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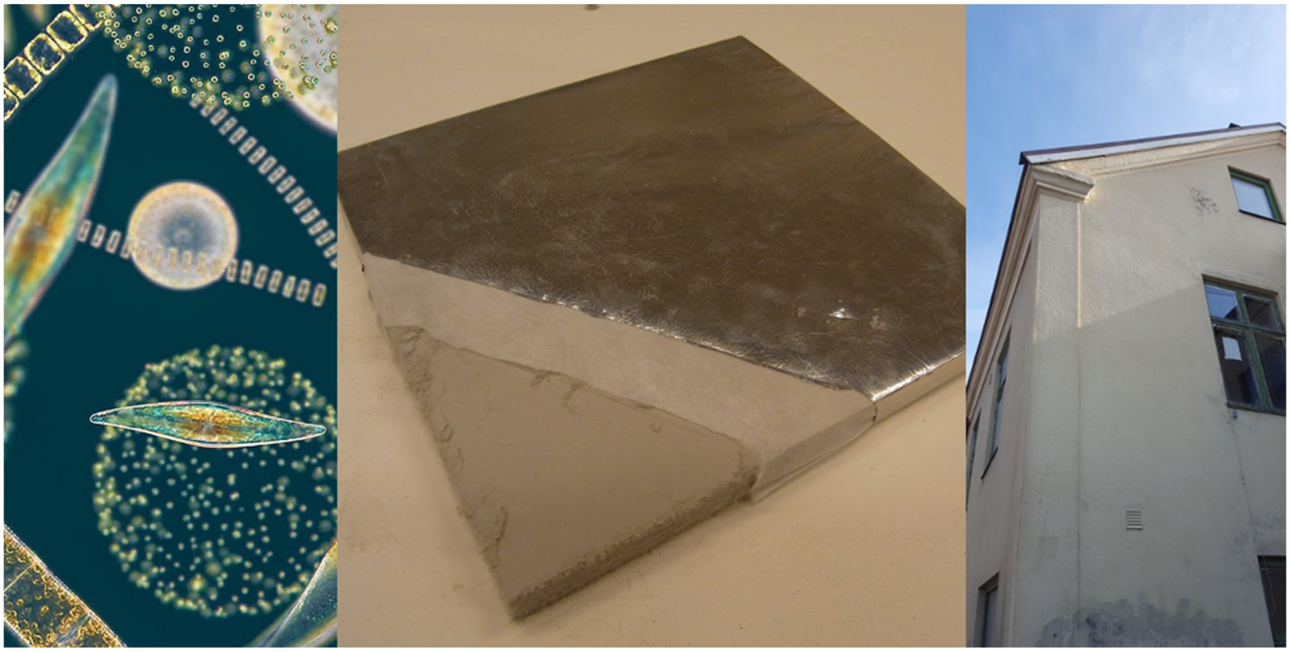

Renovating with vacuum insulation panels

Testing of alternative core material and a renovation case study

Master's thesis in Structural Engineering and Building Technology

SARA BERGSTRÖM

Department of Architecture and Civil Engineering
Division of Building Technology
Research Group Building Physics Modelling
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Master's Thesis BOMX02-19-1
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Cover:
Left: Algae. Photo: Swedish algae factory. Middle: Vacuum insulation panel with inner layers exposed. Photo: Pär Johansson. Right: The simulated building in Mölndal. Photo: Pär Johansson.

Department of Architecture and Civil Engineering
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ABSTRACT

The building sector needs to save energy and the regulations are becoming stricter with regards to energy used for heating. The regulations also apply to renovations, and for some buildings with cultural value external insulation is not a possibility. To minimise the loss of real estate with internal insulation, super insulation materials might be used. For one such material, vacuum insulation panels (VIP), the production process is energy consuming. Previous research has shown that the core materials contribute to around 90% of the total production energy of the panels, and a decrease of up to 45% would be possible with alternative core materials and procedures.

In this study, a possible alternative core material made from algae was tested and characterized with regard to specific heat capacity, density, hygroscopic properties and thermal conductivity. Based on calculations of the thermal conductivity at different pressure, the performance as a core material in a VIP was estimated. The tests and calculations show that the material made from algae does not have the properties that would make it suitable to be a core material in VIP at the current conditions, but further development and more research is needed.

On the building scale, thermal bridges are another aspect of saving energy which become more dominant when insulating with a super insulation material. Simulations to estimate the thermal bridges in a brick building from 1890 with internal insulation of VIP were performed. The study focused on the thermal bridges at and around the floor joist. The results of the simulations show that the thermal bridge from the floor joist is responsible for almost 50% of the total heat flow through the insulated wall. The thermal bridges around the VIP is small in comparison and may, in this scenario, be neglected. However, it may be of more importance in other buildings.

Key words: Super insulation materials, vacuum insulation panel, VIP, thermal bridge, core material

Renovering med vakuumisoleringspaneler

Tester av alternativt kärnmaterial och en renoveringsfallstudie

Examensarbete inom masterprogrammet Konstruktionsteknik och Byggnadsteknologi

SARA BERGSTRÖM

Institutionen för arkitektur och samhällsbyggnadsteknik
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SAMMANFATTNING

Byggsektorn behöver minska sin energiförbrukning och byggreglerna blir striktare med avseende på energi för uppvärmning. Reglerna gäller även vid renoveringar, och för vissa kulturminnesmärkta byggnader är utvändig isolering inte ett alternativ. För att minimera förlusten av boyta med invändig isolering kan superisoleringsmaterial användas. För ett av dessa material, vakuumisoleringspaneler (VIP), är tillverkningsprocessen väldigt energikrävande. Tidigare studier visar att kärnmaterialet bidrar till ca 90 % av tillverkningsenergin för panelerna, och en minskning på 45 % är möjlig med alternativa kärnmaterial och tekniker.

I den här studien har ett möjligt alternativt kärnmaterial testats och karaktäriserats med avseende på specifik värmekapacitet, densitet, hygroskopiska egenskaper och värmeledningsförmåga. Baserat på beräkningar av värmeledningsförmågan vid olika tryck har lämpligheten som kärnmaterial i VIP uppskattats. Testerna och beräkningarna visar att materialet framställt från alger inte har de egenskaper som krävs för att göra det lämpligt som kärnmaterial i vakuumisoleringspaneler i nuvarande form, men fortsatt utveckling av materialet och mer omfattande studier behövs för att dra säkrare slutsatser.

På byggnadsnivå är köldbryggor en annan aspekt av energihushållning, som blir mer framträdande när man isolerar med superisoleringsmaterial. Simuleringar gjordes för att uppskatta köldbryggorna i en tegelbyggnad från 1890 med invändig vakuumisolering. Studien fokuserade på köldbryggorna i och runt mellanbjälklagen. Resultaten av simuleringarna visar att köldbryggan från bjälklaget står för nästan 50 % av det totala värmeflödet genom den isolerade väggen. Köldbryggorna runt vakuumisoleringspanelerna är små i jämförelse och kan bortses från i detta scenario. De kan dock ha större betydelse i andra byggnader.

Nyckelord: Superisoleringsmaterial, vakuumisolering, vakuumisoleringspaneler, VIP, köldbrygga, kärnmaterial

Contents

Preface

This study was carried out in Gothenburg, at the division of building technology at Chalmers under the supervision of associate professor Pär Johansson. After contact with Sofie Allert at Swedish algae factory it was decided to evaluate the thermal properties for a silica powder made from algae, as a prospective core material for vacuum insulation panels. Swedish algae factory provided the samples needed for the tests and the information needed to make the calculations. All the test equipment used were provided by the division of building technology at Chalmers.

The other study, a case study of an old brick building in Mölndal undergoing renovations, focused on the thermal bridges of vacuum insulation panels and their effect on the heat flux compared to other thermal bridges in the construction.

I would like to thank everyone who has helped me with this thesis, by sharing their knowledge and experience and by encouragement in other ways. Special thanks to my supervisor Pär Johansson for much appreciated support, encouragement and patience. Thanks to Sofie Allert at Swedish algae factory for the idea of the tests and much needed information. Thanks to Bijan Adl-Zarrabi for sharing his knowledge on films for VIP and to Fredrik Domhagen for support and encouragement along the way.

Göteborg August 2020

Sara Bergström

1 Introduction

1.1 Background

Sweden is aiming to reduce the specific energy use in the building sector by 50% until 2050 (IVA, 2012). The building sector is responsible for 37% of the energy consumption in Sweden, of which 78% is heating (Boverket, 2016).

Around 50 % of the heated area in Sweden is built between 1940 and 1960, and are usually not as well insulated as modern houses (Boverket, 2010). Since most of the buildings are already built, and new buildings are not built in a rate that would compensate for the difference in energy use, we need to improve the energy efficiency of the already existing buildings. One way to do so is to increase the insulation when renovating or retrofitting.

According to calculations from BETSI (Boverket, 2010), 57 TWh per year is needed in Sweden to compensate for the heat losses and maintain desired indoor temperature. Almost 60 % is used by single family homes, almost 30 % by multi-family homes and around 15 % by businesses and public premises.

Every house that is going through retrofitting or a larger renovation should apply to the new building regulations, if possible, energy and effect requirements among others. These rules also apply to buildings of cultural significance and buildings that in any way has limitations regarding how the façade can be affected (Boverket, 2016). For these buildings the only possible way to insulate them may be on the inside of the wall. To minimize the waste of real estate a thin yet efficient insulation is preferred.

For buildings of cultural or historical value the regulations for new buildings may be hard or almost impossible to follow at the same time as the rules for historical buildings when making any significant changes. For this reason, there are also recommended U-values for different building parts if the overall energy demands cannot be met. For walls that value is 0.18 W/(m^{2}K) (Boverket, 2016).

One way the building sector is reducing the energy use is by using super insulation materials, especially when retrofitting older buildings. One such material is the vacuum insulation panel, which usually has a core made of silica. Unfortunately, the process of producing silica is very energy consuming, which makes the total energy savings less than they could be when considering a life cycle perspective (Karami et. al., 2015).

Swedish algae factory has developed a silica powder from algae that might be a possible alternative as a core material, with a more energy efficient production process.

1.2 Purpose

The aim of this study is to find some solutions to two of the biggest problems concerning energy efficiency for vacuum insulation panels (VIP). One of them is the energy consumption and environmental impact from the production of the panels, where the core material is the biggest factor. This study investigates performance criteria for alternative core materials for VIP to see if it is possible to replace the silica currently used with a silica powder made from algae.

The other problem is how to handle and reduce thermal bridges when insulating with VIP. This study focuses on how to handle thermal bridges when using vacuum insulation panels as internal insulation in a brick building from 1890. The aim is also to study how moisture affects the thermal performance of a brick wall with a wooden floor joist, and if that is something to consider when planning a renovation.

1.3 Limitations

This thesis focuses on vacuum insulation panels only, no other super insulation material is considered. The measurements carried out are made using available tools in the Building Technology lab. Only the silica powder provided from Swedish algae factory has been considered as an alternative core material and is compared to fumed silica.

The characteristic size of the silica powder is assumed to be equivalent to the pore size. The pore sizes are assumed to be evenly distributed.

For the simulations, this study focuses on buildings in Sweden, more specifically older buildings in or around Gothenburg. In the model for the simulations, the insulated wall is simplified and consists of just the original wall, one layer of VIP and gypsum boards. The simulations are made on a small part of the wall with a wooden floor joist. No other thermal bridges from the original construction are considered in this study.

2 Super Insulation Materials – an Introduction

Super insulation materials are materials with very low thermal conductivity. The biggest contributor to the thermal conductivity in conventional insulation materials are the air inside the material, with a thermal conductivity of 25 mW/m·K (Hagentoft, 2001). Reducing or even eliminating the gas conductivity gives an insulation material with much better thermal properties. The gas conductivity can be reduced by using a pore size that is close to or smaller than the mean free path, more in Section 2.2 and 3.5, or by evacuating the air. The air can be replaced with another gas with lower thermal conductivity or, as in the case with vacuum insulation panels, evacuated and sealed, creating a mild vacuum. The vacuum insulation panels use both small pores for the core material and vacuum, making it a very efficient insulation material. (Simmler et al, 2005)

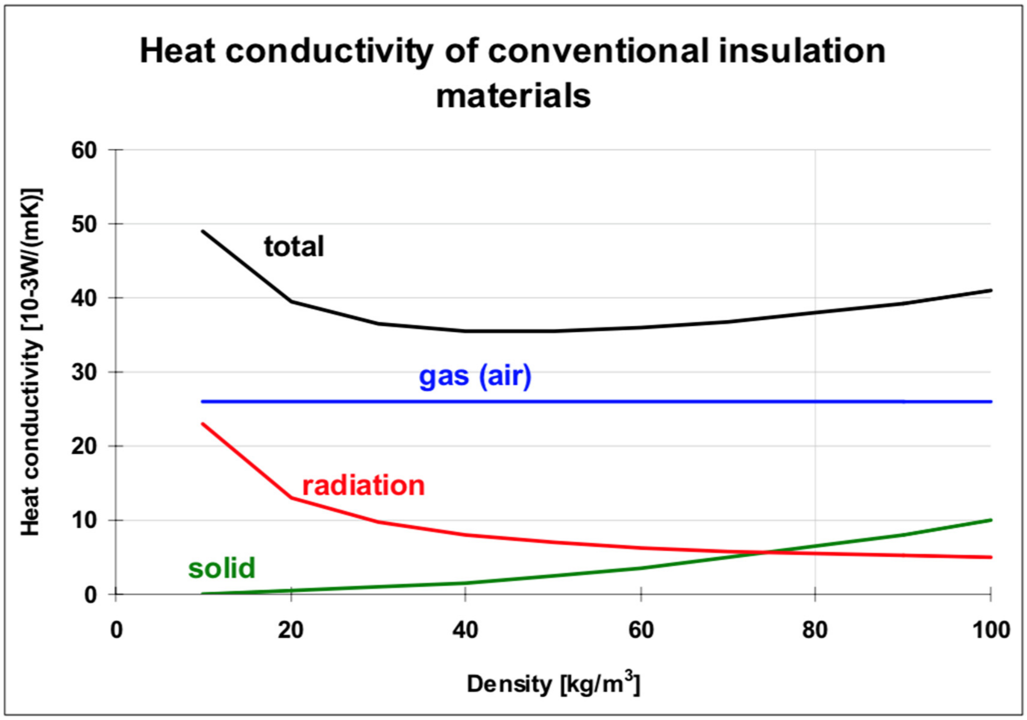


Figure 2.1 Heat conductivity of conventional insulation materials. Gas conductivity is the main contributor. (Simmler et al., 2005)

Examples of super insulation materials are vacuum insulation panels (VIP) and aerogel.

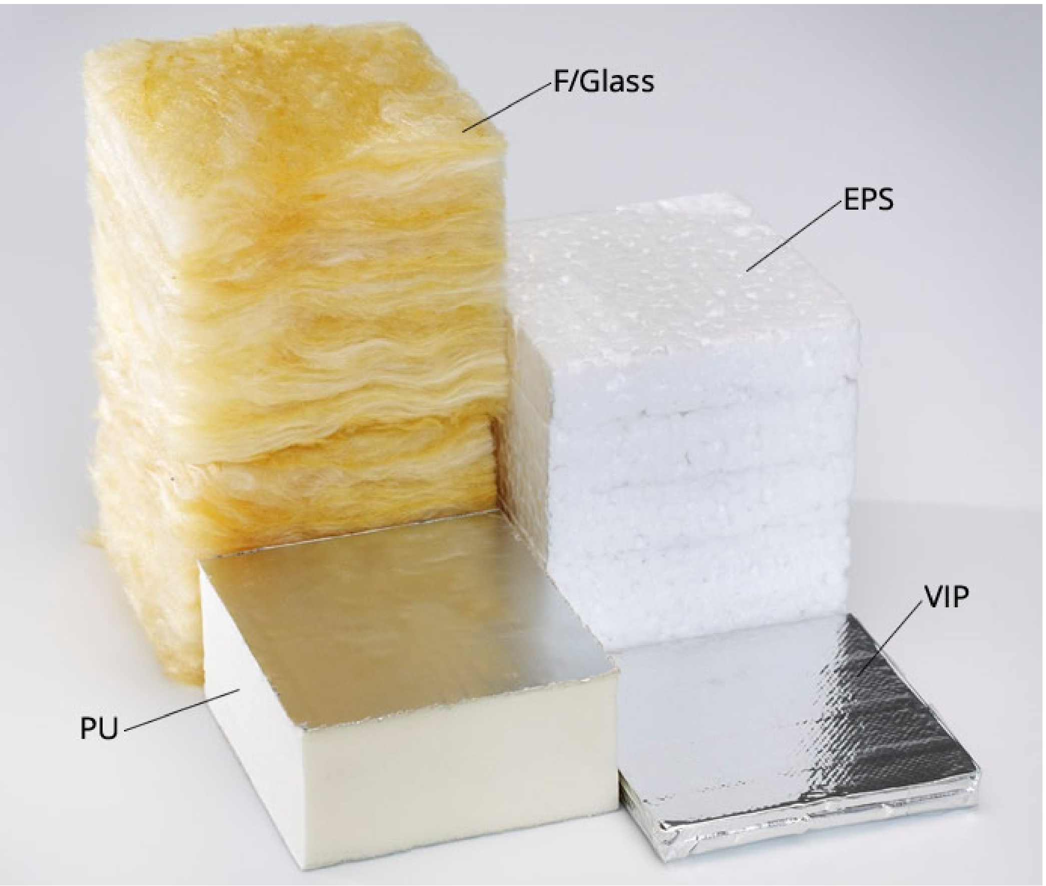


Figure 2.2 Comparison of insulation materials with the same thermal resistance. Photo: Kevothermal

2.1 The anatomy of a vacuum insulation panel

The vacuum insulation panel, also called VIP, consists of a core, a wrapping material and an outer film. The core material is usually made of fumed silica, with addition of silicon carbide and fibers (Karami et al., 2015). There are different types of films as well, such as Aluminum foil, stainless steel foil and a metallized film (Tenpierik et al., 2007).

Common thickness of VIP is 20-50 mm. For thicker insulation several layers can be used. The standard sizes are 300-1200 mm x 300-600 mm, but it can also be made to order in other sizes. (Kingspan, 2019)

Since the vacuum in the panel is crucial for its function, and the film surrounding it is thin, it is important to handle the panels with caution to avoid puncture. The delicacy of the product makes installation difficult and thermal bridges can be hard to avoid since there has to be a gap between some panels to allow for fastening of the surrounding layers. Some joints can however be sealed with a special adhesive aluminum tape. (Binz et al., 2005)

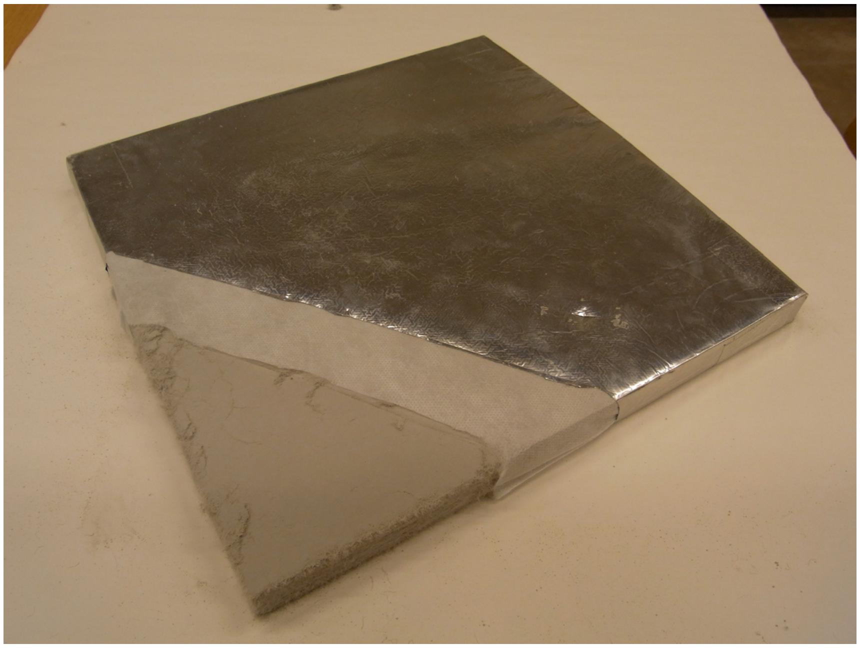


Figure 2.3 Vacuum insulation panel with core material, wrapping material and outer film visible. Photo: Pär Johansson

While the use of vacuum insulation panels in a building may significantly reduce the energy use during operation compared to a standard building, the energy used by the production of the material is so high that the total energy use is higher for a well-insulated building with VIP than a standard building. This is mostly due to the energy intensive production of the core material. The core material uses 90% of the total production energy for VIP. Alternative core materials and more efficient processes could reduce the energy use by 45% (Karami et al., 2015).

To be a suitable core material for vacuum insulation panels the material has to have certain qualities. It has to have an open cell structure to allow for adequate and quick evacuation of the panels and small pore size to give a lower gas conduction. It also has to be stable enough to withstand the compression due to the pressure difference between the inside and the outside. Radiation needs to be low as that in combination with the solid conduction is the main contributors to the thermal conductivity in the vacuum insulation panel. (Simmler et al., 2005)

2.2 Heat transfer in super insulation materials

The main function of a super insulation material is to reduce the heat flow through the construction. The heat transfer through an insulation material generally consists of three different parts, conduction through the solid matter, gas conduction and radiation. Convection can also contribute to the heat flux, but is considered negligible for vacuum insulation panels since the pore size is under 1 μm.

Conduction through the solid matter is normally the largest of the modes of heat transfer. To avoid that, insulation materials usually have a high porosity and a smaller part solid material. The conduction through the solid matter is dependent on the physical properties of the material, which makes some materials more suitable as insulation materials than others.

Heat transfer through radiation is the electromagnetic radiation that is emitted by all surfaces. The resulting heat transfer is the difference between the radiation from the warmer surface and the radiation from the colder surface. Increased surface temperature can give a rapid increase in radiation, that can however be reduced with an opacifier, such as silicon carbide.

The gas conduction is dependent on the type of gas used and its thermal conductivity. The heat is mostly transferred when gas molecules collide with each other. The collision between gas molecules and the solid material in the pore walls is elastic and transfers less energy. Smaller pores increase the likelihood of collision with the pore walls instead of other gas molecules and results in a lower gas conduction. This is called the Knudsen effect. The mean free path is a measure of the average distance between the collision of two gas molecules. This depends on temperature, pressure and molecular area. At standard temperature and pressure the mean free path of air is around 70 nm. The ratio between the mean free path and the pore size largely affects the gas conduction. (Berge et al., 2012)

3 Laboratory Measurements

After being contacted by Swedish algae factory, it was decided to perform laboratory measurements on a silica powder made from algae. The aim was to investigate if the powder would be a suitable substitute for the conventional silica in vacuum insulation panels.

The laboratory measurements were performed on a nanoporous silica powder made from algae. Swedish algae factory cultivates the algae and extracts the silica powder made for these measurements. To see if the algae silica would be suitable as a core material for vacuum insulation panels, measurements were made on specific heat capacity and thermal conductivity. Measurements on density and influence of moisture were also performed.

While there is no exact data available on the energy use during production of the algae silica, it is assumed to be significantly lower than that of conventional silica for VIP.

3.1 Specific heat capacity

The specific heat capacity is a measurement of the energy needed to heat a kilogram of the material 1 degree Kelvin. It is measured to achieve a more accurate value of the thermal conductivity.

3.1.1 Method

The specific heat capacity was measured with a differential scanning calorimeter, DSC. The machine used was from TA Instruments and used liquid nitrogen for cooling. For this test, a 100 µl aluminum container was used. First the empty container was weighed on a scale with a precision of 0.00001 g before it was filled with the material. To fasten the small lid, a special device was used, to make sure that the container was properly closed. The container was weighed again, and the weight of the test material was calculated. After entering the values into the experiment data and choosing test method, the container was placed in the machine. Next to it, an empty container of the same size and material was placed as a reference.

The method chosen for this experiment started with cooling of the containers to 10°C, before heating from 10°C to 100°C with a rate of 10 K per minute. After the first experiment, the results indicated that there was moisture in the material. Therefore, the powder was dried in a 105°C drying oven over night before the test was repeated with a new sample and the same procedure as described above.

Table 3.1 Sample weights for testing.

	Empty container	Filled container	Material weight
Test 1	79.76 mg	86.53 mg	6.77 mg
Test 2	79.58 mg	86.65 mg	7.07 mg

Figure 3.1 The silica powder in a plastic container and the samples for testing of specific heat capacity in small aluminum containers.

3.1.2 Measurement results

The specific heat capacity was found to be 0.45 J/g·K at 20°C when the powder was dry. Without drying the specific heat capacity was tested to 2.0 J/g·K at 20°C. As a comparison, fumed silica has a specific heat capacity of 0.85 J/g·K (Simmler et al., 2005).

3.2 Density

The density was measured to enable translation between volumetric and specific heat capacity. Since it is a lightweight powder, it does not compress by itself. Therefore, it was decided to measure the density for two different degrees of compaction.

3.2.1 Method

To obtain the volumetric heat capacity, the density of the silica powder needed to be known. Using a volumetric flask of 2 ml, the density was measured for two different degrees of compaction, spontaneously packed and shaken. The volumetric flask was first weighed empty, before carefully filled with the powder up to the 2 ml mark. The flask was then weighed again. After subtracting the weight of the flask itself and divided by the volume, the density for the spontaneously packed powder was obtained. The flask was gently shaken sideways to compact the powder. More powder was added, the flask was shaken again and repeated until the shaken powder reached the 2 ml mark. The flask with the compacted powder was weighed and the density of the shaken powder was calculated.

3.2.2 Measurement results

The density of the silica powder was found to be around 80 kg/m^3 when spontaneously packed, and around 100 kg/m^3 when shaken, see table 3.1. As a comparison, fumed silica has a bulk density of 38 kg/m^3 (Flexicon, 2019) and a tamped density of 50 kg/m^3 (Evonik, 2019).

Table 3.2 Density of the material, spontaneously packed and shaken.

	Empty flask	Flask with 2 ml material	Material weight	Density
Spontaneously packed	7.28319 g	7.44792 g	0.16473 g	82.4 kg/m^3
Shaken	7.28319 g	7.48068 g	0.19749 g	98.7 kg/m^3

3.3 Hygroscopic properties

To evaluate how fast the powder absorbed moisture from the surrounding air, the hygroscopic properties were examined. This was made to enable proper handling of the material regarding exposure to moisture in the following tests.

3.3.1 Method

Around 15 ml of the material was placed in a 100 ml heat resistant glass container. To ensure that the powder did not escape the container, while still allowing moisture to evaporate, a piece of paper was taped over the top. The container was weighed before placing it in a drying oven of 105°C. The next day, the sample was weighed again before it was put back in the oven. To ensure that the material did not attract any moisture between the oven and the scale, a piece of aluminum foil was held over the paper. After one more day in the oven, the sample was weighed again and compared to the last measurement, to see if the material was completely dry, before the testing began. The testing took place in a climate stable room at 20°C and 50% RH. The paper was removed and the container with the material was weighed again. A timer was started, with weighing every 2.5 minutes for 15 minutes, until the sample weight was higher than the weight before drying, which can be seen in diagram 3.2. The material was then placed in the oven again, and other tests followed when it had dried again.

3.3.2 Measurement results

The test shows that the absorption rate is high, after 15 minutes the test weight exceeds the weight before drying, indicating that the powder needs to be stored in an airtight container and exposed to surrounding air as little as possible when performing tests.

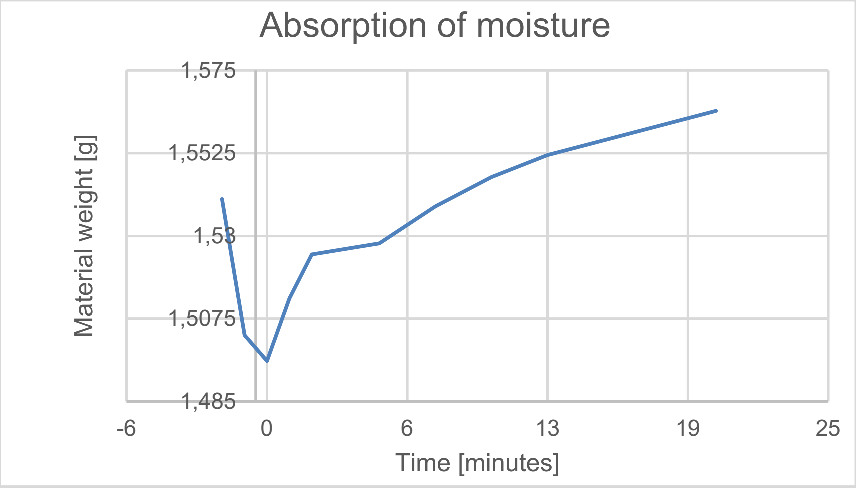


Figure 3.2 Absorption of moisture for the material.

3.4 Thermal conductivity

The thermal conductivity is measured to compare the performance with the current core materials.

3.4.1 Method

To measure the thermal conductivity, the transient plane source method (TPS) was used. The tests were performed in a temperature stable room, at 22.0°C.

The experiments started with one measurement, to confirm that the settings and placement of the sensor was accurate. After that followed a scheme with 5 minutes initial wait, followed by 5 measurements, with 30 minutes paus between them to ensure that there was no residual heat left from the previous measurement. The measurements were made with 10 mW heating power during 10 seconds. The sensor used is called 7577, with a diameter of 2 mm of the heating strip.

The powder was placed in a plastic jar that had a horizontal opening in the side for the sensor, 8 mm from the bottom of the jar. When making this type of measurement on a powder, it is important that the sensor is kept plane and placed inside the material. Therefore, the jar was first filled to the opening before the sensor was carefully placed through the opening and an equal amount of powder was poured on top of it.

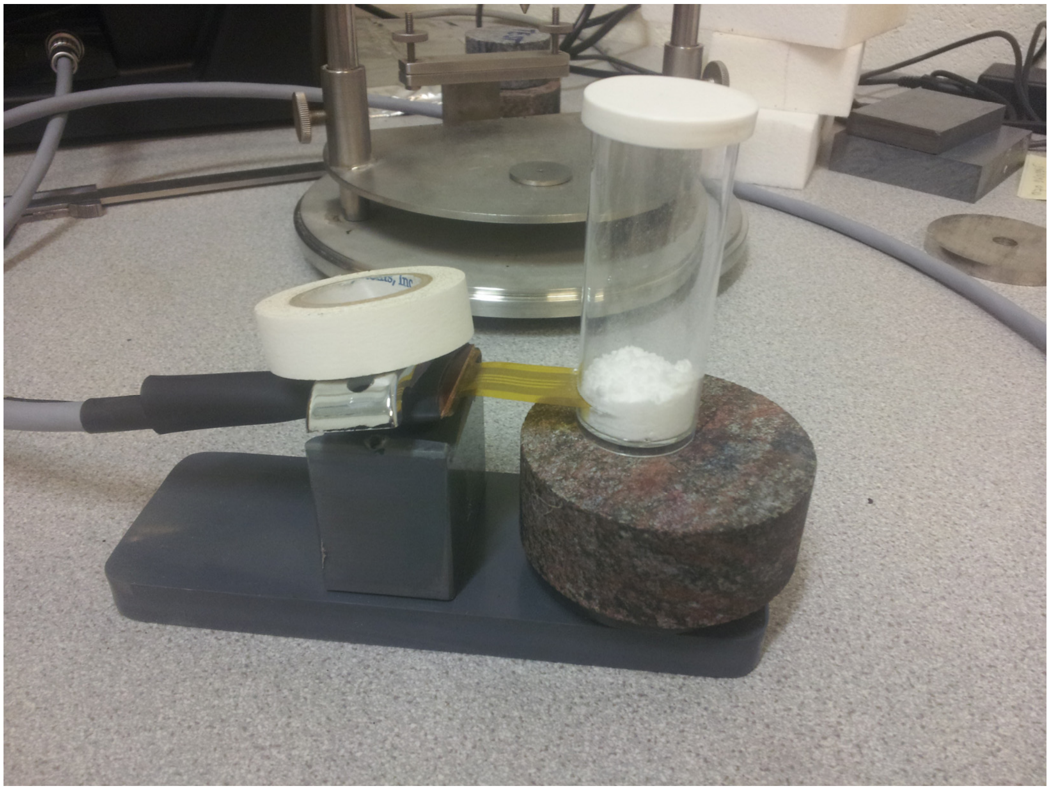


Figure 3.3 Test setup for measurements of thermal conductivity.

3.4.2 Measurement results

The thermal conductivity of the silica powder is around 39 mW/m·K, comparable to glass fiber or EPS.

Table 3.3 Test results from the last measurement of thermal conductivity.

Temp.	Th. Conductivity	Th. Diffusivity	Spec. Heat	Pr. Depth
22.0	0.0385	0.855	0.045	4.55
22.0	0.0387	0.859	0.045	4.56
22.0	0.0388	0.863	0.045	4.57
22.0	0.0390	0.868	0.045	4.58
22.0	0.0392	0.871	0.045	4.59

3.5 Thermal conductivity at low pressure

To evaluate if the algae silica was a realistic alternative as a core material in vacuum insulation panels, the thermal conductivity at low pressure was calculated.

To reduce the gas conduction, smaller pore size and lower pressure is used. The smaller pore size results in lower probability for air molecules to collide with each other and transfer energy as they are more likely to collide with the pore walls. The low pressure in a vacuum insulation panel means that there are fewer air molecules and further reduces the probability of a collision and therefore a reduction of the gas conduction.

To calculate the gas conduction, the Knudsen number is used. The Knudsen number is a dimensionless number, a ratio between the mean free path for that pressure and the characteristic system size. In this thesis, the characteristic system size is assumed to be the pore size of the powder. The mean free path is the average distance between collisions of molecules for a specific gas at a certain pressure.

The gas conductivity is calculated with the following equation:

$$\lambda_g = \frac{\lambda_{g0}}{1 + 2\beta K_n}$$

λ_g is the gas conductivity at a specific pressure, λ_{g0} is the gas conductivity at standard conditions, β is a constant describing the efficiency of heat transfer between the gas molecules and the pore walls and K_n is the Knudsen number, which is calculated with the following equation:

$$K_n = \frac{l_{mean}}{\delta}$$

Where l_{mean} is the mean free path and δ is the characteristic system size, which in this case is assumed to be equal to the pore size. The mean free path is calculated with the following equation:

$$l_{mean} = \frac{k_B T}{\sqrt{2} \cdot \sigma \cdot P_g} \ (m)$$

Where k_B is the Boltzmann constant, T is the temperature, σ is the molecular cross-sectional area and P_g is the gas pressure. For air at standard temperature and pressure the mean free path is around 70 nm. The vacuum insulation panels are evacuated to around 1 mbar. At that low pressure, the mean free path is much longer than at atmospheric pressure. (Berge et al., 2012)

According to Swedish algae factory, the pore size of the powder is 200 nm for the outer pores and 30 nm for the inner pores. It is assumed to be an equal portion of inner pores, outer pores and pores in between with the average size, 115 nm.

The calculations were made with three different values of thermal conductivity from the previous tests, to obtain an average value. Since the pores were of varying sizes, the calculations were made with each pore size separately and then weighed together. The pore size is assumed to be evenly distributed.

The average thermal conductivity from the calculations is 31mW/m·K.

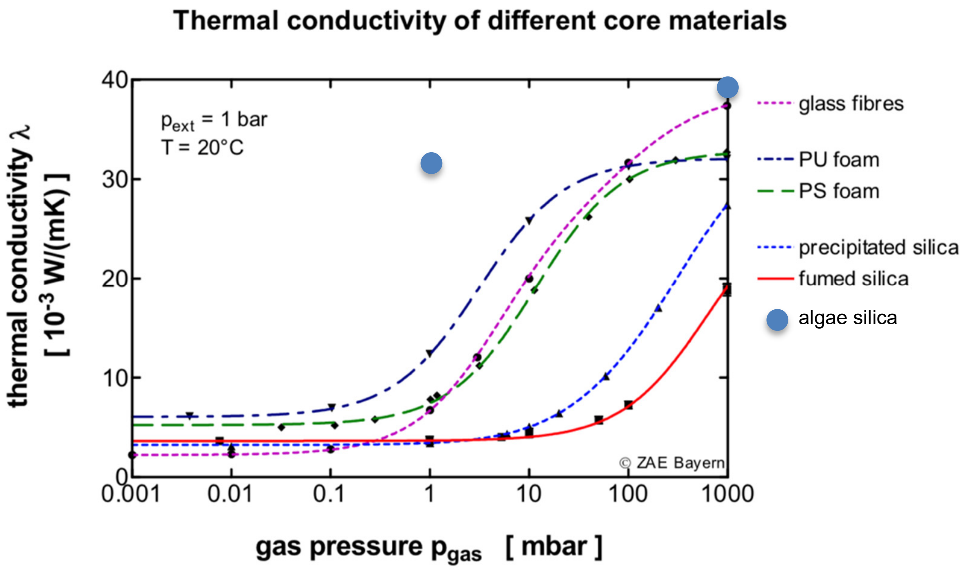


Figure 3.4 Thermal conductivity at different pressure for different core materials (Simmler et al., 2005). The tested silica powder marked in blue.

4 Simulations

4.1 Modelled building – a brick building from 1890

Figure 4.1 The modelled building in Mölndal. Photos: Pär Johansson

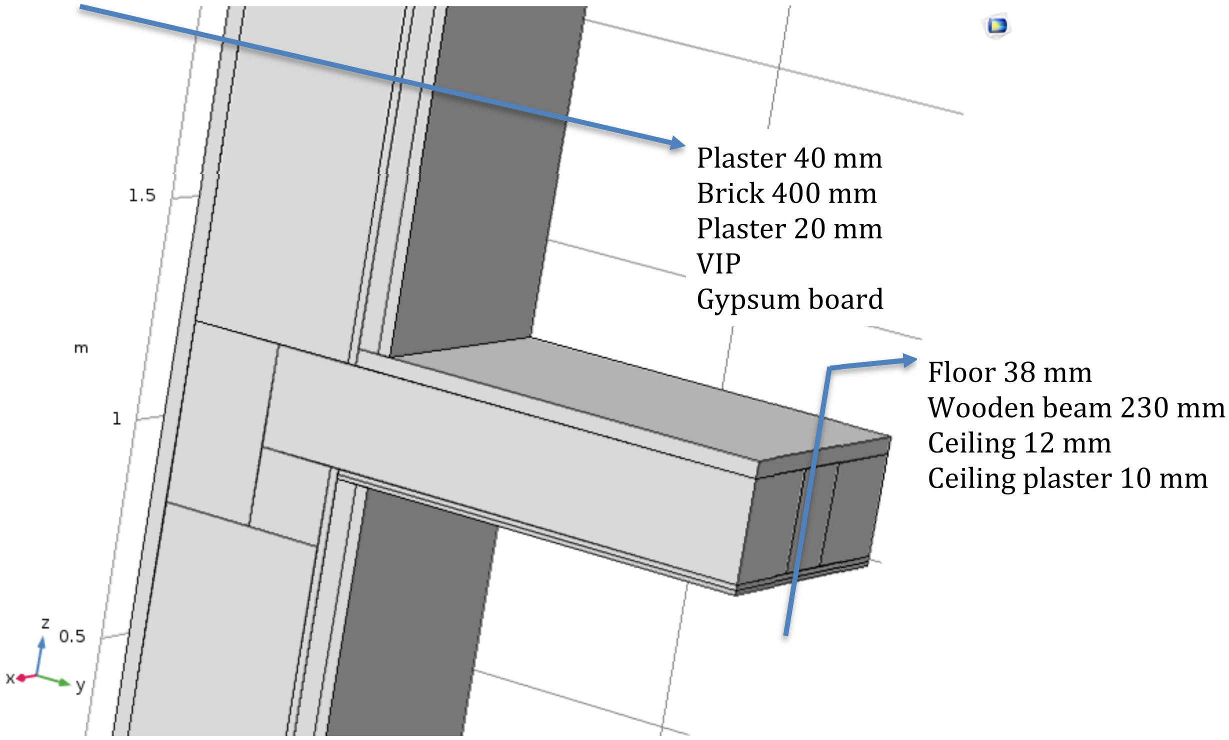
The modelled building is a brick building from the 1890s in Mölndal that is renovated to a new use as an office building. Part of the measurements used in the model are from the building, some are approximations and some are from the description of typical buildings from Björk et al. (2008). The building part modelled in this study is a part of the wall with the floor joist. The model and simulations are made in COMSOL Multiphysics.

The simulations are made to assess whether the moisture content of the materials is affecting the thermal performance of the wall and if the thermal bridges around the vacuum insulation panels are significant compared to the other thermal bridges in the modelled part.

The wall before renovation is assumed to consist of an outer layer of plaster of 40 mm, a solid brick wall of 400 mm and an inner layer of plaster of 20 mm.

The floor joist is modelled according to Björk et al. (2008) and consists of wooden beams 6” x 9” (150 x 230 mm) orthogonal from the wall, a wall plate 7” x 7” (180 x 180 mm) along the wall, a 38 mm thick wooden floor on top of the wooden beams and under the beams are a ceiling and ceiling plaster. The thicknesses are approximated to be 12 mm for the ceiling and 10 mm for the ceiling plaster. Between the floor beams there are sawdust, from findings on site.

For the insulated version of the wall vacuum insulation panels of 50 mm is used as a reference. The panels are placed on the inside of the wall. The needed thickness is also calculated. Between the panels and the room are 30 mm of gypsum boards.



Plaster 40 mm
Brick 400 mm
Plaster 20 mm
VIP
Gypsum board

Floor 38 mm
Wooden beam 230 mm
Ceiling 12 mm
Ceiling plaster 10 mm

Figure 4.2 COMSOL model of the wall with materials.

4.2 Moisture dependent thermal conductivity

For some materials, the moisture conditions affect the thermal conductivity. The wall is modelled with the thermal conductivities for different moisture content for the wood and the brick, to see if the moisture content of the materials has a considerable effect on the thermal performance.

The resulting moisture contents for a relative humidity of 40, 60 and 80 % were used. The thermal conductivity for different moisture content was gathered from the WUFI database.

The brick is not considerably affected by the moisture at that level. When the moisture content reaches saturation level the difference in thermal conductivity is big. It is however considered unlikely that the brick will reach those levels of moisture content for more than short periods of time. The wood is somewhat affected by the moisture, but since it is closer to the inside environment, it is assumed to be unlikely that it gets very humid. As can be seen in Figure 4.3, the heat flow through the floor joist (the top of the curves) varies slightly with different moisture content, but it will probably not have a significant effect on the overall heat flow.

The heat flux was measured in the center of the wall along the height. The measurements were made on the uninsulated wall, as the vacuum insulation panels have a moisture tight outer film. If the moisture content would have a significant effect on the heat flow through the wall, simulations would be made for the insulated wall as well to see in what way it affected the overall thermal performance and the thermal bridges.

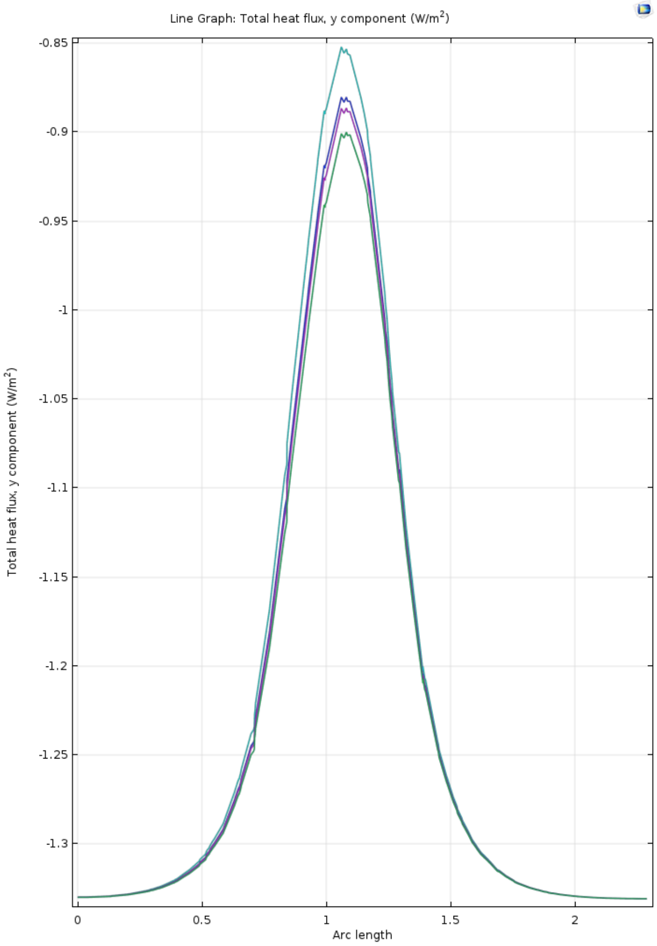


Figure 4.3 Heat flow through the wall with different moisture content for the materials.

4.3 Thermal bridges

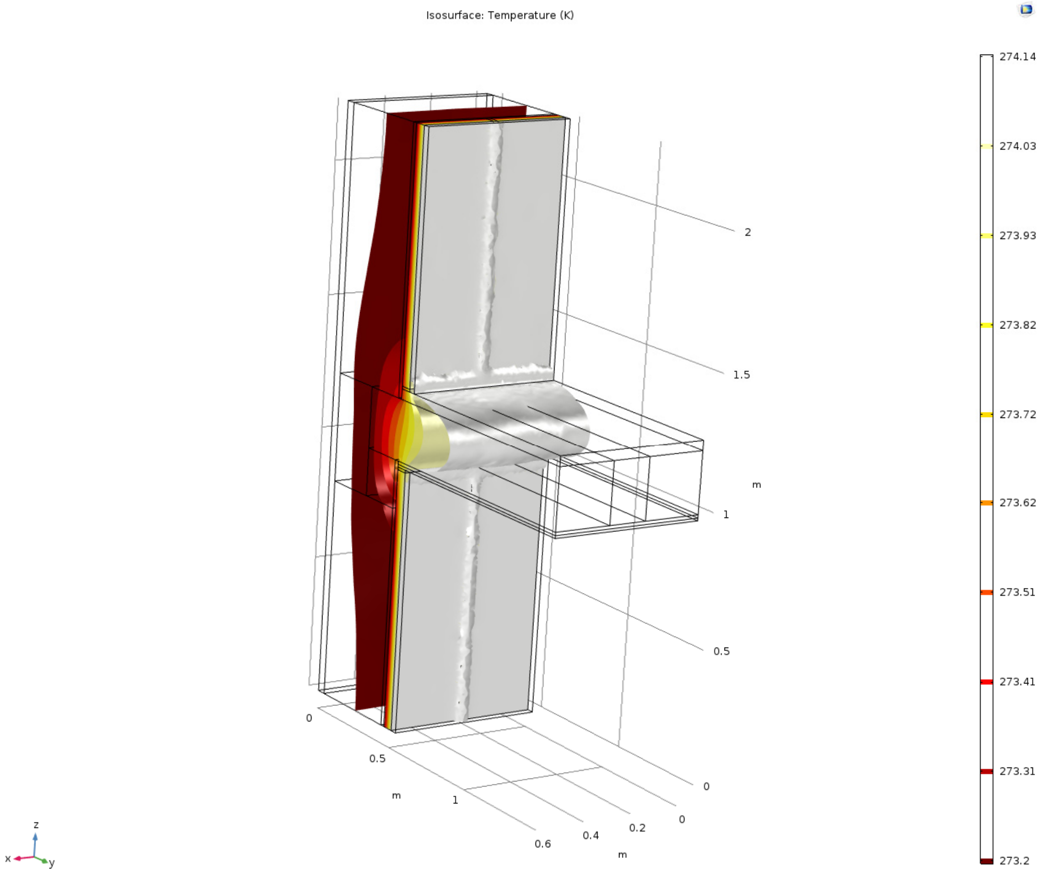


Figure 4.4 Isothermal contours of the insulated wall with mineral wool between the panels.

The thermal bridges of the wall were evaluated in different ways. Several simulations were made with different properties on the wall. The heat flow was measured and compared for different thermal bridges to evaluate their relative contribution to the overall heat flow.

The insulated wall was modelled first with a homogenous vacuum insulation panel on either side of the floor joist and then with two panels on either side with 20 mm mineral wool around them. The heat flow from the two simulations was compared, partly using isothermal contours. There was a difference in heat flow through the wall for the different cases, although the heat flow through the floor joist was much bigger.

To evaluate the size of the thermal bridge at the floor joist, the heat flow through the wall with floor joist and a homogenous VIP was measured and compared to the heat flow through a wall without any thermal bridges. The results show that the heat flow through the wall with floor joist is double compared to the wall without thermal bridges, making the thermal bridge responsible for half of the heat flow through the modelled part of the wall.

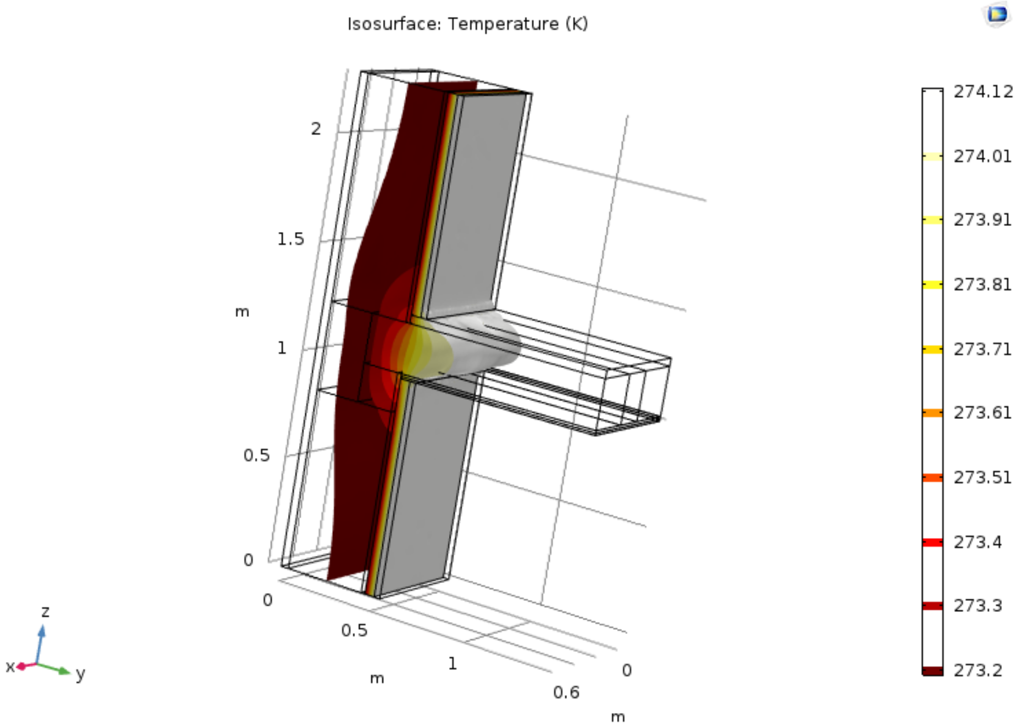


Figure 4.5 Isothermal contours of the insulated model without gaps between the vacuum insulation panels.

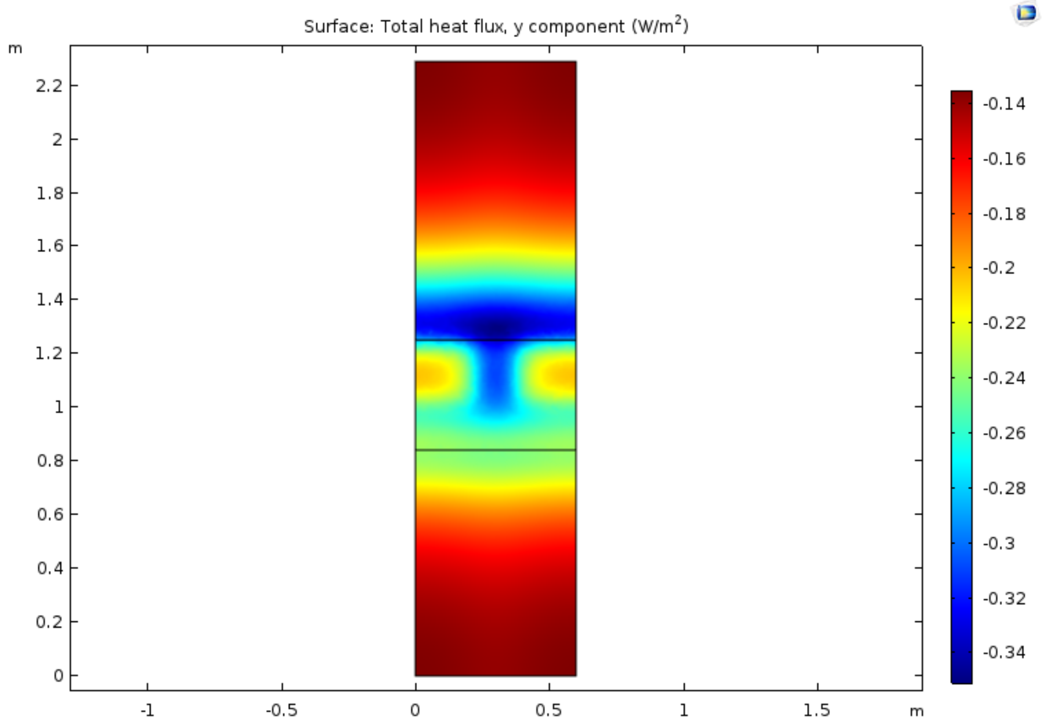


Figure 4.6 Heat flux in the wall 20 cm from the outside for the insulated wall with gaps between the panels.

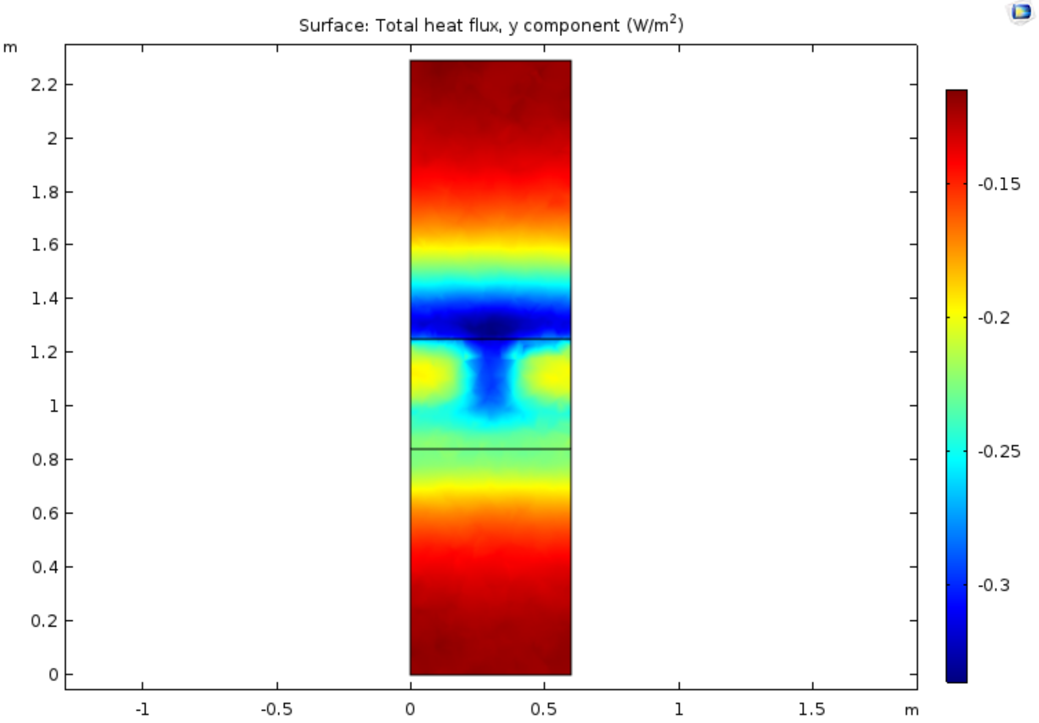


Figure 4.7 Heat flux through the wall 20 cm from the outside for the insulated wall without gaps between the panels.

5 Results and Conclusions

5.1 Results and conclusions from laboratory measurements

Table 5.1 Comparison of properties between tested silica powder from algae and fumed silica.

	Specific heat capacity	Density (bulk/tamped)	Thermal conductivity STP	Thermal conductivity 1mbar
Tested silica from algae	0.45 J/g·K	80/100 kg/m^3	39 mW/m·K	31 mW/m·K
Fumed silica	0.85 J/g·K	38/50 kg/m^3	20 mW/m·K	4-6 mW/m·K

The tested silica from algae have a lower specific heat capacity than fumed silica, but higher density and thermal conductivity, both at atmospheric pressure and at 1mbar.

The powder absorbs moisture from the air quickly, which means it needs to be handled in a way that it is exposed to surrounding air as little as possible. This is important since the thermal performance of the algae silica changes when the powder is not dry, leading to a higher thermal conductivity and specific heat capacity. Without drying the thermal conductivity at atmospheric pressure was 60 mW/m·K and the specific heat capacity was 2.0 J/g·K.

These tests show that the silica powder is not yet suitable as a core material in vacuum insulation panels, as the thermal conductivity at low pressure is too high.

5.2 Results and conclusions from simulations

At normal conditions, the moisture content of the materials will not affect the thermal performance of the wall in a considerable way. After a heavy rainfall the thermal conductivity may be temporarily higher, but will return to normal as soon as the wall dries again.

The floor joist is made mainly of wood and in the uninsulated wall it is the most insulating part of the wall. When insulating the inside of the wall with VIP the floor joist becomes a thermal bridge, since the wood has a much higher thermal conductivity than the vacuum insulation panels. When using a VIP thickness of 50 mm roughly 50 % of the heat flow through the wall goes through the floor joist. The thermal bridges from the VIP film and the gaps between the panels are relatively small. If using panels with metallized film, the thermal conductivity of the film is relatively low compared to other films and does not generate as big thermal bridge.

The required thickness of the VIP to achieve a U-value below 0.18 W/m^{2}K for the wall, as recommended in the regulations, is 30 mm. The floor joist is however a large thermal bridge, so it can be argued to use a thickness of 50 mm to compensate for that. However, the average U-value of the whole building and the specific energy use are the main parameters to consider when planning a renovation and consequently another thickness may be needed to comply to the regulations.

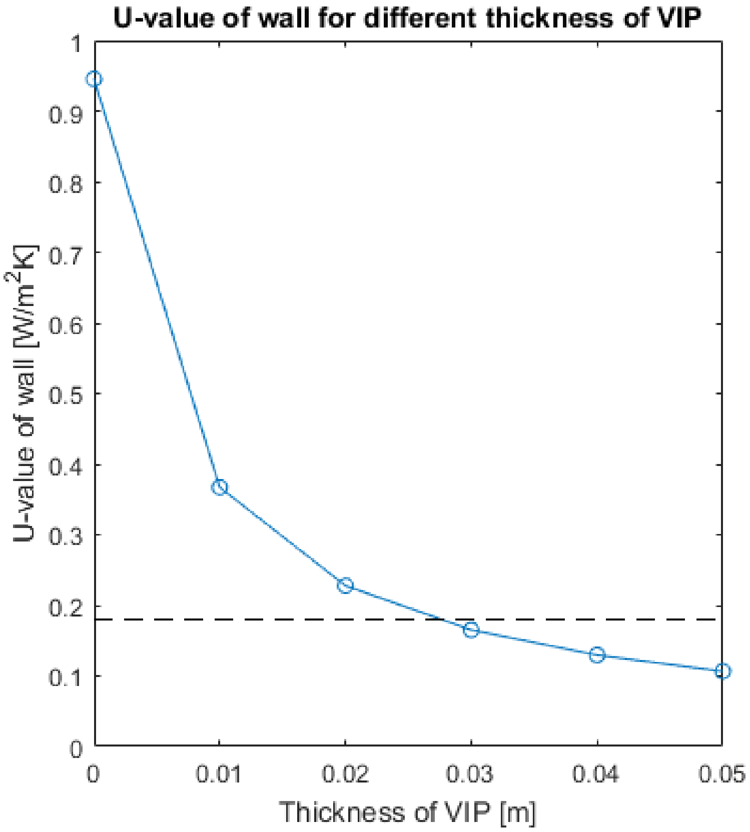


Figure 5.1 Calculated U-value of the wall, without thermal bridge, with different panel thickness.

6 Discussion

Although the tests and simulations were made carefully, there are some possible errors due to assumptions and human error and some ways the study could have been made better. This chapter discusses those possible errors and improvements.

When testing the specific heat capacity and thermal conductivity, the powder is only spontaneously packed, while the core material in the panels are tightly packed. That may make it harder to compare the algae silica with the current core materials. The sample sizes are also a thing to consider for the accuracy of the results. Many of the tests were made with very small samples, which makes the possible error proportionally bigger.

For the tests of thermal conductivity an improvised test jar was used, as there was no equipment available that fit the needs for testing powder with the transient plane source method. The opening in the jar was 8 mm from the bottom and the probing depth was 4.6 mm. To ensure that the probing depth does not risk exceeding the available depth in the jar the opening could be placed higher, or another type of container could be used. In this case it can however be considered enough, as the probing depth is only about half of the available depth.

The characteristic system size is assumed to be the same as the pore size for the calculation of thermal conductivity at low pressure, and an average value from the different pore sizes are used. If the characteristic system size is not equal to the pore size, the thermal conductivity at low pressure will be different. Since the pore sizes are partly assumed, that is a possible error too.

As this is a small study, it only covers a few of many alternatives for the wall construction. To get a fuller understanding of how the vacuum insulation panels contribute to and interact with the thermal bridges, more extensive research is needed.

The wall structure is simplified in this study and does not consider the fastening of the panels. It is modelled as the panels with a 20 mm gap consisting of mineral wool and covered with 30 mm gypsum board. A more realistic and detailed wall structure is needed to get more accurate results of the heat flow through the wall and how the chosen structure contributes to the thermal bridges.

No calculations or simulations were made to determine the exact size of the thermal bridges from the VIP film. Instead, a slightly higher value was used on the panels as an effective thermal conductivity, since the simulations would be too complex and time-consuming if the films were modelled as a freestanding material.

7 Future studies

To evaluate further, some more studies might be conducted. One thing to consider is the silica powder that is under development. It might be possible to mix it with an opacifier, silicone resin or some other material to get better thermal properties. To get more accurate results of the thermal conductivity at low pressure, it is necessary to determine the characteristic system size of the silica powder, if it is not equal to the pore size. The pore size might need to be evaluated with better precision as well.

The stability of the silica powder needs to be evaluated, to ensure that it can withstand the resulting pressure after the evacuation of the vacuum panel. Another option is to consider other insulation materials where the silica powder can be used. One possibility may be in structural insulated panels.

In this study, only one type of VIP was evaluated. To get a more nuanced picture of how thermal bridges affect the building when using VIP, other types of panels need to be evaluated and compared. Different core materials, and especially different types of outer film may result in differences in the thermal bridges. Different gap sizes, additional insulation materials and panel sizes would also need further evaluation to optimize the placements and minimize the thermal bridges.

To get a more accurate understanding of the thermal bridges from the vacuum insulation panels and its outer film, calculations can be made according to Tenpierik et al. (2007). Binz et al. (2005) also have examples of thermal bridges from the barrier film and the equivalent thermal conductivity for the panel for different films. Those values can then be used together with simulations to determine the total effect of the thermal bridges.

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