Manuscript Details

Manuscript number	ENB_2018_1725_R2
Title	Thermal Bridges of Metal Fasteners for Aerogel-enhanced Blankets
Article type	Full Length Article

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The use of silica aerogel-enhanced blankets as a thermal insulation material is one of the most promising solutions to reduce the heat loss through the building envelope. Aerogel-enhanced blankets provide exceptionally high thermal resistance, thanks to a thermal conductivity value as low as 0.014 W/mK. However, a challenge in the use of aerogel-enhanced blankets is represented by the way to connect these highly flexible panels to the backing support. This paper describes the effect of mechanical fasteners over the thermal performance of a brick wall covered with an aerogel-enhanced blanket investigated. The effective thermal transmittance of the selected aerogel-enhanced blanket due to the presence of the metal fasteners is evaluated experimentally using a calibrated chamber. The laboratory measurements are also compared with theoretical calculations conducted both for metal and plastic fasteners. Finally, some conclusions about the ways to reduce the thermal bridging effects during the installation of aerogel-enhanced blankets are provided, and the effective thermal conductivity of aerogel blankets considering different materials (plastic or metal anchors) for their fastening are reported.

Keywords	Silica aerogel; mechanical fixing; steel fasteners; heat transfer; super insulating materials; effective thermal conductivity.
Taxonomy	Thermal Insulation, Engineering

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Highlights

- The challenge of installing aerogel-enhanced blankets are investigated.
- Mechanical fasteners have considerable effect over the effective thermal properties of aerogel-enhanced blankets.
- Equivalent thermal conductivities are experimentally measured and numerical calculated.
- A moderate use of steel fasteners increases the effective thermal conductivity of the aerogel-enhanced blanket by over 50%.
- Calculated values for any concentration of plastic and metal fasteners are reported.

Thermal Bridges of Metal Fasteners for Aerogel-enhanced Blankets

Abstract

The use of silica aerogel-enhanced blankets as a thermal insulation material is one of the most promising solutions to reduce the heat loss through the building envelope. Aerogel-enhanced blankets provide exceptionally high thermal resistance, thanks to a thermal conductivity value as low as 0.014 W/mK. However, a challenge in the use of aerogel-enhanced blankets is represented by the way to connect these highly flexible panels to the backing support. This paper describes the effect of mechanical fasteners over the thermal performance of a brick wall covered with an aerogel-enhanced blanket investigated. The effective thermal transmittance of the selected aerogel-enhanced blanket due to the presence of the metal fasteners is evaluated experimentally using a calibrated chamber. The laboratory measurements are also compared with theoretical calculations conducted both for metal and plastic fasteners. Finally, some conclusions about the ways to reduce the thermal bridging effects during the installation of aerogel-enhanced blankets are provided, and the effective thermal conductivity of aerogel blankets considering different materials (plastic or metal anchors) for their fastening are reported.

Keywords: Silica aerogel; mechanical fixing; steel fasteners; heat transfer; super-insulating materials; effective thermal conductivity.

Nomenclature

φ: heat flux (W/m^2)

λ: thermal conductivity (W/mK)

R-value: thermal resistance (m^{2}K/W)

U-value: thermal transmittance (W/m^{2}K)

Ψ: linear thermal transmittance (W/mK)

χ: point thermal transmittance (W/K)

A: surface area (m^2)

P: supplied power (W)

1. Introduction

In literature, it is repetitively reported that buildings account for about 20% to 40% of the total energy consumption depending on the country, and are responsible for around one-third of the greenhouse gases (GHG) emissions globally [1]. To reduce both the energy consumptions and the GHG emissions due to the energy demand of buildings, construction codes increasingly ask for more insulated building enclosures, a target that requires adopting thick insulating materials within building envelopes. For the application of insulating layers to the rear walls, it is common to use chemical fixing (gluing with silicone sealant, spray adhesive or contact cement) or mechanical fastening (using plastic or steel fasteners).

The preferable attachment method for each insulating material depends on the needed fixing strength and the backing support characteristics. However, according to many codes, and especially for tall buildings, mechanical fixing is often preferred, given its long-term capability to connect different layers with reduced risks of loss of performance compared to chemical fixing. Moreover, fasteners offer an easy way to install the insulating layers and are easily adaptable to building geometries, which would otherwise require time-consuming practices if glues were used. The use of metal fasteners, rarely considered during the design stage, typically results in a significant reduction of the effectiveness of the thermal insulation. Such a poor building design and construction practice is often common for the installation of both foam and mineral insulating materials and may become extremely detrimental when highly insulating materials are adopted. In fact, high-performing insulating layers may see their behavior significantly compromised by the way in which they are secured to the building envelopes.

One of the most promising materials these days, and the object of this study is the aerogel-enhanced blanket. Aerogel is an expensive material that is preferentially used in applications where slim insulating layers are needed [2]. In particular, aerogel-enhanced blankets have a declared thermal conductivity value as low as 0.014 W/mK at room temperature and represent a promising solution for building envelopes in applications such as where glazing or facade systems meet cavity walls, where below-grade-systems meet above-grade systems, and where parapets meet roofs. Aerogel-enhanced blankets can be easily cut and conformed to complex shapes, adhering without difficulty to building products, and are suitable to be installed in difficult profiles such as curves and corners.

Jelle presented a comprehensive review about thermal insulation materials and reviewed the many advantages of recent innovative superinsulation products (i.e. materials with a thermal conductivity below 0.025 W/mK), such as aerogel-enhanced ones, over traditional insulating ones [3]. Cuce et al. also provided a comprehensive review about the advantages of aerogels compared to other materials, stressing the fact that the aerogels provide the same thermal resistance with 50% less thickness than polyurethane and 70% less than glass wool [4]. Although several researchers have reported the possible use of aerogels in translucent or transparent elements [5-8], it is in the opaque portion of the building enclosures that the most promising applications of aerogels have been proposed. In fact, as the energy demand and energy cost increase, aerogel-based products are expected to increase in the future, due to their high thermal insulation characteristics [9].

Galliano et al. reported that aerogel-enhanced layers can be used for efficient thermal insulation in thin panels, but the effective thermal behavior in real applications and under realistic conditions should be considered [10]. Several studies have recently looked at the hygrothermal properties of aerogel-enhanced products, and have investigated their thermal resistance degradation in real applications and under weathering conditions. Júlio et al. investigated silica-based aerogels molecular and pore structure in several renders [11]; Liu et al. studied the use of silane coupling to improve the compatibility between aerogel and mortar [12]; Ng et al. considered the effect on mechanical strength due to a partial replacement of ordinary Portland cement with calcined clay as binder; Gomes et al. studied the influence of moisture on the thermal conductivity of aerogel-based renders [13]; and Ng et al. investigated the effect of curing conditions at elevated temperatures on aerogel-incorporated mortar and ultra-high performance concrete [14,15]. Based on the experimental evaluation of the water uptake measurements and the related sorption curves, Nosrati and Berardi concluded that aerogel-enhanced products can effectively be used as moisture controlling layers thanks to their high water vapor permeability [16]. Similarly, Hoseini and Bahrami [17] and more recently Berardi and Nosrati [18] confirmed that limited reduction in the thermal resistance of aerogel-enhanced products in real conditions and over experimentally reproduced long-term conditions. Stahl et al. [19] and Wakili et al. [20] have recently reported the field monitoring of aerogel-enhanced renders for both the external and internal insulation in historic buildings. Previous studies showed excellent thermal conductivity values of aerogel-enhanced renders, typically around 0.020 W/(mK), but also stressed the importance of conducting studies real conditions and for typical applications.

Meanwhile, a growing literature has focused on aerogel-enhanced blankets, as a modern solution to guarantee high-thermal insulation in prefabricated and lightweight constructions. Aerogel-enhanced blankets are fire-resistant, with a Class A rating, and have an exceptionally low Flame Spread Indexes, often below 5, and Smoke Development Indexes, often below 10. They are hydrophobic, do not settle over time, have a low water retention (often within a few % points by volume) and have a permeability in the range of 2000 ng/Pa·m^2·s [16]. Similar to other aerogel-enhanced products, a growing research interest exists for the effective behavior of aerogel-enhanced blankets in realistic conditions.

Lakatos investigated the effect of humidity conditions above 90% R.H. on the thermal resistance of aerogel-enhanced blankets and found significant increases of the nominal thermal conductivity [20]. Moreover, he observed that the water adsorption of aerogel-enhanced blankets under wetting conditions did not depend on the temperature. Lakatos also analyzed the thermal conductivity of fibrous aerogel blankets fixed to brick walls using glue [21]: this study indicated that the fixing of aerogel-enhanced blankets on the surface of the wall is difficult since the blankets generate dust when handled [22]. Besides the chemical fixing of these blankets with glue, mechanical fasteners are often considered for the easiness and strength of their attachment method, which can be realized with a nail gun. Unfortunately, fasteners negatively influence the overall effective thermal transmittance. This means that laboratory measurements of the thermal conductivity of the aerogel-blankets alone are insufficient for an accurate evaluation of their infield thermal behavior.

Building insulation often suffers the effects of thermal bridges that compromise the thermal resistance of the enclosure. For example, several studies have already pointed out that the effects of mechanical fasteners of building insulating layers are not negligible [23,24]. In the case of the adoption of super-insulating materials, the effect of mechanical metal fastening is particularly significant as a result of the much higher thermal conductivity in the connecting point [25,26]. In this article, the authors focus on the effects of steel anchors over the effective thermal transmittance of aerogel-enhanced blankets. Fibrous aerogel-enhanced blankets were fixed on the wall firstly with glue, and then with different numbers of steel fasteners to replicate typical in-situ applications. Finally, the measurements with the calibrated chamber method were complemented with theoretical calculations to provide more information about the effects of fasteners of different materials and or with a different number of fasteners respect to that used in the experimental study.

2. Effective thermal transmittance

The heat loss through a building component is typically assessed through the thermal transmittance (or U-value) calculated according to the ISO 6946 [27]. In particular, the thermal transmittance is assessed based on thermal conductivity values, which are typically measured on small homogenous samples of building materials according to the ISO 8301 [28] or the ASTM 518 [29] based on the assumption of material homogeneity and constant unidirectional heat flux conditions. However, real building enclosures are not subject to controlled fixed boundary conditions and unidirectional heat fluxes. For example, thermal bridges in building enclosures are points of increased heat losses, lower temperatures, and higher risks of mold growth [30]. The impact of thermal bridges on the heating energy need of the building can be as high as 30% [23-26].

In a building envelope, two types of thermal bridging exist. The first type is a point thermal bridge, which happens when an insulation material is penetrated by a highly conductive one, as it is the case for metal fasteners, and that realizes a higher point thermal transmittance than elsewhere. The other type is a linear thermal bridge, which is characterized by a uniform reduced thermal resistance behavior in one direction. The linear thermal transmittance calculated according to the ISO 14683 [31] defines the measure of the linear thermal bridge. The standard ISO 10211 explains how to model a building element containing a thermal bridge [32]. This method is based on laboratory results of the effects of thermal bridges.

A common way for testing the thermal properties of building elements in laboratory conditions and to assess the effects of thermal bridges, is through the use of the calibrated chamber or the hot box method, as described in the standard ISO 8990 [33].

2.1. Point thermal bridge

The point thermal bridge is a localized thermal bridge whose influence is assessed by a point thermal transmittance. A point thermal bridge can be investigated within a quasi-homogenous layer, which consists of modelling two or more materials with different thermal conductivities, as a homogenous one with an equivalent thermal conductivity (λ_{eq}):

$$\lambda_{eq}=(A_1*\lambda_1+...+A_n*\lambda_n)/(A_1+...+A_n) \quad \text{(Eq. 1)}$$

where A_i is the surface area of each “i” material and λ_i is its respective thermal conductivity. The heat flow through the point thermal bridges is represented with the point thermal transmittance (χ), which is the steady-state heat flow rate compared to a reference heat flow rate, calculated disregarding the thermal bridge, divided by the temperature difference between the environments on either side of a point thermal bridge [32]. The standard ISO describes how to calculate the effect of mechanical fasteners in the U-value of the building facade based on the ISO 10211. The correction of the thermal transmittance for the presence of point thermal bridges is given by:

$\Delta U_f = n_f * \chi$ (Eq. 2)

where ΔU_f is the increase in the thermal transmittance resulted by the anchors and n_f is the number of fasteners The total thermal transmittance can then be obtained as:

$U_{tot} = U_0 + \Delta U_f = U_0 + n_f * \chi$ (Eq. 3)

The determination of the point thermal transmittance is hence [27]:

$\chi = (U_{tot} - U_0)/n_f$ (Eq. 4)

Sprengard et al. found that the metal anchors used for the mechanical fixing of vacuum insulation panels can increase their thermal conductivity up to 60% [34]. They noticed that when anchors cannot be avoided, plastic or glass fiber fasteners should be preferred to steel or aluminum fasteners. More recently, Sadauskiené et al. reported the effect of the mechanical fasteners on the energy performance of passive houses and showed that the point thermal bridges increase the U-value by up to 30% [23], although their tests revealed the strong dependence of the point thermal bridge on the thermal conductivity of the bearing layer material and the thickness of the wall-bearing layer. Ji et al. assessed the effect of different numbers of fasteners and evaluated how the effective thermal conductivity increases both with the number of the anchors and with the head area of the fasteners [24]. They highlighted that the detrimental effect of fasteners can be reduced through the optimized design of anchors application. Theodosiou et al. compared different both plastic and steel mechanical fasteners [35]. Capozzoli et al. presented a sensitivity analysis carried out on 36 thermal bridges, including the most typical junctions of the building envelope, and performed non-linear regression models of each thermal bridge calculated according to the ISO 10211. As expected, they found that the thermal bridges should be accurately considered whenever the thermal resistance of the envelope is significant [26]. Previous studies stressed the importance to consider the influence of mechanical fasteners as sources of potential thermal bridges for the building insulating materials. In the authors experience this is particularly important given the overuse of metal fasteners in real buildings as shown in Fig. 1. While this figure shows two buildings under construction using mineral insulation, it can be observed that the density of fasteners per square meter used to fix the insulating material (a mineral wool) to the backing wall is over 10 fasteners / m^2. Similar issues are commonly observed also in constructions using other kinds of insulating materials. Finally, an even higher density of fasteners can be overserved around corners, complex geometries, and design singularities, confirming the importance to investigate the thermal bridging effects of metal fasteners. For example, Fig. 2 reports the photos of the application of an aerogel-enhanced blanket (different from the one used during the investigation described in this paper) in a residential building in Italy using plastic fasteners, a solution less common and which will be studied in section 4.2.

Figure 1. Application of a mineral wool insulation layer in a commercial (left) and in a residential (right) building in Toronto, ON. The photos show the high number of metal fasteners typically used for the application of the insulation layer.

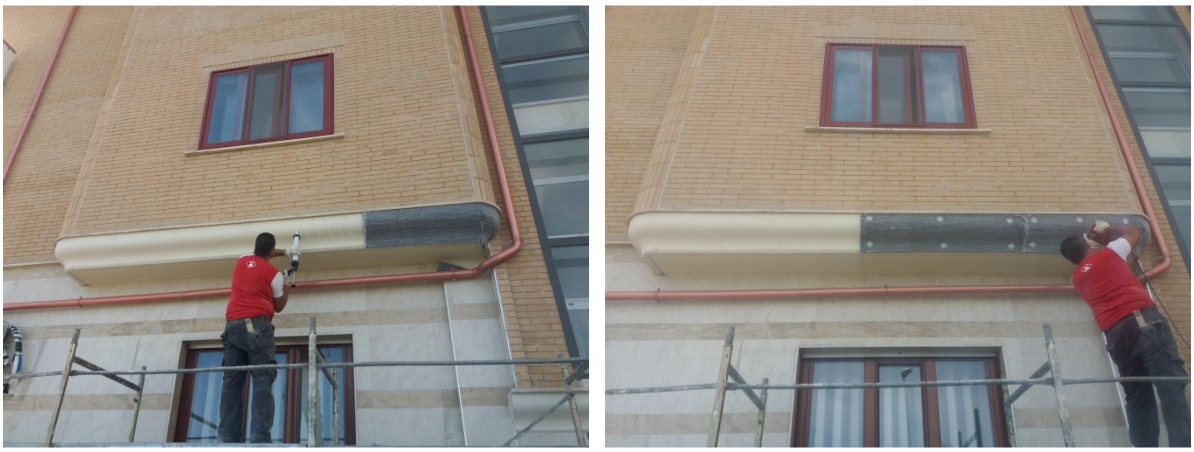

Figure 2. Application of an aerogel-enhanced blanket in a residential building in Troia, Italy. The photos show the application of the blanket first with glue (a silicone weather barrier sealant) and then with plastic fasteners.

The investigation of the steady-state thermal transmittance of a building structure presenting thermal bridges with hotbox method provides a complete thermal characterization. Moreover, the use of infrared thermography helps the quantification of the surface temperatures and so the assessment of the relative thermal bridge [36,37]. Wakili et al. [38] and Asdrubali et al. [39] presented several uses of the infrared thermography technique for the quantitative analysis of thermal bridges with active thermography. Zalewski et al. studied the effect of a steel junction inside a prefabricated panel with a thermography analysis, making a further refinement by heat flow meters and numerical models [40]. Bianchi et al. showed a methodology to investigate the thermal bridges through in-field assessments with IR thermography [41]. In this study, it was hence decided to use IR in conjunction to the hotbox method.

3. Materials and methods

3.1. Aerogel-enhanced blanket

Silica aerogels have extraordinary small pores, which result in remarkable thermal properties. While the compression strength of the aerogels has value around 300 kPa, giving to them a load-bearing capacity, their tensile strength is only 16 kPa, making aerogel extremely fragile [2]. In order to strengthen the tensile properties of the silica aerogels to be used as an insulating material, it has been repetitively proposed to reinforce the aerogels with mechanically stronger materials and non-woven fiber matrixes such as glass, mineral or carbon fibers. When the fibers or fibrous matrix are added to the pre-gel mixture which contains the gel precursors, the resulting dried composite is an aerogel-enhanced blanket [42]. Several studies have investigated the use of aerogel blankets in real buildings, and have discussed the in-situ behavior of such products [43].

Aerogel-enhanced blankets are flexible, highly porous and have a remarkably high thermal resistance. In fact, they have started to be produced and commercialized by several manufacturers worldwide. Aerogel blankets are available in thickness from 5 mm to 20 mm and have a thermal conductivity as low as 0.014 W/(mK). Table 1 reports the main properties of the aerogel-enhanced blankets currently available on the market.

Table 1. Main properties of common aerogel-enhanced blankets on the market.

Commercial name	Fiber composition	Density (kg/m^3)	λ (W/mK)
Thermal Wrap	Polyestere and PET	~70	0.023
Cryogel x201	Polyester/fiber glass	~130	0.014
Cryogel Z	PET / fiber glass	~160	0.014
Corning HPI 1000	Fiber glass	~170	0.015
Pyrogel HPS	Fiber glass	~200	0.014
Pyrogel XTE	Fiber glass	~200	0.014
Pyrogel XTF	Fiber glass	~200	0.014
Spaceloft	Polyester/fiber glass	~151	0.015
Joda fiber blanket	Fiber glass	<300	0.016
Joda ceramic blanket	Ceramic fiber	<301	0.016

The advantages of aerogel-enhanced blankets are that the final panel does not show any granularity of the aerogel since the aerogel particles are chemically attached to the fiberglass matrix. Most of the commercially available aerogel blankets are made with amorphous silica. Figure 3 shows the thermal conductivity values for different aerogel-enhanced blankets, based on the values declared by the manufactures.

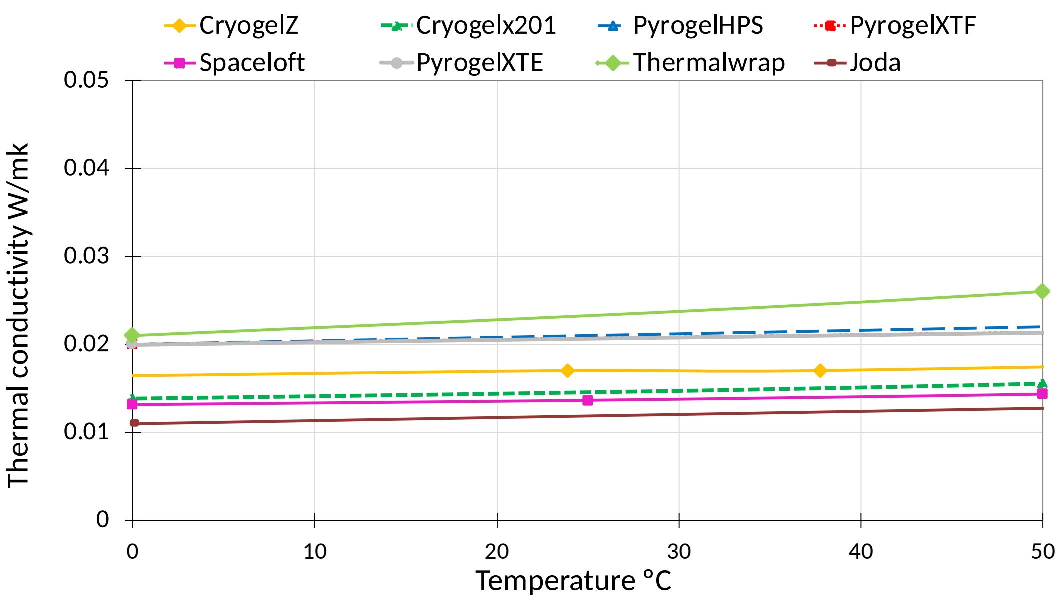

Figure 3. Thermal conductivity values across temperature for different aerogel blankets (this figure was drawn using the thermal conductivity values at different temperatures declared by the manufactures).

The investigation described in this paper was carried out using the Spaceloft blanket (Fig.4). Table 2 reports the properties declared by the manufacturer of the selected aerogel-enhanced blanket [44]. The fibrous aerogel-enhanced blanket is reported having a thermal conductivity of 0.014 W/mK. The product is hydrophobic, water vapor permeable, and does not show a capillary transport mechanism of liquid water. Figure 4 reports a photograph with a water droplet on the surface to show the hydrophobic nature of the product.

Table 2. Properties of the aerogel-enhanced blanket used in this paper [44].

Parameter	Value in the used aerogel-enhanced blanket
Thermal conductivity	0.013 W/m·K at 10°C (0.014 W/m·K at 24°C)
Flame and smoke spread	Class A: FSI <5, SDI 20
Reaction to fire performance	Euroclass C-s1, d0
Compressive stress / strain	80 kPa at 10% strain, 305 kPa at 25% strain
Specific heat	1.000 J/g·K at 40°C
Water vapor transmission rate	1877 ng/Pa·s·m^2 (dry cup method)
Thermal expansion	x: 1.06 x 10^{-5} K^{-1}, y: 1.90 x 10^{-5} K^{-1}
Water vapor sorption	mass gain 1.08%
Porosity	92%

Figure 4. The tested aerogel roll (above) and sample with a water droplet on the surface (below).

3.2. Steady–state thermal transmittance measurements

For the measurement of the thermal resistance, a nearly adiabatic test room, available in the Building Physics Laboratory of the University of Debrecen, was used. Figure 5 shows the measurement setup.

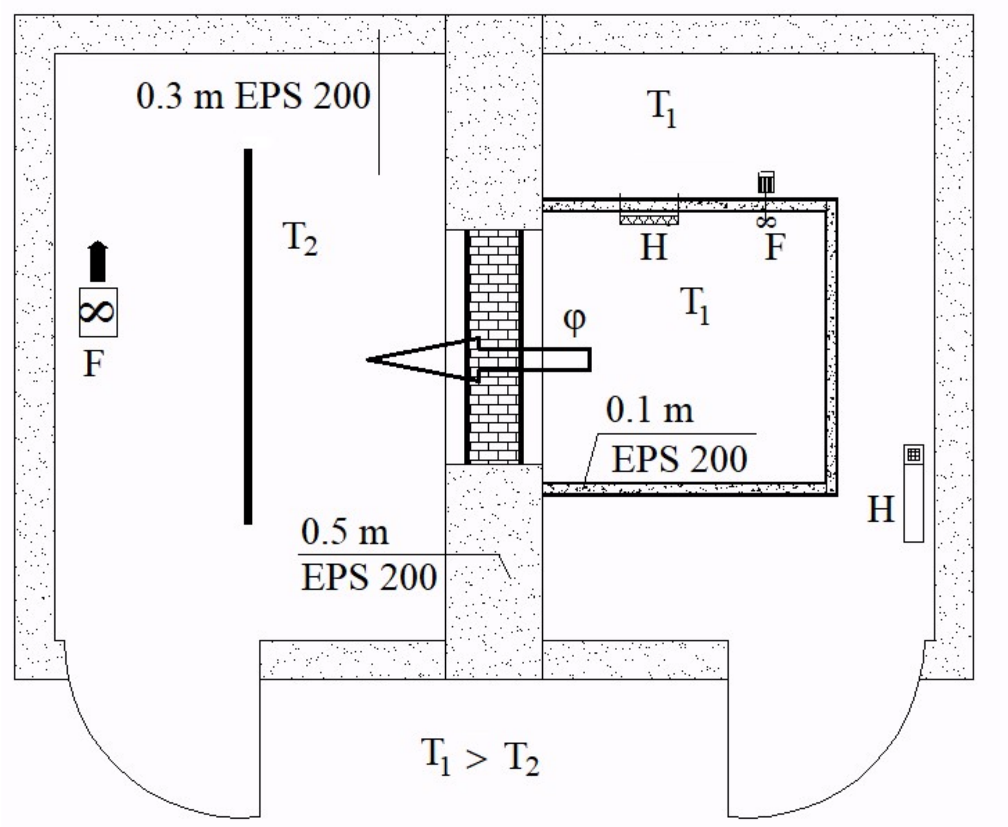

Figure 5. Thermal transmittance measurements setup (H is the heater, F is the fan, and T is the temperature).

The test room is divided into two rooms (cold and warm sides) with 2 m x 3 m floor area on in each side. Thanks to a 30 cm thick expanded polystyrene (EPS) surrounding walls, the test room is nearly adiabatic. In the 50 cm thick EPS dividing-wall, a 25 cm thick brick wall with a surface of 1.44 m^2 can be found. Thanks to the 50 cm thick EPS dividing wall no heat loss through it is expected, while the heat flux between the two chambers is expected to happen across the brick wall. The cold room (T_2) can be chilled down to 250 K by three separated cryogenics; the warm room (T_1) can be heated up by an electric radiator.

The brick wall was mortared with 2 cm thick cement plaster both on the warm and the cold side. On the cold side, the brick wall was then covered with a 13 mm thick aerogel-enhanced blanket. The aerogel-enhanced blanket was fixed firstly only with glue, then with five mechanical fasteners per square meter, and finally with nine fasteners to further strengthen the adhesion of the blanket to the wall. The fasteners were made of steel, their length was 50 mm, and their circle head had a diameter of 10 mm. The measurements in the test room were carried out according to the ISO 8990 standard [33]. The temperature outside the hot box was kept on the same value then inside the box (T_1). For measuring the temperatures of both the air and the surfaces of the wall on either side, Pt-100 thermocouples were used. The surface temperature of the walls was measured at 16 points arranged at equal distances from each other in a 4x4 matrix. Furthermore, the temperature of the air was measured by 4-4 pieces of Pt-100 thermocouples at both sides. The averaged values of the air and wall temperatures (ΔT_{air} and ΔT_{wall} respectively) were calculated both on the warm and the cold sides. Then, the measurement standard deviations were estimated as the ratio of the average deviances over the average temperatures.

In order to reach the ambient temperature inside the box, a small fan was used for circulating air and was heated by two bulbs with 40 W electric power each. The electric power of both the fan and the bulbs was measured outside the box with two calibrated electronic meters (P_1 and P_2 in Watts). On the cold side, one fan and two air baffles were used to reach air temperature homogenization. From the measured surface and air temperatures of the wall, the thermal resistance of the structure without the surface resistances (R_{wall}) was calculated using the following expressions:

$$R_{wall}=\Delta T_{wall}*A/(P_1+P_2)=\Delta T_{wall}/\varphi \quad \text{(Eq. 5)}$$

where $\varphi= (P_1+P_2)/A$ is the heat flux that is obtained from the measured electric power and the surface area. The thermal transmittance from the measured total thermal resistance was calculated according to the ISO 6946 [27]. Finally, the thermal resistance of the wall was obtained as:

$$R_{tot}=\Delta T_{air}*A/(P_1+P_2)=\Delta T_{air}/\varphi \quad \text{(Eq. 6)}$$

4. Results and discussion

4.1. Effects of the point thermal bridges

4.1.1. Measurement results

In Fig. 6, the placement of the steel fasteners on the base wall, and the layer structure with the penetrations are reported. The points labelled ‘I’ show the positions of the fasteners when the mechanical fasteners were 5; the points labelled 'II' show the additional four places of the steel fasteners when the mechanical fasteners were 9.

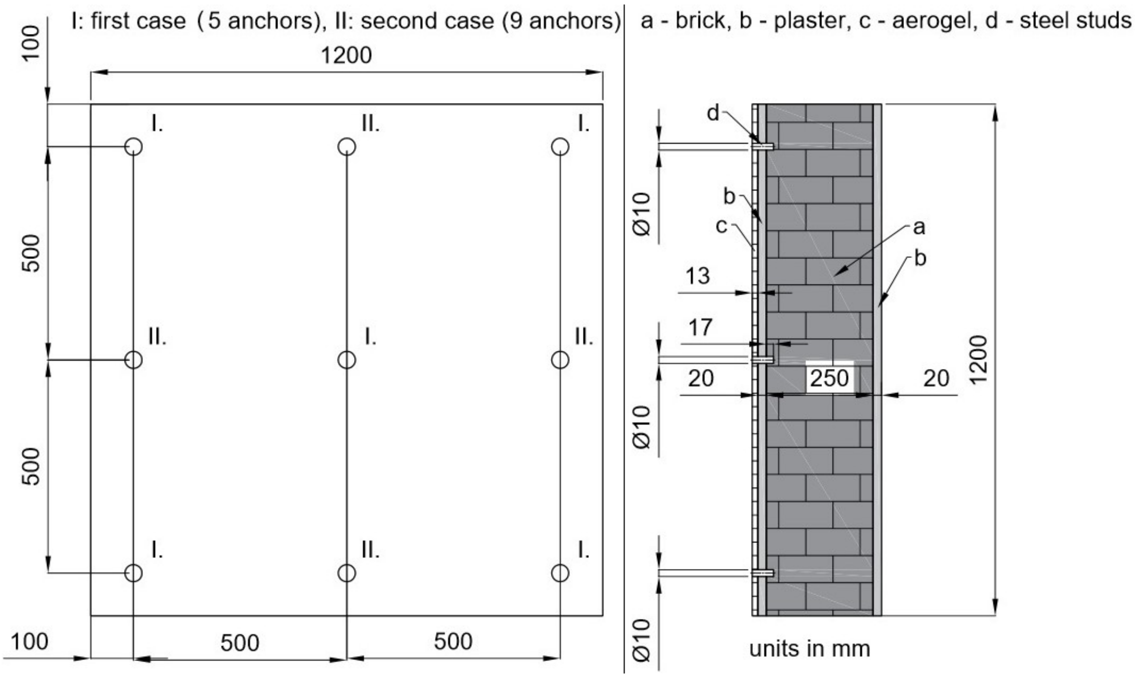

Figure 6. Position of the steel fasteners in the experiments "I" and "II" (left) and cross section of the investigated wall (right).

Figure 7. Photo of the investigated configuration with the aerogel blanket fastened to the back wall.

The steel fasteners penetrated the aerogel and then the brick wall for a total depth of 3.7 cm. The measurement results achieved with the calibrated chamber method on the solid brick base wall covered with 13 mm thin fibrous aerogel-enhanced blanket are reported in Tables 3 and 4. In these tables, besides the wall and air temperature differences, the heat fluxes are indicated too. Table 3 also reports the standard deviation estimated among the temperatures by the several thermocouples.

Table 3. The calibrated chamber measured results for the three conditions studied: only glue, low number of fasteners and high number of fasteners.

No. of fastener/1,44 m^2	No. of fastener/ m^2	Calculated heat flux (W/m^2)	Air temperature difference (K)	*st. dev. (%)*	Wall temperature difference (K)	*st. dev. (%)*
0	0	44.8	37.95	*1.36*	32.3	*1.23*
5	3	54.0	39.6	*1.44*	33.0	*1.18*
9	6	63.5	39.5	*1.42*	31.6	*1.03*

Table 4. Thermal properties calculated based on the results reported in Table 3.

No. of fastener per m^2	Wall thermal resistance (m^2K/W)	*± abs variation among measurements (m^2K/W)*	Overall thermal resistance (m^2K/W)	*± abs variation among measurements (m^2K/W)*	Decrease in thermal resistance of the wall (%)	Effective thermal conductivity of aerogel (W/mK)	*± abs variation among measurements* (W/mK)	Increase in thermal conductivity of aerogel blanket (%)
0	1.038	*0.040*	1.220	*0.044*	0	**0.021**	8.0E-04	-
3	0.880	*0.032*	1.056	*0.038*	15.19	**0.028**	1.0E-03	34
6	0.717	*0.023*	0.896	*0.032*	44.72	**0.044**	1.4E-03	108

The thermal conductivity of the aerogel was calculated with the following equation:

$$\lambda_{eq} = \text{thickness}/(R_f - R_0) = 0.013\text{m} / (R_f - R_0) \quad \text{(Eq. 7)}$$

where R_f is the thermal resistance of the wall covered with aerogel, the f-index refers to the number of the anchors (0, 3, and 6/m^2), and R_0 is the thermal resistance of the brick wall. The deterioration of the thermal resistance of the wall shows that by applying 3 and 6 anchors /m^2, the reduction of the thermal resistance of the wall was reduced by 15% and almost 45% respectively.

It can be noted that the application of 6 fasteners per m^2 resulted in an increase of the effective thermal conductivity of the aerogel-enhanced blanket by more than 100%. The change in the thermal conductivity as a function of the number of the fasteners shows a linear increase. These results are in a good approximation with the simulation predictions of Ji et al. carried out on mineral wool [24].

In order to assess further the effects of the fasteners, infrared thermography measurements were carried out with a thermo-camera on the cold side of the walls. Measurable differences in the surface temperatures emerged, as shown in Fig.8.

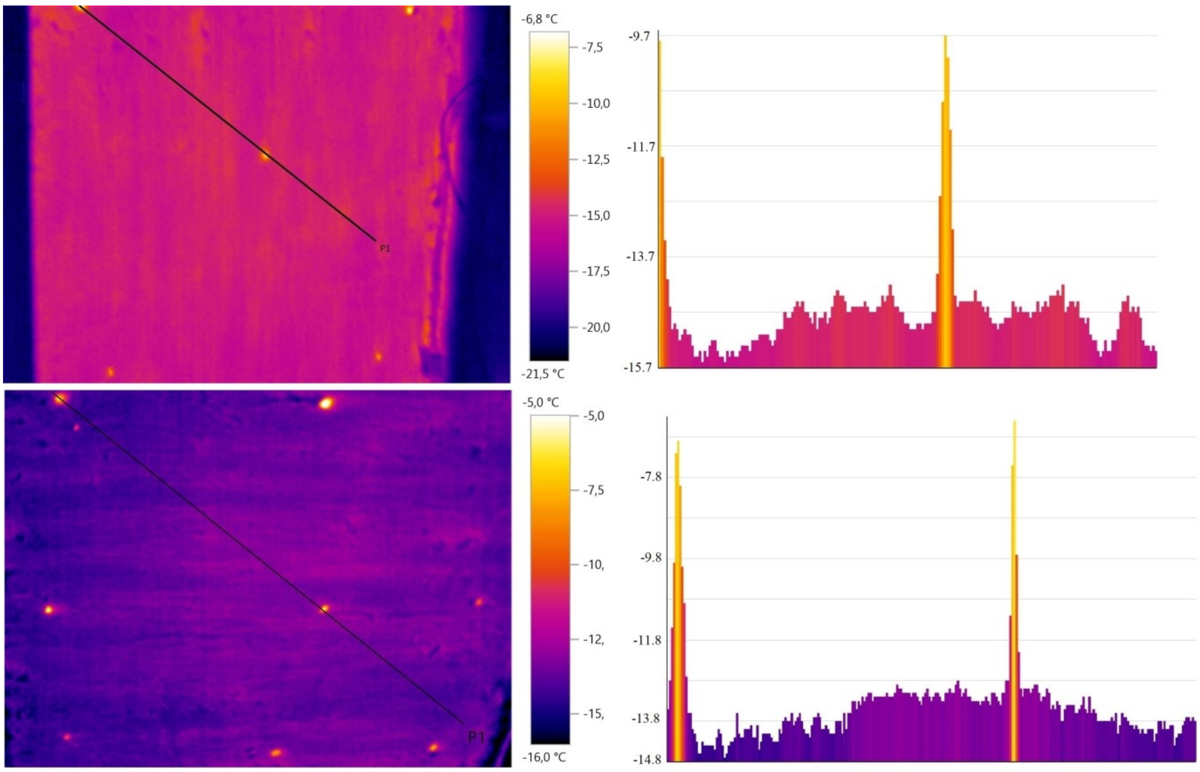

Figure 8. Thermography images of the wall with five (above) and nine (below) metal fasteners.

Figure 8 shows that the temperature images of the wall. The results of the temperature analysis were calculated through the IR software and are presented in Table 6. It is evident from the IR images that the temperatures through the fasteners and on the whole surface are much higher for the wall with 9 fasteners (a density of 6 fastener/ m^2).

Table 6. The temperature results of the infrared thermography reached with the IR software analysis Fig.8.

No. of fastener/1,44 m^2	No. of fastener/ m^2	T min. (^oC)	T max. (^oC)	T mean (^oC)
5	3	-15.6	-9.7	*-14.7*
9	6	-14.7	-6.4	*-13.4*

From the temperature line distribution, it emerges that more than 3 °C difference existed between the maximal temperature of the surface of the anchor was manifested. These results agree with the results of the wall temperature differences presented in Table 4.

4.2 Calculated results

In order to validate the measurement results, calculations of the thermal transmittance and the thermal conductivity were executed. In Fig. 9, the measurement results of the thermal transmittances (U-values) can be observed. Using Eq. (4), the point thermal transmittance values (χ) can be predicted: the χ-value was 0.0458 W/K and 0.0474 W/K for 3 and for 6/m^2 fasteners respectively. The results of the point thermal transmittance (χ-value) show the importance of considering the thermal bridge effects by looking at the in-sit installation techniques of insulating materials.

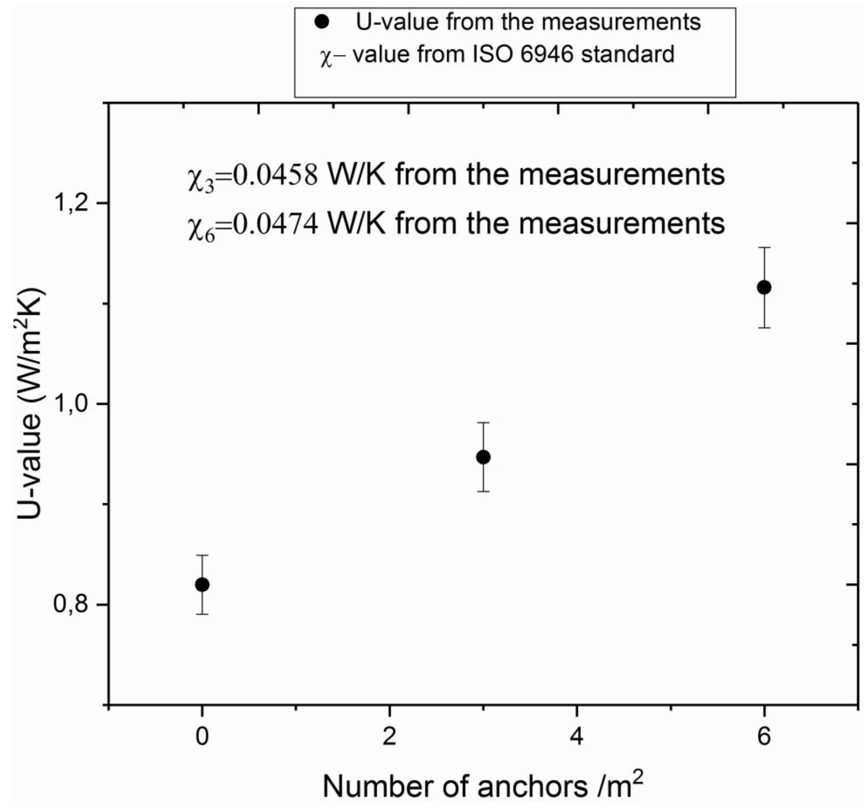

Figure 9. Measured and calculated U-values according to the standard ISO 6946 for the investigated wall in the three different configurations investigated experimentally.

Figure 10 reports the comparison of the measured equivalent thermal conductivities of the aerogel-enhanced blanket with the calculated values taking into account different materials of the fasteners and of their density. The calculation according to the ISO 10211 was done taking into account the head area of the anchors, and using the following thermal conductivity values [45]: an effective value of 0.021 W/mK for the aerogel-enhanced blanket, a thermal conductivity value of 0.09 W/mK for the glue, of 0.20 W/mK for plastic fasteners, and of 46 W/mK and 65 W/mK for steel anchors. The two used values of the thermal conductivity for the steel fasteners aim to represent different chemical compositions of the steel.

As it can be seen in Fig. 10, the equivalent effective thermal conductivity of the aerogel-enhanced blanket calculated assuming that the steel fasteners had a thermal conductivity of 46 W/mK well correlates with the measurement results. Although the results in Fig. 10 show the benefits of using plastic fasteners (as in Fig. 2), their adoption is limited given their poor fire resistance. In fact, the use of chemical and plastic fasteners especially in high buildings or in case of stringent fire regulations, often justify the preference for steel fasteners.

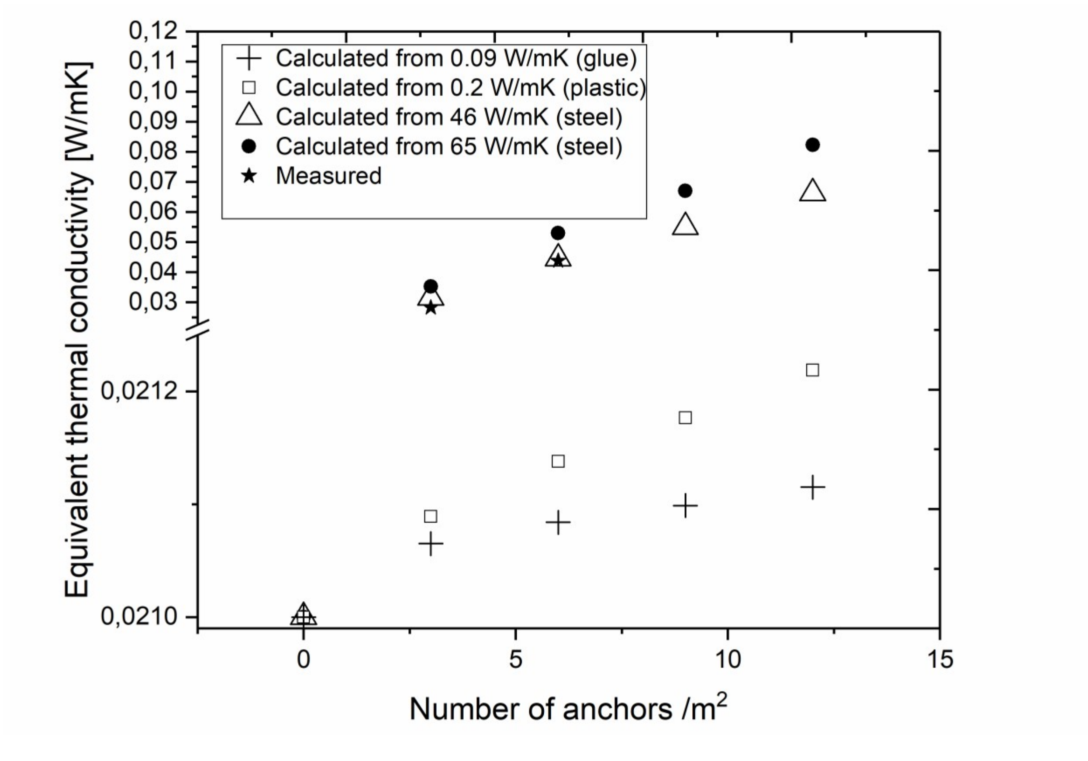

Figure 10. Measured and calculated effective thermal conductivity of the aerogel-enhanced blanket once the effect of fasteners (in different numbers per square meter and of different materials) is taken into account.

5. Conclusions

The study described in this paper allows to find useful practical considerations regarding the adoption of aerogel-enhanced blankets. Laboratory measurements carried out on aerogel-enhanced blanket insulated brick wall were reported. The blanket was fixed mechanically with 3/m^2 or 6/m^2 fasteners. Although the effect of the mechanical fasteners as point thermal bridges depends on the insulation and on the material of the anchors. The changes in the heat fluxes in the thermal resistance and in the thermal transmittance of the wall have been reported and discussed. The paper showed that the thermal resistance of the brick wall insulated with aerogel-enhanced blankets reduced by 15% with 3 anchors /m^2 and by 45% with 6 anchors / m^2. The use of the anchors exerts great negative influence on λ_{eq} of the insulation system. In the case of 3 and 6 anchors / m^2, the equivalent effective thermal conductivity of the aerogel-blanket layer alone increased by almost 30% and 100% respectively. The study hence evaluated the effective thermal resistance that could be obtained through the use of glue or plastic fasteners. The values of point thermal transmittance will allow designers to carry out correct calculations of the thermal resistance of external building components.

Acknowledgments

The first author acknowledges the financial support of the Natural Sciences and Engineering Research Council of Canada (NSERC) for the DG #2016-04904, and the Ontario Ministry of Research Innovation and Science (MRIS) for the ERA award. The work of the second author was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and was also financed by the Higher Education Institutional Excellence Programme of the Ministry of Human Capacities in Hungary within the framework of the Energetics thematic programme of the University of Debrecen.

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