Aerogel as Insulation Material

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Abstract

This Thesis is commissioned by Sweco Structure Ltd In this work I will present Aerogel as an insulation material. I will talk about how aerogel functions and how it can be used as insulation. I will compare aerogel with other insulation materials and examine examples of construction types with aerogel. The purpose of the thesis is to provide a clearer picture of aerogel in the construction industry and to be able to prepare for when aerogel insulation becomes an alternative or when the material becomes more readily available.

Aerogel has the possibility to improve insulation values on buildings while reducing costs and environmental emissions from transport and manufacturing. Aerogel insulation has a better insulation capacity than most of the existing insulation alternatives. The main reason why the material is not used is the expensive manufacturing process, but costs are expected to fall within the next few years.

I have mostly used internet to collect information, but I have also had an interview with a manufacturer of an aerogel-like substance. All calculations were made in Excel and construction types was edited with AutoCAD.

Language: English Key words: Aerogel, Insulation, Construction material

EXAMENSARBETE

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Titel: Aerogel som isoleringsmaterial

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Abstrakt

Detta arbete är gjort på beställning av Sweco Finland. I detta arbete kommer jag presentera aerogel som isoleringsmaterial. Jag kommer prata om hur aerogel fungerar och hur det kan användas som isolering. Jag ska jämföra aerogel med andra material och undersöka exempel på konstruktionstyper med aerogel. Syftet med arbetet är att ge en klarare bild av aerogel inom byggnadsindustrin med tanke på om isoleringen blir ett aktuellt alternativ eller när ämnet blir lättare tillgängligt.

Aerogel har möjligheten att förbättra isoleringsvärden på byggnader samtidigt som det sänker kostnader och miljöutsläpp från transport och tillverkning. Aerogel-isolering har en betydligt bättre isoleringsförmåga än de existerande isoleringsalternativen. Den huvudsakliga orsaken till att ämnet inte används är den dyra tillverkningsprocessen, men kostnaderna antas sjunka inom kommande år.

Jag har använt mest internet för att samla informationen, jag har också intervjuat tillvekare av ett aerogelliknande ämne. Beräkningarna är gjorda i Excel och kosntruktionstyper är editerade med AutoCAD.

Språk: engelska Nyckelord: aerogel, isolering, byggmaterial

OPINNÄYTETYÖ

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Tiivistelmä

Tämän työn on tilannut Sweco Finland. Esittelen tässä työssä aerogeeliä eristemateriaalina. Puhun siitä, kuinka aerogeeli toimii ja kuinka sitä voidaan käyttää eristeenä. Vertailen aerogeelia muihin materiaaleihin ja tutkin esimerkkejä rakennetyypeistä aerogeelin kanssa. Tehtävän tarkoituksena on antaa selkeämpi kuva rakennusteollisuuden aerogeelistä ja pystyä valmistelemaan, jos eristys muuttuu nykyiseksi vaihtoehdoksi tai kun aine on helpommin saatavilla.

Aerogeelillä on mahdollisuus parantaa rakennusten eristysarvoja ja vähentää samalla kuljetusten ja valmistuksen kustannuksia ja ympäristöpäästöjä. Aerogeeli-eristeen eristyskapasiteetti on huomattavasti parempi kuin olemassa olevilla eristysvaihtoehdoilla. Tärkein syy aineen käyttämättä jättämiseen on kallis valmistusprosessi, mutta kustannusten odotetaan laskevan lähivuosina.

Olen enimmäkseen käyttänyt internetiä tietojen keräämiseen, mutta olen myös haastatellut aerogeelimäisen aineen valmistajaa. Laskelmat tehdään Excelissä ja rakennetyyppejä muokataan AutoCAD: lla.

Kieli: Englanti Avainsanat: aerogeeli, eriste, rakennusmateriaali

Table of Content

1 Introduction

With the importance of climate change starting to effect society, the construction and upkeeping of houses is next in line to cut down on their emissions of greenhouse gases. The concrete and steel industries are some of the larger contributors to climate change, but both materials are essential to construction and to maintain integrity in buildings. Having to heat, cool and maintain a pleasant environment inside the building is also crucial, but not energy efficient. The hypothetical best option to reduce energy consumption would be a closed system, a house where the inside does not react with the outside, therefore maintaining its temperature. To reach such a standard there would have to be no way to move from within the house to the outside, and there would have to be no heat transfer through the walls.

Such a concept is impossible in the construction world as factors such as doors, windows and ventilation come into the picture. Other factors such as thermal bridges and insulation material also play a part to when deciding on the final energy usage in the building. Therefore, we could never reach a closed system, but we can still strive to reduce energy consumption with the realistic tools we have at hands.

This is where aerogel can help. Silica aerogel is one of the best heat insulators in the world, and if implemented into buildings could reduce the cooling and heating energy consumption by 40%[1]. Not only that, but the transport costs and emissions would be reduced by 50%, as the thermal conductivity of aerogel insulation is close to half the value of the current options, meaning you can transport twice as much insulation properties per shipment.

This project only covers a few construction types to give an idea of the capabilities of aerogel insulation.

1.1 Client

This Bachelor's thesis is written in collaboration with Sweco Structures Ltd. Sweco has 17,500 employees globally, and work on projects in over 70 countries. Sweco has approximately sales worth 1.9 billion euro, which makes them the leading architecture and engineering firm in Europe. Their Finnish department have 2,500 employees and 36 offices spread out through the country.

[1] Cordis.europa.eu, Keeping warm with aerogel

2 History of Aerogel

Aerogel is a relatively old material. It was discovered sometime between 1929 and 1930 by Dr. Samuel Kistler. The concept for aerogel came from a bet between Dr. Kistler and a Charles Learned. The bet was if it was possible to remove all the liquid from a jelly without damaging the solid structure. It is still unclear when the first aerogel was made, but the first paper on aerogel was published in 1931 in *Nature.* Dr. Kistler then continued his research at the University of Illinois during 1931 to 1935, where many important qualities were discovered, such as the thermal conductivity.

In the early 1940's Dr. Kistler and the Monsato Corp. came upon an agreement to produce silica aerogel in Everett Massachusetts. The Monsato Aerogel plant produced aerogel that was mostly used as an additive or thixotropic agent in cosmetics and toothpaste, but also as insulation for freezers. Dr. Kistler had made aerogel out of many materials such as cellulose, gelatine, and rubber, but the base Monsato Corp. ended up using was based on Silicon dioxide. Dr.Kistler's research however started to move away from aerogel and production also came to a halt, as more affordable alternatives became available.[2]

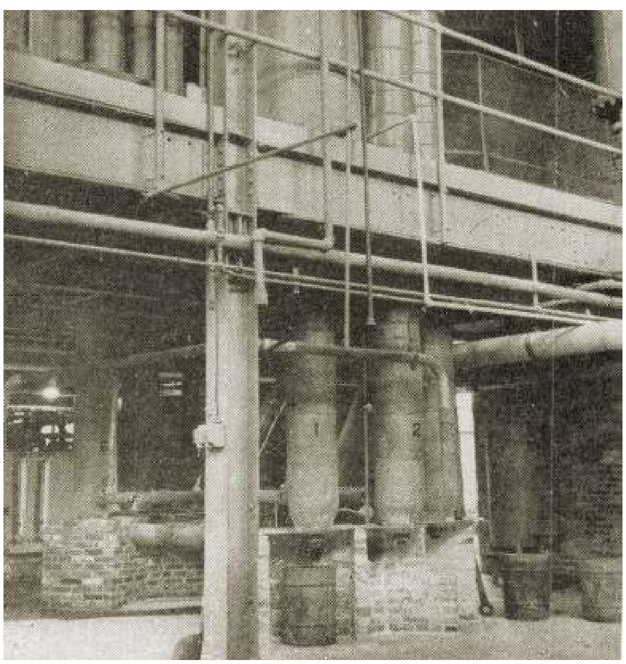

Figure 1. Three autoclaves from the Monsato Corp used in the drying process of Aerogel.[3]

[2] Aerogel.org, The Early Days of Aerogels
[3] Aerogel.org, The Early Days of Aerogels

During the late 1960s the idea of using aerogel became relevant again. This time it was to be used as a medium to store oxygen and liquid rocket fuel. Stanislaus Teicher was approached with the task by the French Government and delegated it further to one of his graduate students, who went on to find a more efficient way of producing aerogel. This caused an increased interest in the material which led to new discoveries and the product becoming more refined.[4]

2.1 Recent History

The modern era for aerogel starts in the 1970's. The Monsato Corp had abandoned their production of aerogel, mostly due to competitors having found out much safer and more cost-effective ways to produce the material. In the 1980's the so-called sol-gel process of making aerogel became less toxic and much safer by replacing the alkoxide compound with a safer one and changing the supercritical drying technique to use supercritical carbon dioxide instead of supercritical alcohol. With this new discovery, the interest from the scientific community increased, most noticeable was Lawrence Livermore National Laboratory and NASA. The researchers at LLNL manufactured the world's lightest aerogel, at only 0.003g/ cm^3. They also improved techniques to create aerogels out of organic materials, which gave them aerogel based on pure carbon. Carbon aerogels would later enable the possibility of supercapacitors, which revolutionised energy storage.[5]

The 1990's and 2000's aerogel really started to become interesting for the scientific community. NASA started to use aerogel as insulation in their space projects such as the Mars Pathfinder mission. NASA also insulated the electronics of the Spirit and Opportunity Exploration Rovers with aerogel and used silica aerogel as a water absorbent to catch vapor in the air inside the machines. Due to the structure of the aerogel, it was also used to collect dust from a comet, as particles would break the frail skeleton on impact and get stuck in the material. These missions helped to bring attention to aerogel and its many uses.[6]

[4] People.wou.edu, Aerogel Project, Discovery, and History
[5] Aerogel.org, The 1970's: The Aerogel Renaissance
[6] Aerogel.org, The 1990's: New Techniques and the Final Frontier

Figure 2 Comet dust trapped in aerogel[7]

In the 2000's the idea of metal aerogels became a reality. Previously only metal oxide aerogels have been made, but in 2005 researchers at the LLNL started to come close to the result. But in 2009 the first real metal aerogel was discovered by Prof. Leventis. It was an iron aerogel that he discovered while attempting to make carbon-metal oxide hybrid aerogels. Prof. Leventis was not new to the subject of aerogel, as earlier that decade he had produced something called x-aerogel, a flexible, more robust version of aerogels.[8]

3 Properties

When Dr. Kistler first made his bet with Mr. Learned the idea was to extract the liquid from a jelly and keeping the structural integrity of the jelly. Since Dr. Kistler's discovery more and more improvements have been made to the material and the process of making it. It has been refined for almost a century and the product that we use today differs a lot from the first batch. Density, thermal conductivity, and other properties of aerogel has made it a popular material to use in everything from spacecrafts to jackets.[9]

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[7] nasa.gov, mission to a comet
[8] Aerogel.org, The 2000's: New Possibilities and Commercialization
[9] Aerogel.org, The Early Days of Aerogels

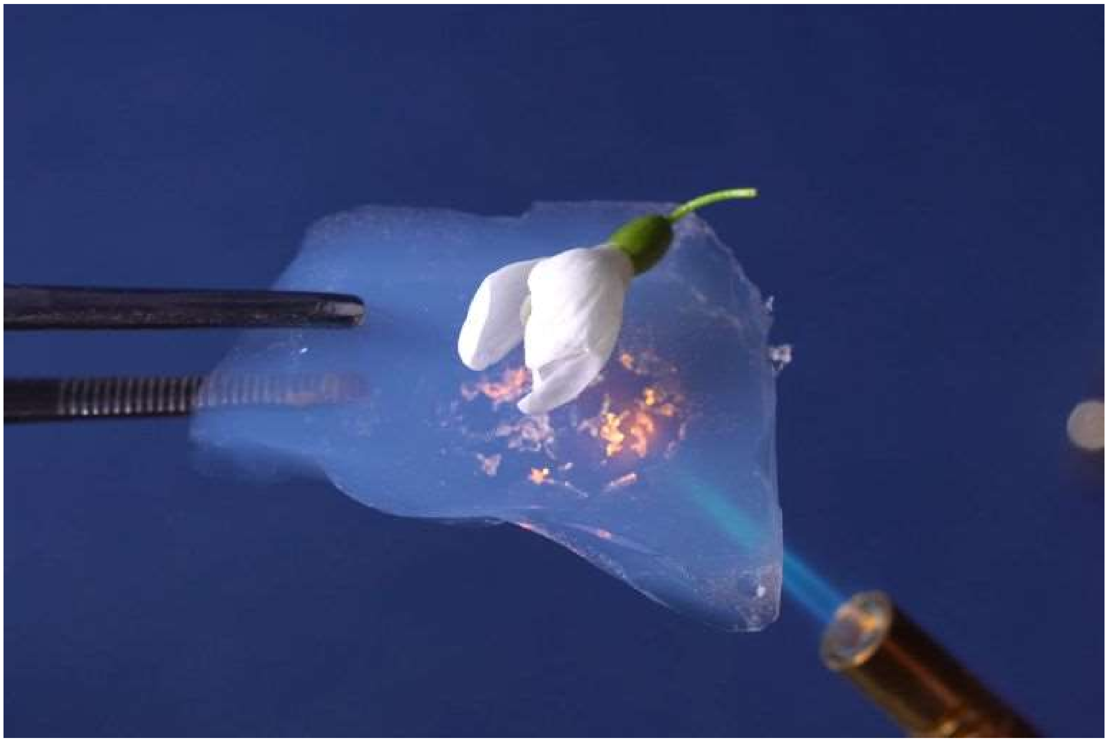

Figure 3 Aerogel protecting a flower from heat[10]

3.1 Creating Aerogel

Aerogel is the term used for the shape or state that different materials take. The definition of aerogel is “An aerogel is an open-celled, mesoporous, solid foam that is composed of a network of interconnected nanostructures and that exhibits a porosity (non-solid volume) of no less than 50%.”, according to Aerogel.org. The regular material for aerogel is silica, or silicon dioxide, which was one of the first materials that was used to create aerogel. However, recently other materials have been used as well, such as carbon, metal oxides and even metals themselves. [11]

The most widely used process of creating aerogel is the Sol-Gel process. A Sol is a liquid filled with solid nanoparticles. In the case for silica gel, the nanoparticles are grown in the solution by connecting molecules. The nanoparticles then connect to form what is called a gel network. The Gel part gets its name from this, defined as a wet solid like material where a network of connected nanostructure reaches throughout the volume. The Sol-Gel process requires heat, to make the particles move more on a nano scale and making it easier to have

[10] Matmatch, Aerogel: Insualtion Material of the Future
[11] Aerogel.org, Silica Aerogel

them bump together. The easiest way to describe the Sol-Gel process is to compare it to making jelly, as the two processes somewhat resemble each other.[12]

The final step of making aerogel is the supercritical drying. It is also the most important part, as it is the fundamental idea of creating an Aerogel, removing the liquid from the gel structure. The safest method uses carbon dioxide and a machine known as autoclave. First the gel is put under pressure and the ethanol in the gel is replaced with liquid CO_2. The ethanol is then removed from the autoclave and the autoclave is heated above the critical temperature of CO_2. The pressure rises and CO_2 is released to maintain a constant pressure just above the critical pressure of CO_2. After that, a controlled release of the remaining carbon dioxide can be done to normalize the system. The whole process can last from 12 hours up to 6 days, depending on the thickness of the gel.[13]

3.2 Thermal Conductivity

Aerogel is an excellent thermal insulator. In fact, aerogel has the lowest thermal conductivity amongst all solids. Due to its nano structure, the heat travels through the pores in the material, buts has a hard time to reach the other side of it. The warm molecules cool down inside the aerogel, as they bounce of the pore walls more often than with each other in a process called Knudsen flow or Knudsen diffusion. This allows aerogel to reach a thermal conductivity value as low as 0.004 W/(mK) depending on the product and material used. The fiberglass and silica aerogel blend that are aimed at construction insulation usually reaches a thermal conductivity of 0.016W/(mK).[14] It also allows for the material to be touched after experiencing extreme heats, as it transfers heats to the body poorly.[15]

3.3 Fire Resistance

Silica aerogel is naturally non-flammable. However, it reaches the national classification of C when made into insulation, meaning it has a limited contribution to fire. The smoke performance level for Silica aerogel insulation is s1 and the drip content level d0, meaning that smoke emission is either absent or weak and there is no dripping of the material.[16] It

[12] Aerogel.org, The Sol-Gel Process
[13] Aerogel.org, Supercritical Drying
[14] Thermal Performance of Building Material and Products – Determination of Thermal Resistance by Means of Guarded Hot Plate and Heat Flow Meter Methods – Products of High and Medium Thermal Resistance EN 12667:2001
[15] AerogelTechnologies.com, why are aerogels such good insulators?
[16] Fire Test to Construction Products and Building Elements – EN 13501-1

works normally in temperatures up to 125°C. There are also products aimed to increase the fire resistance and they are able to reach a fire rating classification of A2.

3.4 Water Resistance

Naturally, silica aerogel is very hydrophilic, meaning that it likes to suck up water when it encounters it. Silica aerogel also absorbs water vapor in the air, which is one of its primary uses in everyday life, as it comes in the form of silica packs with clothes or food. However, this might not be a sought-after trait in many areas, as the aerogel gets damaged and crumble as it absorbs water and loses its insulation properties. Therefore, it needs to be waterproofed before it can be applied in construction purposes.

Luckily, silica aerogel is quite easy to waterproof. At the surface of the skeleton are silanol (Si-OH) groups, which are the same groups that react with water. Due to the -OH groups having a molecular charge it likes to react with other molecules. But adding hexamethyldisilazane ($[(CH_3)_3Si]_2NH$) during the formation or purification step will cause the silanol group to replace with a non-polar group, in this case trimethylsilyl ($-Si(CH_3)_3$), making it waterproof. This makes the aerogel insulation reach a water vapor permeability μ-value of 5,0.[17]

3.5 Acoustic Insulation

Silica Aerogel has the world record for the slowest speed that sound travels through a material, at only 70 m/s.[18] The transmission loss through aerogel insulation is 13dB per 20mm of thickness at 6400 Hz. [19]

[17] Aerogel.org, Silica Aerogel
[18] Aerogel.org, What is Aerogel?
[19] Sciencedirect.com, Thermal and Acoustic Properties of Aerogels: Preliminary Investigation of the Influence of Granule Size

3.6 Reaction to UV Radiation

In an experiment about aerogel and its usage to help inhabit mars, researchers found that silica aerogel blocks both UVA and UVB radiation and nearly entirely blocked UVC radiation, the most dangerous one.[20]

3.7 Enviromental Impact & Health

The aerogels used for insulation are environmentally friendly. The material used are usually recyclable. In the case for Silica aerogel, which is made up of Silicon dioxide, the material is environmentally friendly. Silicon dioxide is normally found as sand in nature, but also in living organism. However, aerogels made with other materials might not be as kind to nature as silica-based aerogel. Depending on the material used to create aerogel, they might only be disposed at landfills and in some cases, they might even need to be disposed at a toxic waste location.[21]

Some steps in the production process can be heavy on the environment. Supercritical drying requires high temperatures and pressures to be maintained for a long period of time, which requires a lot of energy.

Aerogel has also been created with a plant base. At the University of Helsinki, a plant-based aerogel was created using renewable recourses such as plants, meaning that there were no dangerous chemicals used in the process. According to the creator, Abdul Ghafar," These bio-based composite aerogels are safe for food and food-related applications because the cross-linking technique does not involve any toxic chemicals during the aerogel processing" Which means they could replace the silica packs that absorb moisture in the future. However, there is no information if this could be implemented in construction material.[22]

Other environmental uses for aerogel are also being tested now. One major study is to try to create an aerogel that absorbs oil that has been spilled into the ocean. Using aerogel, theoretically 100% of the oil could be reused, as it could be extracted from the aerogel later.[23]

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[20] Enabling Martian habitability with silica aerogel via the solid-state greenhouse effect, R. Wordsworth, L.Kerber, C.Cockell, October 2019
[21] Aerogels.weebly.com, Guidelines and Impact
[22] Helsinki.fi, Plant-based aerogels with minimal environmental impact could be the answer for various needs in the food industry
[23] Aerogels.weebly.com, Guidelines and Impact

Aerogels might have some personal health risks linked to it in the production process. The process to create aerogel using ethanol instead of CO_2 in the supercritical drying requires much higher temperatures and pressures.[24] This is a more risk filled way of producing aerogel and is unsafe if not done with proper caution. Divided crystalline silicon dioxide is toxic if inhaled, and can lead to many terminal diseases, such as lung cancer or silicosis. Crystalline silicon oxide is however not used in the production of silica aerogel.[25]

4 The Future of Aerogel

The largest problem with Aerogel is the high cost, but a lot of people are trying to find a way to manufacture it at a lower cost. One of those companies is Svenska Aerogel and their product Quartzene. Quartzene is an aerogel-type powder made in a patented way that can be valued at up to a 60% lower price then aerogel created by older methods. It is also healthier to the environment to produce, as the only waste product is water but with a slightly higher salinity.[26]

I had the possibility to interview Roland Ek, Product manager on Svenska Aerogel about Quartzene. The interview took place on the 20.11.2020. The rest of chapter 4 is from that interview.

4.1 Quartzene

Quartzene is a product that has been developed to be used in filtering products, but there was also an interest in sustainable building from the start. The main goal was to produce an aerogel while avoiding some steps in the process that are heavy on the environment, mainly supercritical drying. And by avoiding these steps it would also reduce the overall cost as well as any eventual working hazards that comes with high temperature and high pressure. Their method is entirely water based and still must be dried at the end, but the process does not require any solutions or high pressure like the conventional method of creating aerogel.

[24] Aerogel.org, Supercritical Drying
[25] osha.gov, “Crystalline Silica Exposure” Health Hazard Information for general Industry Employees
[26] cordis.europa.eu/

4.1.1 Environment

The product is very environmentally friendly. The raw material used in the process is silicate, one of the most common materials on earth. The material is not dangerous to handle in either the manufacturing stage, usage of the material or disposal of the material. There is no shortage or danger to the environment when extracting the raw material from nature. Since the process is water based, the only biproduct is water with a slightly higher salinity, which is not dangerous, as the salts are quite normal in nature. The product does not contain any crystalline silicon oxide, but when still in powder form should be handled with proper care.

4.1.2 Production

Svensk Aerogel are still in the beginning stages of their manufacturing process. They have recently built a factory able to produce up to 220 ton/year. It has the capability to be expanded so that production could reach 1000 ton/ year. Their idea is to also expand with new factories near their main customers, as the density is so low on the material that transporting it for long distances is less efficient.

The manufacturing stage of Quartzene is much shorter than that for aerogel. During the conventional drying process, it can take anywhere from 12 hours to 6 days, but Quartzene is processed on a line, going from the water-based pasta onto a conveyor belt and getting dried and ready in a fraction of the time of conventional aerogels.

4.1.3 Market

The current volume of aerogel on the global market is 27,9 kilotons. However, in a projection of the aerogel market done by Markets & Markets in November 2020, volume of the aerogel market would reach 69.7 kilotons by the year 2025. One of the biggest contributors to the growth is construction companies and the demand for aerogels different properties. Also, with a lot of new products and companies launching, market investors are projected to increase within those 5 years as well when new profitable opportunities become available. By using the old method there would be a cap on the market, as the product would be very expensive and time consuming to make.

Since 2016 Svenska Aerogel has focused on getting the product out on the market. Svenska Aerogels focus is paint and coating manufacturers. There are also projects with insulation companies where they want to either reduce thickness or improve the thermal resistance. There are not many competitors for them as the market have not seen many new ideas when it comes to insulation. However, there is an obstacle of convincing people to try new insulation solutions, as the construction market often gets comfortable in its old ways.

4.1.4 Future

The usage of aerogel insulation has not grown that much over the last couple years, mostly because of the costs and the conservative views of the construction market. One of the markets that will open to aerogel insulation are the transportation market, as harder regulations will require the market to use better insulation in vehicles.

The cost reduction is also on its way. Due to the small scale of the company, they are not able to put a dent in the overall cost of aerogel products. If the demand for Quartzene increases and therefore their production, then the cost would slowly start to reduce as well. Right now, their products reach all over the world and are used in many different projects.

5 Different forms of Aerogel Insulation

Aerogel insulation is quite new to the construction market, yet there have been many different solutions on how to incorporate aerogel insulation into our homes as well as industry buildings. To start the process off, Silica aerogel needs to be woven into a fibre blanket. This blanket is the foundation of every type of aerogel insulation on the market. After that, it can be bought as is or used in wall panels. Aerogel can also be made into a powder and put in paint or coating, to reduce the heat transfer between the body and the material.

The products have been chosen based on availability, reliability, and how far the product was developed. The list might not be complete and other alternatives might be on the market. These items are also meant to be projected as a standard, just to give the reader a general idea of what to expect of from aerogel products going forwards.

5.1 Aerogel Insulation Blankets

Aerogel insulation blankets are probably easiest to compare to a thin layer of mineral wool. It usually comes in 10mm thickness, to make it easier to apply to smaller spaces and bend around curved walls, but thicker sizes are also widely available. When using aerogel blankets, it is important to follow the instructions given to avoid creating any cold bridges, as it would damage the integrity of the insulation.[27]

5.1.1 SLENTEX

Figure 4. SLENTEX insulation blanket[28]

SLENTEX is an aerogel insulation mat that is applied to the outer layers off wall constructions, both the façade and inner wall can have the insulation applied to them. Using mortar, staples, plugs or adhesives, the insulation blanket can be used on almost any surfaces and even to itself to create thicker layers. Its slim thickness allows it to be used in cramped areas and makes it a good alternative as extra insulation to refurbishment projects. The slim material is also able to fit in ventilated facades. It is also good for tricky surfaces, as the insulation can be bent and cut easily, only needing as much as a drywall knife. It is shipped in 40m rolls that are 1500mm wide and the usual thickness is 10mm.

It was specifically made to reach the fire rating classification of A2 as well as being a vapor permeable insulator. The product is CE marked[29]

[27] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020
[28] plastics-rubber.basf.com, SLENTEX - The high-performance insulating material for the highest demands
[29] SLENTEX 100/1 High Performance Insulation Material User Guide

SLENTEX	
Thermal Conductivity λ	0.019 W/mK
Water vapour permeability[30] μ	5
Density	200 kg/m³
Fire rating classification	A2
Combustibility	s1, d0
Compressive strength	35 kPa

Figure 5. Table of properties of SLENTEX insulation blanket[31]

5.1.2 Spacetherm Blanket

Another form of an aerogel blanket is the Spacetherm Blanket, an aerogel composite insulation. Like SLENTEX, the Spacetherm Blanket can be fixed directly to the wall with different kinds of adhesives or staples. Its uses are pretty much the same as other aerogel blankets, as it is very useful in small spaces as well as extra insulation in refurbish projects. It is shipped as 1200mm wide, and either 1200mm or 2400mm high. It has one of the lowest Lamda-value, even amongst other aerogel insulation, however it only reaches fire rating classification of C. The product is CE marked[32]

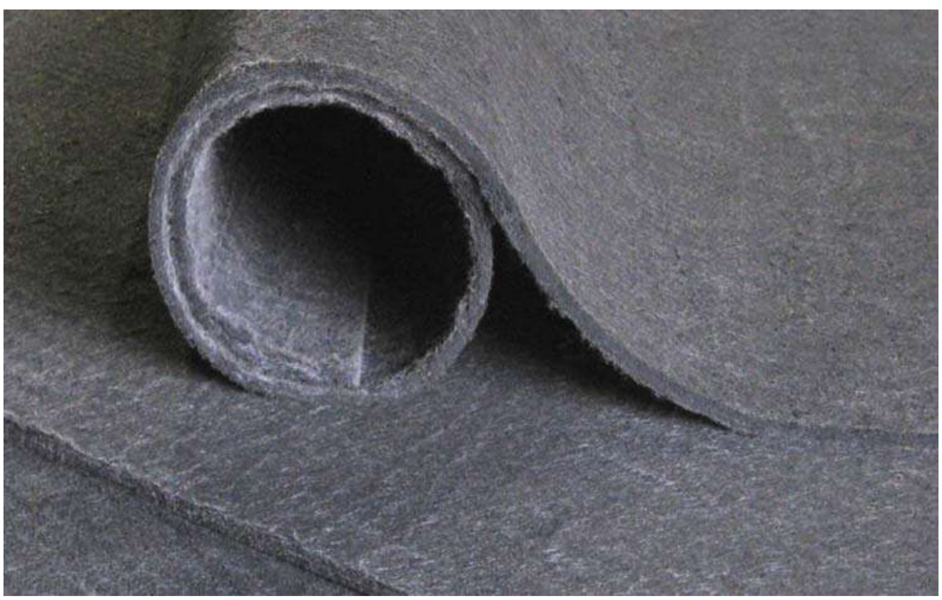

Figure 6. Spacetherm Blanket[33]

[30] Thermal Insulating Products for Building Application. Determination of Water Vapour Transmission Properties, EN 12086:2013
[31] SLENTEX 100/1 High Performance Insulation Material User Guide
[32] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020
[33] Proctorgroup.com, Spacetherm

Spacetherm Blanket	
Thermal Conductivity λ	0.015 W/mK
Water vapour permeability µ	5
Density	150 kg/m³
Fire rating classification	C
Combustibility	s1, d0
Compressive strength	5 kPa

Figure 7. Table of properties of Spacetherm insulation blanket[34]

5.1.3 Spaceloft

Spaceloft is another brand of aerogel insulation blanket. Like the previous blankets, it can wrap around difficult geometries and conserve on space. Its properties are the same as the Spacetherm blanket, with only the dimensions differing. Spaceloft is available in both 5mm and 10mm thicknesses and available in 1500mm rolls. The product is CE marked[35]

Spaceloft	
Thermal Conductivity λ	0.0165 W/mK
Water vapour permeability µ	5
Density	150 kg/m³
Fire rating classification	C
Combustibility	s1, d0
Compressive strength	5 kPa

Figure 8. Table of properties of Spacetherm insulation blanket[36]

5.1.4 Pyrogel

An aerogel blanket designed to withstand higher temperatures, mostly used in industries. Its maximum temperature is 650°C and can be used to save space while insulating steampipes, chemical processing, and other equipment. It has a slightly higher thermal conductivity than aerogel blankets used in residential and commercial buildings. Pyrogel has a flame spread index value of ≤ 5 and smoke developed index value of ≤ 10. (Values according to ASTM – E84 International standard, no European standard available)

[34] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020
[35] Technical Guidance Document, Spaceloft Aerogel Blanket
[36] Environmental Product Declaration, Spaceloft Aerogel Insualtion 18.8.2015

Pyrogel	
Thermal Conductivity λ	0.022 W/mK
Water vapour permeability μ	-
Density	200kg/m³
Fire rating classification	-
Combustibility	
Compressive strength	20 kPa

Figure 9. Table of properties of Pyrogel insulation blanket[37]

5.1.5 Cryogel

The opposite of pyrogel, an aerogel blanket designed to withstand extremely low temperatures. Its max temperature is only 125°C, but its focus is on lower temperatures and is therefore suited to be used in sub-ambient, cold cycling and cryogenic uses. The blanket is covered with a vapor retarder. Pyrogel has a flame spread index value of ≤ 25 and smoke developed index value of ≤ 50 . (Values according to ASTM – E84 International standard, no European standard available.)

Cryogel	
Thermal Conductivity λ	0.017 W/mK
Water vapour permeability μ	-
Density	160kg/m³
Fire rating classification	-
Combustibility	-
Compressive strength	35 kPa

Figure 10. Table of properties of Spacetherm insulation blanket[38]

5.1.6 Wraptherm

Wraptherm differs from the other blankets, as its focus is to improve airtightness levels. It is applied to the internal face of the façade to provide a vapor neutral and airtight layer. Wraptherm consists of an airtight membrane and a 10mm thick Spacetherm blanket. It comes in 1200mm wide panels, either 2400mm or 1200mm high.[39]

[37] Flexible Aerogel Insulation for Industrial Applications, 2020
[38] Flexible Aerogel Insulation for Sub-Ambient and Cryogenic Applications,2020
[39] Wraptherm Thermal insulation Data sheet, February 2019

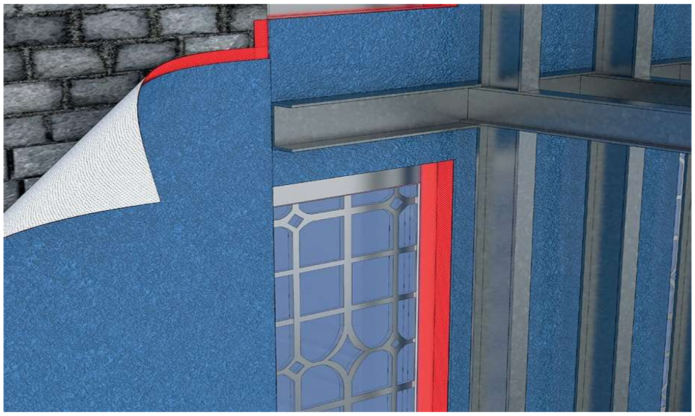

Figure 11. Wraptherm applied on a wall[40]

Wraptherm	
Thermal Conductivity λ	0.015 W/mK
Water vapour permeability μ	8.806
Density	150kg/m³
Fire rating classification	C
Combustibility	s1,d0

Figure 12. Table of properties of Wraptherm insulation blanket[41]

5.2 Aerogel Insulation Panels

Spacetherm has a couple of insulation panels that combines the insulation material with a treated surface ready to be finished. These are applied the same way as ordinary dry wall or plywood boards. They are thicker than the usual wall board, as there is the layer of aerogel insulation, as well as a panel on the surface. There are options with a plywood board between the insulation and the drywall that helps with the panel fix to the wall better. The usual measurements are 1200mm by 2400mm. The products are CE marked and has European Technical Approval.

[40] proctorgroup.com, New Product - Wraptherm
[41] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

5.2.1 Spacetherm Wallboard

Spacetherm has a couple of these panels, the simplest being the Spacetherm Wallboard. It consists only of two layers; a spacetherm aerogel blanket and a drywall board. It can be installed either directly fixed onto the wall or using straps. The standard version available has a foil faced drywall to help reduce condensation. This can be removed if requested. The thickness of the aerogel can vary anywhere from 5mm to 20mm with 5mm intervals. The drywall reaches a fire rating classification of A2, but the aerogel only reaches class C.[42]

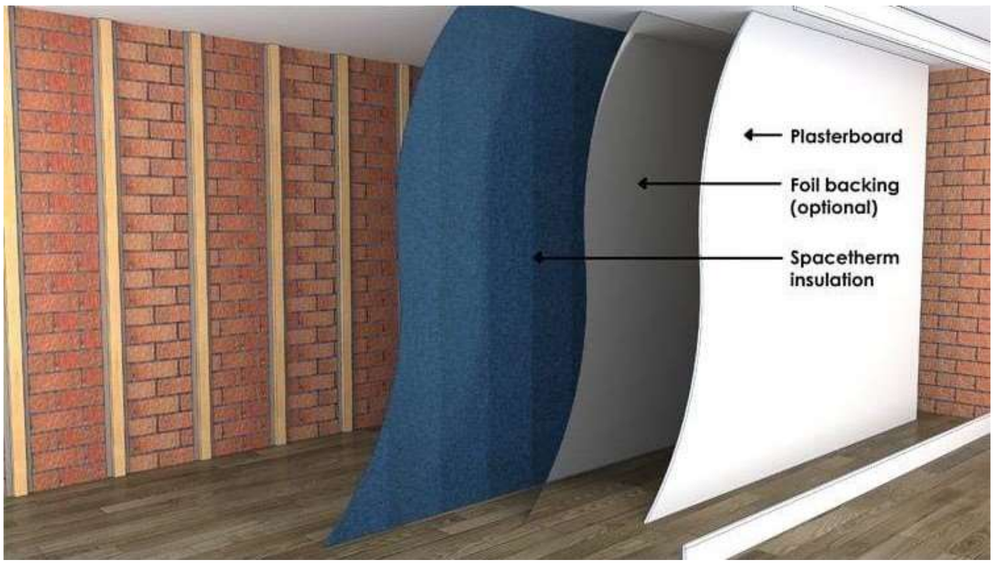

Figure 13. Spacetherm Wallboard broken up into layers[43]

Spacetherm Wallboard		Spacetherm A2 Wallboard	
Aerogel		**Aerogel**	
Thermal Conductivity λ	0.015 W/mK	Thermal Conductivity λ	0.019 W/mK
Water vapour permeability μ	5	Water vapour permeability μ	5
Density	150kg/m³	Density	200kg/m³
Fire rating classification	C	Fire rating classification	A2
Combustibility	s1, d0	Combustibility	s1, d0
Drywall		**Drywall**	
Thermal Conductivity λ	0.19 W/mK	Thermal Conductivity λ	0.19 W/mK
Fire rating classification	A2	Fire rating classification	A2
Combustibility	s1, d0	Combustibility	s1, d0

Figure 14. Table of properties of Spacetherm Wallboard insulation panel[44]

[42] Spacetherm Wallboard Data sheet, December 2020
[43] Spacetherm Wallboard Data sheet, December 2020
[44] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

5.2.2 Spacetherm Directfix

Spacetherm Directfix is like the Spacetherm Wallboard and consists of an aerogel layer and a drywall layer but adds a layer of plywood in between to help reinforce the connection between the wall and the panel. It can be directly fixed to existing walls. It has a vapour control layer built into the panel. It comes as a 1200mm by 2400mm panel and the aerogel insulation can vary from 5mm to 20mm with 5mm intervals. The aerogel blanket reaches a fire rating classification of C, while the drywall reaches A2. The plywood only reaches class D.[45]

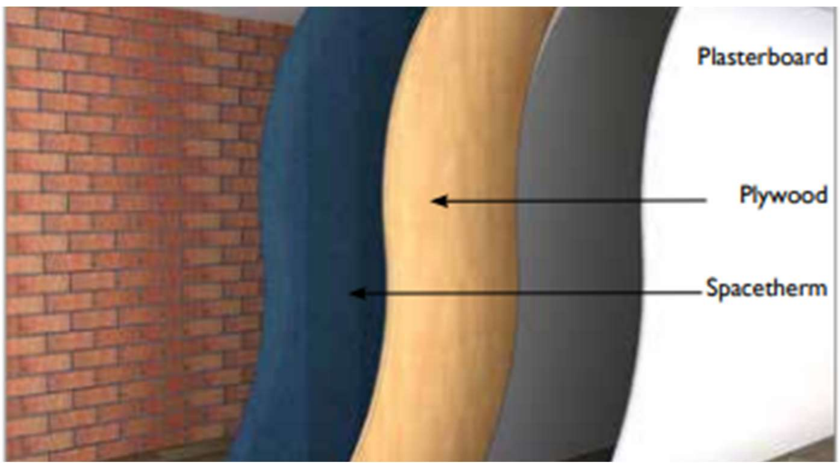

Figure 15. Spacetherm Directfix broken up into layers[46]

Spacetherm Directfix		Spacetherm A2 Directfix	
Aerogel		**Aerogel**	
Thermal Conductivity λ	0.015 W/mK	Thermal Conductivity λ	0.019 W/mK
Water vapour permeability μ	5	Water vapour permeability μ	5
Density	150kg/m³	Density	200kg/m³
Fire rating classification	C	Fire rating classification	A2
Combustibility	s1,d0	Combustibility	s1,d0
Drywall		**Drywall**	
Thermal Conductivity λ	0.19 W/mK	Thermal Conductivity λ	0.19 W/mK
Fire rating classification	A2	Fire rating classification	A2
Combustibility	s1,d0	Combustibility	s1,d0
Plywood		**Plywood**	
Thermal Conductivity λ	0.13 W/mK	Thermal Conductivity λ	0.13 W/mK
Fire rating classification	D	Fire rating classification	D
Combustibility	s2,d0	Combustibility	s2,d0

Figure 16. Table of properties of Spacetherm Directfix insulation panel[47]

[45] Spacetherm Directfix Data sheet, December 2020
[46] Spacetherm Directfix Data sheet, December 2020
[47] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

5.2.3 Spacetherm Multi

Spacetherm multi is a panel that works for both walls and floors. It is made to be fixed immediately onto the existing layers to provide extra insulation. It consists of a magnesium oxide (MgO) board as the outer layer and a spacetherm blanket for insulation. The smaller panels are good for cramped spaces, such as lofts, where the big panels can be hard to handle. The panels come in size 1200mm by 600mm and 2400mm by 1200mm. The thickness of the insulation can vary from 5mm to 40mm, with larger thicknesses being able to order if needed. The aerogel blanket reaches a fire rating classification of C, but the MgO board reaches class A1.[48]

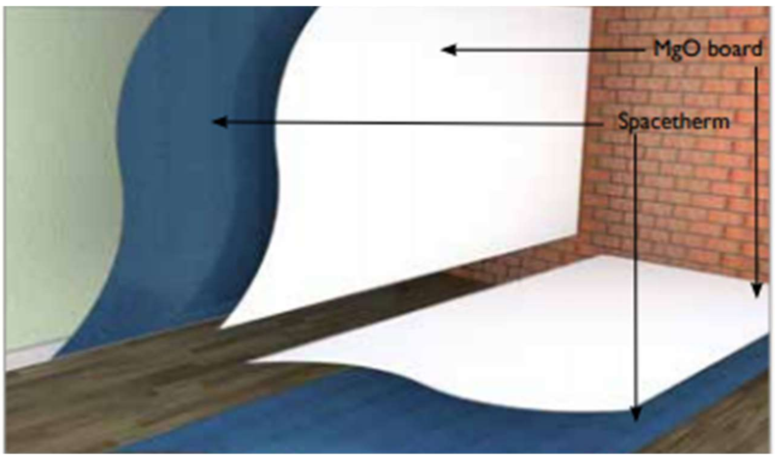

Figure 17. Spacetherm Multi broken into layers[49]

Spacetherm Multi		Spacetherm A2 Multi	
Aerogel		**Aerogel**	
Thermal Conductivity λ	0.015 W/mK	Thermal Conductivity λ	0.019 W/mK
Water vapour permeability µ	5	Water vapour permeability µ	5
Density	150kg/m³	Density	200kg/m³
Fire rating classification	C	Fire rating classification	A2
Combustibility	s1,d0	Combustibility	s1,d0
Magnesium oxide board		**Magnesium oxide board**	
Thermal Conductivity λ	0.19 W/mK	Thermal Conductivity λ	0.19 W/mK
Fire rating classification	A1	Fire rating classification	A1
Combustibility	s1,d0	Combustibility	s1,d0

Figure 18. Table of properties of Spacetherm Multi insulation panel[50]

[48] Spacetherm Multi For Walls Data Sheet, December 2020
[49] Spacetherm Multi For Walls Data Sheet, December 2020
[50] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

5.2.4 Spacetherm WL

Spacetehrm WL (Wall Liner) is like Spacetherm Multi but made to be fixed onto wall with only adhesives. It limits the board to only have a 10mm layer of aerogel insulation but with the 3mm MgO board gives the panels only add a 13mm extra thickness to the existing walls. The MgO surface can be easily be treated with a paint or coating to create a finished surface. The panels come as 1200mm by 600mm and has a weight of 5kg. Fire rating classifications are the same as for Spacetherm Multi, C for the aerogel blanket and A1 for the MgO board.[51]

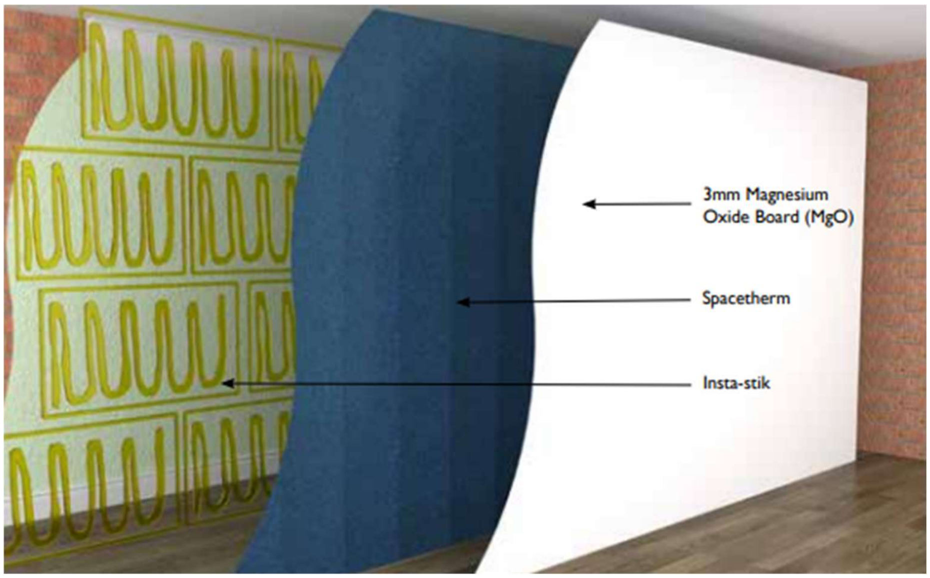

Figure 19. Spacetherm WL broken into layers with adheasive[52]

Spacetherm WL		Spacetherm A2 WL	
Aerogel		**Aerogel**	
Thermal Conductivity λ	0.015 W/mK	Thermal Conductivity λ	0.019 W/mK
Water vapour permeability μ	5	Water vapour permeability μ	5
Density	150kg/m³	Density	200kg/m³
Fire rating classification	C	Fire rating classification	A2
Combustibility	s1,d0	Combustibility	s1,d0
Magnesium oxide board		**Magnesium oxide board**	
Thermal Conductivity λ	0.19 W/mK	Thermal Conductivity λ	0.19 W/mK
Fire rating classification	A1	Fire rating classification	A1

Figure 20. Table of properties of Spacetherm WL insulation panel[53]

[51] Spacetherm WL Ultra-thin Advanced Aerogel Insulation for Solid Walls, March 2019
[52] Spacetherm WL Ultra-thin Advanced Aerogel Insulation for Solid Walls, March 2019
[53] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

5.2.5 Spacetherm A2 product range

Spacetherm as a range of A2 insulation products. These get their name from the SLENTEX Aerogel blanket, as its fire rating classification reaches A2. There are A2 versions of Spacetherm Multi, Directfix and Wallboard, simply named Spacetherm A2 Multi, Spacetherm A2 Directfix and Spacetherm A2 Wallboard. The general Idea is to increase the fire rating at the cost of a little bit of thermal insulation. The A2 range also has thicker insulation options. [54]

5.3 Detailed Insulation

There are also products that aim at more specific uses. Some examples would be cold bridge insulation or window reveal insulation. Cold bridge insulation strips help with improving insulation where cold bridging is an issue such as frame structures. Window reveal insulation is needed if you decide to put extra insulation in your home, as cold temperatures can escape from the window reveals and cause condensation if the rest of the walls are insulated.

5.3.1 Spacetherm Cold Bridge Strip

Figure 21. Spacetherm Cold bridge strip[55]

Spacetherm Cold bridge strip (CBS) can be applied to steel or wooden frame structure to prevent cold bridging through the element. Spacetherm CBS has adhesives already applied

[54] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020
[55] Spacetherm Cold Bridge Strip Data Sheet, December 2020

under a protective paper. It is easy to cut with either a knife or scissors, but the cut end should be sealed up with tape. It comes in 10mm or 20mm thickness and ranges from 38mm to 100mm in width and 1200mm or 2400mm in length. Fire rating classification is C.[56]

Spacetherm CBS	
Thermal Conductivity λ	0.015 W/mK
Water vapour permeability μ	5
Density	150kg/m³
Fire class	C
Combustibility	s1, d0

Figure 22. Table of properties of Spacetherm Directfix insulation panel[57]

5.3.2 Spacetherm Window Reveal Board

The Spacetherm Window Reveal Board is an aerogel insulation panel for the window reveals to help complete the refurbishment and create a solid layer of extra insulation. It consists of an aerogel blanket, either Spacetherm SLENTEX A2 or Spacetherm Aerogel blanket, and a board, either drywall or MgO. It is also possible to add a layer of plywood if needed to reinforce the panel to the wall. Adhesives or conventional fixture methods work to fix the panel to the window reveal. Thickness goes as low as 5mm and depending on the material reaches either 20mm or 40mm. Fire rating classification is C for aerogel blanket, Class A2 for SLENTEX and the drywall, A1 for the MgO board and D for the plywood.[58]

[56] Spacetherm Cold Bridge Strip Data Sheet, December 2020
[57] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020
[58] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

Figure 23. Spacetherm Window Reveal Board[59]

6 Aerogel Compared to other Insulation Materials

Collecting data from different aerogel insulation manufacturers and other insulation manufacturers gives a fine understanding of the properties and abilities of what aerogel insulation can do. The data collected is put here in spreadsheets to easily compare it with other insulation material that are commonly used in constructions. All data are from 2020 and from products already out on the market. The data may change in the future.

Prices are taken from distributors of the materials either in Finland or from international distributors and tax is included in the cost mentioned. They may vary depending on other products. Prices are taken of the available thickness and may therefor vary in price per volume between the different materials.

The carbon emission values describe the kg of CO_2 emissions is created with 1kg of the product, from the production stage (A1 to A3) in the products life. The emission values may vary as they differ from product and company.

6.1 Aerogel Insulations

In the previous chapter addressing the different kind of insulation solutions there was also mentioned the different products properties. The main difference is between SLENTEX products and other aerogel blankets as SLENTEX was manufactured to increase the fire

[59] Spacetherm Solutions Spacetherm SLENTEX A2 and Spacetherm Aerogel Insulation (For Building & Construction), November 2020

rating classification of aerogel blankets but in the process increased the thermal conductivity by a little bit.

	SLENTEX	Aerogel Blanket
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK
Water vapour permeability µ	5	5
Density	200kg/m³	150kg/m³
Fire rating classification	A2	C
Combustibility	s1,d0	s1,d0
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg
Cost		50-70€/m²

Figure 24. Comparison of SLENTEX and Aerogel blanket insulation

The tables show that SLENTEX has a better Fire rating classification than an ordinary aerogel blanket, as SLENTEX reaches Class A2 compared to only Class C. However, SLENTEX is 50kg/m³ denser than the aerogel blanket and only reach a thermal conductivity of 0.019 W/mK, which is good compared to other insulation material, but worse than the aerogel blanket that manages to reach 0.015 W/mK

These two will be the insulations that are used to compare to other insulation materials, as they are the most widely available aerogel-based insulation materials.

6.2 Mineral Wool

Mineral wool is one of the most popular choses when it comes to insulation. It is cheap, easy to use and has been on the market for a long time. Most constructors are familiar with it and know how to handle it well. It has good insulation properties and are a clear contender on the market. The price is only 9€/m² for a thickness of 100mm. The product is CE-marked (NPD means No Performance Declared, as seen in Figure 25.)

	SLENTEX	Aerogel Blanket	Paroc eXtra[60]
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK	0.036 W/mK
Water vapour permeability µ	5	5	NPD
Density	200kg/m³	150kg/m³	25-90kg/m³
Fire rating classification	A2	C	A1
Combustibility	s1,d0	s1,d0	Non-combustible
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg	1,5 kg CO_2e/kg
Cost		50-70€/m²	9€/m²

Figure 25. Comparison of SLENTEX, Aerogel blanket and Mineral wool insulation

[60] Paroc.fi, PAROC FPS 8a

6.3 XPS-Insulation

Extruded polystyrene insulation or XPS-Insulation is a hard foam insulation. Finnfoam has a large range of products and is considered one of the leading brands in Finland and have branched themselves outside of the Nordic countries. Their insulation panels are used in a lot of constructions, as they are easy to use and widely available. The cost is 17€/m² for a thickness of 100mm. The products are CE-marked.

	SLENTEX	Aerogel Blanket	FinnFoam FI-300[61]
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK	0.037 W/mK
Water vapour permeability μ	5	5	NPD
Density	200kg/m³	150kg/m³	32kg/m³
Fire rating classification	A2	C	F
Combustibility	s1,d0	s1,d0	-
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg	2,6 kg CO_2e/kg
Cost		50-70€/m²	17€/m²

Figure 26. Comparison of SLENTEX, Aerogel blanket and Finnfoam insulation

6.4 PIR-Insulation

PIR insulation is a polyurethane board usually with an aluminium laminate to stop diffusion on both sides of the material. Kingspan is an Irish manufacturer but have had a factory in Finland since 2015. Their Therma series focuses on construction elements and have specific sizes and products for each element of the construction. Prices change depending on thickness, but a 40mm thick board costs 24€/m². Their products are CE marked.

	SLENTEX	Aerogel Blanket	Kingspan Therma[62]
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK	0.022 W/mK
Water vapour permeability μ	5	5	NPD
Density	200kg/m³	150kg/m³	32-38kg/m³
Fire rating classification	A2	C	E
Combustibility	s1,d0	s1,d0	NPD
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg	4,2 kg CO_2e/kg
Cost		50-70€/m²	24€/m²

Figure 27. Comparison of SLENTEX, Aerogel blanket and PIR insulation

[61] Finnfoam.fi, Declaration of Performance, Nro 002-FF-2016-01-04
[62] Kingspan.fi, Therma-eristeet

6.5 Phenolic Insulation Board

Phenolic insulation boards are made from plastic foam between two flexible facing layers. It gets its insulation properties from small air bubbles in the material. Kingspan Kooltherm is one example of phenolic insulation boards. The product reaches a lower λ-value then PIR insulation. The cost is higher, a 100mm thick board costs around 67€/m². The product is CE-marked.

	SLENTEX	Aerogel Blanket	Kingspan Kooltherm[63]
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK	0.020 W/mK
Water vapour permeability μ	5	5	NPD
Density	200kg/m³	150kg/m³	35kg/m³
Fire rating classification	A2	C	C
Combustibility	s1,d0	s1,d0	S1,d0
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg	4,6 kg CO_2e/kg
Cost		50-70€/m²	67/m²

Figure 28. Comparison of SLENTEX, Aerogel blanket and phenolic insulation board

6.6 Vacuum Insulation

Vacuum insulation is designed to use the vacuum as a thermal insulator, letting the insulation system reach incredibly low λ-values, up to five times that of traditional insulation materials. Kingspan has a product in this range, OPTIM-R. Its thickness can vary from 20 mm up to 50mm. The product cannot be cut to specific sizes. The price is around 100€/m² for a board with a thickness of 20mm. The product is CE marked.

	SLENTEX	Aerogel Blanket	Vacuum insulation[64]
Thermal Conductivity λ	0.019 W/mK	0.015 W/mK	0.007 W/mK
Water vapour permeability μ	5	5	NPD
Density	200kg/m³	150kg/m³	180-220kg/m³
Fire rating classification	A2	C	E
Combustibility	s1,d0	s1,d0	NPD
Carbon emission	12,8 kg CO_2e/kg	12,3 kg CO_2e/kg	42,2 kg CO_2e/kg
Cost		50-70€/m²	100€/m²

Figure 29. Comparison of SLENTEX, Aerogel blanket and vacuum insulation

[63] Kingspan.fi, Kooltherm-eristeet
[64] Kingspan.fi, OPTIM-R Tyhjiöeriste

7 Design types with Aerogel

When talking about constructions with aerogel insulation as the main insulator, there are two alternatives that must be taken into consideration; If the U-value should be kept to the standards and the thickness of the wall reduced, or the thickness kept the same or close to the same as other insulation materials but reduce the U-value. The general idea is that aerogel insulation reduces the thickness of the needed insulation by half since the thermal conductivity of aerogel insulation is roughly half of that of the usual insulation options. It is also important to consider aerogel as extra insulation to already existing buildings, as that is what the market is mostly aimed at.

By keeping the U-value standards set by the government we can reduce the thickness of the needed insulation by half, which means we can get a thinner construction and over dimensioned walls could become closer to a more efficient value. By keeping the thickness, we could, however, reach a U-value under 0.1, which would be highly beneficial for a smarter building, as the energy required for heating and cooling could be reduced by about 40%.[65]

Since most conventional insulations have a higher thermal conductivity then aerogel insulation, they can be calculated together with the wood as an inhomogeneous layer. But due to the difference in thermal conductivity between wood and aerogel insulation being so high (wood being more than five times as conductive as Aerogel insulation), wood must be counted as a cold bridge in the construction.

The design types are made to focus on the thermal resistance and insulation properties of the wall; therefore, the water vapor permeability of the whole wall is not considered. Especially in refurbishment projects this needs to be considered.

The λ- value of other construction parts are either from previously stated material or stated otherwise. Formulas for calculating the U-value come from SFS-EN 6946.

[65] cordis.europa.eu, Keeping warm with aerogel

7.1 Wall Construction

For walls, the main idea is that the insulation needed can be reduced. Since a lot of walls are over dimensioned due to the insulation need, there is a possibility to reduce the thickness of the wall by changing the main insulation to one with a lower thermal conductivity, in this case aerogel insulation.

The layers of Figure 31 beginning from the outside:

1. Façade plaster ~8mm
2. Concrete 80mm
3. Insulating layer 150mm
4. Vapor barrier
5. Concrete 120mm

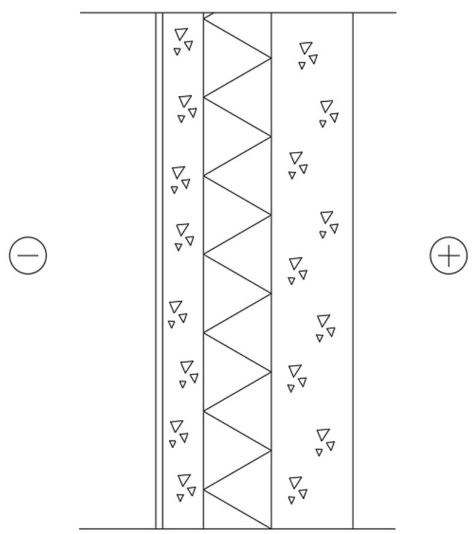

Figure 31. Example of a sandwich element construction[66]

[66] vicover.fi, US201

Figure 31	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,011
Concrete	2,5	0,08	0,03
Mineral Wool	0,036	0,15	4,17
Vapor barrier			0,02
Concrete	2,5	0,12	0,05
Rsi			0,13
		R total:	4,45
		U-value	0,22 $W/(m^2K)$

Figure 32. Thermal resistance calculations of Figure 31

7.1.1 Keeping the Thermal Resistance

When keeping the thermal resistance requirements set by the government we want to come as close to the value they propose. In the case of the exterior walls with a warm, partially warm, or cooled space in Finland, the U value is set at 0.17 W/(m²K). In the case of massive timber walls (with an average thickness of at least 180mm) the value is 0.40 W/(m²K). [67]

Figure 31	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
Concrete	2,5	0,08	0,03
Aerogel Blanket	0,015	0,065	4,00
Vapor barrier			0,02
Concrete	2,5	0,12	0,05
Rsi			0,13
		R total:	4,61
		U-value	0,22 $W/(m^2K)$

Figure 33. Thermal resistance calculations of Figure 31 with Aerogel blanket as insulation

Figure 33 show the concrete sandwich element but with aerogel blanket insulation instead of the Mineral wool used in Figure 31. By reducing the thermal conductivity of the insulation to 0.015 W/mK we managed to reduce the thickness of the insulation needed by over 50%. The total thickness of the wall would end up at around 275mm thick, reducing the overall thickness by 21%.

[67] Ympäristöministeriön asetus uuden rakennuksen energiatehokkuudesta,24§

Figure 31	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
Concrete	2,5	0,08	0,03
SLENTEX	0,019	0,08	3,95
Vapor barrier			0,02
Concrete	2,5	0,12	0,05
Rsi			0,13
		R total:	4,49
		U-value	0,22 $W/(m^2K)$

Figure 34. Thermal resistance calculations of Figure 31 with SLENTEX as insulation

When using SLENTEX in the same way as in the previous scenario, we only reduce the thermal conductivity to 0.019 W/mK, and therefore only manage to reduce the thickness of the insulation by a little over 45%. The overall thickness is reduced by roughly 20%.

7.1.2 Optimizing Insulation

When optimizing insulation, we want to use as much insulation as possible to improve the insulation properties of the construction. To have some sort of limit, we will only use as much thickness as the original construction had. This helps understand what thermal resistances we would be able to achieve with similar building methods and sizes.

Figure 31	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
Concrete	2,5	0,08	0,02
Aerogel blanket	0,015	0,15	10,00
Vapor barrier			0,02
Concrete	2,5	0,12	0,05
Rsi			0,13
		R total:	10,28
		U-value	0,010 $W/(m^2K)$

Figure 35. Thermal resistance calculations of Figure 31 with Aerogel blanket as insulation

We see that by reducing the thermal conductivity by over 50% the U-value decreases to 0.1 W/(m²K). This is under the requirement set by the government but can be useful in projects planning on being energy efficient, such as passive houses.

Figure 31	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
Concrete	2,5	0,08	0,02
SLENTEX	0,019	0,15	7,89
Vapor barrier			0,02
Concrete	2,5	0,12	0,05
Rsi			0,13
		R total:	8,18
		U-value	0,12 $W/(m^2K)$

Figure 36. Thermal resistance calculations of Figure 31 with SLENTEX as insulation

By choosing SLENTEX instead Aerogel blankets there is not much difference in the result. The lower the U-value we achieve, the more insulation we need to reach the next step. These constructions designs are only theoretical.

7.1.3 Extra insulation

Aerogel as extra insulation is where it currently is most used. A lot of the products are marketed towards refurbishment projects to improve the thermal resistance and save as much space as possible. Using a panel or aerogel blanket as extra insulation on either the outside or inside of the construction will greatly improve the U-value. Log walls, brick walls and other older constructions can benefit from having a layer of aerogel insulation on either the interior or exterior side, or both if there is a need for it. In Finland there is almost always necessary to add extra insulation on the exterior of the construction, as a layer on the interior wall adds a high risk of condensation within the construction.

When adding extra insulation to an already completed structure there is a need to consider the water vapour permeability of the whole part of the structure, and control if additional vapor barriers are needed.

The layers of the brick wall in Figure 37 beginning from the outside:

1. Façade plaster ~ 8mm
2. Bricks 450 mm
3. Interior plaster ~ 8mm

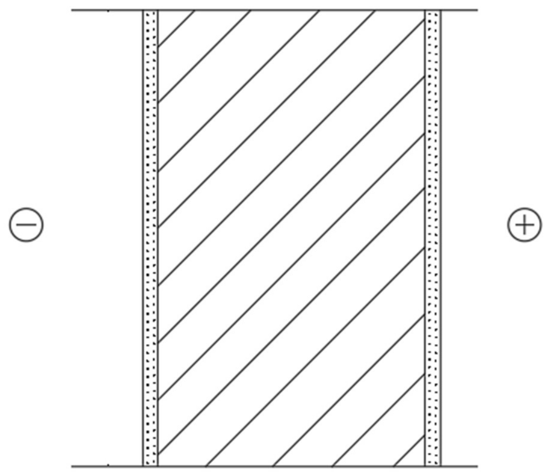

Figure 37 example of a Brick wall[68]

Figure 37	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,011428571
Bricks[69]	0,6	0,45	0,75
Interior plaster	0,7	0,008	0,011428571
Rsi			0,13
		R total:	0,94
		U-value	1,06 $W/(m^2K)$

Figure 38. Thermal resistance calculations of Figure 37

[68] vicover.fi, US101
[69] energihandbok.se, Värmeledningsförmåga och U-värden för olika material

The U-value is quite high for such a thick construction. But adding a of layers of aerogel insulation brings the value down quite substantially. In the examples below I used the thickest insulation available on demand as the extra insulation. Calculated Façade plaster would not be a possibility in Finnish environments.

Figure 37	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
Aerogel Blanket	0,015	0,02	1,33
Facade plaster	0,7	0,008	0,01
Bricks	0,6	0,45	0,75
Interior plaster	0,7	0,008	0,01
Rsi			0,13
		R total:	2,29
		U-value	0,44 $W/(m^2K)$

Figure 39. Thermal resistance calculations of Figure 37 with Aerogel Blankets as main insulation

Figure 37	λ(W/mK)	d(m)	R
Rse			0,04
Facade plaster	0,7	0,008	0,01
SLENTEX	0,019	0,04	2,11
Facade plaster	0,7	0,008	0,01
Bricks	0,6	0,45	0,75
Interior plaster	0,7	0,008	0,01
Rsi			0,13
		R total:	3,06
		U-value	0,33 $W/(m^2K)$

Figure 40. Thermal resistance calculations of Figure 37 with SLENTEX as main insulation

The SLENTEX insulation improves the insulation drastically. Due to SLENTEX being available as 40mm it has the advantage of being more thermal resistant in this case. However, aerogel blankets can also be ordered in such sizes upon request. Both insulation materials can also be ordered in sizes thicker than 40mm upon request.

7.2 Floor Construction

Aerogel is mostly useful as extra insulation in floor constructions since harder insulations help with absorbing low frequencies and vibrations from the ground. Therefore, using aerogel insulation products as an extra layer on top of the existing floor is the most useful way of implementing the material. This method however is very risky as it might create condensation into the construction. The requirement is 0.16 W/(m²K) for floors against the ground[70].

This calculation does not take into consideration any additional insulation at the edge of the floor and only for a capillary breaking layer of 200mm.

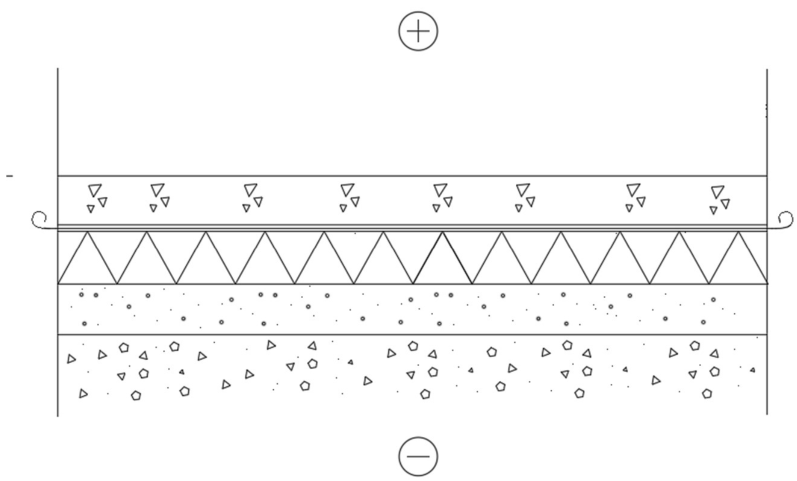

Figure 41. Example of a floor construction[71]

The layers of the floor in Figure 41 beginning from the outside:

1. Capillary breaking layer >200mm
2. Hard Insulation 100mm
3. Plastic film
4. Concrete slab 100mm

[70] Ympäristöministeriön asetus uuden rakennuksen energiatehokkuudesta, 24§
[71] vicover.fi, AP402

Figure 41	λ(W/mK)	d(m)	R
Rse			0,04
Capillary breaking layer	0,2	0,2	1
Insulation	0,033	0,1	3,03
Plastic Film			0,02
Concrete slab	2,5	0,1	0,04
Rsi			0,17
		R total:	4,30
		U-value	0,23 $W/(m^2K)$

Figure 42. Thermal resistance calculations of Figure 41

7.2.1 Extra insulation

Figure 41	λ(W/mK)	d(m)	R
Rse			0,04
Capillary breaking layer	0,2	0,2	1
Insulation	0,033	0,1	3,03
Plastic Film			0,02
Concrete slab	2,5	0,1	0,04
Aerogel Blanket	0,015	0,02	1,33
MgO panel	0,19	0,003	0,016
Rsi			0,17
		R total:	5,65
		U-value	0,18 $W/(m^2K)$

Figure 43. Thermal resistance calculations of Figure 41 with aerogel blanket panels as insulation

Figure 41	λ(W/mK)	d(m)	R
Rse			0,04
Capillary breaking layer	0,2	0,2	1
Insulation	0,033	0,1	3,03
Plastic Film			0,02
Concrete slab	2,5	0,1	0,04
SLENTEX	0,019	0,04	2,11
MgO panel	0,19	0,003	0,016
Rsi			0,17
		R total:	6,42
		U-value	0,16 $W/(m^2K)$

Figure 44. Thermal resistance calculations of Figure 41 with SLENTEX panels as insulation

By adding a layer of either Aerogel blanket or SLENTEX based panel we can improve the poorly insulated floor by a lot. Again, the thickness of the insulation is only the thickest available, but the material can be ordered at a thicker size.

7.3 Ceiling Construction

Ceiling constructions can use aerogel as the main insulation. It is important to consider the compressive strength of aerogel insulations, as they usually are not that high. When using aerogel in wooden roof constructions, it is important to remember that the thermal resistance in wood is greater than 5 times that of aerogel insulations, meaning that it acts as a cold bridge and should be counted as that when calculating the U-value. The thermal resistance requirement is 0.09 W/(m²K)[72].

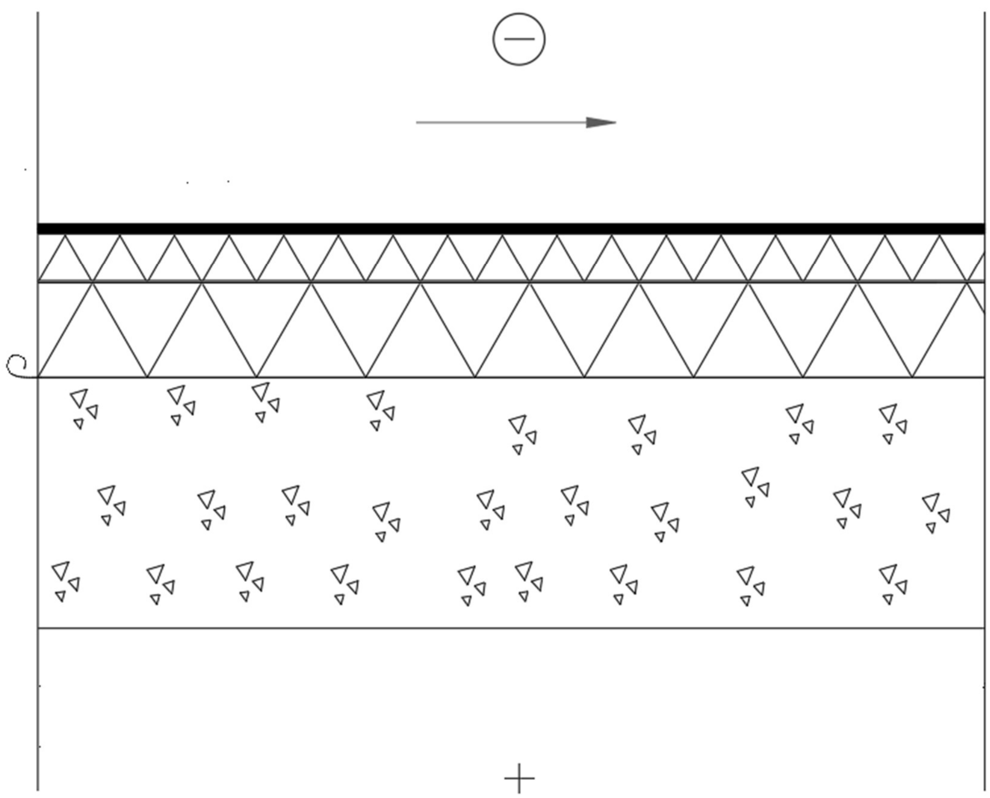

Figure 45. Example of roof construction[73]

[72] Ympäristöministeriön asetus uuden rakennuksen energiatehokkuudesta, 24§
[73] vicover.fi, YP701

The layers of the roof in Figure 45 beginning from the outside:

1. Bitumen 6mm
2. Mineral wool (with ventilation) 50mm
3. Mineral wool 150 mm
4. Vapor barrier
5. Concrete slab 200mm

Figure 45	λ(W/mK)	d(m)	R
Rse			0,04
Bitumen	0,17	0,006	0,04
Mineral wool	0,033	0,05	1,52
Mineral wool	0,033	0,15	4,55
Vapor barrier			0,02
Concrete	2,5	0,2	0,08
Rsi			0,10
		R total:	6,31
		U-value	0,16 $W/(m^2K)$

Figure 46. Thermal resistance calculations of Figure 45

7.3.1 Keeping the Thermal Resistance

The tables show the roof construction in figure 45 but with either an aerogel blanket or a SLENTEX blanket instead of the insulation. To keep the thermal resistance in the wall, we only need about half of the insulation. With an aerogel blanket we reduce the thickness of the roof by 20%, while the insulation is reduced by over 50%. SLENTEX has a slightly worse thermal resistance, but still manages to reduce the overall thickness by over 15% and the insulation thickness needed by 45%.

Figure 45	λ(W/mK)	d(m)	R
Rse			0,04
Bitumen	0,17	0,006	0,04
Mineral wool	0,033	0,05	1,52
Aerogel blanket	0,015	0,065	4,33
Vapor barrier			0,02
Concrete	2,5	0,2	0,08
Rsi			0,10
		R total:	6,10
		U-value	0,16 $W/(m^2K)$

Figure 47. Thermal resistance calculations of Figure 45 with Aerogel blanket as insulation

Figure 45	λ(W/mK)	d(m)	R
Rse			0,04
Bitumen	0,17	0,006	0,04
Mineral wool	0,033	0,05	1,52
SLENTEX	0,019	0,085	4,47
Vapor barrier			0,02
Concrete	2,5	0,2	0,08
Rsi			0,10
		R total:	6,24
		U-value	0,16 $W/(m^2K)$

Figure 48. Thermal resistance calculations of Figure 45 with SLENTEX as insulation

7.3.2 Optimizing Insulation

Keeping the thickness the same and just improving the material properties by introducing aerogel insulation instead the U value is almost halved, meaning the thermal resistance increased dramatically. Since SLENTEX has a slightly higher thermal conductivity, the U-value is slightly higher. Both insulation materials do not come in the stated thickness.

Figure 45	λ(W/mK)	d(m)	R
Rse			0,04
Bitumen	0,17	0,006	0,04
Mineral wool	0,033	0,05	1,52
Aerogel blanket	0,015	0,15	10,00
Vapor barrier			0,02
Concrete	2,5	0,2	0,08
Rsi			0,10
		R total:	11,76
		U-value	0,09 $W/(m^2K)$

Figure 49. Thermal resistance calculations of Figure 45 with Aerogel blanket as insulation

Figure 45	λ(W/mK)	d(m)	R
Rse			0,04
Bitumen	0,17	0,006	0,04
Mineral wool	0,033	0,05	1,52
SLENTEX	0,019	0,15	7,89
Vapor barrier			0,02
Concrete	2,5	0,2	0,08
Rsi			0,10
		R total:	9,66
		U-value	0,10 $W/(m^2K)$

Figure 50. Thermal resistance calculations of Figure 45 with SLENTEX panels as insulation

8 Conclusion

Aerogel insulation is probably one of the best insulation materials that we can expect to have in the foreseeable future, since raw aerogel is the best thermal insulator we have. Still, there are many other materials that can offer insulation as good as aerogel, such as PIR-insulation and vacuum insulation. But aerogel insulation should not be ignored because of that. Other properties, such as the fire rating classification of A2 is something that is remarkable of aerogel insulation, as well as the surprise of a somewhat high compressive strength of SLENTEX. The environmental impact is still high but has the possibility to be significantly reduced in the future.

But we should still consider aerogel insulation in a lot of projects. In refurbishment of old buildings aerogel blankets should be one of the first alternatives to preserve details and space, due to its malleable capabilities. In passive and zero-energy houses aerogel insulation should be considered as an option to improve the energy efficiency as well as reduce emissions.

It is also important to remember the water vapour permeability and how a layer of extra aerogel insulation would affect the water vapour permeability in refurbishment projects.

The market has opened for new aerogel insulation products and these products have started to sell. The innovation shows that there are companies putting time and effort into producing serious insulation solutions that should be considered just as much as other insulation materials.

However, aerogel insulation can reach up to 25 times the cost of other common insulation materials per square meter of construction. There are solutions on their way to reduce the cost drastically and the future for the material should not be overlooked just because the production manufacturing is expensive right now. Using aerogel in construction details can be cost efficient, but at present there are other available options that are more cost efficient to use as main insulation.

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