Thermal performance of nanostructured insulation materials – a comparison

Ákos Lakatos[a,1], Zsolt Kovács[b,c]

[a]*University of Debrecen, Faculty of Engineering, Department of Building Services and Building Engineering, H-4028 Debrecen Ótemető str. 2-4., Debrecen, Hungary*
[b]*INOX-THERM Kft, 1054 Budapest, Honvéd str. 8. 1. em 2, Hungary*
[c]*University of Debrecen, Doctoral School of Earth Sciences*

Abstract
In the European Union, almost 40% of all energy consumption arises from buildings, while another nearly 20-25% comes from transport. In the European Union, including Hungary, only buildings with almost zero energy demand can be built after 2020, and the use of renewable energies must be strengthened. The Renewable Directive stipulates that by 2020, the share of renewable energy in buildings must be 25% and in transport 10%. There are about four million dwellings in Hungary, of which approximately 3 million need to be renovated, and only a few of these (a few hundred) meet the cost-optimized level of the 2020 directive. The use of insulation materials is very important in the transport sector, too. Insulation materials are also used by aircraft and electric vehicles. Therefore, there is a need for using suitable thermal insulation management components that can minimize cooling and heating energy loss within the vehicle and building interiors. Since the investigations executed on insulation materials are very important. In the paper, we will present laboratory investigations and calculations to better understand the properties and behaviour of the nanostructured materials e.g.: vacuum insulation panels, advanced porous materials, or graphite doped polystyrene. The paper will present a comprehensive comparison of the thermal conductivities of different insulation materials reached by both heat flow meter and guarded hot box method.

Keywords: thermal conductivity, thermal insulation, hot box method

1. Introduction
Newly designed and constructed buildings are subjected to increasingly stringent regulations, which emphasize the minimization and, where possible, the elimination of wasteful energy consumption and emissions. As a result of the emergence of increasing energy- and environment-conscious mindset, there is a growing demand on the consumer side for such efforts. Another significant part of energy consumption comes from transport. The use of thermal insulation materials is important not only in buildings, but also in airplanes, electric cars, but even in trains and refrigerated trucks. [1-6] In some cases it is not possible to use thermal insulation tens of ten centimeters thick in buildings, as there is not enough space available and the external shell structure of vehicles also requires the use of "thin" (~ 2-3 cm thick) thermal insulation. As a result of technological advances, the production of thermal insulation materials has also expanded. One of the most widely used thermal insulation materials in the last 20-25 years due to the acceptable thermal insulation capacity and affordability of polystyrene foam. Recently, new materials have also appeared on the market, such as polystyrene foam added with graphite, a vacuum thermal insulation panel, or an aerogel. These are also commonly referred to as advanced or nanostructured thermal insulation materials, but today the latter two are also referred to as "super thermal insulation materials" after the English name "Super Insulation Material (SIM)". Super thermal insulation materials as a new class of these products could play an important role in the future of insulation. It should be noted that there is no precise definition for "SIMs", but Annex 65 of the IEA EBC (International Energy Agency, Energy in Buildings and Communities Program) defines the elements of this group. In the paper, we will present a comprehensive comparison of the thermal conductivities of different insulation materials reached by both heat flow meter and guarded hot box method. [1-8]

2. Measurements
2.1. Thermal conductivity measurements
The measurement of the thermal conductivity of insulation materials can be performed by following the rules of the EN ISO 12664:2001 standard (Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Dry and moist products of medium and low thermal resistance). In order to reveal the exact thermal conductivity coefficient of our samples a Holometrix Lambda 2000 type heat flow meter (HFM) was applied. The used

equipment is manufactured to specify the thermal conductivity coefficient of insulation materials with about 5% accuracy, in agreement with standards: ASTM C518 and ISO 8301.

2.2. Guarded hot box method
During the measurements with the guarded hot box method (see Fig.1.), we followed the directions of the ISO 8990:1994, (Thermal insulation, determination of steady-state thermal transmission properties, calibrated and guarded hot box standard), where the temperatures are measured with calibrated Pt-100 thermocouples. The calibration of the Pt sensors was executed by the Energotest ltd in Hungary. Moreover, measuring the electric energy of both the heater and the ventilator is measured by two certified electric meters by the electricity supplier. With this equipment about ±5% uncertainty can be expected.

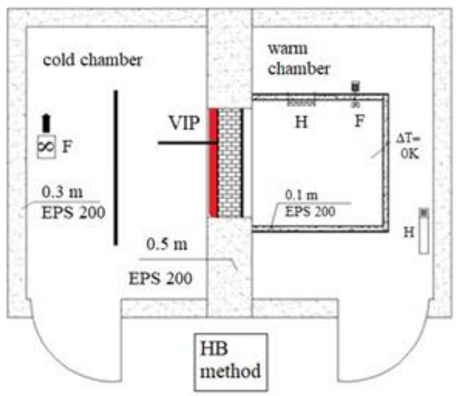

Fig. 1. Picture of a guarded hot box method

2.3. The tested materials with holometrix equipment and the tested structures with guarded hot box method
We have measured the thermal conductivities of different types of insulation materials and wall structures with the above-mentioned methods. The cases can be found in Table 1 and Table 2.

Table 1. Material tested with holometrix equipment

Material tested with holometrix equipment	Information
Expanded Polystyrene (EPS) 80	13.85 kg/m^3
EPS 100	16.7 kg/m^3
EPS 150	22.55 kg/m^3
EPS 200	27.61 kg/m^3
Graphite doped EPS	14 kg/m^3
Spaceloft aerogel	fibrous blanket
VIP “A”	20 mm thick fumed silica, covered with 10 mm thick expanded polystyrene from one side
VIP B	10 mm thick fumed silica core was packed between two 10 mm thick EPS

Table 2. The tested structures with guarded hot box

Structure	Information
Brick wall	25 cm brick small solid brick covered with 1.5 cm thick plaster at both sides
Brick wall covered with thermal insulation paint	thickness of the insulation paint is 2 mm

Brick wall covered with aerogel at the cold side	thickness of the aerogel 1.3 cm
Brick wall covered with EPS 150 at the cold side	thickness of the EPS 5 cm
Brick wall covered with VIP "A"	20 mm thick fumed silica, covered with 10 mm thick expanded polystyrene from one side
Brick wall covered with VIP "B"	10 mm thick fumed silica core was packed between two 10 mm thick EPS

3. Results and discussions

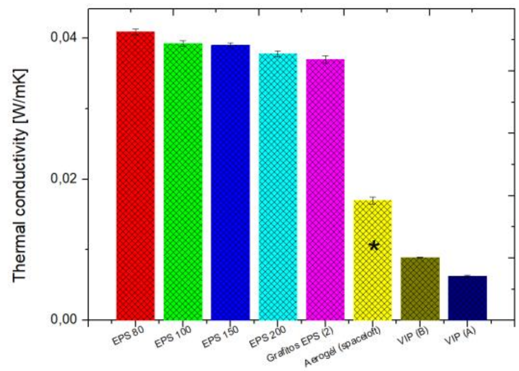

Fig. 2. Thermal conductivity measurement results

It can be seen in Figure 2 that the thermal conductivity of the aerogel material is practically half that of the EPS materials, while the thermal conductivity of the vacuum panels is about the same proportion. It should be mentioned that while the aerogel material is a flexible composite material, which makes it suitable for use in various geometries, the vacuum thermal insulation panel is a brittle, non-formable and extremely fragile material, so its application is particularly limited. For the vacuum panels, two different sandwich (encapsulated/protected) panels were tested. In connection with the vacuum panels, the thermal conductivity of the "packaged" core material derived from the measurement is shown in Figure 2.

The above-mentioned vacuum panel thermal insulations were also measured by applying them to the brickwork using the guarded chamber method. For comparison, I collected the resistance results measured on the brick wall of the thermal insulation paint and EPS 150 material mentioned in an early paper plotted them together with the results for the aerogel in Figure 3. It can be seen from both Figures 2 and 3 that the aerogel can represent the middle path even at this thickness. I should mention that the resistance values associated with the vacuum panels belong to the 3 cm thick material in both cases, while I examined the 1.3 cm thick path from the aerogel. 5 cm thick EPS has a favourable resistance value, but the use of this material is also limited. [9-13]

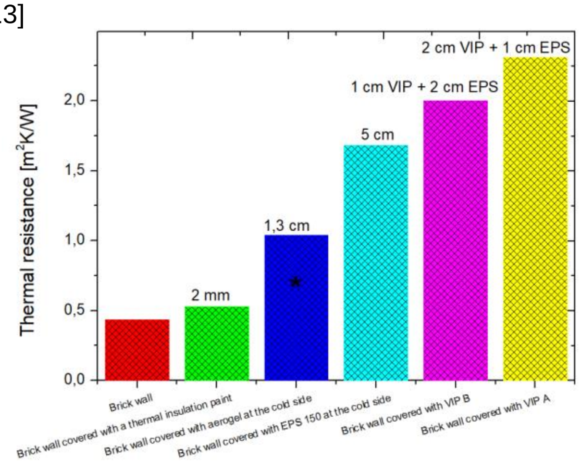

Fig. 3. Thermal resistance measurement results with guarded hot box method

4. Conclusions and outlook

Using the results of thermal conductivity tests on various thermal insulation materials, I have shown that the aerogel is in fact an effective thermal insulation material. I compared the results of my measurements on the aerogel with the values measured on other materials and found that the aerogel is a good transition between conventional and super heat insulating materials due to its flexibility, good compressive strength and low thermal conductivity.

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