Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 376 – 381

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Effect from a Variable U-Value in Adaptive Building Components with Controlled Internal Air Pressure

Axel Berge[a]*, Carl-Eric Hagentoft[a], Paula Wahlgren[a] ,Bijan Adl-Zarrabi[a]

[a]*Chalmers University of Technology,Sven Hultins Gata 8, 412 96 Göteborg.*

Abstract

A variable U-value would be beneficial for a buildings thermal performance. One way to switch the U-value of a wall, insulated with nano-porous material, is to change the internal pressure of the insulation This paper present thermal conductivity measurements showing a possible variation around of 3 times for a fumed silica and less than 2 times for an aerogel blanket when the pressure was varied between 1 and 100 kPa. The variation factor of 3 was used in building energy simulation of a Swedish office showing that a U-value which can be varied within that range can give a significant reduction energy demand. Especially when energy used for cooling is weighted as worse than energy used for heating.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Adaptive façades, Switchable U-value, Variable U-value, Adaptive U-value, Thermal Conductivity, Energy balance

1. Introduction

For cold climates and buildings with a high heat load, the optimal U-value varies. When the heat load peaks, there is a need for cooling while heating still is needed cold days and when the activity is low. A low U-value would help to keep the warmth indoors when heating is needed while a high U-value would help to cool the building when the outdoor temperature is lower than the indoor temperature. Hagentoft shows that an adaptive U-value would have a positive influence on the indoor temperature [1]. For a building with controlled indoor temperature, the adaptability would rather decrease the energy used in the climate system.

* Corresponding author. Tel.: +46-31-772 1990.
E-mail address: axel.berge@chalmers.se

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.677

There are already many different systems or concepts for adaptive façades. Loonen has made an extensive literature survey finding a lot of examples [2]. Most examples are concerning transparent facades and the adaptability is mostly connected to handling the solar gains. For opaque walls, the U-value can commonly be made lower than for transparent walls, why it is of interest to create adaptable solutions for these as well.

In conventional air filled insulation, the gas conduction can be considered constant and independent of the material. The solid conduction and radiation are, on the other hand, dependent of the density, where a low density will lower the solid conduction while the radiation increases. For materials with a high porosity, the thermal conduction through the gas represents the larger part of the thermal conduction. The thermal conductivity of the material could be switched by alternating the internal pressure, a concept that have been presented in a patent already 1976 [3]. A problem with the concept is that a very low pressure is needed to reduce the gas conductivity under normal circumstances. One solution to this is to have a chemical reaction releasing and reabsorbing a gas in an isolated cavity, thus changing the pressure. One such solution uses metal hydrides to vary the hydrogen amount in stainless steel panels [4,5]. They study the application mainly for automotive applications and solar collectors.

Another way would be to use nano-porous materials for which even a smaller change in internal pressure gives a noticeable change in the thermal conductivity. The possibility to utilize this phenomenon is studied in this paper.

1.1. Scope

The aim of this study is to investigate the impact on the energy demand by using a variable U-value for a commercial building in Swedish climate. The U-value is varied by changing the internal pressure in nano-porous insulation material. The study covers measurements of thermal conductivity in an aerogel blanket and a fumed silica at various pressure levels. The results of the measurements was used for simulation of the building energy demand.

1.2. Method

The thermal conductivity measurements was made in a guarded heat flow meter apparatus on a sample in an airtight bag with varying internal pressure. The energy simulations were done according to Petersson [6] for one year of measured hourly data in Göteborg, Sweden.

2. Thermal conductivity in nano-porous materials

The thermal conductivity of a gas in a porous insulation material can be calculated by Equation (1) [7]:

$$\lambda_g(p_g) = \frac{P\cdot\lambda_{g,0}}{1+2\cdot\beta\cdot\frac{l_g}{D}} \qquad (1)$$

where λ_g (W/(m·K)) is the thermal conductivity of a gas, p_g (Pa) is the gas pressure, P is the porosity (-) of the material, $\lambda_{g.0}$ (W/(m·K)) is the thermal conductivity of the gas at ambient pressure, β is energy transmittance coefficient for collisions between gas molecules and the pore walls, Baetens et al. gives this a typical value between 1.5 and 2 [8], lg (m) is the mean free path of the gas defined as the length a gas molecule would travel before colliding with another gas molecule and D is a characteristic pore diameter of the pore system.

The influence of the pressure on the thermal conductivity is shown in Fig. 1 based on Equation (1) and air molecules. For materials with small pores below 100 nm, the thermal conductivity changes almost linearly with a change in pressure. For aerogels pore diameters in the range of 0.3 to 100 nm can be derived [7] and for silica aerogels in particular Soleimani Dorcheh et al give a typical average pore diameter around 20 nm [9].

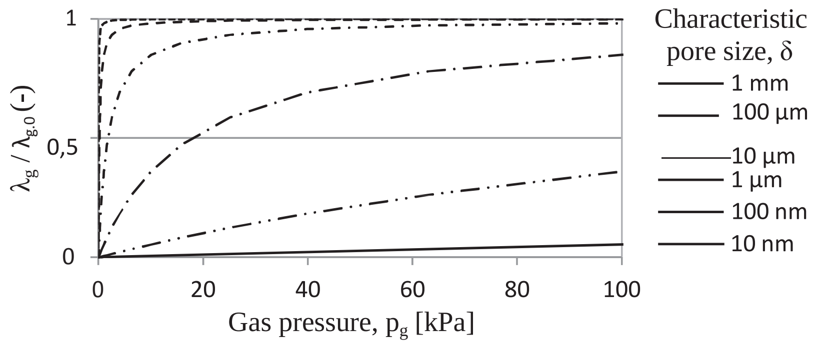

Fig. 1. Theoretical relation between the thermal conductivity of a gas and the gas pressure for various characteristic pore sizes.

3. Measurements with Guarded Heat Flow Meter

The thermal performance of evacuated nano-porous insulation has been measured in a Guarded Heat Flow meter. Measurements have been performed on one sample each of an aerogel blanket and fumed silica. The test set-up is presented in Fig. 2. The samples were placed in an air tight sample bag surrounded by a perforated tube to guarantee a good evacuation. The air is evacuated through a polyurethane filter to avoid material particles to damage the vacuum pump and the manometer. The internal pressure is controlled by the valve.

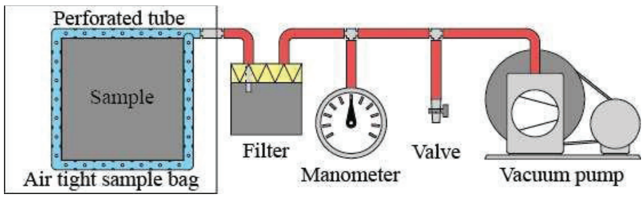

Fig. 2. Measurement set-up for thermal conductivity measurements on samples with varying pressure.

The sample with the dimensions 300x300 mm^2 was put in a Guarded Heat Flow meter. The heat flow is measured through the center of the cold side of the sample (100x100 mm^2). The results from measurements at steady state are presented in Fig. 3. The results indicate a close to linear variation in the apparent thermal conductivity with varying pressure. The apparent thermal conductivity is calculated from the nominal material thickness to represent the materials function in a wall assembly, otherwise the evacuated material would appear to perform better since the evacuated sample would is compressed. Using the measured results, the variability was calculated, defined as the highest thermal conductivity divide by the lowest and denoted by ξ. The variability is around 3 for the fumed silica and less than 2 for the aerogel blanket. It is worth noticing that none of the materials have been optimized for this type of application.

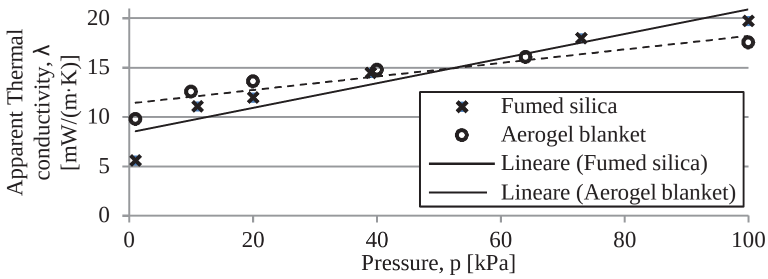

Fig. 3. Thermal conductivity at various pressures for a fumed silica and an aerogel blanket.

The thermal conductivity was also measured continuously while the pressure changed between 1 kPa and atmospheric pressure. For the fumed silica, the pressure was changed every 40 min and the results are presented in Fig. 4. The measurements show some delay of the change in heat outflow, presented as an apparent thermal conductivity. At the start of the change there are some small peaks. Some reasons for this behavior might be:

- The delay could be explained by the gas molecules taking some time to be evenly spread in the nano-porous structure.
- The delay could also be explained by a thermal resistance between the regulated cold plate and the sample in the measurement equipment, creating a new steady state temperature gradient.
- The peak could be an effect of the thermodynamic impact on temperature, when the pressure is changed.
- The peak, when refilling the sample, could also be influenced by the room temperature air entering the sample.

The transient effects have been further investigated by Berge et al. [10].

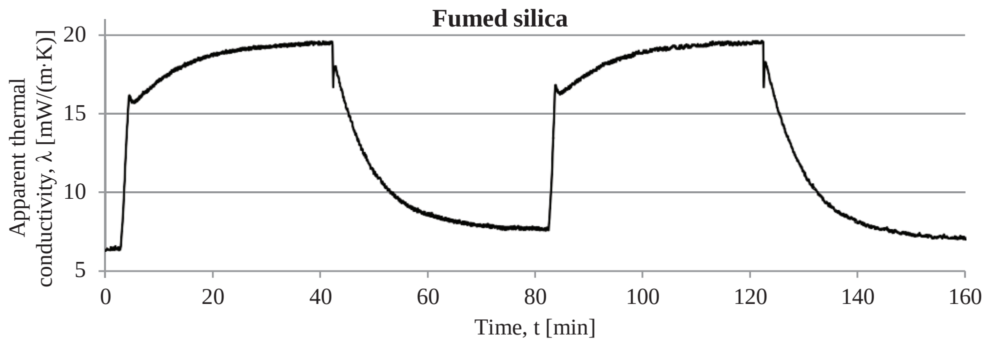

Fig. 4. Transient variation in the measured thermal conductivity for a fumed silica sample where the pressure has been alternated between atmospheric pressure and a pressure of 1 kPa.

4. Office simulations

A small office has been simulated both with variable insulation and without. The energy performance have been calculated according to Equation (2) [6]. The solar data and the exterior temperature was taken from hourly data weather file for Göteborg, Sweden.

$$Q_{balance} = Q_{int} + Q_{sol} \cdot g - K \cdot (T_i - T_e) \tag{2}$$

where $Q_{balance}$ (W) is the need for heating or cooling (if it is negative or positive respectively), Q_{int} is the internal heat load, Q_{sol} is the heat load from the sun, K is the conductance from ventilation and transmission calculated as in Equation (3) varying between a minimum while heating and a maximum when cooling, Ti is the internal temperature varying in between a minimum and a maximum and Te is the external temperature. By summing the results from Equation (2) for hourly input an energy demand is obtained.

$$K = \begin{cases} K_{min} = K_{vent} + K_{leak} + K_{win} + U_{wall} \cdot A_{wall} & \text{If } T_e < T_{Balance,heat} \\ K_{max} = K_{vent} + K_{leak} + K_{win} + U_{wall} \cdot \xi \cdot A_{wall} & \text{If } T_e > T_{Balance,cool} \end{cases} \tag{3}$$

where K_{vent} and K_{win} (W/K) are the conductance by ventilation and through the windows calculated according to Hagentoft [13], K_{leak} (W/K) is the conductance calculated from an assumption of 4% of the air flow at 50 Pa pressure difference [6], U_{wall} (W/(m^{2}K)) and A_{wall} (m^2) is the U-value and area of the whole envelope excluding the windows, ξ (-) is the variation factor defined as the maximum U-value divided by the minimum U-value and $T_{Balance}$ for heating and cooling is the limit temperature when the need for heating or cooling starts, defined in Equation (4) and Equation (5)

$$T_{BalanceHeat} = T_{i.min} - \frac{Q_{int} + Q_{sol} \cdot g}{K_{min}} \tag{4}$$

$$T_{BalanceCool} = T_{i.max} - \frac{Q_{int} + Q_{sol} \cdot g}{K_{max}} \tag{5}$$

where $T_{BalanceHeat}$ and $T_{BalanceCool}$ is the balance temperatures for heating and cooling respectively (°C), $T_{i.min}$ and $T_{i.max}$ are the minimum and maximum accepted indoor air temperatures (°C) and K_{min} and K_{max} are the lower and upper limit of the variability in the conductance through the envelope (W/K).

The input data of the office is presented in Table 1.

Table 1 Input data for a Swedish office.

Temperature (min/max) , T	21 / 23[1]	°C
Length, L	30	m
Width, W	15	m
Height, H	12.5	m
Window amount, p_{win}	40	%
g-value, g	0.5[1]	-
Ventilation rate (7-19[3]/19-7), Ra_{vent}	1.5 / 0[1]	$l/(s\cdot m^2_{floor})$
Leakage rate, Ra_{leak50}	0.3[2]	$l/(s\cdot m^2_{walls})$
Internal heat loads (7-19[3]/19-7), Q_{int}	21.5 / 3.45[1]	W/m^2_{floor}

[1] [11], [2] [12], [3] Working hours

Fig. 5 (a)shows the simulation for a variation of the minimum U-values. For the variable walls the U-value varies between the minimum multiplied by the variation factor ξ. A reference wall with constant U-value is presented with a variation factor of 1.

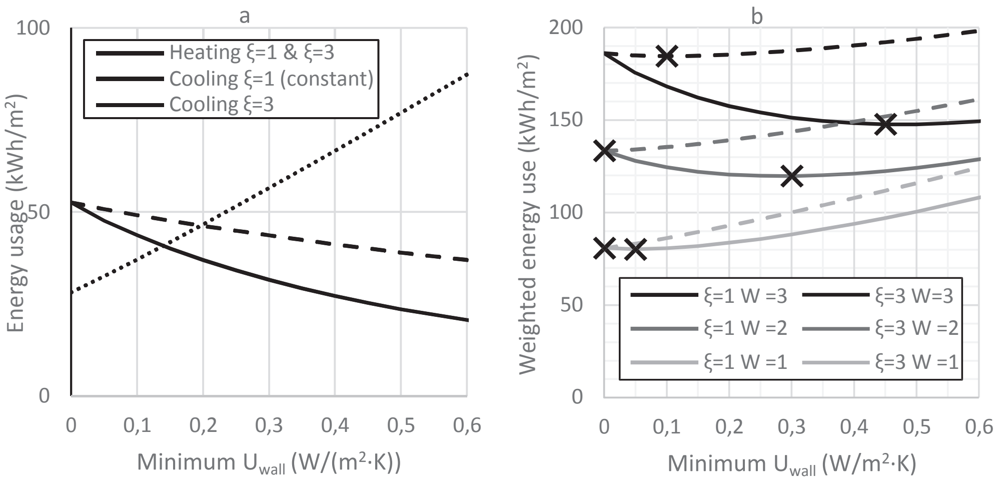

Fig. 5. (a) Simulated energy demand for heating and cooling in the office building. (b) . Total energy use of the office with different weightings of the relation between cooling and heating energy

Fig. 5 (b) show the total weighted energy usage, defined as the sum of the heating demand and the cooling demand multiplied by a weighting factor, denoted W(-). For all cases, the total weighted energy loss is lower for a variable envelope compared to a constant value. For a higher weighting factor, valuing a reduction in cooling more than a reduction in heating, the improvement of a variable U-value increases. The weighted energy use is reduced by 0.7

percent for a weighting factor of 1, 10 percent for a weighting factor of 2 and 20 percent for a weighting factor of 3. The variability also have a higher minimum U-value in the optimum which could lead to thinner walls.

5. Conclusions

The material measurements show an almost linear relation between pressure and thermal conductivity. The variation factor, defined as the highest thermal conductivity divided by the lowest, was measured to around 3 for fumed silica and less than 2 for the aerogel blanket.

The change in thermal conductivity is somewhat delayed. A fumed silica sample reached a value close to a steady state approximately after 40 min.

The simulations show that a variable insulation with a variability factor of 3 would decrease the energy demand in a Swedish office. The improvement gets more valuable when energy used for cooling is weighted as worse than energy used for heating. This could be the case when electricity is used for cooling and heating is done by district heating or gas boiler. For a weighting factor of 3:1 against cooling, the variable U-value decreased the weighted energy demand by 20 percent.

A variable insulation also give an optimal U-value at a much higher value than for a constant U-value. This could be used to make thinner walls, without losing thermal performance.

References

[1] Hagentoft C-E. Potential impact on innovative and active building envelope components and materials. Proc. 5th IBPC, Kyoto, Japan: 2012, p. 309–15.
[2] Loonen R. Climate Adaptive Building Shells. Master of science thesis. TU Eindhoven, 2010.
[3] Xenophou T. System of using vacuum for controlling heat transfer in building structures, motor vehicles and the like. US patent No. 3968831. 1976
[4] Benson DK, Potter TF, Tracy CE. Design of a variable-conductance vacuum insulation. SAE Technical Paper; 1994.
[5] Meister M, Horn R, Hetfleisch J, Caps R, Fricke J. Switchable Thermal Insulation for Solar Heating. Therm. Conduct. 24THermal Expans. 12, Lancaster, USA: Technomic Publishing Company Inc.; 1997, p. 417–27.
[6] Petersson B-Å. Tillämpad byggnadsfysik. 3rd ed. Lund: Studentlitteratur; 2009.
[7] Aegerter MA, Leventis N, Koebel MM, editors. Aerogels Handbook. New York, NY: Springer New York; 2011.
[8] Baetens R, Jelle BP, Gustavsen A. Aerogel insulation for building applications: A state-of-the-art review. Energy Build 2010;43:761–9.
[9] Soleimani Dorcheh A, Abbasi M. Silica aerogel; synthesis, properties and characterization. J Mater Process Technol 2008;199:10–26.
[10] Berge A, Hagentoft C-E, Wahlgren P, Adl-Zarrabi B. Changing Internal Pressure to Achieve Variable Thermal Conductivity in Thermal Insulation, Supplied to the Advanced Building Skins Conference, Graz: 2015.
[11] Boverket. Indata för energiberäkningar i kontor och småhus, en sammanställning av brukarrelaterad indata för elanvändning, personvärme och tappvarmvatten.B. Karlskrona: Boverket; 2007.
[12] FEBY. Kravspecifikation för nollenergihus, passivhus och minienergihus- Lokaler. FEBY; 2012.
[13] Hagentoft C-E. Introduction to building physics. Lund, Sweden: Studentlitteratur; 2005.