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INVESTIGATION ON THERMAL CONDUCTIVITY OF VACUUM INSULATING PANELS

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Abstract: The main purpose of thermal insulating materials is to save heat inside the buildings. Thermal conductivity of current thermal insulating materials ranges of 0.026 W/mK to 0.040 W/mK. The main thermal insulating materials are mineral wool, expanded or extruded polystyrene and polyurethane foam. Thermal conductivity of these materials can be reduced about 10 % due to different technological factors. Essentially new group of thermal insulating materials is vacuum insulating materials also known as vacuum insulating panels (VIP). VIPs can save five to ten times more heat energy than traditional thermal insulating materials. Thermal conductivity of these materials can achieve 0.004 W/mK. In the present paper the research of thermal conductivity of VIPs is presented. Different gas barriers, vacuum pressure and core constructions are tested.

Keywords: Vacuum insulating materials, thermal conductivity, energy efficiency, heat preservation, gas pressure, evacuation.

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INTRODUCTION

Energy efficiency of the buildings greatly depends on the performance of the insulating materials used in the building envelope construction (Mukhopadhyayaet al.2008). The building sector accounts for 40 % of the final energy consumption in Lithuania and EU countries (Mickaityteet al.2008). Housing, working and leisure places lightening, heating, cooling and water heating energy consumption is higher than in transport or even industrial sectors. Furthermore, this consumption continues to grow as well as buildings energy proportion in final consumption and are thus at the focal point of work being done to reduce global CO_2 emissions. At present, for the thermal insulation of buildings the most widely mineral wool (MW) – rock wool and glass wool, polystyrene foam (EPS), extruded foam(XPS) and rigid polyurethane foam (PUR) are used. All these materials together account for more than 75% of all insulating materials used in construction and building insulation (Papadopoulos 2005). Using these modern building materials in the envelopes according to Lithuanian building norm thermal insulation thickness reaches20–30 cm. Using the modern technologies thermal conductivity of insulation materials can be reduced. As shown in Fig 1thermal conductivity can be reduced in three ways: by reducing the gas (air) transport, reducing emissions (or increasing reflection) and reducing the amount of solids(Fricke 2001).Reduction of thermal conductivity through the reflection effect is already used several decades – polystyrene foam with graphite dust, reflective thermal insulation. Thermal conductivity related with heat conduction is very low thermal insulating material reaches 99 % porosity. Reduction of convection effects on thermal conductivity are studied in various countries of the world, including Lithuania. The smaller are pores of material, the lower effect of convection. The total thermal conductivity may be described by

formula:

$\lambda_{tot} = \lambda_g + \lambda_r + \lambda_s$ (1)

where λ_g– thermal conductivity of free gas (air); λ_r–describes the radiation transfer;

λ_s– the solid conduction within the material skeleton.

The world is currently intensively started the research in the vacuum insulating panels (VIP). Thermal conductivity of such material can be obtained at less than 0.004 W/(m·K). The evacuation process makes the number of air molecules inside the VIPs 100.000 to 1.000.000

times smaller. This is why vacuum insulation panels are such excellent thermal insulation. The most important advantage of using VIP is the reduction of the insulation layer in building panels used in facade constructions.

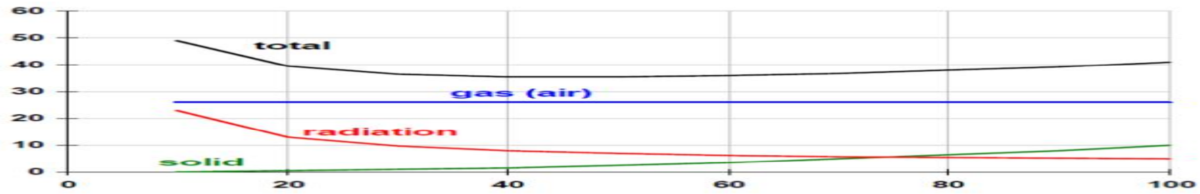

Fig 1. Total thermal conductivity

Vacuum insulating material is a similar principle as the thermos: porous honeycomb coated with a coating impermeable to air and evacuated from the comb (Fig 2). While the thermos has created more than 100 years ago, but based on this principle, the insulating material started in right now. So far, there have been few attempts to create the vacuum insulation, but it was quite severe, short live. This problem was solved when it was created by coating capable of maintaining a vacuum up to 50 years (Hoogendoorn 2001; Fricke et al. 2007; Caps 2006)The outer envelope is one of the critical components of a VIP and is responsible to maintain the vacuum in the panels. The envelope of VIPs is composed of multi layer films covering the whole element, including the edges. The use of an aluminum layer in these multi layer films is common because of the very low gas and water vapour permeation. Due to the relatively high thermal conductivity of such an envelope, the heat flux increases at the edges and corners. Because of this, the design of a VIP envelope will not only be done from the point of view of gas and water vapour tightness, but also from the point of view to minimize these thermal edge losses (Baetens et al. 2010). Important for the service life of the VIPs is maintaining the inner vacuum. To increase their service life, getters and desiccants are often added in the VIPs: continuously adsorbing the gasses (getters) and the water vapours (desiccants) in the VIP core material, they prevent the increase of the internal gas and vapour pressure.

The inner water vapour pressure and gas pressure will stay equal to the manufacturing conditions until the capacity of the getters and desiccants is reached. As a consequence, they prevent the increase of the thermal conductivity due to the higher pressure and they increase the lifetime of the VIP. Some core materials of VIPs have the possibility to fulfil the function of getters and desiccants themselves, but not all of them. This makes it importantto add these chemicals to the core although they decrease thermal resistance of the VIP and increase the manufacturing costs. (Baetens et al. 2010). However, also the sound insulation properties of VIPs are important if they are used as building insulation.

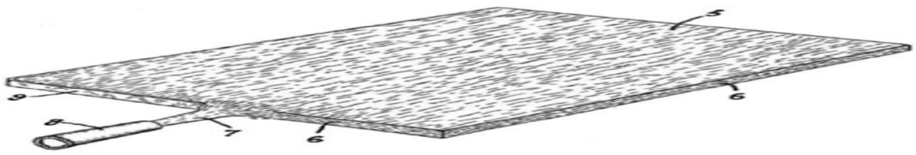

Fig 2. Picture of a VIP from the patent US 2700633granted in 1955 (Fricke et. al. 2008)

Research on these properties is very shabby. Research of vacuum insulation is intensified, when the Bavarian Center for Applied Energy Research (ZAE Bayern) manufactured about 100 vacuum insulating panels and integrated them into the facade of its new building in Wurzburg in 1999 (Randel 2001). The production of the evacuated materials face two main challenges: the

selection of barrier coating, which is good for a long time and keep the vacuum and high load-bearing honeycomb selection, who spent little heat, are well-evacuated and deformed. Evacuated core material must withstand100 kN/m2 load (approximately 10 tons/m2). Since the vacuum material is planned to operate up to 50 years, it is necessary to assess the impact and creep, which develops compressive deformation (Gnip et al. 2006; Vaitkus et al.2007). Vacuum insulation material used for production of honey combs of different materials: glass fibers, perlite, polyurethane foam, polystyrene foam, precipitated silica, fumed silica (Mukhopadyaya et al. 2008; Eicher 2001;Hoodendoorn 2001; Simmler and Brunner 2005). Of these materials the most noteworthy is fumed silica. Fumed silica is higly porous nano structured material with alow thermal conductivity. A pioneer for nano materials was Samuel Kistler, who first made silica aerogels in the1930s in a wet-chemical process (Fricke 2001). He found that their thermal conductivity in air was around0,020 W/(m·K). He also observed that evacuation to a pressure of 10 mbar was sufficient to suppress gaseous thermal conduction, at list for aero gel monolith and fine aerogel powders. Silica aerogel looks like glass and feels like solidifieds moke. Aerogels are made by taking a wet gel – amesh work of molecules in liquid, such as water – and removing the water to leave a spongy structure. Silicaaerogels also have many other applications in fibre optics, insulation against sound, and miniature pumps for built-in refrigeration systems in packaging (Du *et al*. 2009).However as thermal insulation VIPs are very expensive thermal insulation. If now for example the square meter prize of VIPs lies between 80 to 145 €/m2 including transportation, installation and VAT, which equals for a floor space heigth of 3.6 m 288 to 522 €/m facade length and if the cost of a conventional insulator is between15 €/m2 for mineral wool and 26 €/m2 for polystyrene or 54 to 94 €/m façade length, the difference in cost

between vacuum insulation and conventional thermal insulation varies between 194 and 468 €/m2 façade length(Tenpieric and Cauberg 2006).The aim of this work is to choose core material oflow cost and good thermal conductivity in conventional conditions and evacuated environment.

2. Materials and investigation methodologies

For the tests wood wool with cement binder, mineral wool, wood fiber, expanded polystyrene and rigid polyurethane foam boards were used. These materials were chosen for their radically different structure: polystyrene foam closed cellular plastic pores with different sized spaces between them, rigid polyurethane foam – a small porous plastic enclosed a couple of evenly distributed throughout the volume, wood wool in a matrix – open sufficiently large air gaps between long strands of wool, wood fiberboard – small fibers, and several smaller gaps between the fibers (Gibson and Ashby 2001; Vaitkus et al. 2006;Walther 2001). Tests samples were multilayered and homogeneous. Wood fiber products were homogeneous, consisting of 4 layers. Other materials were multilayered, consisting of core material inside the construction and outer layer of wood fiber board. Mineral wool slabs with density 160 kg/m3 after evacuation collapsed and for further testing were not used. The outer envelope consists of four layers: central aluminum barrier layer laminated between two layers of PET and inner layer – of polyethylene. The thickness ofthe envelope layers are shown in Table 1.

Table 1. Envelope for vacuum insulating materials

Number of layer (from inner)	Designation of layers	Thickness, µm
1	polyethylene (PE)	80
2	Polyethylene terephthalate (PET)	20
3	aluminum foil	10
4	Polyethylene terephthalate (PET)	20
Total		130

Tests were carried out in two stages. In the first stage for measuring of thermal conductivity of thermal insulating material in conventional conditions with an average sample temperature of 10 °C were done. In the second stage thermal insulating material was tightly wrapped in gas-impermeable envelope, each sample was equipped with a valve. The air was evacuated from the sample through the valve. Thermal conductivity was determined at different vacuum level is 100 kPa to 0.1 kPa. Outer layer of wood fiber board was used not just as core material but also as a protective coating to prevent envelope damage (Fig 3).

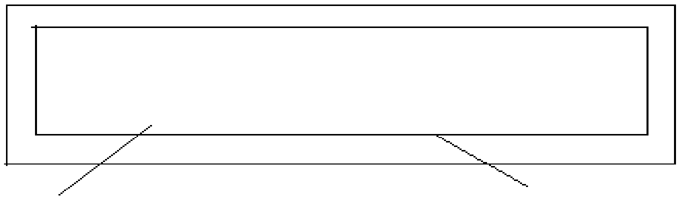

Fig 3.VIP design: 1 – core material; 2 – protective material

Thermal conductivity measurements on 500×500 mm in length and width samples were done. Thickness of the samples ranged from 50 to 75 mm. Measurements of thermal conductivity are made using a guarded hot plate apparatus EP500 Lambda- Meßtechnik GmbH (Germany). The measurement ranges are of 0.5000 W/(m·K) to 0.0050 W/(m·K), measurements accuracy – 0.0001 W/(m·K). The measuring device is connected to a computer. All measurement parameters controlled by a computer: temperature of measurements, preload of the samples or its thickness, measurement bounds.

3. Research results analysis

Test results of thermal conductivity of thermal insulating material are presented in Fig 4.

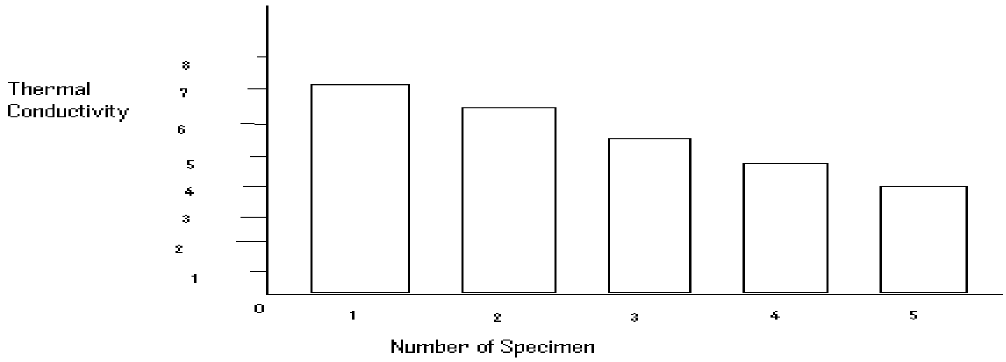

Fig 4. Thermal conductivity of different materials:1 – wood wool with cement binder; 2 – wood fiber(density – 220 kg/m3); 3 – wood fiber (density –160 kg/m3); 4 – expanded polystyrene; 5 – rigid foam polyurethane.

The highest thermal conductivity shows wood wool and smaller – wood fiber, polystyrene foam and rigid polyurethane foam specimens. Thermal performance of these products can be roughly determined in accordance with their density, but in our case requires very precise values in order to measure the changes of thermal conductivity after their evacuation. In order to better identifythe materials their densities were determined: woodwool – 300 kg/m3; wood fiber – sample 2 – 220 kg/m3, sample 3 – 160 kg/m3, polystyrene foam products – 35 kg/m3, solid polyurethane foam products – 60 kg/m3.The initial density of sample and thermal conductivity are expressed in kg·W/(m4·K). These units show a thermal conductivity coefficient of the size of one kilogram ofmaterial. Calculated results are shown in Table 3.

Table 2. Changes of thermal conductivity of different materials

Thermal conductivity, W/(m·K)	WW	WF2	WF3	EPS	PUR
Specimen in normal Conditions	0,07	0,043	0,041	0,034	0,032
Evacuated (pressure 0,1 kPa)	0,02	0,008	0,006	0,009	0,006
Changes of thermal conductivity, in times	3,5	5,3	6,7	3,8	5,3
Changes of thermal conductivity, in W/(m·K) units	0,050	0,035	0,035	0,025	0,026

Table 3. Thermal conductivity expression though material weight

Designation of material	kg·W/(m4·K)
PUR	1,9
Wood fiber1	9,5
Wood wool	21
Wood fiber2	6,6
EPS	1,2

After measurements of thermal conductivity in conventional conditions evacuated samples were prepared

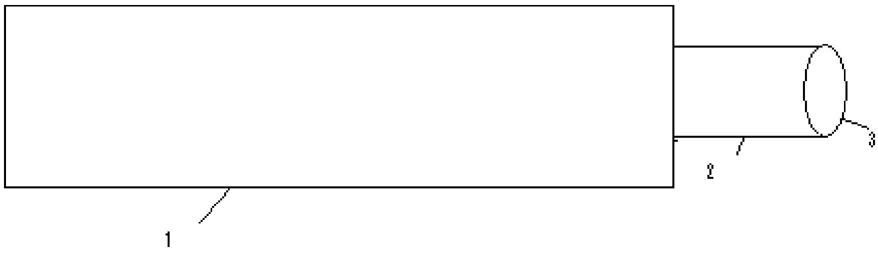

Fig 5. Principal sheme of vacuum insulating materials: 1 – vacuum insulating material; 2 – steel tube with valve; 3 –vacuummeter

The results presented in the Table 3 shows the biggest value for wood wool, and the smallest value 1,2 – for EPS. It mean that 1 kilogram of expanded polystyrene about 17,5 times is more useful as thermal insulating material. After evacuation this proportion decrease to 16,7 times. In the Table 2 presented results shows, that thermal conductivity coeficient after evacuation for wood fiber(specimen 2) and PUR is 0,006 W/(m·K). The diference between values presented in table 3 is about 3,5 times. After evacuation proportion decrease to 2,7. It mean, that structure of wood fiber specimens about 1,3 times is more suitable for evacuation than XPS.Results of thermal conductivity of measured materials in different pressure environment are shown in Fig 6. Thermal conductivity tests are done in pressure from 100 kPa to 0,1kPa. Decrease of thermal conductivity is seen when the pressure is less than 10 kPa. The highest thermal conductivity is for wood wool with cement binder. Differences between measurements in conventional conditions and evacuated environment is about 3,5 times. Thermal conductivity of polystyrene is lower than wood wool samples in conventional conditions, but after evacuation thermal conductivity decrease just 3,8 times. The lowest thermal conductivity is for wood fiber and rigid polyurethane foam. In the evacuated state thermal conductivity of both materials decrease to 0,006 W/(m·K). The largest changes after evacuation procedure shows wood fiber specimens – 6,7 times. Otherwise, the largest decrease in W/(m·K) shows wood wool specimens – 0,050, and the smallest – EPS and PUR specimens – 0,025 and 0,026 respectively. It shows that not only the value of thermal conductivity after evacuation must be evaluated. Other rates is very important too when core material for VIPs is chosen.

Conclusions:

1.For the development and manufacturing of vacuum insulating materials may be used homegrown renewable materials such as wood wool and wool fiber materials. The structure of wood fiber samples is more suitable for evacuation procedure.

2.Vacuum insulating materials are working effectively in the range of vacuum pressure from 10 kPa to 0,1 kPa. Thermal conductivity of measured materials in these range varies from 0,020 W/(m·K) to 0,006 W/(m·K).

3.For the choice of core for vacuum insulating materials the great importance has the cost of material and its derivation.

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