				30.48		–0.57	–0.47
50		1.25	0.65						–1.00	–0.25
51		0.44	0.06				30.42	–1.12	0.83	
52	30.71	0.85	–0.40				30.68	–0.10	0.77	
53	30.43						30.67	0.07	0.50	
54	30.60	–0.45	–1.17				30.57	0.30	0.89	
55		–0.75	–0.85				30.48	–0.79		–0.86
56		–0.39	–0.93				30.48	–0.16		–1.03
57	30.50	–0.48	–0.85				30.49	–1.10		0.19
58		0.65	–0.47				30.50	–0.39		–0.63
59		0.35	–0.09				30.53	–0.30		–0.53
60		0.09	1.02				30.53	–0.61		0.98
61		0.21	–0.35					0.50		1.43
62		1.01	–0.65				30.52	–0.86		0.48
63	30.47	–0.41	0.09							0.22
64										1.47
65	30.49	1.32	0.38							
66	30.56	0.62	–0.85							
67	30.54	1.29	–0.44							
68	30.53	1.20	–0.51							
69		0.09	1.36							
70	30.37	1.01	0.59							
71	30.31	0.31	0.13							
73		1.38	1.28							
74	30.31	1.22	–0.09							
75		–0.13	1.28							
Avg	**30.46**	**0.15**	**–0.15**	**–0.02**	**0.11**	**0.04**	**30.43**	**–0.31** (–0.38)	**–0.01**	**–0.23**
Std. dev.	**0.11**						**0.14**			
Abs. Avg dev.		**0.58**	**0.66**	**0.38**	**0.46**	**0.65**		**0.56** (0.62)	**0.52**	**0.65**
Abs. Std dev.		**0.40**	**0.48**	**0.28**	**0.36**	**0.41**		**0.38** (0.48)	**0.31**	**0.44**
number	22	61	61	18	22	22	32	49 (51)	13	36

Notes: EPS, expanded polystyrene board; MW, fibreglass board; IRMM 440; Std.dev., standard deviation; Abs., absolute.

different periods does not necessarily correspond to measurements in the same instrument.

The IRMM 440 test specimens used within the scheme are owned by the individual laboratories. The results show that the mean of 30.45 mW/m·K obtained for IRMM 440 during the comparative testing is very close to the reference value of 30.48 mW/m·K and the standard deviation is from 0.11 to 0.14 mW/m·K corresponding to 0.35%–0.45% of the mean thermal conductivity value.

The results of the measurements of the test specimens with undisclosed Keymark values for all three time periods clearly show that the test equipment (both GHP and HFM equipment) are capable of reproducing results within ±1.5% for all the materials and thickness used to date. These results are better than that achieved in earlier intercomparisons in Europe (Salmon & Tye, 1999a, Germany) and USA (Salmon & Tye, 1999b).

The deviation of the mean from expected Keymark values shows that the European calibration level is achieved and maintained for all laboratories and equipment within this scheme. The method of selecting test specimens and defining the Keymark values has been found to be very robust (mean deviation from Keymark value 0.13%, 0.04 mW/m·K). The absolute mean deviation between equipment is ~0.6% corresponding to ±0.2 mW/m·K for individual measurements with a standard deviation of 0.4% (±0.1 mW/m·K).

For the testing carried out between 2011 and 2013, there are two test results that are marked in red, and average standard deviation has been calculated with those values omitted. In one case the equipment was scrapped after the comparative testing, and in the other (an HFM), a calibration mistake was corrected. For the first two periods, similar issues were identified and actions taken by the respective laboratories and new tests with other undisclosed Keymark value test specimens are included in Table 3. Laboratories that did not become registered are omitted. For the latest comparative testing that took place between 2011 and 2013, a couple of results from non-registered equipment are included, as those laboratories have continuously participated in the comparative testing.

The comparative testing for all three time periods shows a high level of agreement partly not only because of the excellent cooperation between the expert and registered laboratories in the actual testing programs but also because of the high commitment by all laboratories to achieve a higher level of professional performance in testing of thermal conductivity.

During the last 10 years, several items of old equipment have been scrapped by institutes. Simultaneously, many of the institutes have invested in new equipment, both GHP and HFM, and have done extensive work on equipment manuals and uncertainty budgets.

4.1 Participating laboratories

The following alphabetical list of experts and registered laboratories took part in the comparative testing between 2011 and 2013:

- BBA, UK
- BBRI-CSTC-WTCB, Belgium
- BVFS, Austria
- CEIS, Spain
- CSI, Czech Republic
- CSTB, France
- DTI, Denmark
- EMPA, Switzerland
- FIW München, Germany
- IMBiGS Katowice, Poland
- Istituto Giordano, Italy
- Kiwa BDA Testing, the Netherlands
- LNE, France
- MA39-VFA, Austria
- MPA-Bau, Germany
- MPA-NRW, Germany
- MPA-Stuttgart, Germany
- NPL, UK
- OFI, Austria
- SINTEF, Norway
- SP, Sweden
- TZUS, Czech Republic
- VTT, Finland.

In addition, the following laboratories took part in the comparative testing:

- KIWA, the Netherlands
- TSUS, Branch Nitra, Slovakia.

Further European laboratories are in the process of becoming Keymark registered and a few more are currently considering application. The success of the Keymark registration will hopefully convince the remaining independent laboratories of the need to prove their competence by applying for participation or ceasing their activities in this area if they are not able to comply with the generally high quality of thermal conductivity testing among European test institutes.

5. CONCLUSIONS

The Keymark certification scheme rules for the registration of independent laboratories have proven to be very efficient and robust because of the following conditions:

- comparative testing as described in this article in combination with;
- audit of laboratories by a technical expert focusing on the requirements for equipment documentation as described in Rasmussen & ITCC 27 Paper (2003).

This has made it possible to clearly identify those laboratories competent to carry out thermal conductivity testing to the required level of agreement with the European λ_{10} level for thermal conductivity of building insulation.

On participating in the scheme, many laboratories have made a great effort to improve their documentation, measurement procedures, and equipment, as well as preparing detailed uncertainty budgets before applying to become registered.

The activities of the expert and registered Keymark laboratories have shown that it is possible continuously over many years to be able measure thermal conductivity values within the limits of ±1.5%.

More information on the thermal insulation Keymark can be found on the website: www.insulation-keymark.org.

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