Appendix C ASTM E 228 ?LINEAR COEFFICIENT OF THERMAL EXPANSION (NETZSCH)

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Test Results

The system influence (sample holder expansion) was corrected by a calibration measurement of a sapphire standard. The calibration run was carried out under the same conditions as used for the sample.

Figures 2 and 3 plot the thermal expansion (solid line) and CTE (dashed line, technical alpha) curves of the sample. Table 1 gives expansion and CTE values at 5K intervals during the heating segment. The reference temperature is 20°C.

Reference: 621001667 3 February 2009

Appendix C ASTM E 228 ?LINEAR COEFFICIENT OF THERMAL ExPANSION (NETzSCH)

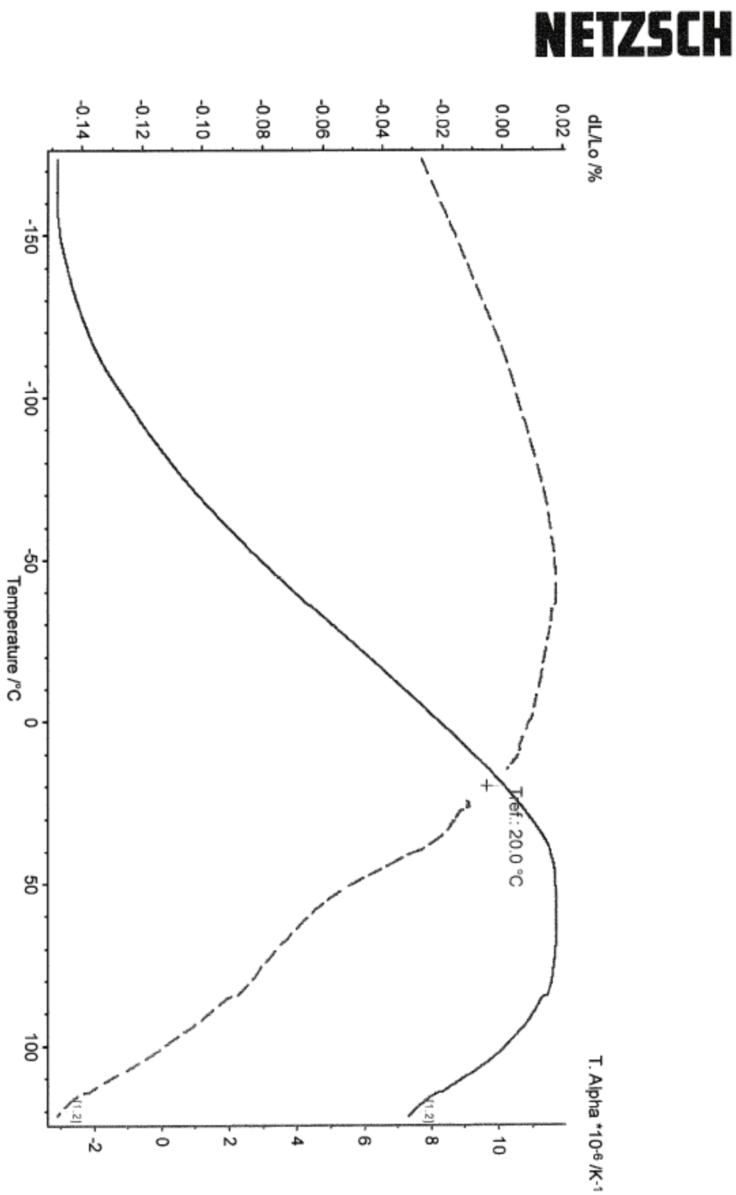

Figure 2- X Direction Thermal Expansion and CTE

Reference: 621001667 4 February 2009

Appendix C ASTM E 228 ?LINEAR COEFFICIENT OF THERMAL ExPANSION (NETzSCH)

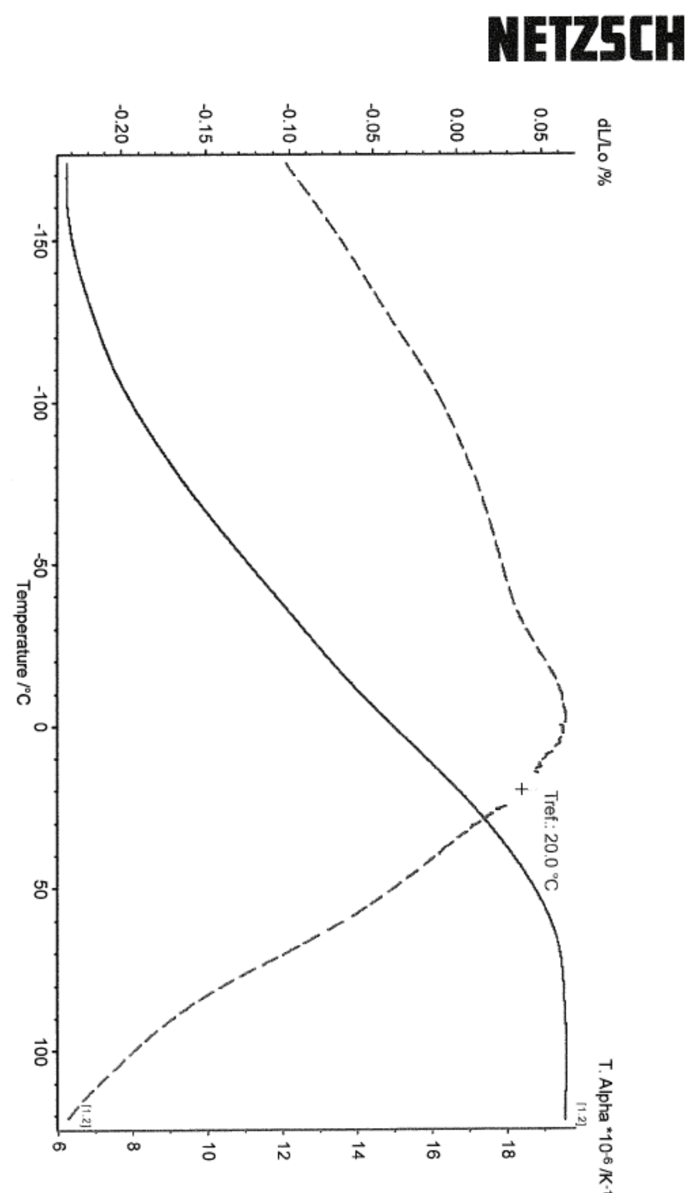

Figure 3- Y Direction Thermal Expansion and CTE

Reference: 621001667 5 February 2009

Appendix C ASTM E 228 ?LINEAR COEFFICIENT OF THERMAL ExPANSION (NETzSCH)

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Table 1 – Thermal Expansion and CTE

Ref.temp.=20°C				
	X Direction		Y Direction	
Temp./°C	(dL/Lo)/%	T. Alpha/(1/K)	(dL/Lo)/%	T. Alpha/(1/K)
-170	-1.48E-01	7.84E-06	-2.33E-01	1.23E-05
-165	-1.49E-01	8.05E-06	-2.33E-01	1.26E-05
-160	-1.48E-01	8.27E-06	-2.32E-01	1.29E-05
-155	-1.48E-01	8.49E-06	-2.31E-01	1.32E-05
-150	-1.48E-01	8.70E-06	-2.30E-01	1.35E-05
-145	-1.46E-01	8.90E-06	-2.28E-01	1.38E-05
-140	-1.45E-01	9.10E-06	-2.25E-01	1.41E-05
-135	-1.44E-01	9.30E-06	-2.22E-01	1.44E-05
-130	-1.42E-01	9.50E-06	-2.19E-01	1.46E-05
-125	-1.40E-01	9.70E-06	-2.16E-01	1.49E-05
-120	-1.38E-01	9.90E-06	-2.12E-01	1.52E-05
-115	-1.36E-01	1.01E-05	-2.09E-01	1.55E-05
-110	-1.33E-01	1.03E-05	-2.04E-01	1.58E-05
-105	-1.30E-01	1.04E-05	-2.00E-01	1.60E-05
-100	-1.26E-01	1.05E-05	-1.94E-01	1.62E-05
-95	-1.22E-01	1.07E-05	-1.89E-01	1.64E-05
-90	-1.19E-01	1.08E-05	-1.83E-01	1.66E-05
-85	-1.15E-01	1.10E-05	-1.76E-01	1.68E-05
-80	-1.11E-01	1.11E-05	-1.70E-01	1.70E-05
-75	-1.06E-01	1.12E-05	-1.63E-01	1.72E-05
-70	-1.02E-01	1.13E-05	-1.55E-01	1.73E-05
-65	-9.68E-02	1.14E-05	-1.48E-01	1.75E-05
-60	-9.17E-02	1.15E-05	-1.40E-01	1.76E-05
-55	-8.65E-02	1.16E-05	-1.32E-01	1.77E-05
-50	-8.11E-02	1.17E-05	-1.24E-01	1.78E-05
-45	-7.55E-02	1.17E-05	-1.16E-01	1.80E-05
-40	-6.98E-02	1.17E-05	-1.08E-01	1.81E-05
-35	-6.33E-02	1.16E-05	-1.00E-01	1.83E-05
-30	-5.72E-02	1.15E-05	-9.19E-02	1.85E-05
-20	-4.50E-02	1.13E-05	-7.55E-02	1.90E-05
-15	-3.90E-02	1.13E-05	-6.69E-02	1.92E-05
-10	-3.31E-02	1.12E-05	-5.78E-02	1.94E-05
-5	-2.72E-02	1.10E-05	-4.84E-02	1.95E-05
0	-2.14E-02	1.09E-05	-3.87E-02	1.95E-05
5	-1.56E-02	1.07E-05	-2.87E-02	1.94E-05
10	-1.01E-02	1.06E-05	-1.86E-02	1.90E-05
15	-4.69E-03	1.02E-05	-8.98E-03	1.88E-05
20	4.26E-04	9.64E-06	3.99E-04	1.84E-05
25	4.96E-03	9.05E-06	9.35E-03	1.79E-05
30	9.15E-03	8.72E-06	1.76E-02	1.72E-05
35	1.30E-02	8.35E-06	2.54E-02	1.66E-05
40	1.57E-02	7.62E-06	3.26E-02	1.61E-05
45	1.70E-02	6.62E-06	3.93E-02	1.56E-05
50	1.75E-02	5.68E-06	4.53E-02	1.50E-05

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Appendix C ASTM E 228 ?LINEAR COEFFICIENT OF THERMAL ExPANSION (NETzSCH)

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55	1.76E-02	4.92E-06	5.06E-02	1.44E-05
60	1.78E-02	4.35E-06	5.51E-02	1.37E-05
65	1.79E-02	3.87E-06	5.84E-02	1.29E-05
70	1.75E-02	3.41E-06	6.08E-02	1.21E-05
75	1.70E-02	3.01E-06	6.21E-02	1.12E-05
80	1.63E-02	2.65E-06	6.29E-02	1.04E-05
85	1.38E-02	2.05E-06	6.34E-02	9.69E-06
90	1.02E-02	1.40E-06	6.38E-02	9.06E-06
95	6.39E-03	7.96E-07	6.43E-02	8.52E-06
100	1.27E-03	1.06E-07	6.46E-02	8.02E-06

Reference: 621001667 7 February 2009

Appendix D DIN 52275-2 ?DETERMINATION OF LINEAR DIMENSIONS AND DENSIT y (FRAUENHOFER INSTITUTE)

Fraunhofer
IBP

[illegible]

Institutsleitung
Univ.-Prof. Dr.-Ing. Gerd Hauser
Univ.-Prof. Dr.-Ing. Klaus Sedlbauer

Prüfbericht HoFM-08/2009

Bestimmung von feuchtetechnischen Material-kennwerten

Auftraggeber:
Knauf Insulation GmbH
Heraklithstraße 8
84359 Simbach am Inn

Holzkirchen,
28. Mai 2009

Fraunhofer-Institut für Bauphysik
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www.ibp.fraunhofer.de

Institutsteil Holzkirchen
[illegible]
www.bauphysik.de

Projektgruppe Kassel
[illegible]

Appendix D DIN 52275-2 ?DETERMINATION OF LINEAR DIMENSIONS AND DENSITY (FRAUENHOFER INSTITUTE)

Geprüftes Material: **„Aspen Aerogels Spaceloft"**
Dämmmatte mit Aerogelpulver, Farbe: weiß
mittlere Dicke: 12 mm
mittlere Rohdichte (lufttrocken): 114 kg/m³

Probennahme

Das zu prüfende Material wurde dem Fraunhofer-Institut für Bauphysik, Holzkirchen, vom Auftraggeber zugesandt und ist am 3. Februar 2009 eingegangen. Aus dem gelieferten Material sind mehrere Proben für die Prüfungen herausgeschnitten worden.

Probenbeschreibung und Probenbezeichnung

Die Proben zeigen keine Mängel oder Besonderheiten.
Probenbezeichnung: H997_1 bis H997_6: rechteckig, Länge x Breite: 200 mm x 100 mm.
H997_21 bis H997_23: rechteckig, Länge x Breite: 200 mm x 100 mm
H997_7 bis H997_18: Stücke unterschiedlicher Größe

Prüfverfahren

- Bestimmung der Trockenrohdichte in Anlehnung an DIN 52275-2, Ausgabe Februar 1978.
- Bestimmung der Reindichte mit dem Heliumpyknometer.
- Bestimmung der Wasserdampfdurchlässigkeit nach DIN EN ISO 12572, Ausgabe September 2001.
- Bestimmung des Wasseraufnahmekoeffizienten nach EN ISO 15148, Ausgabe März 2003.
- Bestimmung der hygroskopischen Sorptionseigenschaften nach DIN EN ISO 12571, Ausgabe April 2000.
- Bestimmung der freien Wasseraufnahme nach DIN 52103, Ausgabe April 1988.
- Ermittlung der Kapillartransportkoeffizienten aus dem w-Wert: M. Krus, A. Holm, T. Schmidt, Bauinstandsetzen 3 (1997), H. 1, S. 219-234.
- Bestimmung der Transportkoeffizienten für die Weiterverteilung aus einfachen Trocknungsversuchen und rechnerischer Anpassung: A. Holm, M. Krus, Bauinstandsetzen 4 (1998), H. 1, S. 33-52.

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Appendix D DIN 52275-2 ? DETERMINATION OF LINEAR DIMENSIONS AND DENSIT y (FRAUENHOFER INSTITUTE)

Prüfergebnisse
Die Prüfungen wurden im Zeitraum vom 27. Februar bis 24. April 2009 durchgeführt.

Materialkennwerte

Probe Nr.	Eigenschaft	Einheit	Ergebnis	
			Einzelwerte	Mittelwert
H997_1 H997_2 H997_3 H997_4 H997_5 H997_6	Rohdichte lufttrocken	kg/m³	110 113 112 118 117 116	114
H997_17 H997_18	Reindichte	kg/m³	1616 1577	1597
	Porosität	Vol.-%		92,9
H997_1 H997_2 H997_3	Diffusionswiderstandszahl μ (23-0/50)	-	5,6 5,7 5,3	5,5
H997_1 H997_2 H997_3	Diffusionswiderstandszahl μ (23-50/93)	-	5,3 5,3 4,8	5,0
H997_4 H997_5 H997_6	Wasseraufnahmekoeffizient w_w	kg/m²√h	0,01 0,01 0	0,01
H997_7 H997_8 H997_9	Bezugsfeuchte-gehalt bei 23°C u. 65 % r.F.	[Vol.%]	0,23 0,23 0,22	0,23
H997_10 H997_11 H997_12	Bezugsfeuchte-gehalt bei 23°C u. 80 % r.F.	[Vol.%]	0,33 0,33 0,32	0,33
H997_13 H997_14 H997_15	Bezugsfeuchte-gehalt bei 23°C u. 93 % r.F.	[Vol.%]	0,45 0,44 0,43	0,44
H997_21 H997_22 H997_23	freie Wassersättigung	[Vol. %]	6,0 6,2 6,7	6,3

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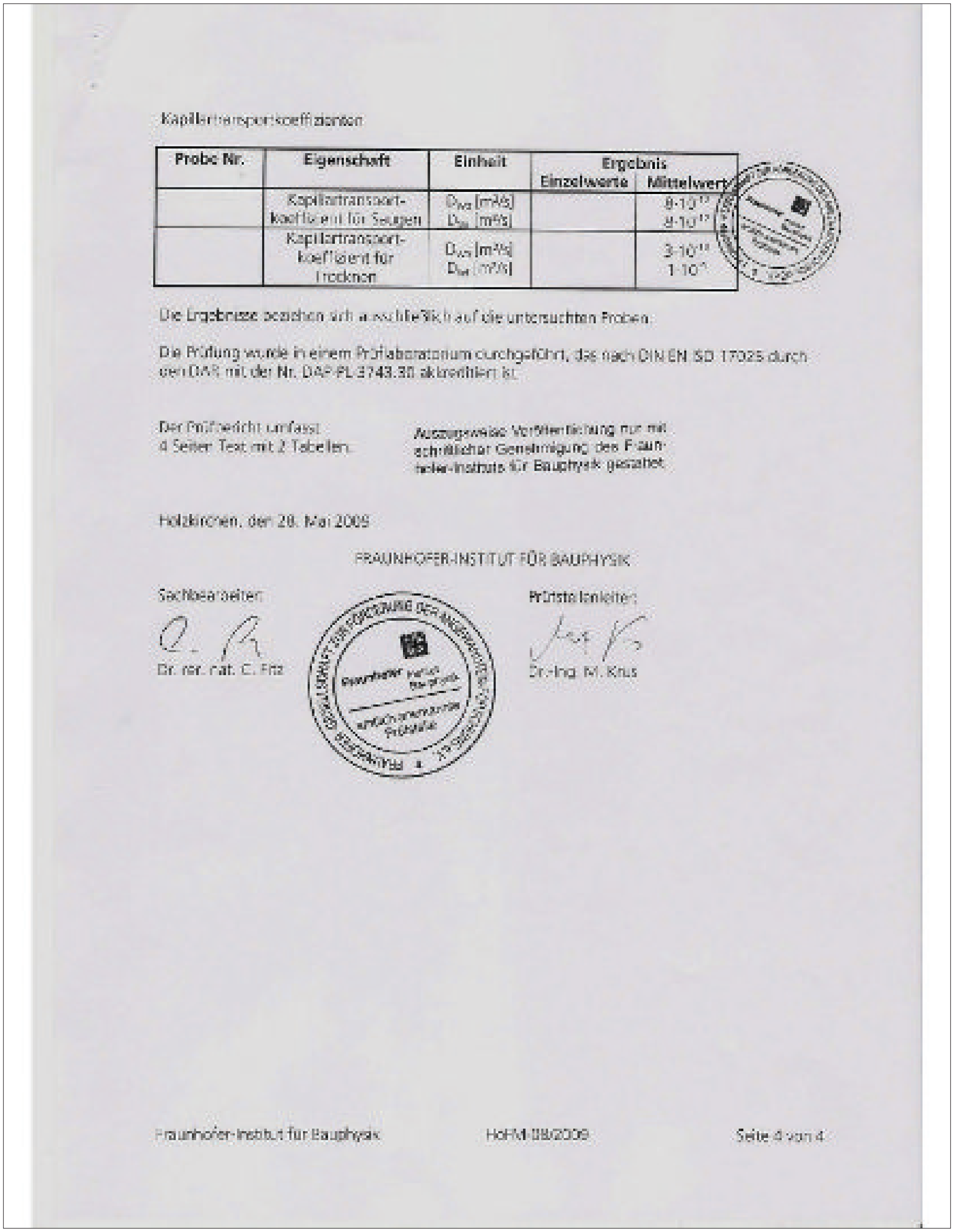
Appendix D DIN 52275-2 – DETERMINATION OF LINEAR DIMENSIONS AND DENSITY (FRAUENHOFER INSTITUTE)



Kapillartransportkoeffizienten

Probe Nr.	Eigenschaft	Einheit	Ergebnis Einzelwerte	Ergebnis Mittelwert
	Kapillartransportkoeffizient für Saugen	D_{ws} [m²/s] D_{ww} [m²/s]		$8 \cdot 10^{-11}$ $8 \cdot 10^{-12}$
	Kapillartransportkoeffizient für Trocknen	D_{ws} [m²/s] D_{ww} [m²/s]		$3 \cdot 10^{-11}$ $1 \cdot 10^{[illegible]}$

Die Ergebnisse beziehen sich ausschließlich auf die untersuchten Proben.

Die Prüfung wurde in einem Prüflaboratorium durchgeführt, das nach DIN EN ISO 17025 durch den DAR mit der Nr. DAP-PL-3743.30 akkreditiert ist.

Der Prüfbericht umfasst:
4 Seiten Text mit 2 Tabellen.

Auszugsweise Veröffentlichung nur mit schriftlicher Genehmigung des Fraunhofer-Instituts für Bauphysik gestattet.

Holzkirchen, den 28. Mai 2009

FRAUNHOFER-INSTITUT FÜR BAUPHYSIK

Sachbearbeiter:

Dr. rer. nat. C. Fitz

Prüfstellenleiter:

Dr.-Ing. M. Krus

Fraunhofer-Institut für Bauphysik HoFM-08/2009 Seite 4 von 4

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

Report on the

APPARENT THERMAL CONDUCTIVITY and THERMAL RESISTANCE of AEROGEL BLANKET

Prepared for:

Aspen Aerogels Inc.
30 Forbes Road
Northborough, Massachusetts 01532

Prepared by:

NETZSCH Instruments, Inc.
Testing Services
37 North Avenue
Burlington, MA 01803

Report Number: 621001452

Work Performed Under Purchase Order Number 306574

Submitted By:

Robert C. Campbell
Applications Laboratory Manager

June 2008

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

Report on the

Apparent Thermal Conductivity and Thermal Resistance of Aerogel Blanket

NETZSCH Instruments was contracted by Aspen Aerogels to evaluate one aerogel blanket insulation material for apparent thermal conductivity at nominal mean temperatures of -160, -100, -50, 0, 100 and 150°C by the guarded hot plate method.

The sample was received as a pair of blankets approximately 305 mm square by 10 mm thickness and was identified as given in Table 1.

The test results are given in Table 1 after a description of the procedure.

Thermal Conductivity

Thermal conductivity is the material property that determines the amount of heat that will flow through an object when a temperature difference exits across the object. Thermal conductivity is a steady state property; it can only be directly measured under conditions in which the temperature distribution is not changing and all heat flows are steady. The fundamental equation that governs steady-state heat flow in a slab geometry is:

$$Q = (\lambda \times \Delta T \times A) / \Delta x \quad (1)$$

where

Q = the rate of heat flow through the slab (W or Btu/h)

λ = the thermal conductivity of the slab material (W/m K or Btu/h-ft-°F)

ΔT = the temperature difference across the slab (°C or °F)

Δx = the thickness (m or ft)

A = the cross sectional area (m^2 or ft^2)

Materials that have low values of thermal conductivity allow only a small amount of heat flow and are called thermal insulators. Materials with large values of thermal conductivity allow more heat to flow across the slab with the same temperature difference. Thermal conductivity is a material property and does not depend upon the

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

geometry of the sample. In general, thermal conductivity is a function of the mean sample temperature. The material comprising the slab is often a mixture of materials. It could be a layered composite or a material containing gas cells in which heat can be transferred by convection and radiation as well as by conductivity through the material. In these cases the parameter, λ, defined in Equation (1) is an "effective" or "apparent" thermal conductivity for the heterogeneous material.

Experimental Procedure for Testing by ASTM C 177-97

Testing was performed in accordance with ASTM C 177-97, *Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus,* utilizing a Holometrix Model TCFGM guarded hot plate instrument (SN 16A-0395-LAB-1). A schematic diagram of the test facility is shown in Figure 1. Two samples sandwiched a heating unit, which consisted of a central metering section and an annular guard section. This composite stack was mounted between two cooling units and surrounded with an environmental heater unit, a fluid-cooled shroud, and edge insulation. The metering section of the heating unit consisted of a metering area heater and metering area surface plates, while the guard section was comprised of a single guard heater and guard surface plates. The cooling units consisted of a cooling plate, a cooling unit heater, and a cooling surface plate. All surface plates were fabricated of 10 mm (0.38 inch) thick aluminum, were smoothly finished to conform to a true plane to within 0.025 percent, and were treated to have a total hemispherical emittance of 0.82 at 24 °C (75 °F).

The heating unit was fabricated by sandwiching a two-element mica heater unit between two thin sheets of ceramic fiber paper and two surface plates. The overall geometry of the heating unit was 300 mm (12 inches) square, with the metering area being the central 150 mm (6 inch) square section. The unit was bolted together at five points, one being in the metering section. The two sections of the heater unit were separated by a 3 mm (0.125 inch) gap around the perimeter of the metering section. The area of the gap represented 3.3 percent of the total metering section area. The area of the metering section was determined by measurements to the centers of the gap. A 16-junction differential thermopile was installed between the mica heating unit and the ceramic fiber sheets such that alternate junctions were in the metering and guard sections respectively and close to the annular gap between the sections. This thermopile was fabricated of 32-gauge Type-K Chromel/Alumel wire. The sensitivity of this thermopile was approximately 0.33 mV/°C (0.18 mV/°F) at 24 °C (75 °F).

The metering area heater was connected to a Sorenson DCS 40-25 DC Power Supply. A 0.001 Ω precision resistor was connected in series with the heater and the voltage drop across this resistor (0.001 times the current) was monitored. The voltage across the heater was measured directly. The output of the differential thermopile was connected to a differential temperature controller which supplied power to the guard heater such that the

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

thermopile output was minimized. The voltage drops, current, and thermopile output were metered with an Agilent Data Aquisition Unit, Model 34970A, having a range of ± 1μV to 300V. The resolution of the meter is 1 microvolt with a maximum error of 0.01 percent of the output and± 2 microvolts over an eight-hour period.

The cooling units consisted of a 10 mm (0.38 inch) thick copper plate which had a series of interconnected 6 mm (0.25 inch) diameter copper tubes soldered to the plate and foamed in place with a spray urethane foam, a mica electric resistance heater unit, and a surface plate. The plates and heater were similar in cross section to the heating unit. The tubing was connected to a temperature controlled circulating chiller unit or a continuous flow of liquid nitrogen and a control thermocouple was attached to the underside of the surface plate and connected to a temperature controller. Temperature control at the surface plates was accomplished by cooling continuously and reheating with the electrical resistance heaters.

The environmental heating unit consisted of a sheathed electric resistance cable heater sandwiched between two tightly fitting passivated stainless steel plate sections 400 mm (16 inches) square by 100 mm (4 inches) high. The electric resistance heater was connected to a temperature controller. The environmental heating unit and a 610 mm (24 inch) square by 610 mm (24 inch) high shroud were placed concentrically around the test stack. The temperature of the environmental heating unit was controlled and monitored by thermocouples attached to its inner surface. The interspaces between the test stack, environmental heating unit, and shroud were filled with a loose fill insulation material.

Temperature measurements were performed by utilizing Type-K Chromel/Alumel thermocouples calibrated to the special limits of error specified in ASTM E 230-83, *Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples*. All thermocouple sensors were fabricated with #30 AWG wire. The thermocouples were fixed to the surface plates by cementing them into 1.6 mm (0.062 inch) square grooves that had been machine-cut into all the surface plates. A total of five thermocouples were cemented into each working surface; three in the metering section and two in the guard section. The temperature sensors were referenced to an Acromag Model 320 Electronic Ice Reference and their output measured with a Agilent Data Aquisition Unit, Model 34970A, having a range of ± 1μV to 300V. The setpoint accuracy for the reference is ± 0.5 °C (± 0.9 °F) with a 0.1 °C (0.2 °F) stability over an eight-hour period.

In operation, a steady temperature equilibrium was established in the test system. The temperatures of the cooling surface plates were set to their required levels. The required temperature difference across each sample was maintained by the adjustment of the power to the metering area heater. If no specific temperature difference was requested, a 40 °C (75 °F) difference was used. The temperature of the environmental heating unit was controlled to the mean sample temperature level. The differential output was

Reference: Report No. 621001452 3 June 2008

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

checked and adjusted such that the thermopile output was maintained between ± 0.01 mV. At equilibrium, established after ensuring that during twenty-one regular sets of ten one minute readings, the apparent thermal conductivity did not change by more than 0.5 percent and that there was no consistent drift, the power to the metering area heater was measured with the precision resistor network and the temperatures of the working surfaces were evaluated from thermocouple readings.

The apparent thermal conductivity was calculated from

$$\lambda = \frac{q \times \Delta x}{A \times \Delta T}$$

and the thermal resistance was calculated from

$$R = \frac{A \times \Delta T}{q}$$

where
- λ = apparent thermal conductivity, W/m-K (Btu-in/hr-ft^2-°F)
- q = power dissipation in the metering heater, W (Btu/hr)
- Δx = total thickness of both test specimens, m (inches)
- A = the metering surface area taken twice, m^2 (ft^2)
- ΔT = total temperature difference across both specimens, °C (°F)
- R = thermal resistance, m^2-K/W (hr-ft^2-°F/Btu)

The instrument performance was verified using the National Institute of Standards and Technology Standard Reference Material 1450b. The calibration specimen is a high-density fibrous glass material, 25.4 mm (1.00 inch) thick, having a thermal resistance of approximately 0.803 m^2-K/W (4.56 hr-ft^2-°F/Btu) at 24 °C (75 °F). The overall uncertainty of the thermal resistance of the standard is estimated by NIST to be 2 percent. The instrumentation is verified after any repair or modification.

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

Test Results

The test results are given in Table 1 and are plotted in Figure 2. The results reported apply only to the specimens that were tested.

Rigid spacers were used for each sample at a thickness 10% lower than the sample thickness measured with a drop gauge. Under the testing stack load, the instrument plates made contact with the spacers to ensure a known and uniform plate gap and sample thickness.

The thermal conductivity and resistance results are estimated to be accurate to within ±5%.

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

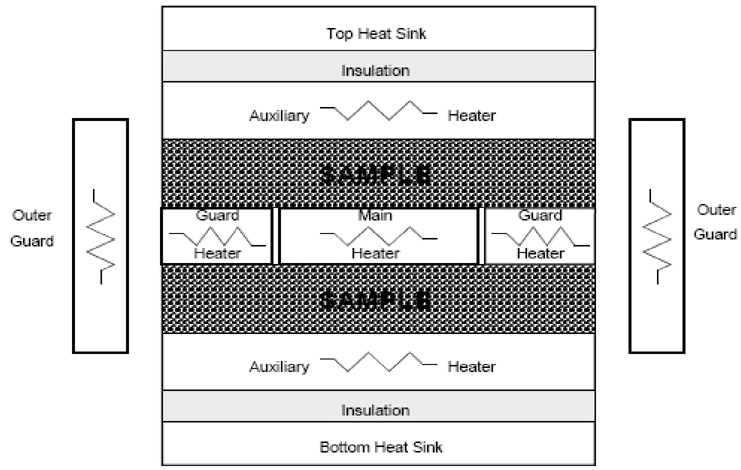


Figure 1. Schematic Diagram of Guarded Hot Plate Instrument

Reference: Report No. 621001452 6 June 2008

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

Table 1

ASTM C177 THERMAL CONDUCTIVITY TEST RESULTS

Specimen	Test Thickness mm	Test Thickness inch	Test Density kg/m³	Test Density lbs/ft³	Temperature Mean ℃	Temperature Mean ℉	Temperature Avg. Delta ℃	Temperature Avg. Delta ℉	Apparent Thermal Conductivity SI	Apparent Thermal Conductivity British	Thermal Resistance SI	Thermal Resistance British
Spaceloft	10.5	0.412	130	8.13	-160	-256	37	67	0.0107	0.0744	0.975	5.54
					-100	-147	39	70	0.0119	0.0826	0.879	4.99
					-50	-57	39	70	0.0130	0.0901	0.806	4.58
					0	33	39	70	0.0141	0.0981	0.740	4.20
					100	213	39	70	0.0183	0.127	0.571	3.24
					150	303	39	70	0.0231	0.160	0.454	2.58

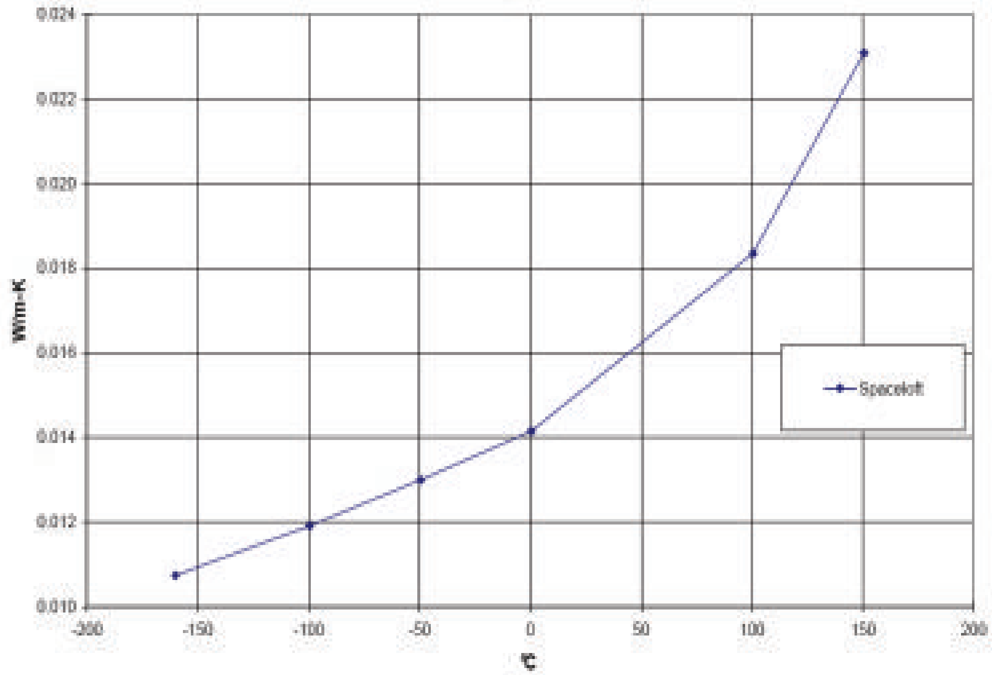
Thermal Conductivity SI Units: W/m-K
Thermal Conductivity British Units: Btu-in/hr-℉-ft ^{2}
Thermal Resistance SI Units: m^2-K/W
Thermal Resistance British Units: hr-℉-ft^2/Btu

Reference: Report No. 621001452 7 June 2008

Appendix E ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, FULL CURVE (NETzSCH)

Figure 2

Thermal Conductivity vs. Mean Temperature



Reference: Report No. 621001452 8 June 2008

Appendix F ASTM C 177 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, 10C (FIW M?CHEN)

Forschungsinstitut für Wärmeschutz e.V. München

FIW München

Thermal Conductivity according to ASTM C 177

Test report No.: F.2-102a/09

Applicant: aspen aerogels, Northborough, MA 01532, Vereinigte Staaten von Amerika

Name of the product: " Spaceloft 10 mm "

Product identification (as given by applicant): Aerogel blanket material; Nominal thickness: 10 mm; Colour: white

Sampling: Sent by applicant on February 2009
Goods Receipt: No. 713 dated 09/02/2009

Test equipment: Guarded hot plate apparatus according to ASTM C 177; Metering section 300 x 300 mm with guard section 500 x 500 mm

Preparation: Tested thickness*): 0.0093 m; Mass*): 0.2960 kg
Surface area tested: 0.2510 m²; Density*): 142 kg/m³

Remarks: The two test specimens were built into the test apparatus without further conditioning.

Experimental data:

Test	Heat flow rate	Temperature of the Warm Side	Temperature of the Cold Side	Average temperature of the specimen	Temperature difference of the specimen	Thermal Conductivity
No.	W	°C	°C	°C	K	W/(m K)
1	4.632	19.1	3.4	11.3	15.7	0.0131
2	4.632	33.1	17.8	25.4	15.3	0.0134
3	4.620	45.2	30.2	37.7	15.0	0.0137
4	----	----	----	----	----	----
5	----	----	----	----	----	----

Uncertainty: < 3%

Properties of the material after conductivity-measurement up to 45.2 °C warm side: *) from values over specimens

Thickness*): 0.0093 m; Mass*): 0.2962 kg
Density*): 142 kg/m³; Change in mass: 0.0 %

Remarks: --

Results:

Mean temperature °C	10	---	---	---	---	---	---	---	---
Thermal conductivity W/(m K)	0.0131	---	---	---	---	---	---	---	---

Evaluation: These thermal conductivity values are material values applicable to material in a dry state. They don't represent design values of thermal conductivity.

Final remarks: ------

Gräfelfing, 25.02.09

Department Specialist: Dipl.-Ing.(FH) W. Albrecht

Tester: [illegible] Berger

[illegible]

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Appendix G EN 12667 ?THERMAL CONDUCTIVIT y VIA GUARDED HOT PLATE, 10C? (FIW M?NCHEN)

Forschungsinstitut für Wärmeschutz e.V. München

FIW München

Thermal Conductivity according to EN 12667

Test report No: F.2-192a/06

Applicant: aspen aerogels, Northborough, MA 01532, Vereinigte Staaten von Amerika

Name of the product: " Spaceloft 10 mm "

Product identification: Aerogel blanket material
(as given by applicant) Nominal thickness: 10 mm
Colour: white

Sampling: Sent by applicant on February 2006
Goods Receipt: No. [illegible]

Test equipment: Guarded hot plate apparatus according to EN 12667;
Metering section 300 x 300 mm with guard section 500 x 500 mm

Preparation: Tested thickness*1: 0.0093 m; Mass*1: 0.2960 kg
Surface area tested: 0.2510 m²; Density*1: 142 kg/m³

Remarks: The two test specimens were built into the test apparatus without further conditioning.

Experimental data:

Test	Heat flow rate	Temperature of the Warm Side	Temperature of the Cold Side	Average temperature of the specimen	Temperature-difference of the specimen	Thermal Conductivity
No	W	°C	°C	°C	K	W/(m K)
1	4.532	19.1	3.4	11.3	15.7	0.0121
2	4.532	36.1	17.8	26.4	18.3	0.0124
3	4.532	45.2	30.2	37.7	15.0	0.0137
4	----	----	----	----	----	----
5	----	----	----	----	----	----

Uncertainty: < 3%

Properties of the material after conductivity-measurement up to 45.2 °C warm side:

Thickness*1: 0.0093 m; Mass*1: 0.2960 kg
Density*1: 142 kg/m³; Change in mass: 0.0 %

*1 Mean values the specimens

Remarks: --

Results:

Mean temperature °C	10	---	---	---	---	---	---	---	---
Thermal conductivity W/(m K)	0.0131	---	---	---	---	---	---	---	---

Evaluation: These thermal conductivity values are material values applicable to material in a dry state. They don't represent design values of thermal conductivity.

Final remarks: ------

Gräfelfing, [illegible]

[illegible]
W. Albrecht
Dipl.-Ing.(FH) W. Albrecht

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Appendix H SPECIFIC HEAT (TPRL)

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West Lafayette, IN 47906
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www.tprl.com

TPRL 4072 r

Specific Heat of Spaceloft

A Report to ASPEN Aerogels

by

J. Gembarovic and J. Gembarovic Jr.

June 2008

Appendix H SPECIFIC HEAT ?(TPRL)

Specific Heat of Spaceloft

I. INTRODUCTION

A sample of aerogel material, identified as 08050092, Cryogel 10201, Blkt 801, (called also the Spaceloft), was submitted for thermophysical property testing. Specific heat (c_p) values were measured in temperature range from -60 °C to 150 °C using a differential scanning calorimeter (DSC).

Specific heat is measured using a standard Perkin-Elmer Model DSC-2 calorimeter with sapphire as the reference material (ASTM E1269) in combination with Netzsch 409 DSC. The standard and sample were subjected to the same heat flux as a blank and the differential powers required to heat the sample and standard at the same rate were determined using the digital data acquisition system. From the masses of the sapphire standard and sample, the differential power, and the known specific heat of sapphire, the specific heat of the sample is computed. The experimental data are visually displayed as the experiment progresses. All measured quantities are directly traceable to NIST standards.

II. RESULTS AND DISCUSSION

The specific heat results are given in Table 1 and Figure 1. Total relative expanded uncertainty (k = 2) of the specific heat measurement is ± 3 %.

Table 1 Specific Heat Results

T/C	Cp / (J/g K)
-60	0.576
-40	0.683
-20	0.779
0	0.864
23	0.954
40	1.000
60	1.054
80	1.100
100	1.150
120	1.189
140	1.218
150	1.234

Appendix H SPECIFIC HEAT ?(TPRL)

2

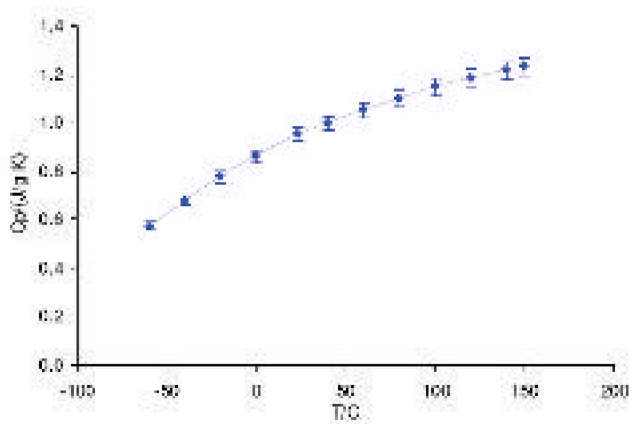

Figure 1 Specific Heat

Appendix I EN ISO 8497 ?DECLARATION OF CONFORMIT y

DECLARATION OF CONFORMITY
(Law 10/91, art. 32 – D.M. 02/04/98, art. 3)

The undersigned *Harry Walloff* in charge as (legal director, technician() of the company

Aspen Aerogels, Inc.

declare

that the production of the insulating material (please indicate **the precise name** of the product) *Spaceloft® (5mm and 10mm)* is in conformity with what is fixed by the law 10/91, art. 32 and by D.M. 02/04/1998, art. 3.

The thermal conductivity is measured in laboratory according to the criteria of the rule ISO 8301 (or similar rules as: ISO 8302, UNI 7891, UNI 7745, EN ISO 8497, DIN 52612) with reference to the average temperature of 10°C. The values are taken 90 days after the production date.

The values declared ($\lambda_{90/90}$) and reported on the product's labels are determined according to the rule **ISO 10456** and represent 90% of the production and with 90% of reliability.

$\lambda_{90/90}$ = *0.014* W/mK

February 3, 2009
date

signature

This declaration under the article 3, first paragraph of the D.P.R. 403/98 can be subscribed by the person concerned in front of the person in charge to receive the documentation. If the declaration will be send by mail, under the article 3 paragraph 11 of the Law 127/97, a photocopy of the identity card (which should be valid) must be attached.

Appendix J EN ISO 15148 ?DETERM. OF W ATER ABSORPTION COEFFICIENT, PARTIAL IMMERSION (GLASGOW CALDONIAN UNIV.)

Report: Spacetherm: Water absorption by partial immersion to BS EN ISO 15148 : 2002

Prepared for: Iain Fairnington
A Proctor Group Limited

Prepared by: Chris Sanders
Centre for Research on Indoor Climate and Health
School of Built and Natural Environment
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7th May 2008

GLASGOW CALEDONIAN UNIVERSITY

Appendix J EN ISO 15148 ?DETERM. OF W ATER ABSORPTION COEFFICIENT, PARTIAL IMMERSION (GLASGOW CALDONIAN UNIV.)

Testing

BS EN ISO 15148 : 2002 , *Hygrothermal performance of building materials and products — Determination of water absorption coefficient by partial immersion* specifies a method for determining, by partial immersion with no temperature gradient, the short-term liquid water absorption coefficient. It is intended to assess the rate of absorption of water, by capillary action from continuous or driving rain during on site storage or construction, by insulating and other materials, which are normally protected. The method is suitable for renders or coatings tested in conjunction with the substrate on which they are normally mounted. It is not intended to assess the absorption of water by materials used under water or in overall contact with saturated ground, where a total immersion test is more appropriate.

The water absorption by partial immersion is determined by measuring the change in mass of the test specimen, the bottom surface of which is in contact with water, over a period which is usually at least 24 h. The water adhering to the surface and not absorbed by the product is completely removed by, for example, blotting with a sponge before the specimen is weighed.

Plotting the mass of water absorbed against the square root of time gives a straight line, and the water absorption coefficient is defined by :

$$A_w = \frac{m_2 - m_1}{\sqrt{t}} \text{ kg/(m}^2\cdot\text{h}^{0.5})$$

Where: m_2 and m_1 are two points on the straight line , in kg
t is the time between the two points in hours (usually 1hr)

Owing to the thin nature of the material, this test was difficult to carry out as it was difficult to maintain a constant level of water around the sample. Also the material appeared to be hydrophobic, it repelled water in contact with it.

Results

Four samples of Spacetherm, each 100mm square, were tested, giving the following results:

	Aw kg/(m^2·h$^{0.5}$)
Sample 1	0.0041
Sample 2	0.0031
Sample 3	0.0110
Sample 4	0.0107
Mean	**0.0072.**

There is a considerable amount of variability in these results, reflecting the difficulty of carrying out this test with this material. We propose to repeat this test in the hope of refining the results.

Chris Sanders
GCU
7/5/08

Appendix K EN ISO 12571 ?DETERM. OF HyGROSCOPIC SORPTION PROPERTIES (GLASGOW CALDONIAN UNIV .)

Report: Spacetherm: Moisture Adsorption Tests to BS EN ISO 12571

Prepared for: Iain Fairnington
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12th May 2008

GLASGOW CALEDONIAN UNIVERSITY

Appendix K EN ISO 12571 ?DETERM. OF HyGROSCOPIC SORPTION PROPERTIES (GLASGOW CALDONIAN UNIV .)

Testing

Moisture adsorption tests were carried out at four relative humidities (RH) according to BS EN ISO 12571:2000 Hygrothermal performance of building materials and products - Determination of hygroscopic sorption properties.

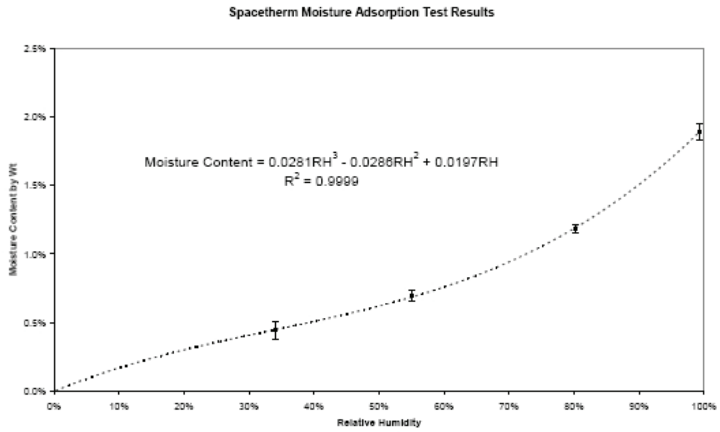
Saturated salt solutions were prepared to give conditions of 33.0%, 53.0%, 79.5% and 94.0% RH. Three samples 100mm × 100mm were prepared for each RH condition. Samples were dried in oven at 50°C to determine dry weights. Samples were placed on a grid over the salt solutions in an sealed container. A Tinytag temperature and humidity sensor was also placed in each container to monitor actual conditions. The containers were then placed in an environmental chamber set to 23°C. Each sample was periodically weighed until equilibrium moisture content was achieved. The start date of the test was 21/4/08 and the test was completed on 9/5/08.

Results

The results are given below in the table and figure. The average test temperature was 23.2°C.

Nominal RH generated by Salt Soln.	Measured Relative Humidity	Sample	Moisture Content [kg/kg]	Average Moisture Content [kg/kg]	Average Moisture Content [% by Wt]
		#5	0.0052		
33.0%	34.1%	#6	0.0039	0.0045	0.45%
		#12	0.0042		
		#1	0.0073		
53.0%	55.0%	#2	0.0071	0.0070	0.70%
		#7	0.0065		
		#9	0.0119		
79.5%	80.2%	#10	0.0116	0.0118	1.18%
		#11	0.0121		
		#3	0.0196		
94.0%	99.3%	#4	0.0185	0.0189	1.89%
		#8	0.0187		

Appendix K EN ISO 12571 ?DETERM. OF HyGROSCOPIC SORPTION PROPERTIES (GLASGOW CALDONIAN UNIV .)



The moisture content at any RH (%) may be estimated from the relationship obtained by fitting a polynomial to the data in the figure above:

Moisture Content = $0.0281.RH^3 - 0.0286.RH^2 + 0.0197.RH$ (% by Wt)

Paul Baker
GCU
12/5/08

Appendix L EN ISO 12572 ?DETERM. OF W ATER VAPOUR TRANSMISSION PROPERTIES (GLASGOW CALDONIAN UNIV.)

Report: Spacetherm: Vapour Permeability Tests to BS EN ISO 12572

Prepared for: Iain Farrington
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Prepared by: Chris Sanders
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7th May 2009

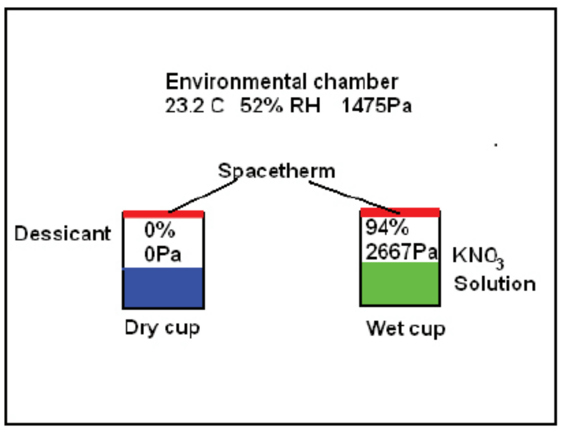
GLASGOW CALEDONIAN UNIVERSITY

Appendix L EN ISO 12572 ?DETERM. OF WATER VAPOUR TRANSMISSION PROPERTIES (GLASGOW CALDONIAN UNIV.)

Testing

The vapour resistance of samples of Spacetherm insulation was tested at Glasgow Caledonian University to BS EN ISO 12572:2001. This note gives some preliminary results.

In the test samples of the material are sealed over the mouth of glass beakers, containing either a desiccant, which reduces the relative humidity in the cup to zero – the ‘dry cup’ or a solution of Potassium Nitrate (KNO_3), which stabilises the relative humidity in the cup to 94% - the ‘wet cup’. The cups are placed in an environmental chamber in a constant temperature and humidity environment as shown below.



The weight of the dry cup increases as water vapour diffuses in through the Spacetherm and that of the wet cup falls as it diffuses out. After a period of stabilisation a constant rate of weight loss or gain is achieved. This is used to calculate the permanence of the sample from :

$$P = g/A.\Delta p \qquad g/s.m2.Pa$$

Where g is the rate of weight loss of gain in g/s
A is the area of the sample in m^2
Δp is the vapour pressure difference in Pa.

This can be related to the more familiar vapour resistance R in MNs/g by

$R = 10^6 / P$ MNs/g

Six wet and dry scups were prepared with circular samples of Spacetherm with diameter 94mm, giving an area of 0.00694m^2. After the material had been conditioned to the environmental chamber conditions testing started on the 25th March, with the samples weighed at daily intervals since until the 28th March.

Appendix L EN ISO 12572 ?DETERM. OF W ATER VAPOUR TRANSMISSION PROPERTIES (GLASGOW CALDONIAN UNIV.)

Results

The values for the vapour resistance of the individual samples of Spacetherm in MNs/g are shown below.

Dry Cup	25/3 – 28/3
	0.325
	0.338
	0.339
	0.328
	0.346
	0.346
Mean	**0.337**
±	**0.009**

Wet Cup	25/3 – 28/3
	0.305
	0.204
	0.281
	0.356
	0.307
	0.198
Mean	**0.275**
±	**0.062**

- These values are low – close to the value required for a low resistance underlay.
- The dry cup values are consistent.
- The wet cup values are much more variable, it is possible that these samples are absorbing water vapour from the air
- Most hygroscopic materials have significantly lower wet cup resistances than for the dry cup, however these initial results show little difference between the two.

Chris Sanders
GCU
7/5/08

Appendix M EN ISO 12087 – LONG TERM WATER ABSORPTION By TOTAL IMMERSION (GLASGOW CALDONIAN UNIV.)

Report: Spacetherm: Long term water absorption by total immersion to BS EN 12087

Prepared for: Iain Fairnington
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Prepared by: Chris Sanders
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7th May 2009

GLASGOW CALEDONIAN UNIVERSITY

Appendix M EN ISO 12087 – LONG TERM WATER ABSORPTION By TOTAL IMMERSION (GLASGOW CALDONIAN UNIV.)

Testing

BS EN 12087: 1997 *Thermal insulating products for building applications - Determination of long term water absorption by immersion*, specifies a test for determining how much water is absorbed when an insulation material is totally immersed in water. The long term water absorption by total immersion is not directly related to the conditions on site, but has been recognized as a relevant condition of test for some products in some applications.

The long term water absorption by total immersion is determined by measuring the change in mass of the test specimen, totally immersed in water, over a period of 28 days. The excess water adhering to the surface, not absorbed by the test specimen, is removed by drainage.

The specimen is weighed when dry, to give m_0 kg, immersed in water for 28 days, and reweighed, after surface water has drained off to give m_{28}, kg.

The water absorption, by volume is then given by

$$W_{lt} = \frac{m_{28} - m_0}{V} \times \frac{100}{\rho_w} \%$$

Where V is the volume of the specimen in m^3
ρ_w is the density of water, assumed to be 1000 kg/m^3

Results

Four samples of Spacetherm, each 200mm square, were tested giving the following results:

Sample 1	6.5%
Sample 2	6.2%
Sample 3	6.5%
Sample 4	6.1%

The consistency of these results suggests that the average value of 6.3% is reliable.

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7/5/08

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