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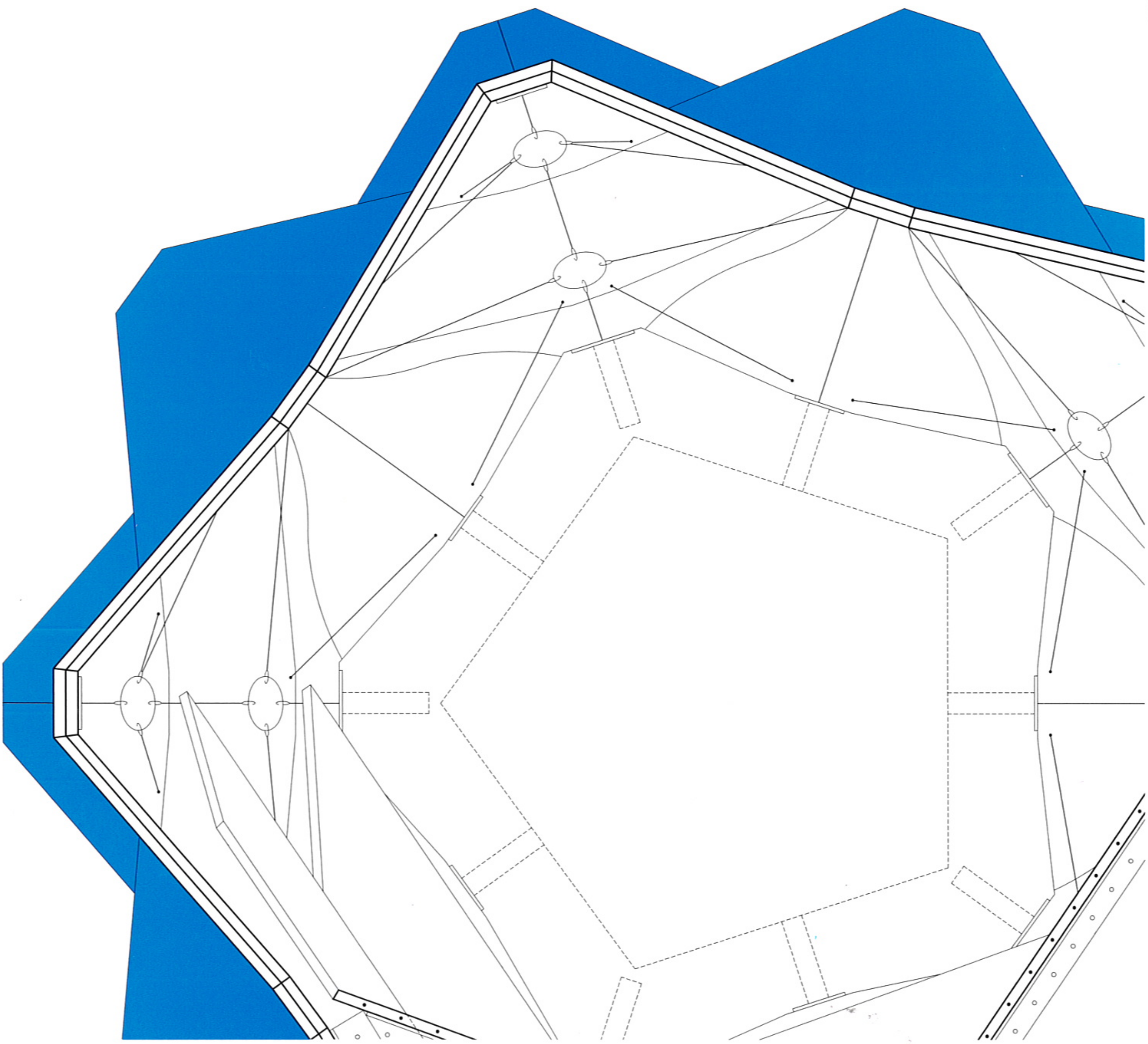

Translucent High-Performance Silica-Aerogel Insulation for Membrane Structures

Jan Cremers, Felix Lausch

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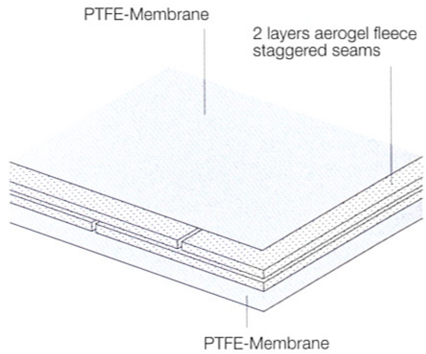
Properties in uncompressed state	
Thickness	3.5 mm and 8 mm
Width of roll	56 cm
Length of roll	up to 100 m
Thermal conductivity	21,0 mW/mK at an average temperature of 12.5 °C
	23,5 mW/mK at an average temperature of 37.5 °C
	26,0 mW/mK at an average temperature of 62.5 °C
Bulk density	approx. 75 kg/m³

D



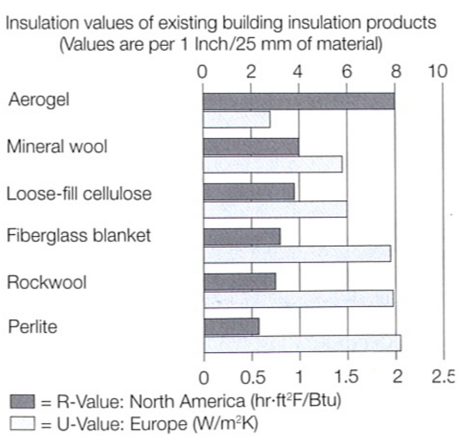
E

Architects are intrigued by materials permeable to light, above all by translucent and transparent membrane materials which can also withstand roof loads. Textiles used in construction are typically employed as weather protection – in other words, to guard against sun, wind, rain and snow – and are advantageous due to their ability to span large distances and to take on any number of shapes. As a result of increased research and development of suitable solar technologies, in the future, the range of tensile-structure applications will increasingly extend beyond weather protection. These developments deal with passive measures such as improving control of solar gain (thermal protection in summer), thermal insulation (thermal protection in winter), as well as optimising acoustic and daylight characteristics. High-performance membranes and foils on a fluorine polymer basis – e.g. translucent membrane materials such as PTFE-coated (polytetrafluoroethylene), glass-fibre fabric or transparent foil of a copolymer of ethylene and tetrafluoroethylene (ETFE) – constitute milestones in the quest for high-performance materials for building envelopes. In the following, we present one of our most promising thermal-insulation developments for translucent foil structures. It involves using granular silica aerogel as insulation material. Not only does aerogel have excellent thermal-insulation properties, but it is translucent, as well.

Silica aerogels in membrane structures
At approximately one fortieth the weight of comparable structures employing glass, inflated and mechanically tensioned membrane structures are unquestionably lightweight. The amount of material required and the silhouette of the supporting structure are minimised. But due to the optimised thicknesses – some are under 0.2 mm thick – and despite the low thermal conductivity of synthetic materials, membrane structures lack favourable thermal-insulation properties. Rectifying this deficit necessitates either working with multi-layer assemblies and air spaces or, if higher values are specified, utilising opaque insulation materials, such as mineral wool or a transparent or translucent thermal insulation. Opaque insulation materials are typically undesirable for a foil structure; silica aerogel is one of the most promising translucent options.

Properties and principles of utilisation
Silica aerogels are organic silicon bonds with a granule size of 0.5 to 4.0 mm, with the pore diameter ranging from 10 to 100 nm and a pore volume fraction of more than 80 %. The light transmission of an aerogel layer is approximately 80 % per cm installed, whereby the insulating properties, in correlation to the thickness of the layer, are twice as good as those of polystyrene foam. In addition, this material is incombustible, sustainable, recyclable, heat resistant to 600 °C, UV resistant, hydrophobic and exhibits long-term stability, making it particularly well-suited to use in construction. The bulk density is in the range of 90 to 100 kg/m³, whereby the inner surface is 600 to 800 m²/g at a thermal conductivity of 0.018 W/mK. The original manufacturing process was elaborate because it involved "supercritical drying". In the last decade, the process was simplified to such an extent that little now appears to stand in the way of a wider distribution of this group of materials. Aerogels can now be manufactured in one continuous manufacturing process and are – in contrast to the first generation's varieties – hydrophobic and much more affordable.
Silica-aerogels are available as fine particles, granulate and monolithic blocks, but while fine particles are only suited to use with opaque membranes, granulate can also be employed as thermal insulation in inflated, translucent membrane structures. Aside from the energy-technology aspects, design aspects are also an issue. Aerogel's light-scattering properties not only provide for a uniform underside, but also for comfortable, glare-free indoor light conditions.

A



B

C

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A Granular silica aerogel
B Heat-transmission coefficient of different insulation materials
C–E Fibrous-formation aerogel
D Properties of translucent aerogel blankets, Cabot Corporation
F Properties of translucent aerogel granulate, Cabot Corporation
G Georgia Institute of Technology's Solar Decathlon Pavilion 2007 Georgia Tech

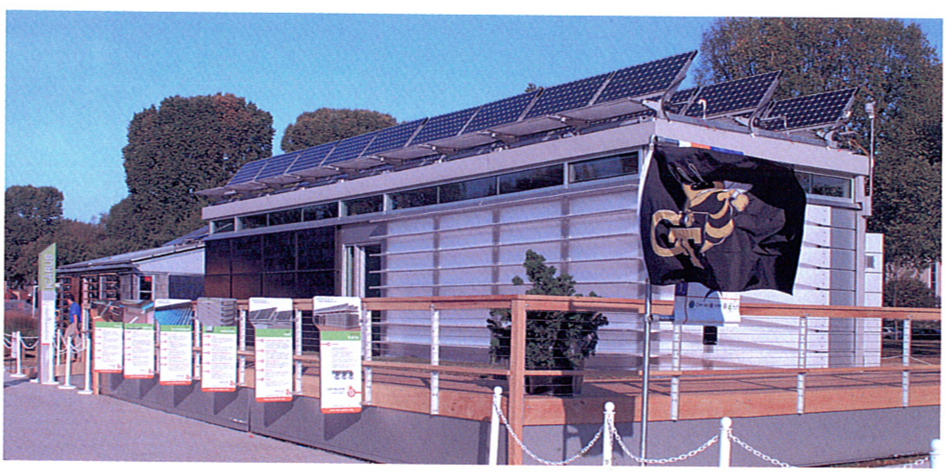
Material thickness Aerogel granulate [cm/Inches]	Properties Light transmission	g-value	U-value [W/m²K]
1.3 cm/0,5"	73 %	0.73	1.4
2.5 cm/1"	53 %	0.52	0.7
3.1 cm/1,25"	45 %	0.43	0.57
3.8 cm/1,5"	39 %	0.39	0.47
5 cm/2"	28 %	0.26	0.35
6.4 cm/2,5"	21 %	0.21	0.28

F

Aerogel filling in pneumatic structures
For utilisation in pneumatic ETFE cushions – where exploiting natural light plays an important role – translucent aerogel is a suitable selection. A thickness of only 3 cm has a thermal transmission coefficient (U-value) of 0.57 W/m²K, and the light transmission factor is 45 % (compare ill. F). Depending on the desired appearance, the aerogel stratum can be installed in the top or bottom layer of the ETFE cushion. To this end, the respective layer is "doubled-up": instead of a single layer, two layers of ETFE foil are specified, between which the aerogel is introduced. The precise amount of aerogel required is determined by consulting the cut plan for the ETFE layers, which is necessary for the production of a 3D form. The material introduced in the ETFE cushion is evenly distributed so that a constant layer thickness results. This will be stabilised by the pressure in the cushion. If the cushion has a third (middle) layer, it would also be possible to introduce insulation here.
ETFE foil is relatively open to moisture diffusion and, as a result, allows small amounts of water vapour to penetrate the insulating level. But thanks to aerogel's hydrophobic properties, the water is not absorbed by the granules and can subsequently escape from the panel. Due to aerogel's favourable insulation properties, the inner side of the panel does not become cold enough for condensation to form.

Aerogel fleece
Due to the absence of a stabilising pressurisation in mechanically tensioned structures, another type of aerogel insulation is employed. This version is a fleece made of two-component fibres which is sprinkled with aerogel particles. This produces a flexible, pressure-resistant mat which has highly favourable insulating properties (ills. C–E). Fleece can be used both in combination with transparent ETFE foils and with translucent membrane materials such as PTFE-coated, glass-fibre fabric. The translucent fleece is ideally installed directly on the lower membrane layer and only negligibly reduces light transmission. Even distribution of the material – an issue when installing granulate – is not a problem. But, in contrast to granules – with which a uniform appearance is achieved – here the seams of the individual batts can detract from the appearance. Particularly for foil structures of transparent ETFE, this effect may be undesirable. For this type of application, where appropriate, two or more layers of fleece with staggered seams are recommended. This is advisable to avoid compromising the strength of the insulation layer through linear thermal bridges at the butt seams. The desired U-value can be attained by selecting among the available fleece thicknesses and potential multi-layer assemblies.

Employing aerogel cushions – a case study
Georgia Institute of Technology's entry to the competition Solar Decathlon 2007, developed and realised by SolarNext AG in cooperation with Hightex GmbH, implements a concept for a highly insulated, semi-transparent roof in which aerogel's outstanding energy technology and aesthetic characteristics are showcased.
In 2007, the U.S. Department of Energy sponsored its third competition for energy-optimised construction (the first two were held in 2002 and 2005). The designs were to be developed by interdisciplinary teams at universities. The goal was to design and realise an optimised, energy-efficient, solar-powered and architecturally appealing residential unit about 70 m² in size and then to realise it with the students.
All twenty of the selected pavilions were set up on the Mall in Washington for judging (ill. G). Among the evaluation criteria were architecture, structure, technology, lighting and the energy balance. Emphasis was placed on intelligent and innovative utilisation of new materials, as well as on sensible use of established building materials.
The individual roof elements, developed by SolarNext/Hightex expressly for the competition, were prefabricated to as great a degree possible in the factory, because the aim was that the students assemble it on their own, under the direction of a trained supervisor. In order to be keep the structural elements of the roof as simple as possible, the concept foresaw two levels, separated by function. The lower level consists of highly insulated panels which also serve as the underside of the ceiling, while the upper level functions solely as weather protection.
The lower level is comprised of nine ceiling panels measuring 4 × 1.5 m (ills. H, I).
These ceiling panels are made of a thermally separated framework with an optimised cross-section which is tensioned with an ETFE foil and then filled with aerogel. The result is an illuminated ceiling with a uniform appearance over the panel's entire visible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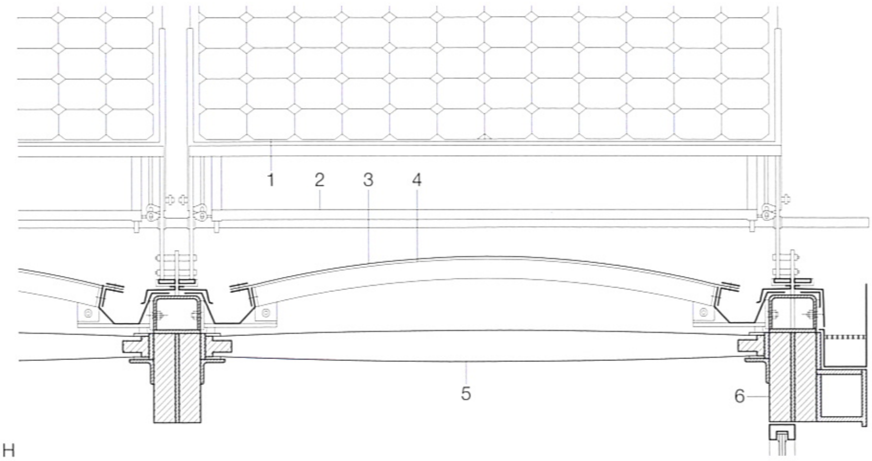

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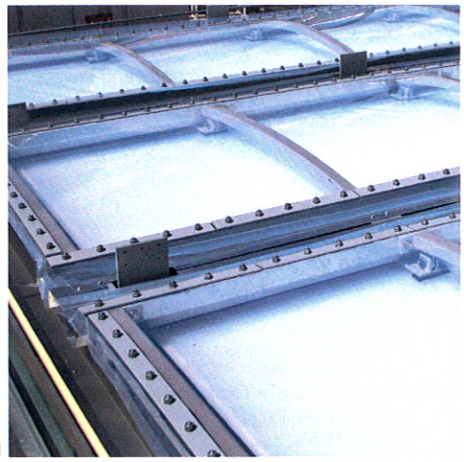

I

K

surface, with a light transmission factor of about 20% and a U-value of approximately 0.3 W/m²K. The nine panels were completely prefabricated off site. In order to meet the tight schedule, the substructure was preassembled to such a degree that the panels merely had to be lifted into position and fastened. The upper level of the roof is an ETFE-tensioned arch which, because it is independent of the insulating level and only spans 1.5 m, enables a correspondingly simple realisation and minimised cross sections, which was an advantage, both for delivery to the construction site and for the handling during installation. It is generally advisable to provide shading devices for translucent wall or roof elements which are insulated with aerogel because otherwise there will be increased energy input. The translucent ceiling for the Georgia Institute of Technology pavilion addressed this by shielding a large portion of the radiation with photovoltaic elements mounted on the roof. In addition, adjustable sun protection was installed. The result is a relatively lightweight, highly insulated roof which, due to its translucence, optimally exploits the available daylight.

Georgia Institute of Technology, College of Architecture,
Project leaders: Ruchi Choudhary, Russell Gentry, Chris Jarrett, Franca Trubiano
Roof team: Jason Brown, Vishwadeep Deo, Bradley Dolphyn, Matthew Erwin, Alstan Jakubiec, Jamie O'Kelley, Arseni Zaitsev

H–K Georgia Institute of Technology's Solar Decathlon Pavilion, 2007
H roof section scale 1:20
1 solar panel
2 sun protection
3 weather protection: 0.25 mm ETFE foil
4 50/50 mm steel SHS, galvanized
5 4.00/1.50 m aerogel panel
0.25 mm ETFE foil
70 mm silica aerogel
0.25 mm ETFE foil
60/60 mm softwood frame
6 60/240 mm timber beam
I The aerogel panels with ETFE foil above
K Bedroom with aerogel ceiling panels

www.solarnext.de/www.hightexworld.com
www.solar.gatech.edu/www.coa.gatech.edu