

APPLICATION OF NANOTECHNOLOGY-BASED THERMAL INSULATION MATERIALS IN BUILDING CONSTRUCTION

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Abstract

Nanotechnology-based materials have previously been used by space research, pharmaceuticals and electronics, but in the last decade several nanotechnology-based thermal insulation materials have appeared in building industry. Nowadays they only feature in a narrow range of practice, but they offer many potential applications. These options are unknown to most architects, who may simply be afraid of these materials owing to the incomplete and often contradictory special literature. Therefore, they are distrustful and prefer to apply the usual and conventional technologies. This article is intended to provide basic information about nanotechnology-based thermal insulation materials for designers. It describes their most important material properties, functional principles, applications, and potential usage options in building construction.

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- Nanotechnology,
- thermal insulation material,
- building construction.

1 INTRODUCTION

The prefix “nano” is derived from the Greek “nanos”, meaning “dwarf”. A nano (symbol: n) is an SI prefix meaning one billionth. In the metric system this prefix denotes a factor of 10⁻⁹. Nanotechnology is science, engineering, and technology conducted on a nanoscale, which is about 1-100 nanometres. It is the study and application of extremely small things and can be used across other science fields, such as chemistry, biology, physics, materials science, and engineering. Its traditional sense means building things from the bottom up, with atomic precision (Leydecker, 2008).

2 BRIEF HISTORY OF NANOTECHNOLOGY

Biological systems often feature natural, functional nanomaterials. The structure of foraminifera and viruses, the wax crystals covering a lotus leaf, spider and spider-mite silk, some butterfly wing scales, natural colloids (milk, blood), horny materials (skin, claws, beaks,

feathers, horns, hair), corals, and even our own bone matrix are all natural organic nanomaterials.

Natural inorganic nanomaterials occur through the growth of crystals in the diverse chemical conditions of the earth's crust. For example, clays display complex nanostructures due to the anisotropy of their underlying crystal structure, and volcanic activity can give rise to opals, which are an instance of naturally occurring photonic crystals due to their nanoscale structure.

The concepts that seeded nanotechnology were first discussed at an American Physical Society meeting at the California Institute of Technology (Caltech, USA) on 29th December, 1959, by the renowned physicist Richard P. Feynman (1918-1988) in his talk, “There's Plenty of Room at the Bottom”, in which he described the possibility of synthesis via the direct manipulation of atoms. The term “nanotechnology” was first used by the Japanese scientist, Norio Taniguchi (1912-1999) in 1974, though it was not widely known. The first fundamental studies about nanotechnology were written by Claes-Göran Granqvist (1946-) and Robert A. Buhrman (1944-) in 1976 (McIntyre, 2012).

However, the term was not used again until 1981, when Kim Eric Drexler (1955-), who was unaware of Taniguchi's prior use of the term, published his first paper on nanotechnology. He popularized the concept of nanotechnology and founded the field of molecular nanotechnology. In his 1986 book, "Engines of Creation: The Coming Era of Nanotechnology", he proposed the idea of a nanoscale assembler. Also in 1986, Drexler co-founded the Foresight Institute to help increase public awareness and understanding of nanotechnology concepts and implications (McIntyre, 2012).

However, when something is as small as an atom, it is impossible to see it with the naked eye. In fact, it is impossible to see with the microscopes typically used in high school science classes. In the 1980s, two major breakthroughs initiated the growth of nanotechnology in the modern era. The first was the invention of the scanning tunneling microscope (STM) in 1981 by Gerd Binnig (1947-) and Heinrich Rohrer (1933-2013) at the IBM Zurich Research Laboratory. It provided an unprecedented visualization of individual atoms and bonds and was successfully used to manipulate individual atoms in 1989. The second invention, fullerenes (Buckminsterfullerene: C60), were discovered in 1985 by Harold Walter Kroto (1939-), Richard Errett Smalley (1943-2005), and Robert Floyd Curl (1933-) at Rice University. C60 was not initially described as nanotechnology. The term was used regarding subsequent work with related graphene tubes, which suggested potential applications for nanoscale electronics and devices (Leydecker, 2008).

3 NANOTECHNOLOGY IN ARCHITECTURE

Nanotechnology can also be used in architecture. The addition of nano-silica to cement-based materials can increase their durability and compressive strength. It can be used to increase the fluidity or water permeability of concrete (Lan et al. 2014; Orbán, 2012a). With the addition of nanotubes or nanofibers, the tensile and bending strength of concrete structures can be strengthened (Orbán, 2012b). Wood can be composed with nanotubes or nanofibers, and these products can be twice as strong as steel (McIntyre, 2012). Titanium dioxide (TiO₂) is used in nanoparticle form to coat glazing because of its sterilizing and anti-fouling properties (Abdelrahman, 2010; Orbán, 2012a). Nanoparticle-based coatings can provide better adhesion, transparency, self-cleaning, corrosion and fire protection (Abdelrahman, 2010).

We can also find some nanotechnology-based thermal insulation materials on the market:

- Expanded polystyrene products, including graphite powder additive
- Aerogel used for insulating transparent building structures
- Nanoparticle-based vacuum insulation panels
- Nano-ceramic thermal insulation coatings

4 NANOTECHNOLOGY-BASED THERMAL INSULATION MATERIALS

Nanotechnology-based thermal insulation materials generally have a better thermal insulation quality than traditional materials. There are three ways of heat transport in traditional thermal insulation materials: thermal conduction (vibration of molecules inside cellular walls), heat flux (between air particles enclosed in cells) and thermal radiation (between opposing cellular walls). In nanotechnology-based thermal insulation materials, one or more ways of heat transport is hampered or blocked. This is why they can decrease the heat transfer coefficient of building structures. The well-known formula of heat transfer coefficients is the following:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{i=1}^n \frac{d_i}{\lambda_i} + \frac{1}{h_e}} \quad (1)$$

In the formula U is the heat transfer coefficient [W/m²K]; d_i is the individual thickness of each structural layer [m]; λ_i is the individual thermal conductivity of each structural layer [W/mK]; h_i is the internal convective heat transfer coefficient [W/m²K]; and h_e is the external convective heat transfer coefficient [W/m²K].

This U -value can be decreased in two ways by nanotechnology-based materials. Some of them have a lower thermal conductivity than traditional materials, but some materials can reduce the convective heat transfer coefficient of the insulated surface.

4.1 Expanded Polystyrene Products, Including Graphite Powder Additive

Expanded polystyrene products, including graphite powder additive (hereafter, "EPS Graphite"), are applied to a wide range of materials in building construction (e.g., Austrotherm Grafit®). At the same time a foaming agent (pentane) is added, micro-size graphite powder is mixed with polystyrene during production. Besides the grey colour the end product is different from the traditional expanded polystyrene products because of the 20% lower thermal conductivity. In this material one way of heat transport is balked because thermal radiation is partially diffused and reflected by the graphite powder (Austrotherm Ltd., 2015).

Tab. 1 Main physical parameters of EPS graphite thermal insulation (Plundstein, 2007)

Physical parameter	Symbol	Dimension	Value
Density	ρ	kg/m ³	15-30
Compressive strength	σ_c	kPa	60-150
Tensile strength	σ_t	kPa	80-100
Bending strength	σ_b	kPa	50-120
Specific heat	c	kJ/kgK	1500
Water absorption	W	V/V %	1-5
Water vapour resistance	μ	-	20-100
Thermal conductivity	λ	W/mK	0.031-0.032
Thermal tolerance	T	°C	85

The other physical parameters of EPS Graphite (Tab. 1) are the same as traditional EPS products, so the applications are also similar. Their construction needs special attention. Because of its dark colour EPS Graphite can collect much more heat than traditional products. This is why higher thermal movements may occur in them. In the case of strong sunshine it is recommended that it be placed in shaded surfaces (following the sun). Surface-reinforcing netting should begin as soon as it possible; otherwise, it could become detached from the surface because of the huge thermal movements. A solution to this problem is provided when one side is coated with pink painted EPS graphite insulating sheets (e.g., Austrotherm Grafit Reflex®). The coating prevents the surface from becoming too warm in the bright sunlight. It is important to fasten the boards along their non-painted side on a façade to reflect the sunshine from the surface. Otherwise, we could make a serious design error, because the painted film is unable to enforce its beneficial effect.

EPS graphite products are suitable for insulating the inner or outer side of façade walls (inner side with psychometric calculations) and the lower side of cellar slab structures. Products with higher compressive strength (100-150 kPa) are suitable for insulating cellar slab structures (under a concrete underlayment), flat and green roofs with a direct order of layers, and floors lying on the ground (protection against moisture is necessary) (Austrotherm Ltd., 2015).

Certain products (e.g., Austrotherm Manzard Grafit®) are used for insulating high roofs by placing them on the outer side of rafters (Fig. 1). Their relatively high compressive strength (150 kPa) allows the structure to withstand the net weight of the roofing and meteorological charges (wind and snow loads). Large cross-sectioned counter battens (75 x 50, or 75 x 75 mm) can be fixed with corrosion-standing fasteners through the insulation. The thermal insulation of high ferro-concrete roofs (coffin slabs) is also possible with this product (Austrotherm Ltd., 2015).

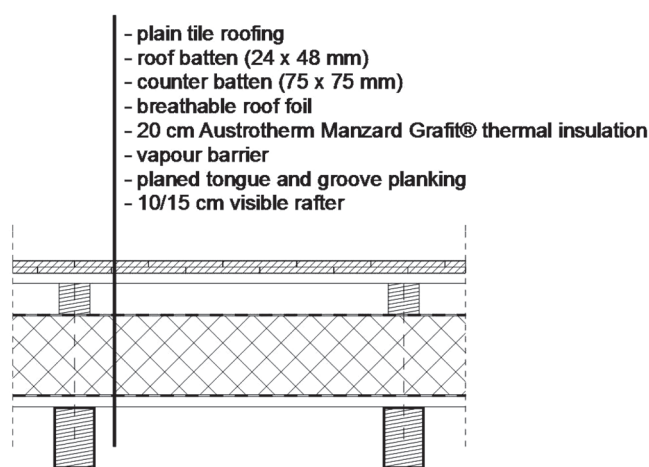


Fig. 1 General order of a roof layer, including EPS graphite

4.2 Vacuum Insulation Panels

Vacuum insulation products were first used for insulating refrigerators and vehicles, but nowadays they are used in building construction to provide better insulation performance than conventional materials (Tab. 2).

Tab. 2 Main physical parameters of vacuum insulation panels (Fricke et al. 2006; Plundstein, 2007)

Physical parameter	Symbol	Dimension	Value
Density	ρ	kg/m ³	150-300
Compressive strength	σ_c	kPa	140-250
Tensile strength	σ_t	kPa	60
Specific heat	c	kJ/kgK	800
Water absorption	W	V/V %	0
Water vapour resistance	μ	-	∞
Liquid water permeability	w	kg/m ² h ^{0.5}	0
Thermal conductivity	λ	W/mK	0.005-0.010
Thermal tolerance	T	°C	80

In vacuum insulation panels two ways of heat transfer are hampered. The interfaces of silica crystals are very small, which causes difficulties in thermal conduction. Moreover, creating a vacuum (0.05 bar) practically eliminates convection, since this relies on the presence of gas molecules to be able to transfer heat energy by bulk movements. A small decrease in pressure has no effect on the thermal conductivity of a gas, because the reduction in energy-carrying molecules is offset by a reduction in collisions between molecules. However, at a sufficiently low pressure, the distance between the collisions exceeds the size of the vessel; then the conductivity does reduce with pressure (Fricke et al. 2006).

Vacuum insulation panels consist of a kernel and a membrane. Kernels consisting of compressed fumed silica are laced with silicon carbide (SiC) or other infrared-opacifiers in order to reduce radiative transport and with organic fibres to enhance stability. The kernel is dried, evacuated to about a 0.1 mbar, and sealed into a high-barrier laminate. The laminate consists of several layers of polyethylene-terephthalate (PET) or polyethylene (PE) coated with 30 nm thin aluminium (Al) layers. The Al-layers serve as barriers to air and water vapour. Since such thin metal layers have pinholes, two or three Al-layers are usually integrated into the laminate. Less often, almost water-tight Al-foils with a PE coating as a sealing layer are employed (Fricke et al. 2006).

Depending on the application method, vacuum insulation panels can be installed as normal or mounted panels or as vacuum insulation sandwich panels (VIS). Under certain conditions that use additional protective covers, vacuum insulation panels are suitable for insulating any building construction (flat and high roofs, slab structures, floors, façade walls). In spite of multiple (usually 6-12) layers, the protective membrane walls are sensitive, so the full packing of VIP panels during the production is essential. Even before installation (i.e., when ordering the material), a well-dimensioned product design is necessary because the panels are fully prefabricated. Vacuum insulation panels are delivered to the site in cut-to-size tables, which are designed for the specific surface. Sometimes numbered tables and a laying plan are required (Orbán, 2012a).

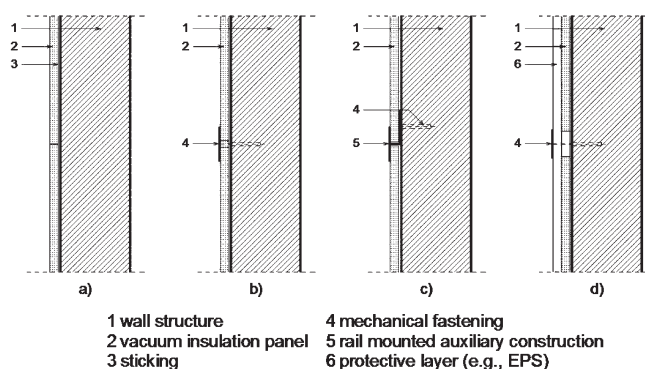


Fig. 2 Fixing methods of vacuum insulation panels on façade walls

The thickness range of panels is generally 10-50 mm. A panel size from 100 x 100 mm to 1250 x 3000 mm is optional. Their shape should be a rectilinear polygon. Air should not leak into the panels. Therefore, it is prohibited to drill through, cut to size, or pierce them subsequently on-site, and the holes of any fixing points are placed in advance. If screw fixation is not necessary (e.g., a floor, flat roof), they can be used without a protective cover. Some kind of fixation is necessary between the plates and the insulated surface on façade walls and the lower side of slab structures. Full surface sticking is possible, but not completely safe; therefore, it is generally not recommended. Vacuum insulation panels can be fastened on façade walls with rail-

mounted auxiliary construction or wall insulation anchors. Anchors are useable if there are pre-placed holes in the panels for them (Fig. 2) (Orbán, 2012a; Orbán, 2012b).

In the absence of anchors the use of mounted or prefabricated sandwich panels is recommended, because there is no vacuum at the corners of the panels. A recent system is known as “LockPlate”. Its essence is that there is 4 cm expanded polystyrene foam around the core of a vacuum insulation panel (Fig. 3).

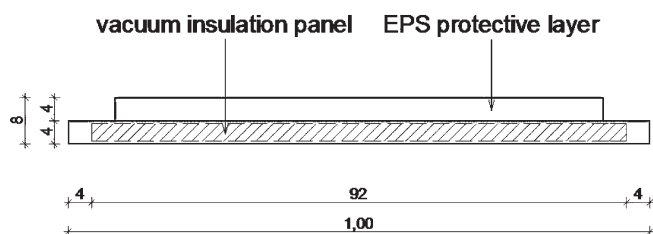


Fig. 3 Vacuum insulation “LockPlate” sandwich panel

An adequate quality of the thermal insulation of the parapet parts of curtain wall façades is only available with thick in-fill thermal insulation. When using vacuum insulation panels, much thinner parapet insulation is required, so that the thickness of the parapet and the thermally insulated window can be the same. Vacuum panels can be placed between two layers of glass or metal tables, which change the optical appearance minimally, because the series of transparent windows are only divided by the opaque parapet elements.

4.3 Aerogel Thermal Insulation

Aerogel is a synthetic, porous ultralight material derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density and low thermal conductivity. It is considered to be the most low-density solid material and has several unique physical properties (e.g., as thermal insulation).

Aerogel was first created by an American chemist, Samuel Stephens Kistler (1900-1975) in 1931, as the result of a bet with Charles Learned over who could replace the liquid in jellies with gas without causing shrinkage. The first aerogels were produced from silica gels. Since then it has been proven that aerogels can be prepared from a number of different materials like alumina, chrome, tin dioxide and carbon.

The synthesis of (silica) aerogels may be divided into three general steps: preparation of the gel by sol-gel processes, ageing of the gel in its mother solution to prevent the gel from shrinking during drying, and drying the gel under special conditions to prevent the gel structure from collapsing (Baetens et al. 2011).

Aerogel insulations were developed in the 1980s by Aspen Aerogels, which is a spin-off venture of the National Aeronautics and Space Administration (NASA). The real breakthrough occurred around the year 2000, when reinforcing fibres were successfully mixed into the material. The result was a flexible building material with good technical parameters, which is widely applicable in the building industry. Admittedly, it was applied in powder form previously as insulation for large roof windows and other transparent building structures.

Silica aerogel is a dendritic network of loose silicon. It is prepared by carefully removing the liquid part from silica alcogel and replacing it with gas, thereby producing the final product containing 99.8% air. It has low thermal conductivity and good physical and mechanical properties (Tab. 3). It does not age or get mouldy, and environmental

problems should not be taken into account during its application. It is hydrophobic (water repellent), water permeable, environmentally safe, and fully recyclable. Its excellent thermal insulation quality is caused by one-dimensional molecular chain. Air cannot circulate in the pore system of aerogels, so all forms of heat transport are limited.

Thermal conduction slowly occurs inside the nanostructure because of the small interfaces between the aerogel particles. In addition, the pores are smaller than the length of the path required by the internal gas molecules for free collisions. They interfere with cellular walls rather than with each other, so any convective heat transport is minimal. The size of the nanopores is also smaller than the wavelength of infrared rays; therefore, the nanocellular walls reflect and dissolve a significant part of the heat rays (Orbán, 2012a; Orbán 2012b).

Tab. 3 Main physical parameters of aerogel thermal insulation (Baetens et al. 2011, Plundstein, 2007)

Physical parameter	Symbol	Dimension	Value
Density	ρ	kg/m ³	60-80
Compressive strength	σ_c	kPa	2-100
Tensile strength	σ_t	kPa	200
Specific heat	c	kJ/kgK	750-840
Water absorption	W	m/m %	100
Water vapour resistance	μ	-	5
Thermal conductivity	λ	W/mK	0.013-0.021
Thermal tolerance	T	°C	650

The application fields of aerogel insulations are limited because of the high cost of nanotechnology methods. It is useful for thermodynamic post-improvements of building constructions, which have become problematic due to a design or constructional error. It is also utilizable to remedy inherently problematic structural junctions of passive and low-energy houses. It can be applied indoors or outdoors to improve the thermal insulation capacity of monolithic concrete structures (lintels, pillars), window edges, roll covers, pipes, and containers. It is step-resistant and can usually be installed in a completely ordinary way without disrupting the structure. Stickable, plasterable and flexible, it is easy to fit to curved surfaces. The most important aerogel thermal insulation products used in building construction are:

- Aerogel thermal insulation blankets
- Self-adhesive insulating strips
- Nanoporous translucent glass

An aerogel thermal insulation blanket (e.g., Spaceloft®) is a flexible composite material, which is actually an aerogel embedded in a fiberglass spatial net. It is available in rolls, which enable rapid and wide-ranging applications. Compressible, plastic, and fire-resistant, it fits well anywhere without a loss of tensile strength and elasticity. Aerogel blankets are available in different widths, thicknesses (2-10 mm), and sizes. It can be optimally composed for different temperature ranges (from -200°C to +650°C).

The physical parameters of self-adhesive insulating strips of aerogel are fully consistent with insulating blankets. They are generally used as a thermal break in lightweight building structures (Fig. 4). They are also easily and practically applicable, and only a 1-2 cm thickness is enough to increase the thermal bridge effect between wall panels and other structural elements.

Aerogel is also used as nanoporous translucent glass (e.g., NANOGEL®). It is preferably used as a thermal insulating window (e.g., curtain walls), skylight window, transparent partition wall, or balcony railing element.

Aerogel is especially very interesting as a translucent or transparent insulation material because of its combination of low thermal conductivity and high transmittance of daylight and solar energy. Two types of highly insulating windows were developed for this purpose based on a granular aerogel and a monolithic aerogel.

Granular aerogel-based windows were developed by ZAE Bayern (Germany). They produce two types of granular aerogel, i.e., semi-transparent and highly translucent granulates. This granular aerogel is stacked in a 16 mm wide polymethyl-methacrylate (PMMA) double-skin sheet between two gaps (i.e., either 12 or 16 mm in width and respectively filled with krypton or argon) and glass panes. Monolithic aerogel-based windows were developed by the HILIT+ project of the European Union. This window is produced in combination with the technology of vacuum glazing by applying a pressure between 1 and 10 mbar (Baetens et al. 2011).

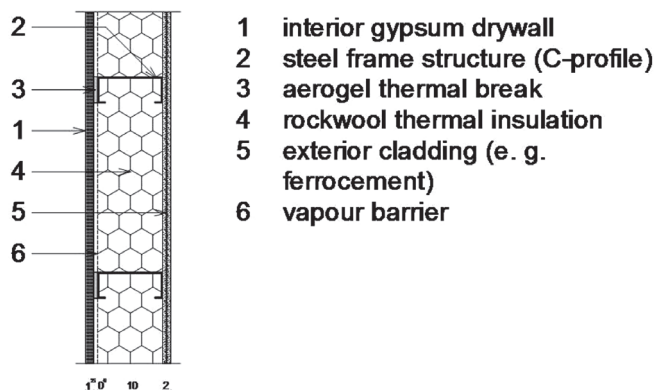


Fig. 4 General order of external lightweight wall layers, including an aerogel thermal break

4.4 Nanoceramic Thermal Insulation Coatings

In the early 1980s, S. Komarneni and R. Roy developed the first method of synthesizing nanoparticles, specifically nanoceramics (Hoffman et al. 1984). They used a process called “sol-gel”, which enabled researchers to test the properties of nanoceramics. This process was later replaced by sintering in the early 2000s and has continued to advance to microwave sintering. Because of these advancements, researchers are able to produce nanoceramics at a more efficient rate.

Paint-on insulation products like Thermo-Shield, Protector, MANTI and TSM Ceramics contain microscopic (with a diameter of 20-120 μm) cellular ceramic microspheres. These vacuum-hollow balls are made of high gas-pressure and high temperature (1500 $^{\circ}\text{C}$) melted ceramic. After they cool down, the pressure ends, leaving a vacuum inside the microspheres. Their binding material is a mixture of synthetic rubber and other polymers. The main components are styrene (20%) and acryl latex (80%). Styrene guarantees the mechanical strength. Acryl latex makes this material resistant to weather conditions and provides adequate flexibility. Other environmental additives (biocides, anti-fouling and antifungal materials) make the final product durable and mould-proof (Fullisol Ltd., 2014; MANTI Ltd., 2015).

Thermal transmission processes happen in these microscopic vacuum spaces in non-traditional ways. There are three ways of heat

transfer in thermal insulation materials: thermal conduction (inside cellular walls), heat flux (between air particles enclosed in cells) and thermal radiation (between opposing cellular walls). But there are small interfaces of ceramic microspheres and cellular walls that are so thin that they slow down thermal conduction. Heat flux is also unstable in vacuum micro spaces. Air particles come up against cellular walls rather than each other, so they are almost unable to transport heat energy. The inner surface of cellular ceramic microspheres works as a heat mirror and reflects 60-80% of the heat radiation.

The special literature provides different technical details about these materials (Tab. 4). Moreover, the thermodynamic details are extraordinarily contradictory. Some sources say that their thermal conductivity is around 0.001-0.003 W/mK (Fullisol Ltd., 2014; Mart Ltd., 2014; SPM Thermo-Shield Inc., 2015; MANTI Ltd., 2015), but others publish much higher values (from 0.014 W/mK to 0.140 W/mK) (Orbán, 2012b; Paul et al. 2010). These details are often not confirmed with laboratory tests or refer to inadequate experiments. For example, some sources indirectly determine the thermal conductivity of this thin coating with heat transfer experiments of wall structures according to MSZ EN 1934:2000 and MSZ EN ISO 8990:2000 standards (Paul et al. 2010; Fullisol Ltd., 2014; Mart Ltd., 2014). Nevertheless, these methods are only suitable for determining the heat transfer coefficient of a global building structure and take account of the standardized heat transmission coefficients on the inner and outer sides of a wall structure. To measure the thermal conductivity of thermal insulation materials, the only suitable standard is MSZ EN 12667:2001 (Title: Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance). According to this method, the thermal conductivity was measured in the Laboratory of Building Materials and Building Physics at Szechenyi Istvan University (Győr, Hungary) with a standard heat flow meter of 0.069 W/mK (Bozsaky, 2015). Based on these experiments, it was concluded that the good thermal insulation quality of nano-ceramic thermal insulation coatings is caused not by very low thermal conductivity but rather by the high convective heat transfer coefficient between the air and surface of the building structure. Further tests are required to determine it exactly.

Tab. 4 Main physical parameters of nano-ceramic thermal insulation coatings (Fullisol Ltd., 2014; Mart Ltd., 2014; SPM Thermo-Shield Inc., 2015; MANTI Ltd., 2015)

Physical parameter	Symbol	Dimension	Value
Density (wet)	ρ_{wet}	kg/m^3	500-745
Density (dry)	ρ_{dry}	kg/m^3	290-410
Tensile strength	σ_t	kPa	200-300
Adhesive strength (concrete)	$\tau_{\text{ad,concrete}}$	kPa	460-920
Adhesive strength (steel)	$\tau_{\text{ad,steel}}$	kPa	470-900
Specific heat	c	kJ/kgK	1080
Water absorption	W	m/m %	20-30
Water vapour resistance	μ	-	2
Liquid water permeability	w	$\text{kg/m}^2\text{h}^{0.5}$	0.16-0.20
Thermal conductivity	λ	W/mK	0.001-0.003, or 0.014, or 0.070, or 0.140
Thermal tolerance	T	$^{\circ}\text{C}$	300

Nano-ceramic thermal insulation coatings are flexible; non-toxic; mould-free; UV, fire and chemical resistant; washable; and friendly to the environment; they form a monolithic membrane that bridges hairline cracks. They can stick well to all types of surfaces such as concrete, ceramic, plaster, metal, glass, wood and plastic.

These coatings are typically used for exterior and interior wall insulation, but they are also suitable for pipe insulation and protect against fire and corrosion. They can be easily transmitted to hard-to-reach areas. Their most important advantage is that they can be applied in places where it is not possible to use thick thermal insulating panels (e.g., scheduled national monuments).

After mixing the ceramic microspheres with the binding material, additives and water, a brush, roller or airless spray can be used to apply them on the surface to be insulated (Orbán, 2012a; Plundstein, 2007). To assure adequate and uniform coverage, spray and roll techniques are recommended. Each coat should be sprayed in the same direction to avoid showing undulations and other imperfections on a wall. Very small areas may be brushed. White or any custom colours are available, but darker colours give a correspondingly lower degree of reflectivity (SPM Thermo-Shield Inc., 2015).

All surfaces must be clean and free from laitance, dust, dirt, rust, oil or grease before painting. Surfaces must be cleaned to remove any loose or chipping paint or other foreign material. No primer layer is usually required, but it is recommended to use it over gypsum board. Generally, two layers of nano-ceramic thermal insulation coating are required, the first of which acts as a primer layer. When the coating is applied by brush, three cross-brushed coats are required for adequate insulation. The drying time of a layer depends on the temperature (at 20 °C, it takes 4-5 hours). The complete solidification takes 72 hours (SPM Thermo-Shield Inc., 2015; MANTI Ltd., 2015).

5 CONCLUSIONS

Nanotechnology-based thermal insulation materials are being used in a wide range of applications in architecture. Due to their non-

traditional method to transfer heat, the heat flow comes up against several obstructions inside them. This is why they have a higher heat transfer resistance than traditional thermal insulation materials.

EPS graphite products are the most common nanotechnology-based materials. They have a much lower thermal conductivity because of the reduced interior thermal radiation blocked by the fine graphite powder. Formerly, they were only used for façade insulation, and their installation needed much more attention. But due to the product improvements, it has overcome its disadvantages and become a widely-used thermal insulation material. The new EPS graphite products with their higher compressive strength are useable for insulating flat and high roofs, floors and slab structures.

Aerogel insulations and vacuum insulation panels are less widely used thermal insulation materials. They can highly inhibit some forms of heat transfer. Therefore, they have much more heat transfer resistance than traditional materials. Vacuum insulation panels are generally used for insulating building envelopes (façade walls, flat roofs, shutter cases) but only in a narrow range because of their special technological demands. The price of aerogel insulations allows for their application only as a thermal break or insulating glass, but they have many applications with the potential to become widespread in the future.

Nano-ceramic thermal insulation coatings are considered to be the most critical nanotechnology-based thermal insulation material. Architects are quite distrustful of this material. Unlike other materials, nano-ceramic thermal insulation coatings are capable of producing an adequate thermal insulation value of building structures in an extremely thin layer. Their high thermal resistance does not depend on their thickness (like traditional materials) but on their high surface heat transfer resistance. Because of the contradictory technical details in the special literature and the product catalogues of manufacturers, more thermodynamic tests and experiments are needed for these materials, which can provide useful information and technical parameters to practising architects for planning building constructional joints and also utilizable technical parameters for heat transfer and other building energy calculations.

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