Transilvania University of Brasov
FACULTY OF MECHANICAL ENGINEERING

ICMS 2019 & COMEC 2019
Brasov, ROMANIA, 21-22 November 2019

THERMAL CONDUCTIVITY EXPERIMENTS ON INSULATING PANELS

Daniela Sova[1], Mariana D. Stanciu[1], Elena Belea[1], Sergiu V. Georgescu[1]
[1] Transilvania University of Brasov, Brasov, Romania, sova.d@unitbv.ro, mariana.stanciu@unitbv.ro

Abstract: *The aim of the paper was to assess the insulating properties of four panels, two rock wool panels with different thicknesses (50 mm and 100 mm) and two cost-effective composite panels consisting in polystyrene, pressed cardboard casings and wool in different proportions. Pressed cardboard casings and wool are waste materials. The thermal conductivity was measured with the* instrument *HFM 436/6 Lambda in three variants of thermal regimes simulating different seasons of the year. The thermal conductivity of all panels is low. The rock wool panels have the lowest thermal conductivity regardless their thickness. The composite panels have higher thermal conductivity than the rock wool panel at the same thickness (100 mm). The thermal conductivity generally increases with the average temperature increase, while there is no rule of the thermal conductivity variation with the change in the temperature difference.*

Keywords: *thermal conductivity, rock wool panels, composite panels, wool, pressed cardboard casings*

1. INTRODUCTION

The reduction of the energy consumption during summer or winter is achieved by insulating the buildings with different materials that are able to preserve energy. The energy is saved by reducing the heat losses, controlling temperatures on surfaces of domestic buildings for people’s comfort or improving the operation efficiency of heating/ventilation/air conditioning systems, processing and feeding processes of commercial and industrial equipment [1].

With respect to their structure (macroscopic or microscopic), these materials are based on fibrous insulations, cellular insulations and granular insulations [2]. The fibrous insulations are made of fibers with a small diameter and air that fills the voids among them. The fibers can be fixed in parallel or perpendicularly to the insulating surface or they can be loose. Usually there are used silica or glass fibers, sinter wool and silica-alumina fibers. The most encountered insulations of this kind are glass fibers and mineral wool. Cellular insulations contain small, individual cells. The cellular material is glass or plastic foam, such as polystyrene (closed cells), polyurethane, polyisocyanurate, polyolefins or elastomers. The granular insulations include small nodules and voids. These are actually not true cellular materials since the gas can go through individual voids. This kind of material can be manufactured as bulk, combined with a binder and fibers, in order to obtain a rigid insulation. Such insulations are calcium silicate, expanded vermiculite, pearl stone, cellulose, diatomaceous earth and expanded polystyrene.

Table 1 indicates the density and thermal conductivity of some materials with good heat-insulating properties.

Table 1: Materials with good heat-insulating properties [3], [4]

Materials	Density ρ (kg /m^3)	Thermal conductivity, k (W/mK)
Glass wool	80/100	0.036/0.041
Concrete with vegetable aggregates	600/800	0.16/0.21
Mineral wool	60/70	0.042/0.045
Felt	50/125	0,038
Fir wood	415/640	0.11/0.15
Chipboards	300/400	0.13/0.14
Softwood bark boards	270/350/750	0.116/0.125/0.216
Reed	250/400	0.09/0.14
Chaff boards	200/300	0.086/0.101
Polyvinyl chloride sheets without textile support	1600/1800	0.33/0.38
Glass fiber boards	16/28/40	0.046/0.038/0.035

Glass fiber boards with textile support	1400/1600	0.23/0.29
Straw boards	120/250	0.05/0.14
Mineral wool mattress	100-130 120-150	0.04/0.045
Mineral wool boards	100/140	0.048/0.04
Glass	2500	1,4
Concrete	2300	1,4
Soil	2050	0,52
Boards of concrete and asbestos	1920	0,58
Bricks	1920	0,72
Plaster	1860	0,72
Stone chips	1800	0,7
Sand	1515	0,27
Clay	1460	1,3
Tufaceous limestone	1300	0,52
Hard vulcanized rubber	1190	0,16
Soft vulcanized rubber	1100	0,13
High density fiberboards	1010	0,15
High density chipboards	1000	0,17
Leather	998	0,159
Paper	930	0,18
Plasterboards	800	0,17
Hardwood (oak, maple) perpendicularly / in parallel with fibers	800	0.23/0.41
Oak	717	0,17
Fiberboards	640	0,094
Low density chipboards	590	0,078
Softwood (fir, pine) perpendicularly / in parallel with fibers	550	0.17/0.35
Plywood	545	0,12
Chopped wood	350	0,087
Diatomite	350	0,069
Medium density fiberboards	300	0,084
Mineralized fiberboards (roof)	265	0,049
Granules of mineral wool with asbestos	190	0,046
Granular cork	160	0,045
Boards of synthetic textile wastes	150	0,05
Expanded vermiculite	122	0,068
Cork	120	0,039
Expanded pearl stone	105	0,053
Upholstery wool	100	0,045
Cotton	80	0,06
Polyurethane foam	70	0,026
Rubber foam (rigid)	70	0,032
Extruded polystyrene	55	0,027
Cellulose	45	0,039
Cellular polystyrene	30	0,042
Expanded polystyrene	16	0,04

The requirement concerning reduction of energy losses and good thermal insulation conducted to the development and marketing of efficient building materials [5]-[12]. The reduction of energy consumption and the minimization of heat losses in walls have a positive environmental impact. Along with the importance of thermal insulation properties of these materials, there are also other requirements like, sustainable manufacturing technology, decrease of pollution, recycling and reuse, improvement of physical and mechanical performances and durability, simplification of the technology of use, increase of fire resistance, improvement of hydro-insulation properties, in order that the walls can breath, and impact on users health.

The aim of the work is to report experimental results of thermal conductivity measurements on panels with different configurations.

2. EXPERIMENTAL SET-UP

2.1. Experimental method

The thermal conductivity was determined experimentally by using Netzsch instrument HFM 436/6 Lambda from the Laboratory L6 of the Research-Development Institute at Transilvania University of Brasov. The tests were performed according to the standard EN 12667 [13].

The test method consisted in the next steps. The sample was fixed between two plates with different temperatures. The heat flux per unit area (q) that flows through the sample was measured with a heat flow transducer. The magnitude of the heat flow depends on different factors: the thermal conductivity of the sample (k); the thickness of the sample (Δx); the temperature difference (ΔT); the area of the sample surface (A). The heat flux is expressed by using Fourier’s law. One or two heat flow transducers measure the heat flux that flows through the sample. The signal of the transducer expressed in Volts is proportional with the heat flux received by the transducer. In the case of the instrument HFM 436/6 Lambda, the zone that delimits the transducer corresponds to the area where the heat transfer takes place and it is the same for all samples. Therefore:

$$\dot{Q} = N \cdot V \tag{1}$$

where $\dot{Q}$ is the heat flux [W], N is a calibration factor that correlates the voltage signal of the heat flux of the transducer with the heat flux that flows through the sample. It follows that:

$$k = N \cdot V \frac{\Delta x}{\Delta T} \tag{2}$$

The output data given by the soft of the instrument are given in Table 2.

Table 2: Characteristics of the thermal conductivity tests indicated by HFM 436/6 Lambda soft

Symbol	Description
Δx	Thickness of the sample (cm)
T upper	The temperature of the upper plate (°C)
T lower	The temperature of the lower plate (°C)
T mean	Average temperature (°C)
T delta	Temperature difference (°C)
Q upper	Heat flux of the upper plate (W)
Q lower	Heat flux of the lower plate (W)
std dev	Standard deviation of N (T); N is the calibration constant at the average temperature of the sample. It is displayed only for calibrations. In case of tests performed for measuring the thermal conductivity, there is valid $k(t)$, where k is the thermal conductivity at the average temperature of the sample (t).
pk/avg	It is a measure of the average between the maximum and minimum of $N(t)$ and $k(t)$ after a certain time span.
$N(t)$	It is the calibration constant of the heat flux of the transducer at the average temperature of the sample (W/m^2).
Kref(t)	It is displayed when a calibration is performed.
$k(t)$	Thermal conductivity of the sample at the average temperature (W/mK)

HFM 436/6 Lambda consists in an insulated enclosure with two plates equipped with temperature sensors. The sample is located between the plates. The input data (density, thickness, surface temperatures selection) are registered by the instrument soft. In order to analyze the behavior of the materials tested with the given instrument, three thermal regimes were set, which are indicated in Table 3. For all regimes, the temperature of the upper plate was maintained at constant value, 20°C, since it is close to the comfort temperature inside a domestic building. For the lower plate, three temperatures simulated the temperatures specific to winter season (-10°C), spring/autumn season (+10°C) and summer season (+35°C).

Table 3: Thermal regimes proposed for measuring the thermal conductivity of insulating materials

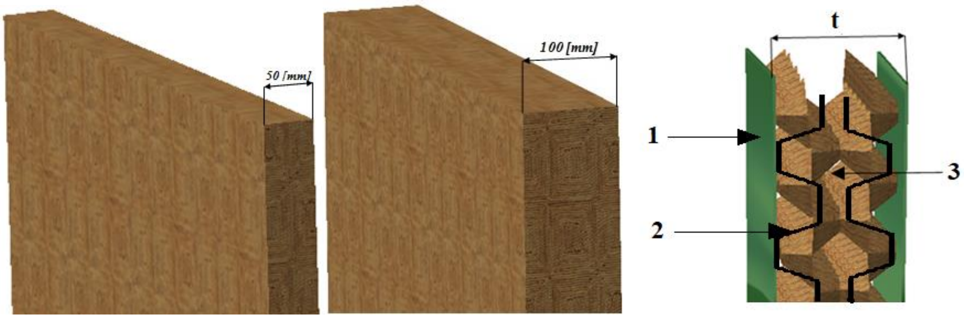
Code of the regime	Upper plate temperature, (ºC)	Lower plate temperature, (ºC)	Average temperature, (ºC)	Temperature difference between the two plates, (ºC)
R1	+20	-10	5	30
R2	+20	+10	15	10
R3	+20	+35	27.5	15

2.2. Materials

The first step in the test performance consisted in the selection of materials that exist on the market for verifying their technical properties. The tested materials were rock wool with the thicknesses 50 mm and 100 mm, respectively. The materials were tested at the dimensions required by the dimensions of the plates of HFM 436/6 Lambda ($L \times l$), which are 0.6 × 0.6 m.

Another kind of materials that were proposed for testing were sandwich panels with two honeycomb layers of pressed cardboard filled with wool fibers and plated with extruded polystyrene with the thickness 3 mm. The panels were conceived based on information regarding the good insulating properties of wool and its availability [14], [15], and the honeycomb geometry with spatial forms of pressed cardboard casings, the latter ones having also acoustic insulation properties.

Fig. 1 shows the panels that were tested: rock wool panel with the thickness 50 mm (Fig. 1a); rock wool panel with the thickness 100 mm (Fig. 1b) and a composite panel (Fig. 1, c). The composite has two extruded polystyrene plates (1), two honeycomb layers of pressed cardboard (2), filled with wool fibers (3).



a) b) c)

Figure 1: Insulating panels proposed for thermal conductivity experiments
(a) Rock wool panel with the thickness 50 mm, (b) Rock wool panel with the thickness 100 mm, (c) composite panel

Table 4 indicates the characteristics of the panels that were tested using HFM436/6 Lambda. The panels were denoted as follows: PRW50 - rock wool panel with the thickness 50 mm, PRW100 - rock wool panel with the thickness 100 mm, PCW1 – composite panel with wool, casings and polystyrene (model 1), PCW2 – composite panel with wool, casings and polystyrene (model 2).

Table 4: Properties of materials

Material	Mass, m (kg)	Density, ρ (kg/m^3)	Length, L (m)	Width, l (m)	Thickness, t (m)
PRW50	1.54	85.55	0.6	0.6	0.05
PRW100	3.085	85.72	0.6	0.6	0.1
PCW1	m_c=0.480 m_p=0.3925 m_w=0.681	32.91	0.6	0.6	0.0983
PCW2	m_c=0.480 m_p=0.3925 m_w=1.330	62.85	0.6	0.6	0.0974

Caption: m_c-casings mass, m_w-mass of wool fibers, m_p-mass of polystyrene

For the determination of the thermal conductivity of the composite panel (sandwich structure consisting in cardboard, wool and polystyrene) two models were conceived, as shown in Fig. 2. The first model has one layer of wool fibers located between two pressed cardboard casings and two polystyrene layers (Fig. 2a). The second model has the inner layer consisting in three wool layers fixed between two casings (Fig. 2b). All materials, except polystyrene, are waste materials.

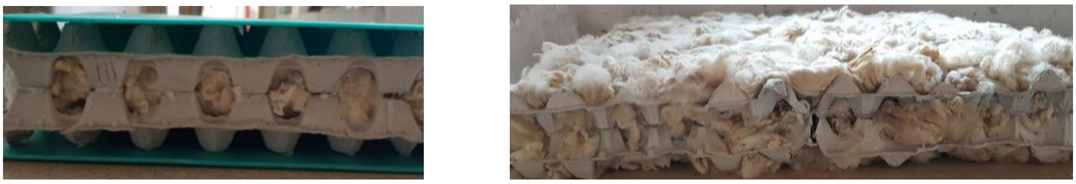

a) b)

Figure 2: Sandwich structure consisting in wool fibers, casings and polystyrene
(a) structure with one wool layer , (b) structure with three wool layers

3. RESULTS AND DISCUSSION

The results obtained from experiments are indicated in Table 5 and Fig. 3, respectively. They reveal that the thermal conductivity of the two first panels, PRW50 and PRW100, increases with average temperature increase. There is not a significant difference between the two panels regardless the thermal regime. The thermal conductivity is slightly lower for the sample with the smaller thickness when the first and second thermal regimes were applied. As regards the third thermal regime, the thermal conductivity of the panel with smaller thickness is higher than the thermal conductivity of the thicker panel. That might be due to measurement errors.

Table 5: The values of the thermal conductivity obtained from experiments

Thermal regime				Thermal conductivity *k* (W/mK)			
Temperature t_1 (°C) (upper plate)	Temperature t_2 (°C) (lower plate)	Temperature difference $\lvert \Delta t \rvert$ (°C)	Average temperature *t* (°C)	PRW50	PRW100	PCW1	PCW2
+20	-10	+30	+5	0.03381	0.03435	0.06938	0.04914
+20	+10	+10	+15	0.03554	0.03644	0.06952	0.04341
+20	+35	+15	+27,5	0.03811	0.03807	0.08417	0.05506

The other two panels, PCW1and PCW2, have higher thermal conductivity as compared to rock wool panels, especially PCW1. The thermal conductivity of the two panels is in a ratio of 1.5, approximately. This shows the good insulation capacity of wool that fills the voids of the casings, which is better than that of air from the voids of the casings. Convection processes may occur because of the large dimensions of the voids and the temperature differences and thus, the heat transfer is enhanced. The thermal conductivity increases in the case of the two panels with average temperature increase, except the thermal conductivity of PCW2 for the second thermal regime, which is lower than that corresponding to the first thermal regime. This is more influenced by the lower temperature difference than by the higher average temperature.

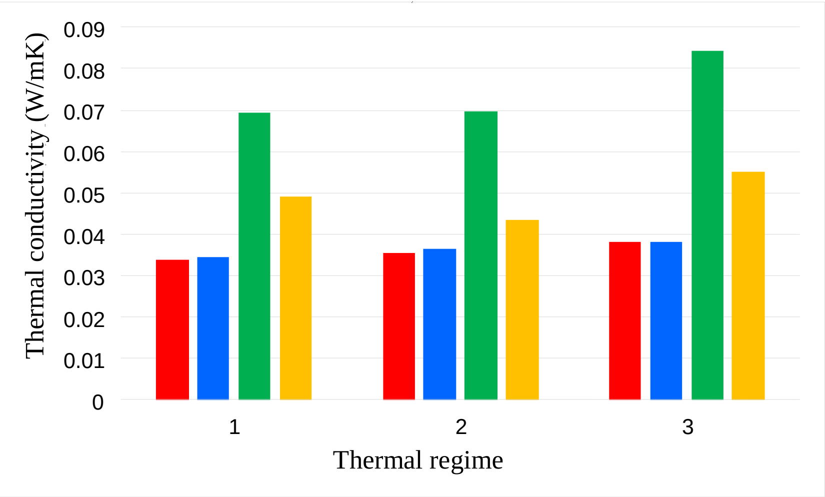


Figure 3: The thermal conductivity of insulating panels as function of thermal regimes
(PRW50-red, PRW100-blue, PCW1-green, PCW2-yellow)

Also, there is a significant increase of the thermal conductivity of PCW1 if the third thermal regime is applied. It is important to mention that the panels PRW100, PCW1, PCW2 have almost the same thickness, but different thermal conductivity, indicating that the structure of a panel influences significantly the thermal conductivity.

4. CONCLUSIONS

The panels that were analyzed in the paper have all low thermal conductivity, recommending them as insulating materials. Among all panels, the rock wool panels have the lowest thermal conductivity. Their thickness has not an important influence on the thermal conductivity and the thermal regime shows a minor influence on the thermal conductivity. The panels with pressed cardboard casings, wool and polystyrene have the same thickness with the rock wool panel PRW100, but higher thermal conductivity. The panel with higher wool content has a lower thermal conductivity, since wool replaces the air that has a motion inside the voids of the casings due to the temperature difference, thus increasing the heat transfer by convection. Even if the thermal conductivity of the panels with wool is higher, they can be used as insulation materials due to the good insulation properties and low cost of the waste materials. The thermal conductivity generally increases with the average temperature increase, while there is no rule of the thermal conductivity variation with the change in the temperature difference.

Thermal conductivity experiments on panels with different structure or geometry are very useful in setting their insulation properties.

REFERENCES

[1] Gellings C.W. (editor) Efficient use and conservation of energy-Volume 1, Encyclopedia of life support systems. EOLSS Publisher, 2009.

[2] Tychanicz-Kwiecień, Wilk. J., Gil P. Review of high-temperature thermal insulation materials. Journal of Thermophysics and heat transfer, 33(11), 1-13, 2018.

[3] Incropera F.P.,Dewit D.P., Bergman T.L., Lavine A.S. Fundamentals of heat and mass transfer, John Wiley & Sons, New York, 2007.

[4] Raznjevic K. Handbook of thermodynamic tables and charts. McGraw-Hill Book Company/Hemisphere Publishing Corporation, 1976.

[5] Jelle B. P., Gustavsen A., Baetens R. The high performance thermal building insulation materials and solutions of tomorrow. Proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings XI International Conference (Buildings XI), Clearwater Beach, Florida, USA, 5-9 December, 2010.

[6] Jelle B. P., Gustavsen A., Baetens R. The path to the high performance thermal building insulation materials and solutions of tomorrow. Journal of Building Physics, 34 (2), 99-123, 2010.

[7] Alotaibi S.S., Riffat S. Vacuum insulated panels for sustainable buildings: a review of research and applications. International Journal of Energy Research, 38:1-19, 2014.

[8] Baetens R., Jelle B. P., Thue J. V., Tenpierik M. J., Grynning S., Uvsløkk S., & Gustavsen A. Vacuum insulation panels for building applications: A review and beyond. Energy and Buildings, 42(2), 147-172, 2010.

[9] Craig S., Grinham J. Breathing walls: The design of porous materials for heat exchange and decentralized ventilation. Energy and buildings 149: 246-259, 2017.

[10] Imbabi M. S. E. A passive-active dynamic insulation system for all climates. International Journal of Sustainable Built Environment, 1: 247-258, 2012.

[11] Berge A. Assessment of novel applications for nano-porous thermal insulation in district heating pipes and building walls. PhD thesis. Chalmers University of Technology, Göteborg, Sweden, 2016.

[12] Sova D., Stanciu M.D., Belea E., Bidu V. Innovative thermal insulation panels with air channels, 8th International Conference on Advanced Concepts in Mechanical Engineering-ACME, June 07-08, 2018 *http://iopscience.iop.org/issue/1757-899X/444/6*.

[13] EN12667:2001. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods-Products of high and medium thermal resistance.

[14] http://www.casaculana.ro/produse/

[15] http://www.greenspec.co.uk/building-design/insulation-materials-thermal-properties