BYGT2900 Bachelor's Thesis Construction

Translucent aerogel solar walls as a façade material of the future: an environmental impact and energy-efficiency assessment

Translusente aerogel solvegger som et fasademateriale for fremtiden sett i et energi- og miljøperspektiv

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Project description and goals

The building industry is constantly adjusting regulations to increase the energy efficiency of buildings, which will also result in more powerful structures. Because of the extremely low heat conductivity of aerogel, the translucent solar walls have great potential in the construction industry. Using aerogel as a façade material enables slimmer building envelopes, reduced energy demands, and possibly improved lighting. Thus, the thesis will evaluate the performance of translucent aerogel solar walls to determine if they could be the façade material of the future.

Previous research surrounding the properties of solar walls is evaluated. This includes parameters such as thermal conductivity, acoustic properties, light transmittance, and energy saving potential.

To compare the use of translucent aerogel solar walls with conventional façade materials, the building simulation software IDA ICE (IDA Indoor Climate and Energy) is used to simulate an industrial building model, provided by AFRY Consult AS. The digital model has been used as a reference building to evaluate the effects of implementing translucent aerogel solar walls into the construction of a building.

Additionally, a life cycle assessment (LCA) of the solar walls has been performed, giving an indication of the system's environmental impact. By varying the system's parameters, it'll be easier to determine where the greenhouse gas emissions may be reduced, whilst maintaining adequate system performance. Finally, the results of the new system were compared to existing work, in order to fully determine the potential and practicality of translucent aerogel solar walls.

Keywords:

Aerogel, solar wall, energy-efficiency, energy simulation, life cycle assessment, LCA, environment.

Preface

This bachelor's thesis is dealing with the energy and environmental perspective of translucent aerogel solar walls, and is written as a scientific article which is submitted to *Building and Environment*. It was carried out spring 2022 within the specialization House Building Technique, and concludes my three years of study at the Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU). The thesis has been written in collaboration with AFRY Consult AS.

Throughout my three years of study, I've gained a great interest in sustainable engineering. I wanted to learn something new and useful, not to mention deliver a thesis valuable for the research community. I did not know anything about aerogel from before, and there was a lot to familiarize myself with. By working on this thesis, I got to learn a new simulation software and acquire a deeper understanding of life cycle assessments.

Firstly, I would like to express my gratitude to my internal supervisor Bjørn Petter Jelle at the University of Science and Technology for all his guidance, teaching and encouragement throughout my work. I also would like to thank my external supervisor Jon Aaleskjær from AFRY Consult AS for providing me with a digital model and continually support. You both made every meeting so much more interesting and fun, and I thank you for that.

Special thanks to Mohamed Hamdy for his help with the energy simulations, and Rolf André Bohne for his help with the life cycle analyses. It has been really helpful, and I could not have done it without the help from all of you. I would also like to thank everyone else that helped me, both professors and friends.

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Abstract

This study focuses on the energy and environmental perspective of aerogels and translucent aerogel solar walls. A brief introduction to the material is given, followed by the thermal, optical and acoustic properties of the solar walls. Environmental perspectives are discussed before energy building simulations are carried out for a given reference building where windows are replaced with aerogel solar walls. The energy results demonstrate the effects provided by implementing the aerogel product to the building. Thereafter, a life cycle assessment is executed on aerogel and the aerogel solar wall. The influence of recycling, transport, emission intensity of the energy and material composition are investigated in relation to their overall impact on the emissions. Finally, results from the energy simulations and life cycle assessment are linked to each other in order to evaluate the potential of the solar walls for future utilization with respect to current requirements and ideals.

Sammendrag

Oppgaven fokuserer på energi- og miljøperspektivet av aerogel og translusente aerogel solvegger. Det blir gitt en kort introduksjon til materialet, etterfulgt av solveggenes termiske, optiske, brann og akustiske egenskaper. Miljøperspektiver blir også først diskutert vagt, før det videre gjøres en energisimulering av et gitt referansebygg i Fredrikstad hvor vinduer skiftes ut med aerogel solvegger. Ved å se på energiresultatene ser man effekten av å implementere produktet i bygget. Deretter gjøres det en livsløpsanalyse av aerogel og aerogel solvegger. Her ses det på hvor mye resirkulering, transport, energiintensitet og materialsammensetning kan påvirke panelets totale utslipp. Til slutt kobles resultatene opp mot hverandre for å se om materialet kan være et fremtidsmateriale, sett i lys av dagens krav og idealer.

Table of contents

List of Figures

List of Tables

Translucent aerogel solar walls as a façade material of the future: an environmental impact and energy-efficiency assessment

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Abstract

This study focuses on the energy and environmental perspective of aerogels and translucent aerogel solar walls. A brief introduction to the material is given, followed by the thermal, optical and acoustic properties of the solar walls. Environmental perspectives are discussed before energy building simulations are carried out for a given reference building where windows are replaced with aerogel solar walls. The energy results demonstrate the effects provided by implementing the aerogel product to the building. Thereafter, a life cycle assessment is executed on aerogel and the aerogel solar wall. The influence of recycling, transport, emission intensity of the energy and material composition is investigated in relation to their overall impact on the emissions. Finally, results from the energy simulations and life cycle assessment are linked to each other in order to evaluate the potential of the solar walls for future utilization with respect to current requirements and ideals.

Keywords: Aerogel, solar wall, energy-efficiency, energy simulation, life cycle assessment, LCA, environment.

1. Introduction

The global construction and property sector is constantly growing and will continue to do so because of the population growth. Today the sector stands for about 40% of global greenhouse gas emissions, and it is therefore crucial to find more sustainable and energy efficient solutions if we want to reduce the emissions [1].

A number of innovative thermal insulation technologies have been developed throughout the years as the energy demand continues to grow. For the new insulations to be sustainable, we need to find a balance between performance, thickness, costs, and climate impacts. It is essential that the life cycle does not overshadow the benefits so that we get a sustainable solution that is also beneficial for the society in an economical and feasible way. Aerogel is not a new material, but due to its high costs, implementing the material in the building industry has proven to be rather challenging. Today however, due to new technological developments that are driving the costs down, the use of aerogel in insulation materials has increased [2].

Aerogel may be used in several different types of applications, which includes mainly opaque, translucent or transparent products. The article focuses on translucent aerogel glazings, or solar walls as referred to in this article, built up by a grid core filled with silica aerogel granules between two sheets of fiberglass reinforced polymer faces.

The application of aerogel glazings can possibly reduce the energy consumption of a building through its unique thermal and optical properties, although there is limited with public information about this field. Thus, the aim of this study is to investigate the potential of reducing artificial lighting by implementing translucent aerogel glazings in buildings, whilst also reducing the need for heating and cooling, in addition to addressing the environmental aspects.

To investigate if the energy consumption may be reduced, an energy simulation has been performed using a building energy simulation software. Note that the following analyzes are limited to a reference building in Norway. It does not take in account parameters like different climates or how higher amounts of aerogel glazings can affect the energy results of the building. For the environmental aspect, an LCA of the glazings has been performed. Due to limited access of data and time constraints only the production and transportation of the product is included. Conclusions are based on these premises, and are hence meant to be interpreted as an indicator of the value of aerogel glazings.

2. Building envelope

A building envelope is everything that physically separates the exterior environment and internal building, including the roof, foundation, external walls, windows and doors [3]. The function of the building envelope is to protect the interior space from the outdoor climate (e.g., rain, wind, temperature, and humidity). Thus, the building envelope plays a major role in a building's energy efficiency [3].

Windows are responsible for a heat gain and loss on approximately 25 - 30 % of the residential heating and cooling energy use [4]. Additionally, windows play an important role on the indoor climate regarding comfort. Aerogel is a promising material that may be used in translucent building applications such as aerogel solar walls, and reduce the utilization of windows in buildings. The solar walls give a full spectrum diffused light, which reduces contrasts from regular windows [5].

Consequently, the study focuses on the energy and environmental perspective of silica aerogel used in building applications such as aerogel solar walls.

3. Silica aerogel

Silica aerogel, or usually just referred to as aerogel, is a synthetic and extremely porous material that is also said to be one of the most effective insulating materials in the world [6].

Aerogels are made by extracting the liquid from a silica gel in a way that still preserves most of the framework's pore structure [7]. By doing this, in the most extreme cases aerogels can end up consisting of 99.8 % air contained in pores smaller than 50 nm. Depending on one's needs, aerogel may be produced in a granular, powdered, or monolithic form. However, the fragility of silica aerogels has proven to be a critical barrier for the production of monolithic silica aerogels.

Aerogel have primarily a low sound velocity (~100 m/s) and excellent fire properties [8]. Densities usually range from ~0.003 to 0.1 g cm^{-3}, depending on the porosity. Most notably, aerogel has an extremely low thermal conductivity (~0.005 - 0.02 W/(m·K)) [9].

When used for insulation applications like solar walls, normally aerogel granules are used. The particle size may vary, but changing this will however also change the optical and thermal properties of the solar walls [9]. Smaller particles usually scatter light more efficiency, and the visual light transmittance (VLT) will decrease along with the particle size of the aerogels.

The aerogel glazings in the following energy simulation and life cycle analysis uses Lumira® Translucent Aerogel LA1000 [10]. The particle size ranges from 1.2 mm to 4.0 mm, with a pore diameter around 20 nanometers. Thermal conductivity of the particle is 0.012 W/(m·K), but with a bulk density on 68 kg/m^3 the thermal conductivity will be somewhere between 0.017 W/(m·K) and 0.022 W/(m·K) [10].

In Figure 1 you can see a comparison of required thickness (m) for a thermal transmittance (U-value) of 0.2 W/(m^2·K) for some of the most standard insulation materials in the building industry. Values for the thermal conductivity of mineral wool, EPS, XPS and PUR are taken from SINTEF Community [11], while silica aerogel is based on the given thermal conductivity of 0.017 W/(m·K).

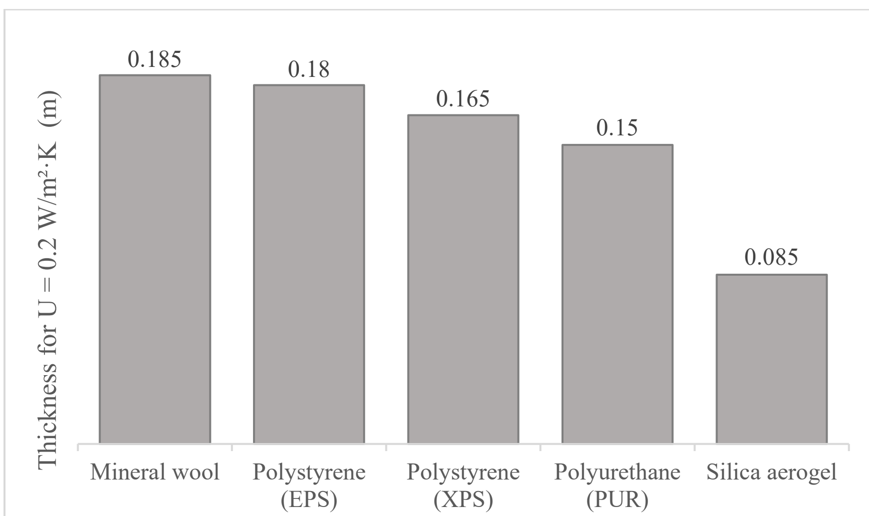


Figure 1. Comparison of thermal transmittance of some common thermal insulation materials.

4. Aerogel solar walls

Aerogel solar walls, or glazing units, usually consist of a grid system filled with silica aerogel granules which lies between two sheets of glass. It is also possible to produce the solar walls with monolithic aerogel, but this is less favorable due to the fragility and difficulty of production of monolithic aerogel in a large scale. For that reason, the focus in this study is on the former.

Unlike regular glass windows, the aerogel solar walls are not transparent. For this reason, the solar walls should be implemented on to the building in a way that does not necessarily replace all windows, so that the residents still have a view of the outdoor surroundings. However, the solar walls are not as insulating as regular walls, but as they are much thinner, they may save the building for some square meters of space.

Products from Kalwall will essentially be used. Solar walls with a thickness of 70 millimeters are selected. This gives a metric U-value of 0.28 W/(m^2·K), which equals to an imperial U-value of 0.05 Btu/(h·ft2·°F). Its performance data, taken from the manufacturer's datasheet, are summarized in Table 1 [12]. The U-values are given in an imperial unit, and only the dark gray field includes panels with aerogel as an insulation material. An explanation of the colors is given at the bottom of Table 1.

Table 1. Performance data: 70 mm glazing system from Kalwall [12].

FRP Face Sheet Combinations		**Visible Light Transmission (VLT) % by NFRC 202**					**Solar Heat Gain Coefficient @ 0° by NFRC 201**				
Exterior FRP	Interior FRP	0.53 U	0.29 | **0.23 U**	0.22 | **0.14 U**	0.18 | **0.10 U**	**0.05 U**	0.53 U	0.29 | **0.23 U**	0.22 | **0.14 U**	0.18 | **0.10 U**	**0.05 U**
Crystal	White	37%	26%	13%	7%	20%	0.44	0.30	0.15	0.09	0.27
White	White	23%	16%	9%	4%	14%	0.30	0.22	0.11	0.08	0.20
Crystal	Crystal	58%	35%	14%	9%	N/A	0.60	0.39	0.15	0.10	N/A

Air Gap Only	Fiberglass 'Batts'	Lumira® Aerogel

Kalwall is one of the biggest manufacturers of aerogel panels internationally. There are several manufacturers of silica aerogel in Europe, but no one that produces aerogel glazings.

4.1. Thermal properties

By implementing aerogel in daylighting systems, we may get a U-value as low as 0.28 $W/(m^2 \cdot K)$. The thermal performance of aerogel glazing may be tailor-made during the production process, thus increasing the aerogel layer thickness will lead to a corresponding reduction in the U-value.

The solar walls have a rather low total thermal conductivity, including a very low convection. This allows them to retain their excellent properties regardless of whether they are standing vertically, horizontally or tilted [13]. These properties makes them ideal for skylights.

4.2. Optical properties

The aerogel solar walls can bring in and scatter natural daylight in a completely different way than normal windows. Instead of getting high contrasts and “hot spots” the solar walls will diffuse daylight and solar heat. This way, less radiant heat inside the building will produce heat as a result of coming in contact with interior objects [14]. Using a normal window, this radiation would normally be converted from shortwave energy to longwave energy inside the building, i.e., heat. The longwave energy will stay inside and result in a higher demand of cooling to get rid of the excessive heat. Shortwave energy on the other hand can easily pass through the window again and exit the building [13]. This makes the aerogel solar walls favorable in use, as it will prevent the same amount of shortwave energy from being converted to longwave energy, so that most of the energy coming in to the building also can disappear without the need of electrical appliances.

The diffused light has also been documented to increase the resident’s well-being and ability to concentrate. It optimizes the visual comfort by reducing glare and make the indoor lighting more uniformly [5]. Advanced Glazings LTD has done a radiance daylighting simulation with SOLERA® Insulated Glass Daylighting Units [5]. This demonstrates how aerogel solar walls diffuses natural light by reducing contrast and increasing the overall ambient light level, as seen in Figure 2.

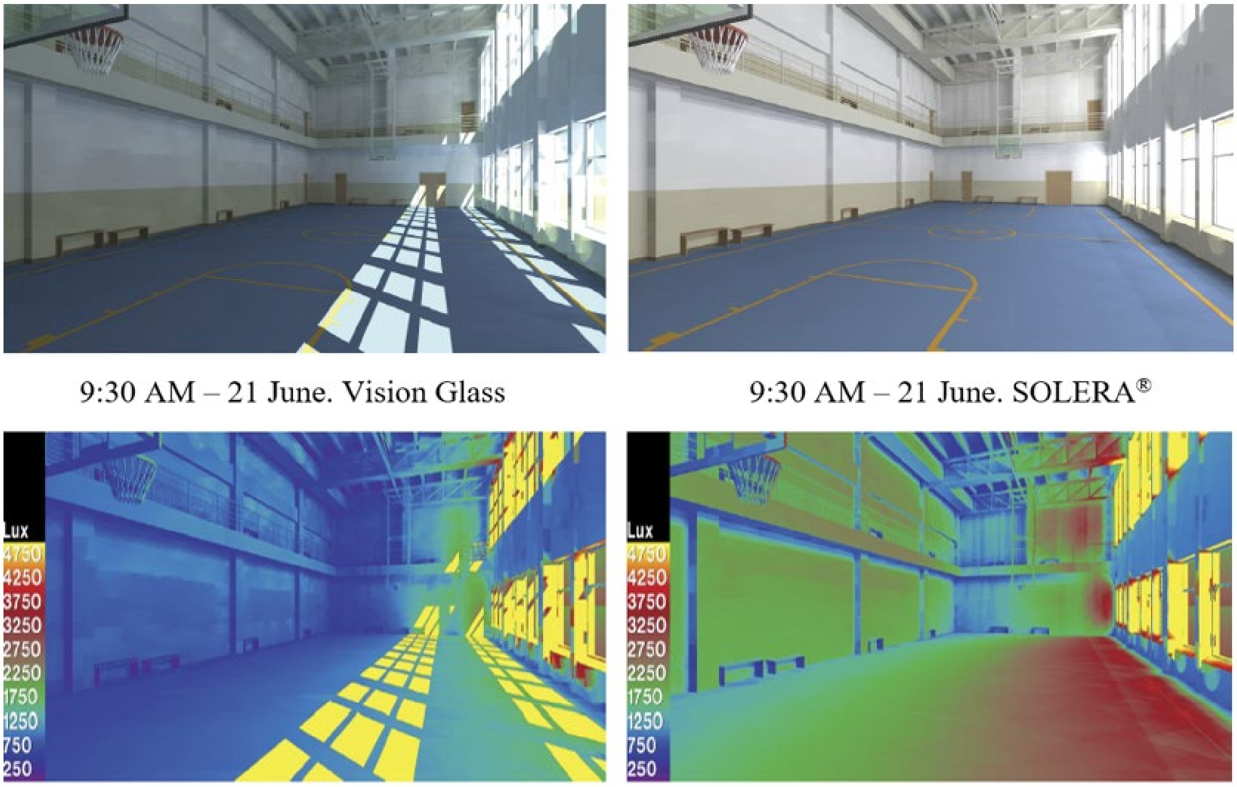


Figure 2. Radiance daylighting simulation with normal windows (left) and SOLERA® (right) with daylight appearance (top) and daylight level in lux (bottom) [5].

Depending on the type of sheets used, the visual light transmittance and solar heat gain coefficient will change. With white sheets the solar walls become less transparent, which will result in less light and radiation passing through. The simulations carried out in IDA ICE are based on crystal exterior FRP and white interior FRP where corresponding visual light transmittance (VLT) is 20% and the solar heat gain coefficient (SHGC) is 0.27.

4.3. Acoustical properties

When evaluating the quality of acoustic properties for sound reduction, we can look at the sound transmission class (STC) to get a better picture. The STC rating tells us how much sound is blocked from going through the material or product, which means the higher the value, the better soundproofing.

There is no public data to be found about the sound properties of Kalwall's products, but we can look at a similar product by Advanced Glazings LTD [15]. With a nominal thickness of 76.2 millimeters and U-value of 0.31 W/($m^2 \cdot K$), the sound transmittance class is described as "may exceed 52" [15]. By looking at Table 2, this categorizes as an "excellent" performance, where loud sounds are faintly heard.

Table 2. STC ratings (left) and the effectiveness of sound insulation performance (right) [16].

STC Rating	What Can be Heard	Performance
25	Normal speech is easily heard	Very Poor
30	Loud speech is easily heard	Poor
35	Loud speech is heard, but not understood	Average
40	Loud speech is heard, but only as a murmur	Good
45	Loud speech is not heard. Music and heavy traffic may be a problem	Very Good
50	Only very loud sounds are faintly heard	Excellent
60+	Virtually little to no sound is heard	Outstanding

4.4. Energy saving potential

According to a study published about energy and built environment in a 40-story commercial office building in Hong Kong, aerogel glazings could reduce window heat gain by 57 % and save cooling energy by 8.5 % compared to double glazing [17].

Due to its low VLT and SHVC value, less radiation and light passes through the solar wall. Because of the low U-value, there will also be less heat loss than with a standard window. Both VLT, SHVC and the U-value have a great influence on cooling and heating energy consumption, and may lead to a significant energy consumption loss.

However, the glazings could also potentially lead to an increase if not implemented cleverly. If the aerogel glazing is to be replaced with a structure of the building envelope with a lower U-value, like walls, a higher heat loss would occur. There would still be a reduction in artificial lighting as more natural light would be brought into the room, but the heat loss could potentially lead to an increased energy consumption.

4.5. Environmental impacts

The production and use of silica aerogels are said to have a low impact on the environments by being recyclable, noncombustible and nontoxic [18]. Since most of the material is air, there is not much waste either [19]. However, producing silica aerogels requires toxic chemicals and a lot of solvent. Depending on the drying process, demanding appliances have to run for a long time and consequently use a lot of electricity. Based on the emission intensity of the energy mix, this could potentially result in a high environmental impact.

One of the substances used in the production of silica aerogel is tetramethyl orthosilicate. This is basically a liquid source of silica, which also makes it really dangerous to handle. When in contact with water, tetramethyl orthosilicate turns back to silica. If this process occurs in someone's lungs and eyes it can cause serious health problems, like permanent blindness. It is therefore really important with good safety protocols and measures.

In total, aerogel has a higher embodied impact than most regular insulations (mineral wool, fiber glass, etc.), but by implementing it in construction elements like glazings it may possibly pay off through use by bringing more daylight in and reduce the need for artificial lighting, while also reducing the cooling and heating demand (e.g., as a result of aerogel solar walls having a lower thermal transmittance than regular windows).

5. Method

5.1. Building case studies

A building for car dealership in Fredrikstad, Norway, is used as a case study for the energy analysis. The address is Mosseveien 104, and the building will hereby be referred to as such. More detailed geographical information about the location is given in Table 3.

Table 3. Geographical information of the location. Table shows latitude, longitude, elevation and time-zone.

City and country	Latitude [°]	Longitude [°]	Elevation [m]	Time zone [h]
Fredrikstad, Norway	59.23 N	10.91 E	6	1.0 E

The building is at the longest approximately 50 meters long and 20 meters wide. It is a two-story building, where the car dealership is situated on the ground floor, together with a car washroom, toilets, garages and two offices. On the first floor, offices, meeting rooms, toilets and a kitchen are located.

As the building is still under construction, some of the elements needed for the energy simulations are assumed, based on regulations from TEK17 (Building acts and regulations) and meetings with AFRY Consult AS. This includes elements such as components of the building structure, thermal bridges, and HVAC system.

For the comparison scenarios, the aerogel solar walls have been implemented and replaced with the regular windows. No new window areas are added, so the only thing changing in the building models are the type of window.

Beside the window base case with regular windows used, two simulations have been performed with the aerogel solar walls (Table 4). The first one refers to an aerogel and window combination, which includes a partial replacement based on user preferences. The second model is an extreme case with maximum exploitation of aerogel, where all existing windows are replaced with aerogel solar walls.

Table 4. All building cases summarized (left) and explained (right).

Building case	Description of the building case
Window base case	Base case scenario with no aerogel solar walls, only regular windows.
Aerogel and window combination	Windows are partially replaced with the aerogel solar walls, and the residents still have a view of the outdoor surroundings.
Aerogel maximum exploitation	All windows are replaced with aerogel solar walls. This simulates the highest amount of reduction on the energy consumption of the reference building by just changing the window type.

A thermally broken grid core panel from Kalwall filled with Lumira® Aerogel LA1000 [10] are used as a reference for the energy simulation and life cycle assessment. It has a thickness of 70 mm and thermal transmittance of 0.28 W/($m^2 \cdot K$). The solar heat gain coefficient is 0.27 and visual light transmittance is 20 %.

A calculation of the amount of materials in one unit is performed based on CAD details that has been found and downloaded from Kalwall's website (Table 5). Some assumptions have been made where information was missing.

Table 5. Material calculation of one aerogel solar wall in the measurements of 1.2 m x 2.4 m.

Panel dimentions					
Thickness	0.07 m	Surface areal	2.880 m^2		
Width	1.20 m	Total volume	0.202 m^3		
Length	2.40 m	Total weight	86.22 kg		
Frame	Areal [m^2]	Volume [m^3]	[%]	Weight [kg]	[%]
Aluminium frame	0.00048	0.00346622	1.72	9.3588029	10.9
Screw	0.00013	0.00001457	0.01	0.1142394	0.13
Distance spacer	0.00057	0.00274910	1.36	7.4225808	8.61
Polyamide thermal break	0.00016	0.00116596	0.58	1.5157434	1.76
Face Sheet	Thickness [m]	Volume [m^3]	[%]	Weight [kg]	[%]
Inside + Outside	0.003	0.00802369	3.98	1.5577658	1.81
Grid Core	Thickness [m]	Volume [m^3]	[%]	Weight [kg]	[%]
Grid frame	0.015	0.01874593	9.30	50.614019	58.7
Aerogel	0.067	0.16398555	81.3	11.151018	12.9
Polyamide thermal break	0.00016 m^2	0.00344897	1.71	4.4836572	5.20

5.2. Energy simulation

The energy building simulation software IDA ICE is used to look at the differences of implementing aerogel solar walls on to the reference building. Each room is divided into its own zone.

For the windows, a standard window type in the IDA ICE database is used with a given solar heat gain coefficient of 0.56, solar transmittance of 0.46, visual light transmittance of 0.72, and where the total thermal transmittance (U-value) is 1.0 W/(m^2·K). There is no integrated or external window shading on neither of the window types, and the control strategy for window opening is set to "never open".

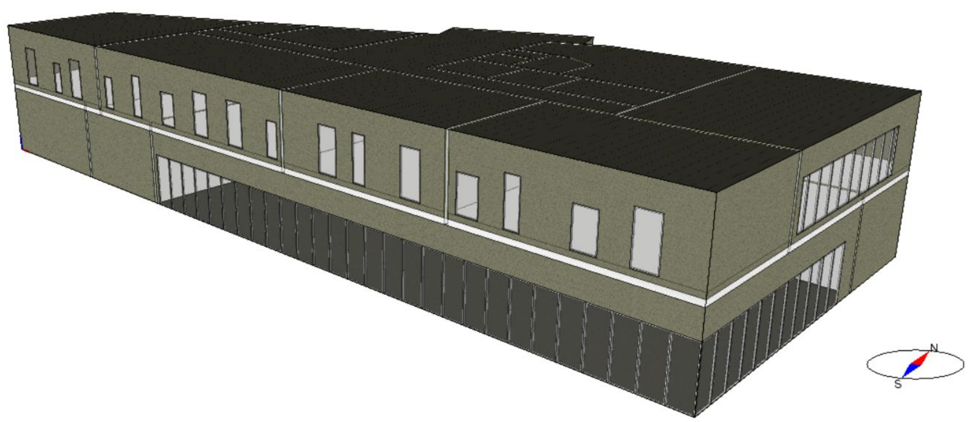


Figure 3. IDA ICE model of Mosseveien 104 (Fredrikstad, Norway).

The aerogel solar walls are modeled in IDA ICE as a detailed window object. Since the solar wall does not exist in the software it is created manually. For simplicity, the solar walls are given one layer with 70 mm thickness where the total glazing properties are added, instead of several separate layers for the FRP faces and aerogel grid core. Heat conductivity is set to 0.021 W/(m·K), which gives a U-value of W/(m^2·K). Diffused solar radiation is 100 % due to aerogel granules (Table 6).

Table 6. Glass pane properties of the aerogel solar wall in IDA ICE.

	Transmittance	Reflectance outside	Reflectance inside
Total shortwave	0.10	0.55	0.55
Visible	0.20	0.55	0.55
Diffusion (solar radiation)	1.00	0.40	0.40

5.2.1. Building defaults

The building is situated in a suburban area not far from Fredrikstad city centre. Pressure coefficients are filled out for a semi-exposed area. The building is oriented clockwise 26.7 degrees, and there is not accounted for any shading objects on the site.

Building elements were decided in meeting with AFRY Consult AS. Thermal transmittance and classification of the elements of construction is summarized in Table 7. Envelope area is calculated as seen from the inside of each zone, with a thermal bridge for the total envelope (including roof and ground) on 0.05 W/K/(m^2 envelope). Ground properties follows the ground model ISO-13370, which is integrated in the software.

Table 7. Thermal transmittance and classification of the elements of construction.

Building component	U-value [W/(m^2·K)]	Comments
Walls		
Internal walls	0.285	Interior wall with insulation.
External walls	0.186	PIR wall sandwich panels EMW-PIR1000.
Floor	0.098	Internal floor with concrete and XPS insulation.
Roof	0.116	Concrete joist roof.
Windows		
Normal windows	1.000	© Saint-Gobain T4-12 m. PLANITHERM ULTRA+ar.
Aerogel glazings	0.282	Kalwall glazing system with aerogel, 70 mm.
Doors	1.085	Entrance door.

5.2.2. Internal heat gains and setpoints

The internal heat gains consist of occupants, equipment, and lighting, and to simplify the model all rooms are considered as office spaces. The number of occupants is set to 1 person per 15 m^2 to ensure enough space for each person [20], and are present from 06:00 to 18:00 on weekdays. Activity level is set to 1 metabolic equivalent of task (MET), which equals to the energy produced of an average person that is resting or sitting still [21]. The occupants have a constant clothing degree of 0.85 ± 0.25. All equipment emits 120 W per unit and are also set to operate within occupied hours. For lighting the number of units are calculated for each room. A lighting armature with 2·54 W is used, with a total of 8900 lumen. Each unit has a rated input of 120 W with a luminous efficacy of 40 lm/W. Lightning is set to operate from 06:00 to 18:00 on weekdays.

Temperature setpoints are the same for every zone, and are set to minimum 21°C for heating and maximum 25°C for cooling. Daylighting in workplace is set to minimum 300 lux and maximum 500 lux, as this is the recommended daylighting for offices [22].

5.2.3. Climate data

EQUA offers a wide variety of climate data for IDA ICE [23]. The weather file for Oslo, Fornebu is used in this case (Table 8), considering the climate in Oslo and Fredrikstad are very much alike.

Table 8. Climate data for Fredrikstad. The table shows monthly values for dry-bulb temperature, direct normal radiation, diffuse radiation on horizontal surface and cloudiness.

	Dry-bulb temperature [°C]	Direct normal radiation [W/m²]	Diffuse radiation on horizontal surface [W/m²]	Cloudiness [%]
Month				
January	-3.8	23.2	8.8	72.5
February	-0.9	35.4	22.2	64.1
March	0.9	79.1	47.4	65.4
April	4.6	100.1	78.1	63.4
May	11.9	163.3	102.2	56
June	14.7	150.2	126.1	57.8
July	17.5	156.8	110.1	59.6
August	16.6	107.5	94	63.9
September	11.1	60	65.8	68.7
October	6.7	44.2	31.9	70.5
November	1.8	21.5	11.5	70.9
December	-1.6	11.2	5.2	74.4
Mean	6.7	79.7	58.8	65.6
Min	-3.8	11.2	5.2	56
Max	17.5	163.3	126.1	74.4

5.2.4. Heating and cooling

All energy delivered to the building is electric energy. The heating and cooling in the building are done by ideal heaters and coolers. Ideal heaters are set to 70 W/m^2 and ideal coolers are set to 100 W/m^2 for every zone. Every zone contains an air handling unit (AHU) with system type CAV, and the supply and return air is 2 L/(s·m^2), which is a default in IDA ICE. Domestic water use is set by an average hot water use of 22 L/per occupant and day.

5.3. Life cycle assessment

A life cycle assessment (LCA) has been performed to evaluate the potential environmental impacts throughout the production and transportation of silica aerogel and translucent aerogel solar walls.

5.3.1. Goal definition, functional unit and system boundaries

The purpose of this study is to evaluate the environmental impacts of the aerogel solar walls in order to see if they would be beneficial in an environmental perspective. The production of Kalwall's aerogel façade system is located in the eastern part of the United States, which results in a great distance from Fredrikstad in Norway. The assessment will therefore also look at the impacts of producing this aerogel façade system in Germany (as a central part of Europe) and Norway.

The functional unit refers to the product whose impacts are calculated by a life-cycle assessment [24]. For the life cycle assessment on the silica aerogel, the functional unit is 1 kg of final aerogel. For the life cycle assessment on the aerogel solar wall the functional unit is set to 1 aerogel solar wall measuring 1.20 m x 2.40 m with U-value = 0.28 $W/(m^2 \cdot K)$. In this way we are able to easily use the results from the aerogel production with the exact needed amount for the solar wall.

The impact categories chosen to measure the impact of the products are summarized in Table 9.

Table 9. Overview of classification and characterization factors in the life cycle impact assessment.

Impact indicators	Unit
Global warming potential (GWP)	kg CO_2-eq
Freshwater Eutrophication Potential (FEP)	kg SO_2-eq
Particulate Matter Formation Potential (PMFP)	kg 1,4-DC
Photochemical Oxidant Formation Potential (POFP)	kg CFC-11
Human Toxicity Potential (HTP)	kg 1,4-DC
Ozone Depletion Potential (ODP)	kg CFC-11

A “cradle-to-site” approach (A1-A4) is used for the life cycle assessment following the EN 15804:2012 standard (Figure 4) [25]. Packaging is omitted as there is no public information on how the products are packaged and transported, and guesswork could lead to major discrepancies in the results.

Stages beyond this were not included in the life cycle assessment also due to the lack of information and time.

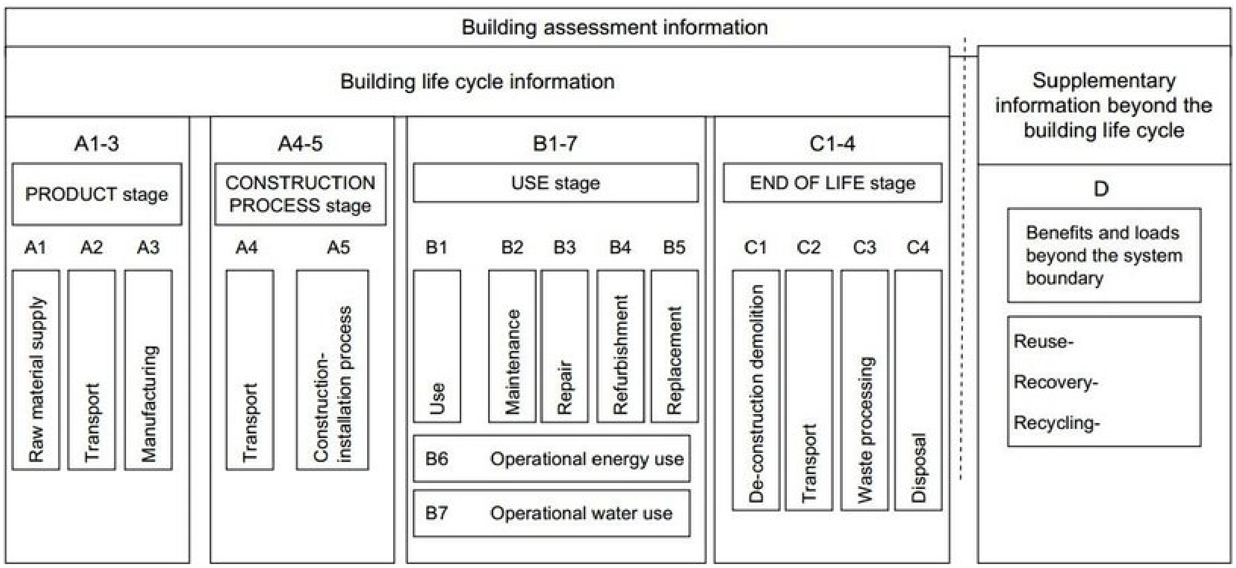


Figure 4. Building assessment modules for a life cycle assessment according to NS-EN 15978:2011 [25] [26].

5.3.2. Data collection

The LCA on the silica aerogel and aerogel solar wall is carried out by using data from the ecoinvent database v3.5, and the ReCiPe 1.13 midpoint method. Finally, the complete LCA was calculated using the MS Excel software [27].

Most of the impact categories for the material and transportation are global, while electricity is taken from the corresponding production area: USA, Germany and Norway. Some of the products used in manufacturing silica aerogel and aerogel solar walls are not to be found in the database, so corresponding products have been used. Each emission category is summarized in Table 10, with information about what material it applies to from the life cycle inventory.

Table 10. Overview of all the product processes (left) used for calculating the emissions for each material, transport type or electricity (right), found in Eibrowser.

Names: Product process	Applied to
Materials	
Market for methanol - methanol/market for methanol/GLO/kg	Methanol
Market for ammonia, liquid/RoW/kg	Ammonia 2 M
Market for tetraethyl orthosilicate/GLO/kg	Tetramethoxysilane, methyltrimethoxysilane
Market for nitrogen, liquid/RER/kg	Nitrogen
Market group for tap water/GLO/kg	Reagent grade water
Market for glass fibre reinforced plastic, polyamide, injection moulded/GLO/kg	Translucent FRP Faces, polyamide thermal break
Market for aluminium, cast alloy/GLO/kg	Aluminium
Market for steel, low-alloyed/GLO/kg	Steel screws
Transport	
Market group for transport, freight train/GLO/metric ton*km	Transportation by train
Market for transport, freight, sea, transoceanic ship/GLO/metric ton*km	Transportation by ship
Market for transport, freight, lorry 16-32 metric ton, EURO6/RER/metric ton*km	Transportation by truck
Electricity	
Electricity, low voltage/market for electricity, low voltage/NPCC, US only/kWh	Electricity in US
Electricity, low voltage/market for electricity, low voltage/DE/kWh	Electricity in Germany
Electricity, low voltage/market for electricity, low voltage/NO/kWh	Electricity in Norway

The manufacturing energy consumption of one aerogel solar wall is based on an aluminum and timber window, scaled up to fit the functional unit [28].

The transportation distance for the corresponding production area is calculated by using Google Maps (Table 11). The truck has a maximum of 32 metric ton, and complies with Euro 6 emission standards.

Table 11. Transportation distance for the corresponding locations for production of silica aerogel and translucent aerogel solar walls, calculated by using Google Maps.

	Material	Origin	Destination	Truck [km]	Train [km]	Ship [km]	Total [km]
US	Lumira Aerogel	Boston, Massachusetts, USA	Manchester, New Hampshire, USA	86	0	0	86
US	Aerogel solar walls	Manchester, New Hampshire, USA	Fredrikstad, Norway	301	0	5955	6256
DE	Lumira Aerogel	Frankfurth, Germany	Essen, Germany	235	0	0	235
DE	Aerogel solar walls	Essen, Germany	Fredrikstad, Norway	571	360	0	931
NO	Lumira Aerogel	Kongsberg, Norway	Kongsberg, Norway	2	0	0	2
NO	Aerogel solar walls	Kongsberg, Norway	Fredrikstad, Norway	148	0	0	148

5.3.3. Life cycle inventory

To this day, no life cycle assessment is publicly available on the production of silica aerogel at an industrial scale. However, several researchers have tried to do conduct such assessments based on various assumptions and calculations. The data used in this life cycle inventory (LCI) is taken from an article where 40 ml of silica aerogel was produced through supercritical drying [29]. The article also made their own assumptions on the emissions from a larger and more effective production, but the work performed in this analysis is unrelated to that.

The data is summarized and scaled up to 1 kg aerogel, based on a bulk density of 68 kg/m^3 for Lumira® Aerogel LA1000. However, the upscaling in Table 12 does not consider any countermeasures for a more effective production, like recycling of methanol used in the production of silica aerogel, which are included later on. Enormous amounts of methanol are used, which gives corresponding high greenhouse gas emissions. Depending on the emission intensity, the energy will also account for a large part of the emissions. Even so, a downscaling of the energy consumption has not been considered in this analysis.

Table 12. Life cycle inventory for 1 kg silica aerogel produced through a high temperature supercritical drying *.

Stage	Item	Unit	Value
Gel preperation	Methanol	kg	4.603
	Reagent grade water	kg	2.941
	Ammonia 2.0 M	kg	0.005
	Tetramethoxysilane (TEOS)	kg	5.382
	Methyltrimethoxysilane	kg	0.500
	Electricity (fan cupboard)	kWh	23.162
	Running time (h): 00:43:00		
Ageing	Methanol - covering samples	kg	2.327
	Methanol - 1st exchange	kg	36.353
	Methanol - 2nd exchange	kg	36.353
	Electricity (fan cupboard)	kWh	5.147
	Running time (h): 00:10:00		
Drying	Methanol	kg	116.324
	Nitrogen (N_2 at 100 bar, 296 K)	kg	0.021
	Electricity (Heater)	kWh	324.265
	Running time (h): 02:15:00		
	Electricity (Temperature sensor)	kWh	4.779
	Running time (h): 04:00:00		

* *Scaled up from the original recipe of 40 ml to 1 kg aerogel.*

Table 13. Life cycle inventory for one aerogel solar wall measuring 1.20 m x 2.40 m *.

Stage	Item	Unit	Value
Product	Lumira® Aerogel LA1000	kg	11.151
	Fiberglass reinforced polymer (FRP) faces	kg	1.558
	Aluminum frame, grid core and spacer	kg	67.395
	Polyamide thermal break	kg	5.999
	Steel screws	kg	0.114
	Electricity	kWh	833.333
Construction Process	Transport		
	USA	tkm	546.793
	Germany	tkm	100.530
	Norway	tkm	12.933

* *The amount of materials are estimated through the process "reverse engineering".*

The methanol used in the gel preparation phase is assumed to be consumed and cannot be recycled directly. The methanol used in the ageing and drying process on the other hand, is assumed to be almost totally recycled, which corresponds to 97.6 % of the total methanol consumption. A low amount of loss is considered by each production cycle, with a total recycling percentage of 80 % and 90 % (Industrial 1 and Industrial 2, as seen in Table 14). Following, Industrial 1 are considered as the "base case", and as a real plausible situation. Through efficient processes, it is possible the recycling percentage could be even higher, although without solid arguments this will not be taken into account, and the formerly mentioned values are applied.

Table 14. The assumed degree of recycled methanol on a bench plant and industrial scale.

Scale	Bench	Industrial 1	Industrial 2
Batch volume [L]	0.04	1	20
Methanol recycled [%]	0	80	90

5.3.4. Life cycle assessment

For the assessment, several scenarios have been looked at where the uncertainty and saving potential have been significant. Besides the recycling of methanol, placement of the production of aerogel and aerogel solar walls have been considered in three different countries, where each country sets different conditions for transportation and emission intensity for the energy. The aerogel solar walls are accessible in bigger and smaller dimensions than 1,2 m x 2,4 m, which affects the material composition of the product. The material calculation shows that the percentage of aerogel increases while aluminum decreases when the panel is reduced in size. This results in a higher weight, which again affects the utilization factor for transportation negatively. Similarly, a larger size in the solar wall results in a decreased percentage of aerogel and increased percentage of aluminum which will make the unit lighter.

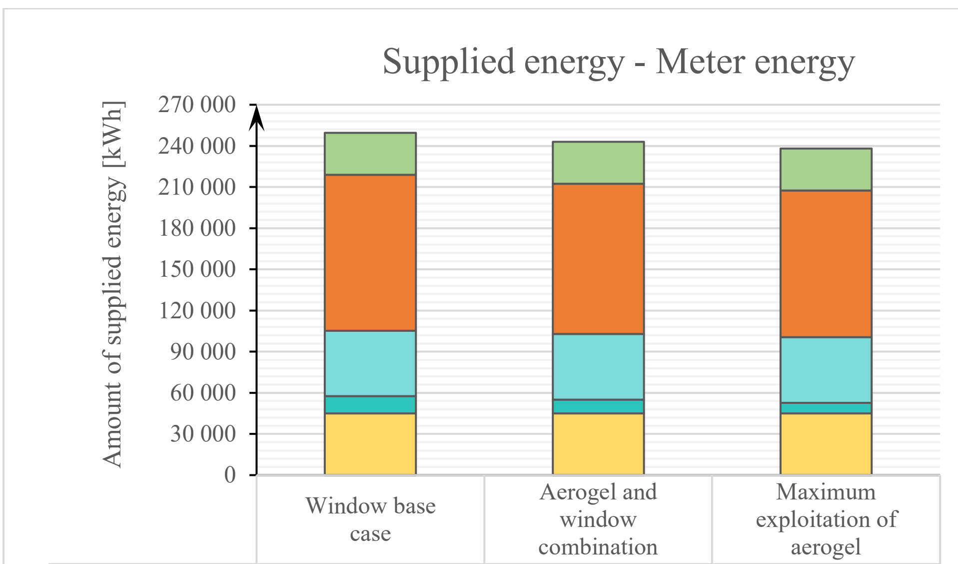
The global warming potential from the different scenarios is then presented against each other through several sensitivity analyses in order to show how the measures affect each other, and to see what has the biggest influencing factor on the results.

6. Results

6.1. Energy simulations

There are several different results that may be obtained from IDA ICE. To see the impact on energy consumption by changing the regular windows to aerogel solar walls, an energy simulation has been performed on each model before being compared to each other and analyzed. When comparing all three models to each other, the changed results can be seen more clearly. In the following figures, the building models defined in chapter "5.1. Building case studies" have been used.

Supplied energy, or delivered energy, is the quantity of energy that enters the building without adjustment for any energy losses [30]. The total supplied energy to each building model is shown in Figure 5 with a small reduction in electric cooling and heating, primarily.



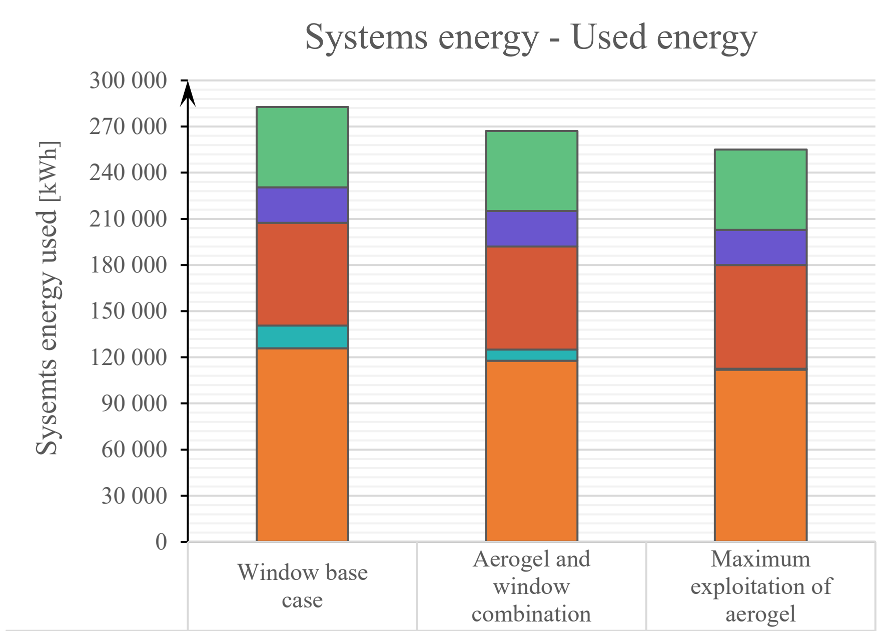
	Window base case	Aerogel and window combination	Maximum exploitation of aerogel
Equipment, tenant	30484	30483	30488
Electric heating	113656	109713	106986
HVAC aux	47740	47742	47742
Electric cooling	12664.2	10136.4	7882
Lighting, facility	44918	44918	44923

Figure 5. Supplied energy to Mosseveien 104 (Fredrikstad, Norway) for each model.

However, this only represents the delivered energy to the building, and not the need or use of energy. When looking at the systems energy for the whole building (Figure 6), we may see a clear reduction in zone cooling from 14 797 kWh to 766 kWh. This accounts for a 95 % reduction of used energy for zone cooling while air handling units (AHU) for cooling remains almost the same.

Cooling, however, is only a small portion of the total used energy, whereas heating represents a far greater part. Zone heating is also reduced by 14 031 kWh, but since the total energy used for zone heating in base case is 125909 kWh, this only represents a 12 % reduction.

AHU for cooling and heating is almost the same for every scenario, disclosing the fact that mainly the local cooling and heating system in each zone reduces in connection with changing the regular windows to aerogel solar walls. Therefore, it may be interesting to look at how the energy consumption behave during heating and cooling separately in the zones.



	Window base case	Aerogel and window combination	Maximum exploitation of aerogel
Dom. hot water	52064	52064	52064
AHU cooling	23193.8	23106.7	22879.9
AHU heating	66694.7	66920.8	67380.3
Zone cooling	14797.5	7302.3	766
Zone heating	125909	117796	111878

Figure 6. Systems energy to Mosseveien 104 (Fredrikstad, Norway) for each model.

The following figures illustrates the energy balance for each instance, and demonstrates how the various elements contributes to heating (positive columns) of the zones, and heat loss or cooling (negative columns). Only sensible energy is accounted for.

The energy for all zones during heating (Figure 7) looks at the portion of the year when additional heating is required. It can be observed in the building cases that window and solar energy increases from -19 847 kWh to 8 965 kWh. Thus, window and solar contributes to heating the zones in the last model with maximum aerogel exploitation. The reason behind this could be that while there is less heat produced through a lower solar heat gain coefficient (SHGC) with aerogel solar walls, the improved and lower thermal transmittance also results in less heat leaving the building. As a result, less local heating units are needed since more heat are gained than lost.

It can also be observed that the contribution of energy from internal walls and masses decreases. This may be caused by less energy stored in the building's thermal masses, as the aerogel solar walls diffuse more daylight, and therefore highly reduces direct solar radiation. Because of this contribution, the total sensible heat is higher in the last building model, although local heating units decreases with 14 031 kWh from window base case to maximum exploitation of aerogel. Thus, a small reduction of needed electricity for heating.

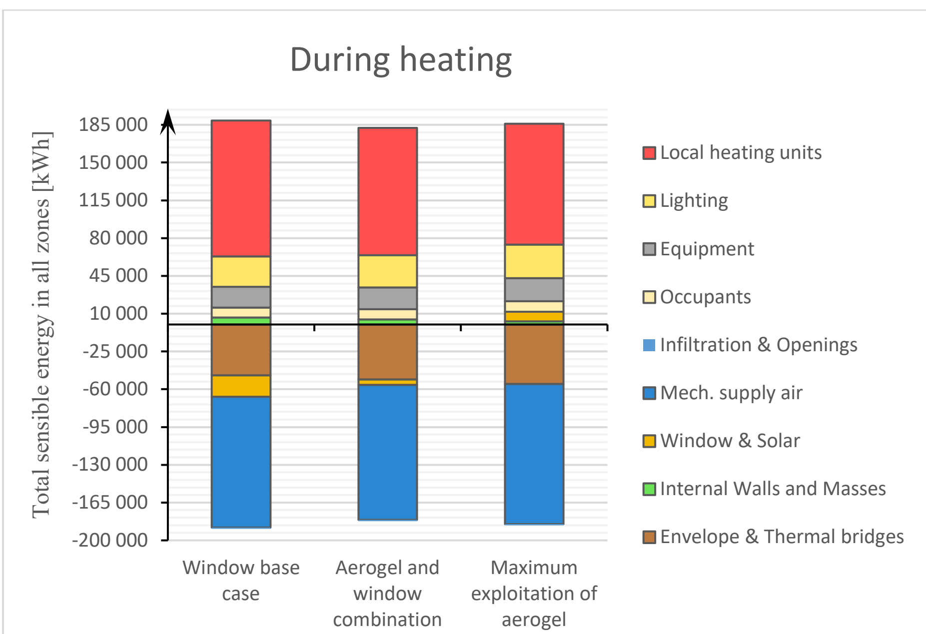


Figure 7. Total sensible energy for all zones during heating, for one year. Comparison of all three building models.

The energy for all zones during cooling (Figure 8) looks at the time portion of the year when cooling is required, mainly associated with the warmer portion of the year.

When cooling is required, no heating units are on. Still, some elements contributes to unwanted heating, and window and solar energy plays a major role in the total cooling demand of the building. In window base case, window and solar energy counts for 35 095 kWh, which is about 71 % of the total. By implementing aerogel solar walls, this gives a reduction of 30 357 kWh which may be amounted to the diffused light that reduces the greenhouse effect. The sensible energy in connection with lighting, equipment and occupants also reduces by each case, but with a much lower rate.

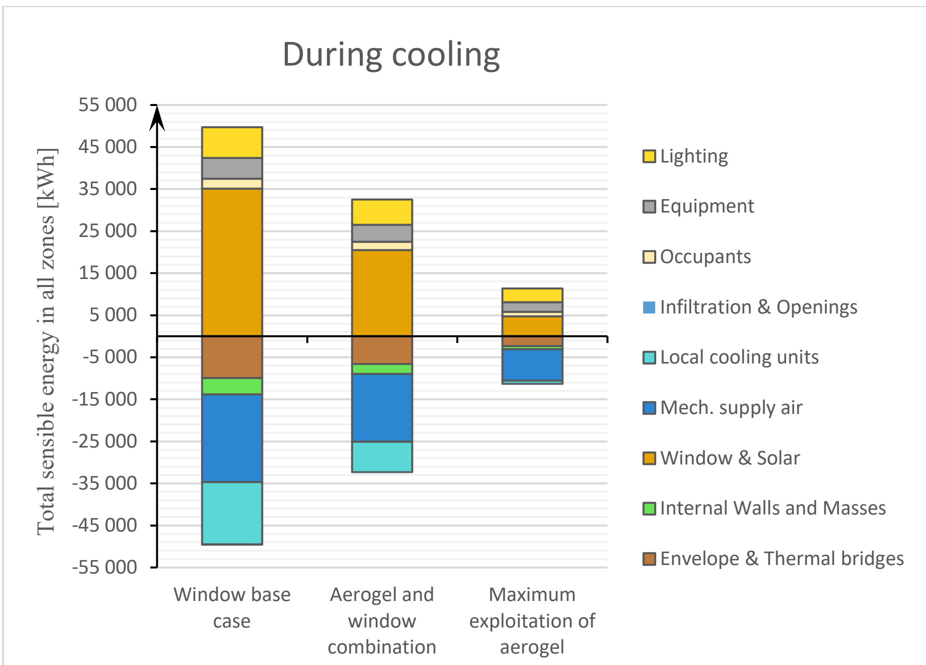


Figure 8. Total sensible energy for all zones during cooling, for one year. Comparison of all three building models.

In regard to local cooling units being almost zero in the last model (Figure 8), all cooling depends on the air handling units that distributes for the whole building. This means that by changing all windows to aerogel solar walls, the local cooling units could be removed. Nevertheless, the amount of AHU cooling is almost the double of local zone cooling, which is almost the same for every model. Including both AHU and local units, total cooling are reduced by 38 %. Meanwhile, total heating for the building are reduced by 7 %.

6.2. Life cycle assessment

The assessment on the aerogel and aerogel solar walls is summarized together in one table.

6.2.1. Life cycle impact assessment

Results from the analysis performed on the aerogel are consecutively used in the analysis of the solar walls, where one unit with the measurements 1.2 m x 2.4 m contains 11.15 kg of aerogel. The total emissions of producing silica aerogel represents this amount, so the total emissions of one solar wall are considered further on (Table 15). Transportation includes cargo ship and truck from USA to the reference building Mosseveien 104 in Fredrikstad, Norway.

Table 15. Emissions from the production and transportation of silica aerogel and aerogel solar walls from USA to Mosseveien 104 (Fredrikstad, Norway).

	Material	GWP [kg CO_2-eq]	FEP [kg SO_2-eq]	PMFP [kg 1,4-DC]	POFP [kg CFC-11]	HTP [kg 1,4-DC]	ODP [kg CFC-11]
Silica aerogel	Methanol	3.0425E+02	5.8354E-02	3.5655E-01	9.9243E-01	9.1348E+01	9.0874E-05
	Ammonia 2 M	1.1998E-01	1.0875E-05	1.4473E-04	2.2855E-04	2.7036E-02	1.8480E-08
	Tetramethoxysilane	2.8990E+02	1.5894E-01	5.7076E-01	9.9457E-01	1.4194E+02	4.6430E-05
	Methyltrimethoxysilane	2.6931E+01	1.4765E-02	5.3021E-02	9.2392E-02	1.3186E+01	4.3131E-06
	Nitrogen	5.7290E-02	5.9393E-05	1.0492E-04	1.4014E-04	3.9891E-02	6.1968E-09
	Reagent grade water	1.7885E-02	1.0021E-05	5.1082E-05	5.9455E-05	1.0075E-02	3.3843E-09
	Electricity	1.1180E+02	3.2997E-02	1.8117E-01	1.7535E-01	3.6718E+01	2.2925E-05
Translucent aerogel solar walls	Translucent FRP Faces	1.3745E+01	1.3710E-03	1.7939E-02	3.5015E-02	1.0226E+00	2.6096E-07
	Polyamide, Thermal Break	5.2936E+01	5.2802E-03	6.9087E-02	1.3485E-01	3.9382E+00	1.0050E-06
	Aluminum (6063-T6 or 600-T5 alloy)	3.4130E+02	1.2743E-01	8.2084E-01	1.1347E+00	1.4875E+02	2.6948E-05
	Steel, Screws	1.8508E-01	1.9068E-04	8.3519E-04	9.2567E-04	3.1004E-01	8.0046E-09
	Electricity	2.6072E+02	7.6947E-02	4.2248E-01	4.0892E-01	8.5626E+01	5.3461E-05
Transport	Ship	5.7702E+00	7.8934E-04	3.6600E-02	8.6068E-02	7.0142E-01	9.2015E-07
	Truck (EURO6) *Lorry 16-32 metric ton*	5.3746E+00	4.4517E-04	7.2335E-03	1.2647E-02	1.5060E+00	9.9038E-07

In total, the aerogel will release about 733 kg of CO_2, which stands for 51,9 % of the total emissions of one aerogel solar wall, making it by far the most impactful material in terms of global warming potential. The transportation on the other hand appears to have very little impact on the total emissions, while electricity make up almost half of the emissions in regard to production and transportation. Aluminum used in production has somewhat higher emission than the electricity, but less than aerogel.

Based on production scale and location, the total emissions will change a lot from the different scenarios (Table 16).

If the production was to be moved to Germany or Norway, it would decrease the transportation distance and consequently transportation emissions. But, according to the energy data used in the analysis, emissions from German energy production amounts to approximately twice of USA's. And because transportation has proven to have a relatively small significance on the total calculation, it stands more beneficial to keep the production in USA. Although there is a great distance between USA and Norway, most of the transportation distance is covered by cargo ship which has a considerably lower emission intensity than a truck or train.

Table 16. Total emissions from the production and transportation of one aerogel solar wall, based on production scale and location.

Production scale		**GWP [kg CO_2-eq]**	**FEP [kg SO_2-eq]**	**PMFP [kg 1,4-DC]**	**POFP [kg CFC-11]**	**HTP [kg 1,4-DC]**	**ODP [kg CFC-11]**
Bench	USA	2.4995E+03	6.8595E-01	3.8099E+00	7.6118E+00	8.5128E+02	5.7264E-04
	Germany	2.8449E+03	1.6308E+00	4.0202E+00	7.9492E+00	1.4104E+03	5.3060E-04
	Norway	2.1557E+03	6.0386E-01	3.2371E+00	7.0186E+00	7.8228E+02	4.9819E-04
Industrial 1	USA	1.4131E+03	4.7760E-01	2.5368E+00	4.0682E+00	5.2512E+02	2.4816E-04
	Germany	1.7586E+03	1.4224E+00	2.7471E+00	4.4057E+00	1.0843E+03	2.0613E-04
	Norway	1.0693E+03	3.9551E-01	1.9641E+00	3.4751E+00	4.5612E+02	1.7372E-04
Industrial 2	USA	1.2773E+03	4.5155E-01	2.3777E+00	3.6253E+00	4.8435E+02	2.0761E-04
	Germany	1.6228E+03	1.3964E+00	2.5879E+00	3.9628E+00	1.0435E+03	1.6557E-04
	Norway	9.3351E+02	3.6946E-01	1.8049E+00	3.0321E+00	4.1535E+02	1.3316E-04

For a regular window, emissions will vary depending on the type (e.g., how many layers there are of glass, if the air gaps are filled with gas, what type of gas, and what material the frame is made of). Windows, unlike aerogel solar walls, are manufactured all over the world. Thus, more easily obtained. As a result, transport lengths may be very short. However, there are no windows on the market today with a thermal transmittance as low as the aerogel solar walls of 0.28 W/($m^2 \cdot K$).

By looking at a window produced by Nordvestvinduet AS with triple glass, an aluminum frame, dimensions 1.23 m x 1.48 m and weight of 66.54 kg, the global warming potential is equivalent to 127 kg CO_2-eq for phase A1 – A3 [31]. However, this also includes packing, which has not been taken into account in the study of the aerogel solar walls.

Another window produced by Gilje Tre AS with triple glass, aluminum frame, same measurements and a weight of 67.09 kg, has a global warming potential equivalent to 151 kg CO_2-eq for phase A1 – A3 (included packing) [32].

Comparing the global warming potential of aerogel solar walls to the windows, solar walls will have a higher embodied impact. But with efficient processes and recycling of materials, a lower emission intensity for the energy and shorter transportation distance, the study shows that the solar walls (measuring 1.20 m x 2.4 m) could get as low as 933.51 kg CO_2-eq.

6.2.2. Interpretation

While the results may not provide a concrete answer to exactly what the emissions are from 1 kg of aerogel or one aerogel solar wall, it provides an adequate indicator of what to expect. Some parts of the analysis are based on calculated assumptions and data that could be very different in other scenarios. For instance, data obtained from EIBrowser, based on ecoinvent database v3.5, gives an emission intensity for German energy of 605 grams CO_2-eq per kWh. Meanwhile, the website Our World in Data states an emission intensity of 364 grams CO_2-eq per kWh for 2021 [33]. The assessment used the data from EIBrowser because of the lack of information about other impact categories than global warming potential (GWP) in the data found on Our World in Data.

How the measures affect each other may be summarized and pointed up against each other. The location of production together with the degree of recycling of methanol are seen in Table 17. In the best case, Norwegian-produced solar walls with a 90% recycling degree of methanol has a total emission of 934.5 kg CO2-eq. This is three times less than the worst case, with a bench scaled production situated in Germany that causes an emission of 2844.9 kg CO2-eq. Even with aerogel solar walls in Norway with 80 % recycling of methanol, they will score better than solar walls produced in America with 90 % recycled methanol.

In Table 18, the location of production is set up against the material composition. The difference is in this case much lower, due to material composition having a lesser impact than methanol. The emissions vary from 1010.3 kg CO2-eq to 1869.5 kg CO2-eq.

Table 17. Sensitivity analysis of the global warming potential (GWP) due to location of production and the degree of recycled methanol.

Degree of recycled methanol	**Global warming potential [kg CO2-eq]**		
	Location of production *		
	USA	Germany	Norway
Bench (0%)	2499.46	2844.94	2155.65
Industry 1 (80%)	1413.11	1758.59	1069.30
Industry 2 (90%)	1277.32	1622.80	933.51

** Includes both transport and energy intensities for each country.*

Table 18. Sensitivity analysis of the global warming potential (GWP) due to location of production and material composition.

Material composition	**Global warming potential [kg CO2-eq]**		
	Location of production *		
	USA	Germany	Norway
Big (1.5x6.0 m)	1527.58	1869.48	1194.73
Medium (1.2x2.4 m)	1413.11	1758.59	1069.30
Small (0.9x1.2 m)	1356.51	1706.71	1010.32

** Includes both transport and energy intensities for each country.*

7. Discussion

The results of the life cycle assessment may provide a useful insight into how the emissions from the aerogel solar walls may vary in different scenarios. Where the data was uncertain, a sensitivity analysis was performed. For instance, the emission intensity for the energy used in USA, Germany and Norway may differ considerably. In Norway, this was set at 32 grams of CO_2-eq per kWh. However, if the manufacturer had a green certificate for the electricity, this could result in an even lower emission intensity. For Germany, this value is at 605 grams CO2-eq per kWh, and could possibly be reduced as well. If this was to happen (depending on how much it would be lowered), it would change the results of the analysis. If the German emission intensity gets reduced to a lower value than the one for USA, the solar walls ends up becoming more favorable to produce in Germany.

Results from the building energy simulations were not quite as anticipated, as a greater change in the use of artificial lighting was expected. The aerogel solar walls still accounted for a great reduction in cooling, and if the amount of windows and solar walls were to increase, results could possibly be even greater. This makes the aerogel product very favorable in buildings where large areas need lighting (e.g., sports halls and schools).

8. Further perspectives

The results have proven to be quite promising, but there are still many elements that remains to be examined to get a full evaluation of the aerogel solar walls. While the life cycle assessment in this study provides answers to the environmental impacts of production and transportation of the solar walls, all stages should be included for a complete examination of the aerogel product (e.g., assembly, maintenance and repair, and waste management).

The energy simulations from this study focused only on one location in Norway, where climate data were the same for all scenarios. In this case, there was a significant reduction in cooling loads, due to the aerogel solar walls. Hence, investigating how the results change in different climates (e.g., Egypt and Greenland) could give a better understanding of the efficiency of aerogel solar walls. To get a clearer image of how the daylighting affects the results, an advanced daylight calculation could be performed to observe the performance of the daylight factor and illuminance.

Another issue that was not included in this article is costs. In order for the aerogel solar walls to be more used in the future, individuals must find the price appropriate. Today, the solar walls are very expensive due to high production costs of silica aerogel. However, whether they are still cost-effective should be investigated. Despite the high purchase price, the costs can be reduced in connection with a lower energy consumption, quick installation process, and saving space. Nevertheless, maintenance and replacement costs could get expensive due to long distances (e.g., with a production located in USA and building located in Norway).

9. Conclusions

Aerogel is one of the most promising thermal insulation materials on the market today, and increasing the utilization, transparent aerogel solar walls filled with aerogel granules may have significant benefits to become a viable alternative to traditional windows. The solar walls have great thermal properties with a low thermal transmittance, as well as great optical and acoustic properties. Therefore, making the production of silica aerogel and aerogel solar walls more efficient may increase the interest.

The results presented in this study shows that the aerogel solar walls give a reduction in the energy consumption, but the amount will vary on the situation. Artificial lighting in the case study was not affected when changing regular windows to aerogel solar walls, but the need for cooling and heating was reduced. The solar walls lead to a significantly higher emission than ordinary windows, depending on factors such as location, material composition and the degree of recycling of substances used in the production of silica aerogel. The recipe for silica aerogel requires high amounts of methanol, and the solar walls consists of approximately 80 % aerogel. As a result, the recycling degree of methanol has the biggest impact on the total emissions.

Overall, translucent aerogel solar walls show promising results that benefit the building's envelope. Through further advancement and innovation in production, aerogel solar walls may be able to realize its potential as a "façade material of the future".

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Attachments

Attachment 1 – Article

Attachment 2 - Poster of the project (A3)

Attachment 3 - Status reports

Attachment 4 – Timesheet

Attachment 5 – Preliminary project plan

Attachment 6 – Excel

Attachment 7 – IDA ICE energy simulation results

Attachment 8 – Mosseveien 104

Attachment 9 – LCA theory