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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Standard Reference Materials:

Glass Fiberboard SRM for Thermal Resistance

Jerome G. Hust

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Jerome G. Hust

Center for Chemical Engineering
National Engineering Laboratory
National Bureau of Standards
Boulder, CO 80303

Sponsored by:
Office of Standard Reference Materials
National Measurement Laboratory
National Bureau of Standards
Gaithersburg, MD 20899

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Preface

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Standard Reference Materials: Glass Fiberboard SRM for Thermal Resistance

J. G. Hust

Chemical Engineering Science Division
Center for Chemical Engineering
National Bureau of Standards
Boulder, Colorado 80303

The apparent thermal conductivity data that provide the basis for the certification of glass fiberboard as an SRM of thermal resistance are reported and analyzed. New data for the extension of the temperature range of this SRM to 100 K are included. Detailed analysis and intercomparisons of previously described NBS and other published data are given. These data are represented by an equation describing the dependencies of the data on temperature and density. Certified values of thermal resistance are given for temperatures from 100 to 330 K and densities from 113 to 145 kg/m^3.

Key words: apparent thermal conductivity; density; glass fiberboard; Standard Reference Material; temperature; thermal resistance

1. Introduction

The National Bureau of Standards (NBS) has an on-going program to establish physical property Standard Reference Materials (SRM's) as needed to improve measurement reliability. The Center for Chemical Engineering (CCE) has been active in a portion of this effort for about 20 years in establishing SRM's for thermal conductivity over a broad range of conductivities and temperatures. The status of this effort was recently summarized by Hust [1]. The Center for Building Technology (CBT) has supplied calibrated transfer specimens (CTS's) for thermal resistance of insulations for over 50 years. More recently they have utilized the large data base of the CTS effort to provide the basis for establishing glass fiberboard as an SRM [2,3].

During the mid 1970's, the American Society for Testing and Materials recognized the strong need for thermal insulation SRM's. As a consequence, a task group was established under the auspices of ASTM subcommittee C16.30 on thermal measurements. The recommendations for establishing thermal insulations SRM's was published in 1978 [4].

The purpose of the present publication is to describe the combined effort of CCE and CBT of NBS to establish the first of a series of insulation SRM's as recommended by the ASTM subcommittee. The first insulation SRM is a glass fiberboard material. It was established as an SRM of thermal resistance by Siu and Hust [2] for the temperature range 255 to 330 K in 1982. The new data provided in this publication are the basis for extending this certification down to 100 K. First, a description of the basis for the new certification is presented. Comparisons between this new certification and the previous certification and other published data are also included.

2. Material Characterization

During the past twenty five years, CBT has performed over 300 thermal resistance calibrations for industry and government laboratories. Several distinct lots of material have been used for this purpose. These lots are designated in this publication by the year in which they were acquired by NBS, e.g., lot 58, 59, etc. The thermal resistance data from these calibrations have been compiled and published by Siu [3]. Four lots of material (58, 59, 61, and 70) are described by Siu [3]. The material for each lot consists of fibrous glass made into a semirigid board with a phenolic binder. The fibers are oriented with their lengths extending primarily parallel to the face of the boards.

Subsequent to the publication by Siu [3], two additional lots of material were acquired by NBS and are designated as lots 80 and 81. Because the earlier lots were rapidly consumed as CTS and SRM material, the 80 and 81 lots represent the present NBS supply of material for SRM 1450b.

Although nominally the same, these lots differ somewhat in their thermal characteristics. These differences are attributed to variations in manufacturing processes and the resultant differences in fiber diameter and orientation as well as differences in phenolic content. The bulk densities of the material in the lots range from 70 to 150 kg/m^3.

3. Measurements

The data reported and described in this publication were obtained from three NBS apparatus:

a) The CBT square guarded hot plate with a 20 cm square plate and a 10 cm square meter section. This apparatus has been used many years for CTS calibrations but is not specifically described in the literature.

b) The CBT line source guarded hot plate with a 30 cm diameter plate and a 15 cm diameter meter section. It is described by Hahn [5].

c) The CCE circular guarded hot plate with a 20 cm diameter plate and a 10 cm diameter meter section. It is described by Smith, Hust, and Van Poolen [6].

Prior to 1980 numerous measurements were conducted on four lots of similar fiberboard material. The results of these tests are discussed in section 5.

After 1980 specimens from lots 80 and 81 were measured by both CBT and CCE. These data indicated that lots 80 and 81 were indistinguishable and the data were used to certify the two lots as SRM 1450b [2]. At that time, the density dependence of these lots had not been well-established for low temperatures and, consequently, only informational values were presented for temperatures below 255 K. Since that time, CCE conducted low temperature measurements on specimens over the entire density range of the 80/81 lot. The data for the 80/81 lot are reported in Tables 1, 2, and 3 and are the basis for this certification from 100 K to 330 K.

Table 1. CCE thermal conductivity data for lot 80.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
310	322.560	298.267	128.67	2.5367	36.548	.68
310	322.713	298.236	121.14	2.5367	36.397	.81
325	337.826	312.867	121.12	2.5372	38.174	.60
119	131.157	105.900	121.46	2.5301	14.396	-.09
129	141.303	116.067	121.44	2.5304	15.604	-.26
139	151.448	126.301	121.43	2.5307	16.936	.29
152	167.898	136.545	121.41	2.5312	18.563	.39
108	121.220	95.755	121.47	2.5298	13.279	.62
169	181.980	156.650	121.38	2.5317	20.412	-.52
179	191.949	166.843	121.37	2.5320	21.587	-.39
159	171.760	146.477	121.40	2.5314	19.147	-.92
190	202.213	176.964	121.35	2.5324	22.760	-.20
200	212.243	187.005	121.33	2.5327	23.864	-.12
210	222.335	197.070	121.32	2.5330	24.970	.04
220	232.403	207.215	121.30	2.5334	26.063	.18
230	242.446	217.266	121.28	2.5337	27.150	.32
240	252.481	227.356	121.27	2.5341	28.241	.45
250	262.534	237.443	121.25	2.5344	29.313	.46
275	287.758	262.587	121.21	2.5354	32.047	.32
300	312.791	287.758	121.16	2.5363	34.865	-.01
300	312.829	287.870	144.58	2.5363	35.592	.20
326	337.988	313.013	144.53	2.5372	38.673	.18
108	121.140	95.713	144.95	2.5298	13.812	-.16
118	131.138	105.792	144.93	2.5301	14.864	-1.22
128	141.161	115.748	144.92	2.5304	16.023	-1.48
139	151.599	126.064	144.90	2.5307	17.394	-.75
152	167.936	136.123	144.87	2.5312	19.293	.94
159	171.941	146.574	144.86	2.5314	20.186	1.00
169	181.987	156.712	144.84	2.5317	21.339	.81
179	192.000	166.873	144.82	2.5320	22.481	.72
190	202.306	176.986	144.81	2.5324	23.618	.69
200	212.252	187.044	144.79	2.5327	24.546	.03
210	222.306	197.105	144.77	2.5330	25.668	.25
220	232.246	207.099	144.75	2.5334	27.020	1.38
230	242.399	217.299	144.73	2.5337	27.845	.50
240	252.340	227.314	144.71	2.5341	28.829	.28
250	262.529	237.387	144.69	2.5344	29.958	.46
275	287.641	262.507	144.63	2.5353	32.754	.54
230	242.345	217.132	144.73	2.5337	27.723	.11

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 2. CCE thermal conductivity data for lot 81.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
310	322.562	298.203	142.47	2.5367	36.986	.84
311	322.916	298.149	133.80	2.5367	36.273	-.51
107	119.494	93.827	136.93	2.5298	13.643	1.77
130	144.470	115.978	136.89	2.5305	16.469	1.30
148	160.236	134.978	136.86	2.5310	18.283	-.47
198	210.574	185.271	136.77	2.5326	24.048	-.35
226	237.697	213.533	136.72	2.5336	27.159	.42
249	259.504	238.649	136.68	2.5344	29.684	.61
274	284.902	263.464	136.63	2.5353	32.343	.28
298	309.240	286.603	136.58	2.5362	34.946	-.18
316	328.058	304.479	136.54	2.5369	36.974	-.71
336	347.823	324.087	136.50	2.5377	39.348	-.90
336	348.019	324.087	136.50	2.5377	39.633	-.21
336	347.771	324.099	136.50	2.5377	39.588	-.29
298	309.178	286.631	136.58	2.5362	34.962	-.13
249	259.754	238.855	136.68	2.5344	29.541	.05
249	259.743	238.858	136.68	2.5344	29.577	.17
298	309.311	286.641	136.58	2.5362	34.849	-.47
336	348.215	324.097	136.50	2.5377	39.536	-.49
307	319.220	294.562	136.56	2.5365	36.848	2.06
307	319.224	294.562	136.56	2.5365	36.513	1.16
319	343.568	294.659	136.54	2.5370	37.563	-.14
319	343.579	294.658	136.54	2.5370	37.593	-.06
331	343.419	319.118	136.51	2.5375	39.411	.76
331	343.440	319.200	136.51	2.5375	39.446	.83
331	343.468	319.226	136.51	2.5375	38.839	-.72
331	343.650	319.217	135.50	2.5565	39.256	.39
331	343.365	319.127	137.55	2.5184	38.573	-1.46
106	119.098	93.400	136.93	2.5298	13.302	-.38
119	131.178	106.108	136.91	2.5301	14.984	.92
118	131.147	105.687	136.91	2.5301	15.028	1.39
118	131.014	105.601	136.91	2.5301	14.385	-2.93
139	151.619	126.427	136.88	2.5307	17.440	.64
164	176.850	151.718	136.83	2.5315	20.217	-.69
184	197.109	171.842	136.80	2.5322	22.380	-1.27
210	222.063	197.116	136.75	2.5330	25.070	-1.20
235	247.568	222.427	136.71	2.5339	27.937	-.30
249	259.715	238.762	136.68	2.5344	29.693	.59
250	260.700	238.799	136.68	2.5344	29.472	-.35
250	260.934	238.830	135.66	2.5535	30.094	1.77

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 3. CBT thermal conductivity data for lot 81.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
297	309.109	284.901	122.30	2.5220	34.471	-.11
303	314.616	290.679	133.50	2.5590	35.546	.15
297	308.886	284.818	128.60	2.5310	34.453	-.61
325	336.112	313.591	128.80	2.5270	38.113	.06
255	265.766	243.950	128.70	2.5290	29.552	-1.19
324	335.811	312.971	120.60	2.5390	38.020	.56
297	309.217	285.258	120.40	2.5680	34.457	-.08
256	267.123	245.808	120.80	2.5350	29.734	-.42
326	336.654	314.677	136.70	2.5530	38.508	.26
297	309.379	285.408	136.80	2.5520	34.713	-.69
297	309.021	285.536	112.60	2.5250	34.332	.17
255	265.517	243.653	113.30	2.5260	29.204	-.85
327	338.088	316.088	141.50	2.5720	38.495	-.58
297	309.408	285.056	141.50	2.5720	34.853	-.60
258	268.459	246.639	141.50	2.5730	30.152	-1.30
314	326.265	302.564	137.80	2.5790	37.063	.06
291	302.743	278.327	137.40	2.5010	34.003	-.46
279	289.249	268.599	132.90	2.5690	32.325	-1.12
305	317.058	293.551	133.10	2.5640	35.928	.35
318	329.630	306.632	119.40	2.5400	37.090	.25
303	314.816	290.667	119.40	2.5400	35.167	.15
269	279.396	257.635	133.70	2.5560	31.182	-1.13
326	337.591	314.999	135.90	2.5600	38.337	-.34
302	314.482	290.506	136.90	2.5510	35.371	-.55
327	338.448	315.835	141.40	2.5750	38.706	-.04
297	309.336	285.056	141.60	2.5730	34.994	-.19
258	269.522	247.073	141.40	2.5740	30.133	-1.63
297	308.844	285.114	112.50	2.5270	34.277	.12
289	301.164	277.573	133.10	2.5280	33.697	-.61
314	324.535	302.498	133.10	2.5280	33.846	.12
297	308.933	285.002	131.30	2.5790	34.901	.43
304	315.950	292.434	131.30	2.5800	35.893	.77
297	309.087	284.733	126.40	2.5430	34.776	.48
297	308.756	284.777	128.40	2.5300	34.843	.56
275	284.907	264.978	128.60	2.5260	31.894	-.69

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

4. Data Analysis

This report is the basis of the certification of SRM 1450b over the extended temperature range from 100 to 330 K with air as the fill gas at atmospheric pressure.

To provide a basis for the certification, a model was selected and optimized to represent the data for lots 80 and 81. A variety of models from the literature were examined for this purpose. None of them proved adequate for the entire temperature range of this certification. As a consequence, an empirical modification of the form presented in the previous certification by Siu and Hust [2] was obtained. This model described the 114 data points from the 80 and 81 lots with no systematic deviations either as a function of temperature from 100 to 340 K or a function of density from 113 to 145 kg/m^3. The model is given by equation (1).

$$\lambda(T,\rho) = a_1 + a_2\rho + a_3T + a_4T^3 + a_5 \exp -[(T-180)/75]^2 \tag{1}$$

where the values of the parameters, a_i, are given in Table 4, ρ is the bulk density in kg/m^3, T is temperature in K, and $\lambda(T,\rho)$ is the apparent thermal conductivity in mW·m^{-1}·K^{-1}.

The deviations of the data from this model are shown in figure 1 as a function of temperature, and in figure 2 as a function of bulk density. Two times the standard deviation computed from the residuals of the fit, 2s, is 1.5%. For illustration, values of $\lambda(T,\rho)$ are calculated and plotted in figure 3 as a function of temperature at a density of 130 kg/m^3, and in figure 4 as a function of density at a temperature of 300 K.

5. Comparisons

Prior to 1980 measurements were conducted at CCE on several specimens from lots 58 and 70 at temperatures ranging from 100 K to 330 K. In addition, the CCE measurements were conducted with various fill gases (air, nitrogen, argon and helium) and over a range of fill-gas pressure from atmospheric pressure to high vacuum. The CCE measurements also involved a range of temperature differences between the hot cold plates from as small as 10 K to as large as 100 K. These variations in test conditions were helpful in separating the heat transfer mechanisms in this material. The data obtained prior to 1980 by CCE have been reported [7, 8, and 9].

To facilitate comparison equation (1) was also fitted to the atmospheric pressure data obtained by CCE with air and nitrogen as fill gas for lots 58 and 70. The data are listed in Tables 5 and 6. The coefficients for each fit are listed in Table 4. The large interlot variation of the a_4 parameter in Table 4 is noted. This indicates that the radiant heat transfer is a small part of the total in this material.

The deviations of the lot 58 data from the model are shown in figure 5 as a function of temperature, and as a function of density in figure 6. No systematic trends are observed for either variable. Two times the standard deviation of the data, 2s, is 2.1%.

Table 4. Coefficients determined by least squares fitting of equation (1) to the indicated data sets.

	Coefficients for		
i	80/81 lot[a] CBT & CCE	58 lot[b] CCE only	70 lot[c] CCE only
1	-2.228	-3.002	4.935
2	0.02743	0.04137	0.034
3	0.1063	0.1030	0.1128
4	64.73×10^{-9}	6.579×10^{-9}	-56.42×10^{-9}
5	1.157	0.4551	0.6315

NOTE: Equations describing the CBT data on the 58, 59, 61 and 70 lots are reported by Siu [3].

a - The experimental data are listed in Tables 1, 2, and 3.

b - The experimental data are listed in Table 5.

c - The experimental data are listed in Table 6.

Table 5. CCE thermal conductivity data for lot 58.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
302	314.673	289.783	127.07	2.5900	33.329	-.82
302	314.630	290.047	127.07	2.5900	33.258	-1.07
104	112.198	95.327	127.07	2.5900	12.750	-2.85
118	130.161	106.128	127.07	2.5900	14.503	-1.13
171	182.074	159.135	127.07	2.5900	20.024	-1.37
225	236.819	213.318	127.07	2.5900	25.688	-.54
275	285.470	264.168	127.07	2.5900	30.726	-.22
273	285.724	260.876	127.07	2.5900	30.362	-.92
230	248.759	210.312	127.07	2.5900	26.172	-.37
251	256.752	246.112	127.07	2.5900	28.235	-.73
274	285.331	262.523	127.07	2.5900	30.653	-.17
239	244.066	233.597	127.07	2.5900	27.465	1.00
239	244.092	233.571	127.07	2.5900	27.301	.40
273	285.589	260.570	127.07	2.5900	30.787	.54
101	110.958	90.614	127.07	2.5900	12.791	-.03
224	235.378	213.198	127.07	2.5900	26.050	1.15
273	285.173	260.691	127.07	2.2900	31.070	1.50
178	197.529	159.054	127.07	2.5900	21.169	.41
178	197.526	159.032	127.07	2.5900	21.262	.85
99	106.418	91.026	127.07	2.5900	12.639	.53
99	106.430	90.893	127.07	2.5900	12.541	-.20
122	134.455	110.134	127.07	2.5900	14.983	-.89
122	134.431	109.981	127.07	2.5900	15.316	1.37
172	184.917	159.503	127.07	2.5900	20.538	.36
172	184.938	159.565	127.07	2.5900	20.571	.50
97	104.042	90.264	127.07	2.5900	12.155	-2.05
121	134.299	108.344	127.07	2.5900	15.381	2.40
147	159.669	134.459	127.07	2.5900	18.060	1.48
198	210.271	185.369	127.07	2.5900	23.186	.37
248	260.628	235.379	127.07	2.5900	28.284	.64
297	308.983	285.709	127.07	2.5900	33.292	.58
297	309.110	285.715	127.07	2.5900	33.122	.05
297	308.941	285.691	127.11	2.5892	33.696	1.78
297	308.996	285.674	127.11	2.5892	33.342	.73
297	308.993	285.790	147.23	2.5892	34.267	.96
297	309.168	285.787	147.23	2.5892	33.872	-.22
297	309.059	285.820	147.23	2.5892	33.838	-.31
297	308.969	285.818	147.23	2.5892	33.852	-.25
147	159.777	134.172	147.53	2.5839	18.661	.17
198	210.061	185.095	147.43	2.5856	23.791	-.54
248	260.606	235.579	147.33	2.5873	28.968	.06
297	309.021	285.894	104.90	2.5892	32.548	1.09
248	260.607	235.369	104.97	2.5873	27.048	-.52
100	108.078	92.556	105.17	2.5825	12.071	1.94
147	159.732	134.898	105.11	2.5839	16.988	.45
198	210.356	185.872	105.04	2.5856	22.061	-.72
99	104.536	93.999	114.78	2.5824	12.303	1.48
147	159.816	134.854	114.71	2.5839	17.248	-.36
198	210.341	185.143	114.64	2.5856	22.677	.43
247	256.779	238.144	114.56	2.5873	27.591	.22
297	309.002	285.860	114.48	2.5892	32.860	.83
298	309.022	286.138	114.48	2.5892	32.274	-1.01
298	309.135	286.178	114.48	2.5892	32.434	-.54
349	361.286	336.523	114.39	2.5912	38.204	.66
310	322.820	298.163	116.85	2.5367	33.631	-1.20
147	160.100	134.847	117.11	2.5310	17.078	-2.03
198	210.760	185.175	117.03	2.5326	22.381	-1.43
245	255.245	234.940	116.97	2.5340	27.274	-.44
298	309.557	286.407	116.87	2.5362	32.270	-1.46
298	309.664	286.398	114.43	2.5902	32.479	-.51

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

Table 6. CCE thermal conductivity data for lot 70.

T_{mean} (K)	T_{hot} (K)	T_{cold} (K)	Density (kg/m^3)	Thickness (cm)	λ_{obs} ($mW \cdot m^{-1} \cdot K^{-1}$)	Percent Deviation
312	324.318	298.970	123.65	2.5880	34.092	-.36
312	324.367	298.792	123.65	2.5880	33.869	-1.00
311	323.154	297.896	123.65	2.5880	34.297	.55
188	249.637	125.587	123.65	2.5880	22.228	1.90
165	204.575	125.671	123.65	2.5880	19.879	1.59
153	180.016	125.235	123.65	2.5880	18.241	-.02
139	152.155	125.241	123.65	2.5880	16.640	-.29
115	127.285	102.951	123.65	2.5880	14.072	.97
124	136.921	110.580	123.65	2.5880	15.227	1.84
144	158.013	130.901	123.65	2.5880	17.701	1.96
171	184.235	158.334	123.65	2.5880	20.464	.43
197	209.602	183.821	123.65	2.5880	23.255	.76
220	239.609	199.405	123.65	2.5880	25.288	-.28
240	259.975	219.235	123.65	2.5880	27.353	.11
252	257.784	245.255	123.65	2.5880	28.664	.69
258	268.420	246.794	123.65	2.5880	29.153	.35
283	302.401	264.571	123.65	2.5880	31.537	.01
285	298.358	271.866	123.65	2.5880	31.729	.14
310	323.456	297.534	123.65	2.5880	34.559	1.31
311	323.994	298.544	123.65	2.5880	34.517	.98
332	343.365	320.831	123.55	2.5900	36.229	.24
300	311.812	287.434	123.55	2.5900	32.821	-.76
300	311.921	287.627	123.55	2.5900	32.931	-.47
300	311.786	287.310	123.55	2.5900	33.057	-.02
299	311.837	287.077	123.55	2.5900	33.020	-.11
300	312.040	287.653	123.55	2.5900	32.815	-.84
300	311.927	287.650	123.55	2.5900	32.965	-.37
99	110.760	87.574	123.55	2.5900	12.043	-.22
99	110.937	87.415	123.55	2.5900	11.945	-1.05
108	121.123	94.539	123.55	2.5900	12.951	-1.02
115	135.458	94.437	123.55	2.5900	13.826	-.68
143	181.869	104.709	123.55	2.5900	17.062	-.52
132	163.998	99.722	123.55	2.5900	15.770	-.66
159	177.654	140.721	123.55	2.5900	18.830	-.99
158	177.228	138.651	123.55	2.5900	18.591	-1.52
160	177.468	143.271	123.55	2.5900	19.115	-.20
214	249.081	178.859	123.55	2.5900	24.518	-.97
222	243.068	201.315	123.55	2.5900	25.396	-.89
215	228.239	201.674	123.55	2.5900	24.683	-.96
248	258.948	236.764	123.55	2.5900	27.840	-.99

Percent Deviation = $(\lambda_{obs}-\lambda_{calc})100/\lambda_{calc}$

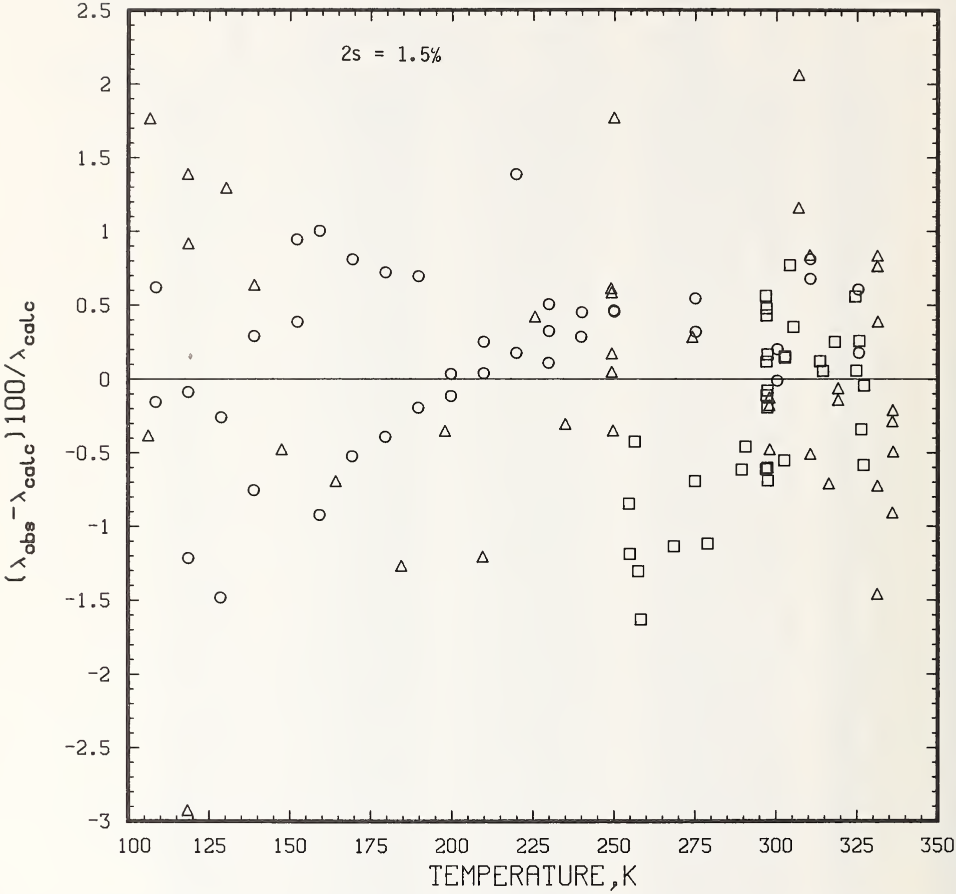

Figure 1 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the mean temperature of the measurements for densities from 113 to 145 kg/m^3

○ - CCE Lot 80
△ - CCE Lot 81
□ - CBT Lot 81

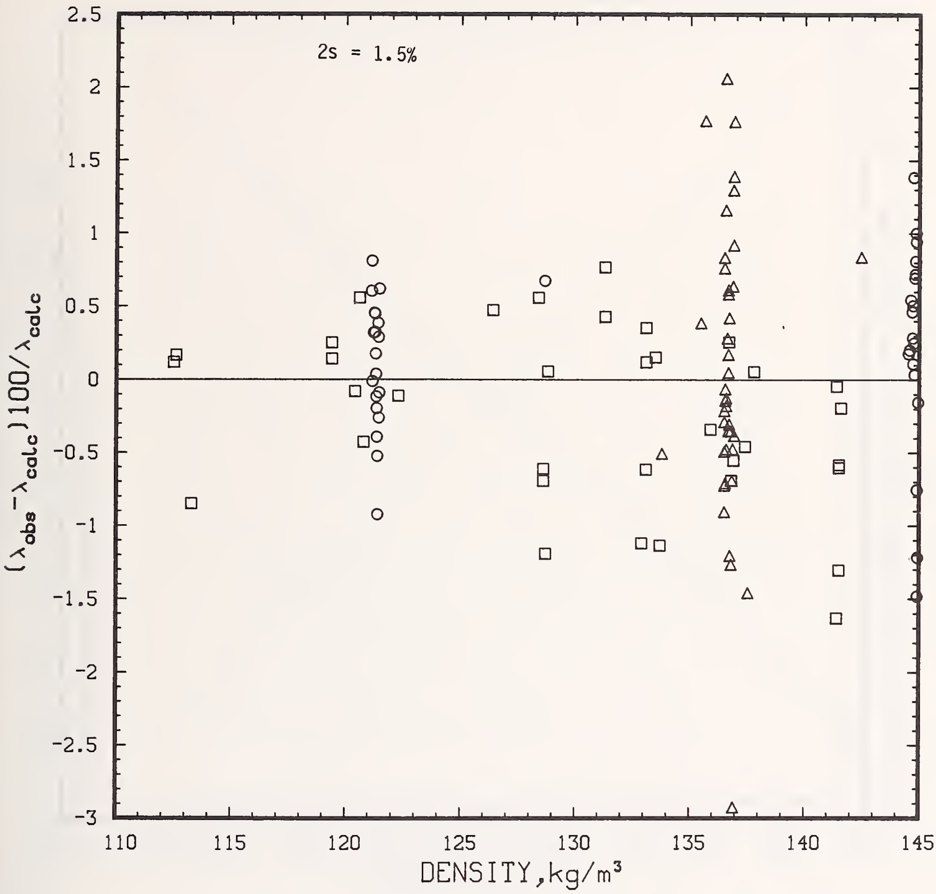

Figure 2 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the bulk density of the specimens for mean temperatures from 105 to 340 K

○ - CCE lot 80
△ - CCE Lot 81
□ - CBT Lot 81

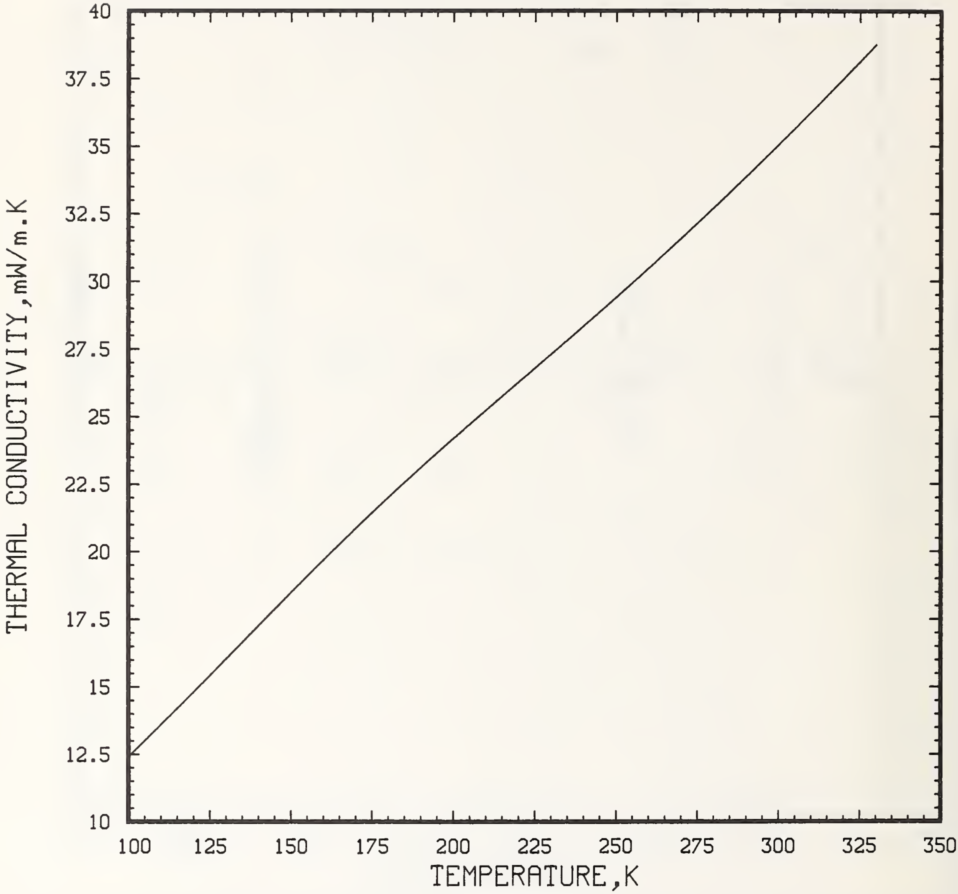

Figure 3 Thermal conductivity as a function of temperature at a density of 130 kg/m^3 as calculated from equation (1) for lots 80 and 81

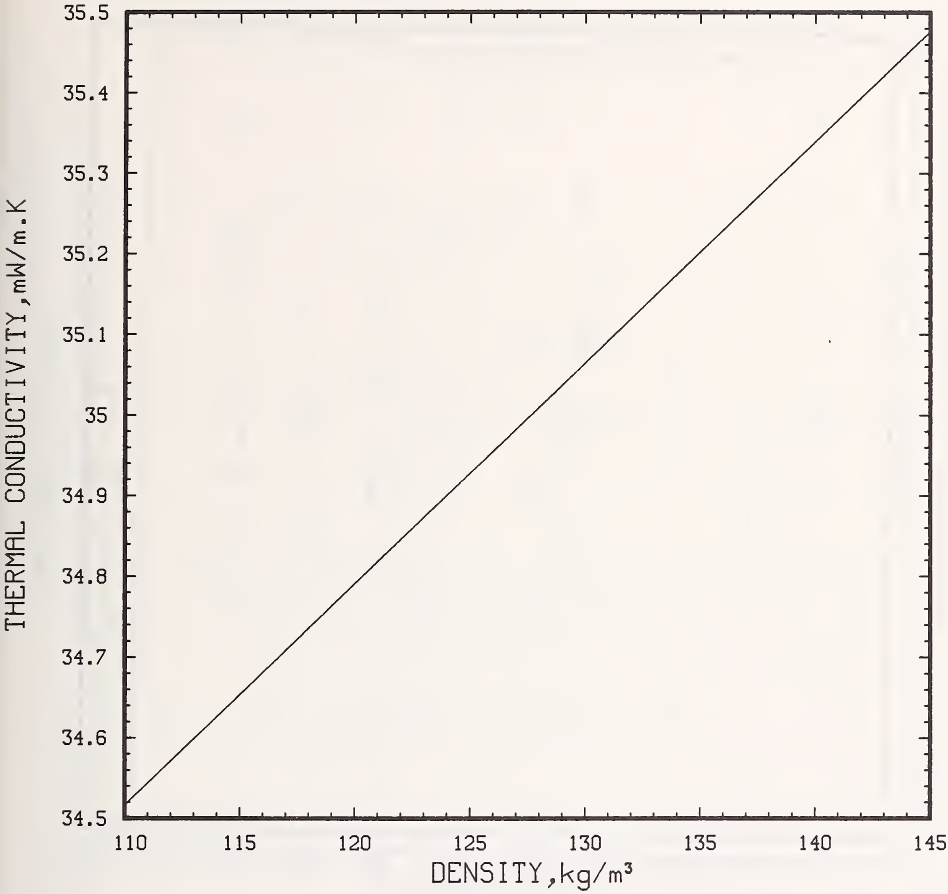

Figure 4 Thermal conductivity as a function of bulk density at a temperature of 300 K as calculated from equation (1) for lots 80 and 81

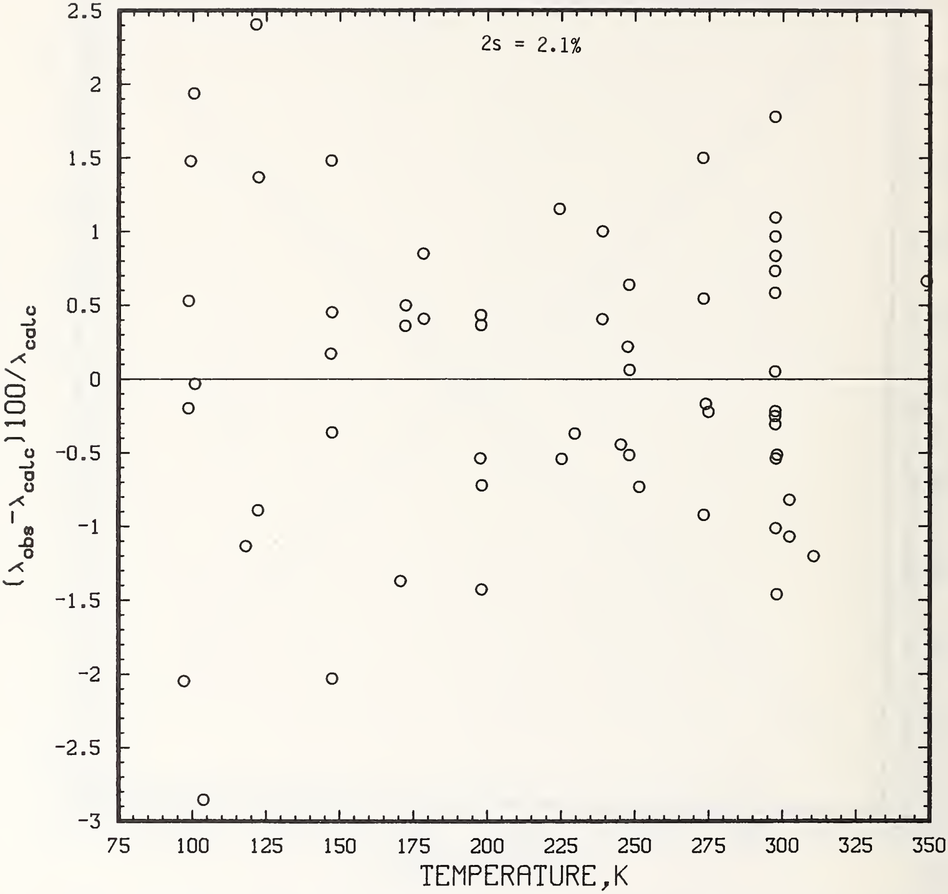

Figure 5 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the mean temperature of the measurements for lot 58 as measured by CCE for densities from 105 to 148 kg/m^3

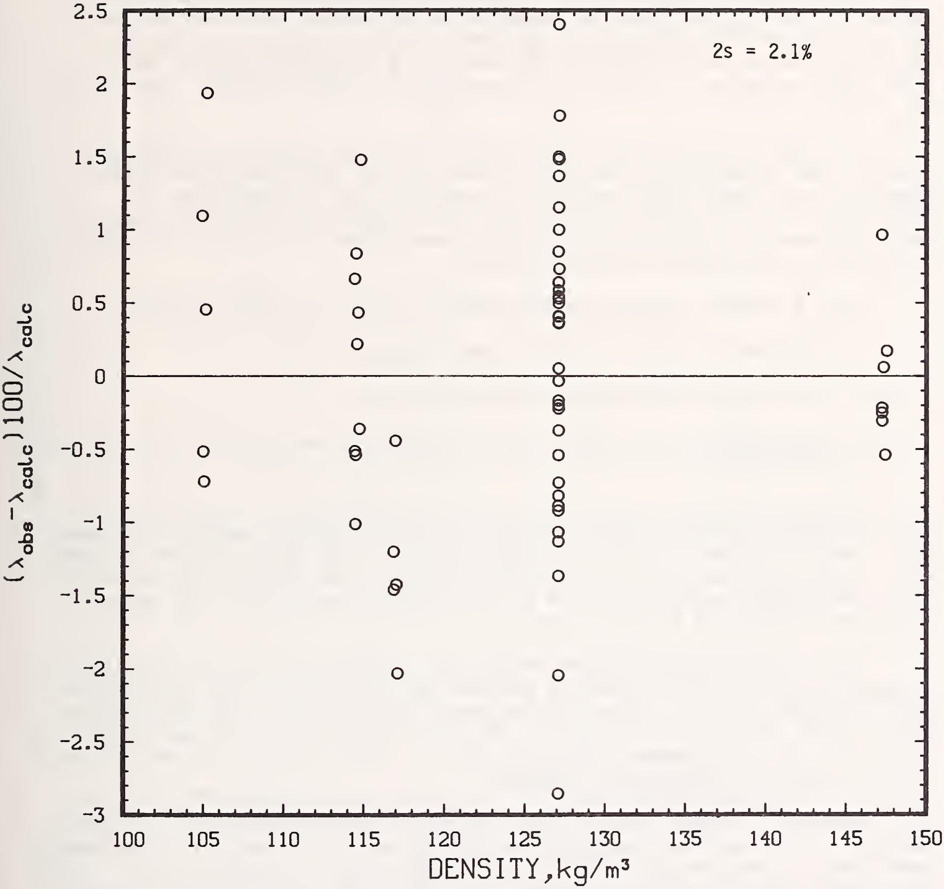

Figure 6 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the bulk density of the specimens for lot 58 as measured by CCE for mean temperatures from 100 to 350 K

The data for lot 70 were previously reported by Smith and Hust [7, 8, and 9], but were smoothed with a different model. For consistency, the above model is used for smoothing. The coefficients are listed in Table 4. The deviations of the lot 70 data from the model are shown in figure 7 as a function of temperature. No systematic trends in the deviations are observed. For the lot 70 data the density term in the model was taken to be the average value for lots 80/81 and 58. This was done because the measured densities ranged only from 123.6 to 125.7 kg/m^3 which was insufficient to determine a coefficient for the density term. As a consequence, deviations versus density are not plotted. Two times the standard deviation of the fit, 2s, is 1.8%.

It is desirable to compare the various lots of the NBS glass fiberboard material (now exhausted) as well as the results from measurements on similar materials from other laboratories to the present 80/81 lot designated as SRM 1450b. It is most convenient to make these comparisons of $\lambda(T,\rho)$ through the use of the models. The baseline for these comparisons will be the values as calculated from the model for the 80/81 lot.

Figure 8 compares the following equations to the lot 80/81 equation:

1. equations for lots 58, 59, 61, and 70 from Siu [3],

2. equations for lots 58 and 70 from this work,

3. equations for the European SRM as reported by DePonte [10] for a density of 88 kg/m^3.

The data reported by Siu [3] on lots 58, 59, 61, and 70 show that the measured values of apparent thermal conductivity (and therefore thermal resistance) within each lot agree to $\pm 2\%$ from the mean value at a given temperature and density. Th smoothed mean values for each of the four lots differ slightly in value and slopes but not appreciably more than the combined measurement and material uncertainty associated with each lot.

Figure 8 shows good agreement between the present certification for the temperature range 100 to 330 K and the previous certification for the temperature range from 255 to 330 K. Figure 8 also shows that lot 80/81 (SRM 1450b) differs significantly from all of the previous NBS lots as well as the European SRM. The latter lots are in agreement with each other to within about $\pm 1\%$ as measured by CCE, CBT, and the European participants.

The reason lot 80/81 differs from the other lots is not clearly understood. However, it is known that the phenolic resin content of lot 80/81 is considerably lower than the previous NBS lots: about 14 wt% compared to about 20 wt%. Other differences, such as in fiber diameter and orientation, are also possible explanations, but these characteristics have not been determined.

6. Certified Values

For certification purposes values of thermal resistance, R, are desirable. Values of R at a thickness of 0.0254 m (1 in), R_0, calculated from equation (2) are listed in Table 7 in units of $m^2 \cdot K \cdot W^{-1}$.

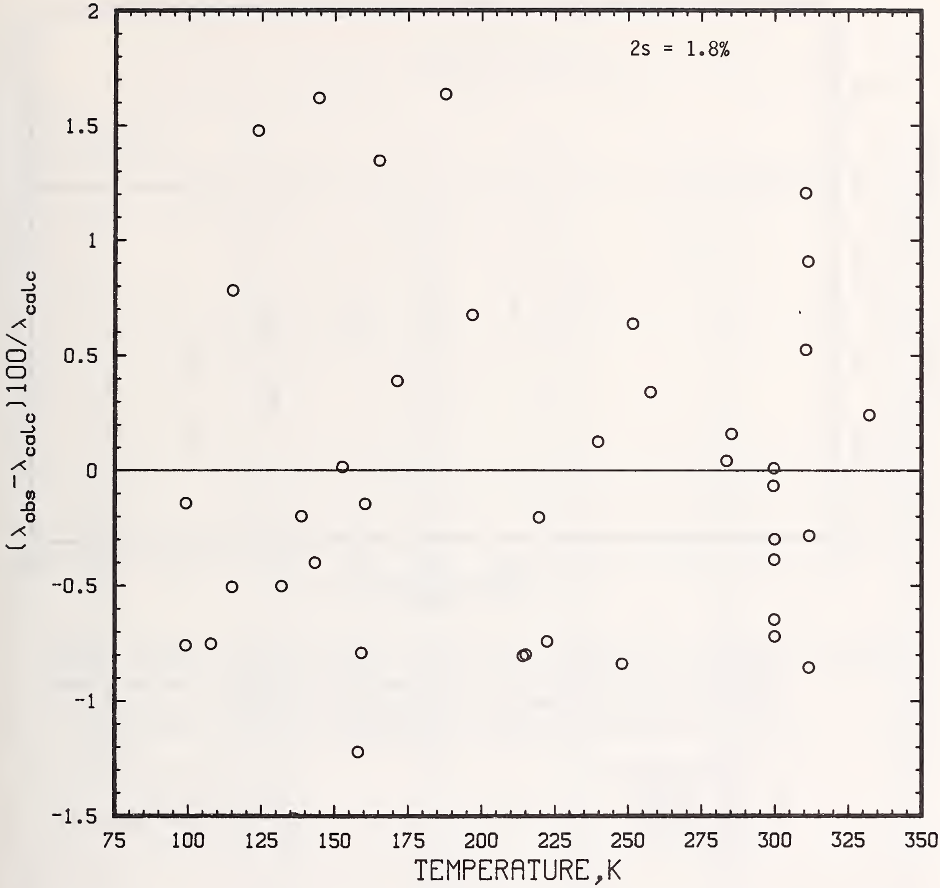

Figure 7 Deviations of measured apparent thermal conductivities from values calculated with equation (1) versus the mean temperature of the measurements for lot 70 as measured by CCE for densities from 123.6 to 125.7 kg/m^3

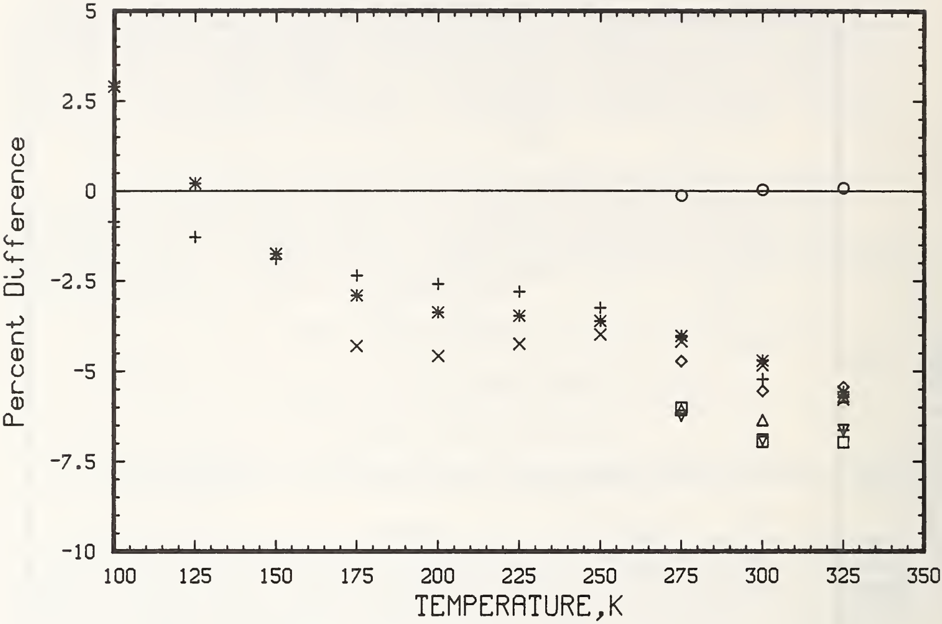

Figure 8 Comparison of various lots of glass fiberboard with respect to the equation for lots 80 and 81 as a function of temperature at a density of 130 kg/m^3 except for the European SRM which is for a density of 88 kg/m^3, percent difference = $(\lambda_i - \lambda_{80/81})100/\lambda_{80/81}$

○ - SRM 1450b [2]
△ - Lot 58 [3]
□ - Lot 59 [3]
▽ - Lot 61 [3]
◇ - Lot 70 [3]
+ - Lot 58 CCE
× - European SRM [10]
✱ - Lot 70 CCE

Table 7. Certified Values of Thermal Resistance of a 2.54 cm Thick Specimen, R_0, as a Function of Density and Temperature (These values have been corrected for the thermal expansion of the measurement plates.)

	Density (kg·m^{-3})				
Temperature (K)	110	120	130	140	150
100	2.143*	2.094	2.049	2.004	1.961
110	1.946	1.906	1.867	1.831	1.795
120	1.780	1.747	1.714	1.683	1.653
130	1.640	1.611	1.583	1.557	1.531
140	1.519	1.495	1.471	1.448	1.426
150	1.416	1.395	1.374	1.354	1.334
160	1.327	1.308	1.290	1.272	1.255
170	1.250	1.234	1.217	1.202	1.186
180	1.184	1.169	1.154	1.140	1.126
190	1.126	1.112	1.099	1.086	1.073
200	1.074	1.062	1.050	1.038	1.027
210	1.028	1.017	1.006	.995	.985
220	.987	.977	.966	.956	.947
230	.949	.939	.930	.921	.912
240	.913	.905	.896	.887	.879
250	.880	.872	.864	.856	.848
260	.848	.841	.833	.826	.818
270	.818	.811	.804	.797	.790
280	.790	.783	.776	.770	.764
290	.762	.756	.750	.744	.738
300	.736	.730	.724	.719	.713
310	.711	.706	.700	.695	.690
320	.687	.682	.677	.672	.667
330	.665	.660	.655	.651	.646

*R_0 values are in units of $m^2 \cdot K \cdot W^{-1}$

$$R_0 = 0.0254/\lambda(T,\rho). \quad (2)$$

The as-tested thickness will most likely be slightly different from 0.0254 m. The R value at different thicknesses, L, are calculated from

$$R = R_0 L/0.0254 \quad (3)$$

where R is the thermal resistance at the tested thickness and R_0 is the certified value interpolated from the table or calculated from equation (2).

It should be noted that this material is certified only for thicknesses within the range of the tests reported, nominally 2.54 cm (1 in). The specimens should be in firm contact with the apparatus plates, but not under excessive pressure. Excessive pressure can lead to both apparatus errors as well as measurable deviations from the certified thermal resistances. Compression of the specimen to a thickness less than 2.4 cm should be avoided.

Values of thermal resistance of this SRM are expected to be within two percent of the computed values at temperatures from 250 to 330 K and increasing to three percent at 100 K. These estimates are based on the experimental data and include both material variability and measurement uncertainty.

7. Summary

New measurements are presented to extend the certification range of SRM 1450b [2] from 255-330 K to 100-330 K. A model is presented that describes the data over the entire temperature and density range to within the imprecision of the data. Comparisons of previously published values for similar material are presented.

8. Acknowledgments

This project has extended over a period of several years. During this time numerous people have contributed to this effort. M. C. I. Siu performed the measurements attributed to CBT in this report. D. R. Smith and A. B. Lankford conducted some of the measurements attributed to CCE. Keith Kirby and Lee Kieffer provided support through the Office of Standard Reference Materials, OSRM. In addition, funding was supplied by the Department of Energy (DoE, ORNL) with the guidance of Ted Lundy and Dave McElroy.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The apparent thermal conductivity data that provide the basis for the certification of glass fiberboard as an SRM of thermal resistance are reported and analyzed. New data for the extension of the temperature range of this SRM to 100 K are included. Detailed analysis and intercomparisons of previously described NBS and other published data are given. These data are represented by an equation describing the dependencies of the data on temperature and density. Certified values of thermal resistance are given for temperatures from 100 to 300 K and densities from 113 to 145 kg/m^3.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

apparent thermal conductivity; density; glass fiberboard; Standard Reference Material; temperature; thermal resistance

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