LABORATORY MEASUREMENTS OF THE TEMPERATURE INDUCED CHANGES IN THE RESISTANCE OF WALL STRUCTURES

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Abstract - In this article laboratory measurements will be presented in order to show the effect of the temperature difference in the thermal resistance of an insulated wall. Insulation of buildings is key action to reduce the energy use of buildings as well as to reduce the emission of green house gases. Laboratory measurements with calibrated chamber method were executed on a 25 cm brick masonry wall covered with 10 cm graphite EPS insulation. In order to see the changes in the thermal resistance of the wall the temperature of the air in the cold room was changed, while the temperature in the warm side was fixed.

Index Terms - Calibrated Chamber Method, Thermal Resistance, Graphite EPS

I. INTRODUCTION

In the European Union, buildings account for about 20-40% of total final energy consumption. One of the key actions to reduce the energy demand of the buildings is the application of thermal insulation materials on the wall. Nowadays the mainly used conventional insulation materials are the expanded or extruded polystyrene (EPS, XPS), and the mineral wool. In order to meet the stricter regulations of the buildings, thicker than thicker materials should be applied. As a result of this the manufacturers are striving to produce better than better insulations. With the development of the technology new insulation materials appeared on the market. These are the so-called nano-technological or advanced/super insulations, namely: the vacuum insulation panels, the aerogel and the graphite enhanced expanded polystyrene. It is said that their thermal conductivity can be much lower than the conventional ones, sometimes lower with a half order of magnitude. [1-3] To provide correct information about the properties of the materials the execution of laboratory measurements are essential. In this article laboratory measurements were performed by using the ISO 8990 standard (Thermal insulation – Determination of steady-state thermal transmission properties – Calibrated and guarded hot box, 1997.) The peculiarity of this article is to represent measurement results carried out on an insulated 0.25 m thick solid brick wall covered with a conventional plaster at both sides. The applied material for the insulation was 0.1 m thick graphite enhanced polystyrene insulation.

II. MATERIALS AND METHODS

A. The graphite enhanced polystyrene

Graphite enhanced polystyrene (GEPS) is highly efficient, rigid foam insulation used in various remodeling and new construction applications, such as behind new siding, below grade, and below slab. It is said that it can provide up to 20% more energy savings than traditional white expanded polystyrene (EPS) insulation.

Figure 1. The tested GEPS sample

In the technology to provide better than better materials the production of nano-composites is spread over. Graphite EPS is a composite material manufactured as the following: the graphite beads are injected into a polystyrene mold then hit with steam, which causes them to expand until they fill the mold. Depending on the shape of the mold, the pieces are either ejected from the mold and packaged, or cut to their finished shape with hot wires. It is said that graphite particles have very good reflection property against the radiation of heat, since it can reduce the thermal conductivity of the materials. A photo image from the tested sample can be seen in Fig. 1.

B. The heat transfer in insulation materials

In a cellular/fibrous insulation material the transfer of the heat from the warmer part to the colder part can happen in four parts: conduction through the solid skeleton ($\lambda_{c,s}$), and the gas filling ($\lambda_{c,g}$), the convection of the gas λ_{conv} and the radiaton of the heat (λ_r).

$$\lambda_{eff} = \lambda_{c,s} + \lambda_{c,g} + \lambda_r + \lambda_{conv} \quad (1)$$

Tha added graphite flakes in the matrix can reduce the radiative part of the effective thermal conductivity of the material. The improvement in reducing the thermal conductivity of PS/EG foams is illustrated quantitatively using an analytical model taking account of the Knudsen effect, which describes thermal conduction of gas molecules in a cavity based on the gas kinetics theory, thermal conduction through the cellular structure, and Rosseland diffusion approximation of thermal radiation. This model qualifies the contribution of each term of the total thermal conductivity. The calculated results based on the noted models are compared to the experimental data. [4-6] In Fig 2. the pore structures of the sample can be seen.

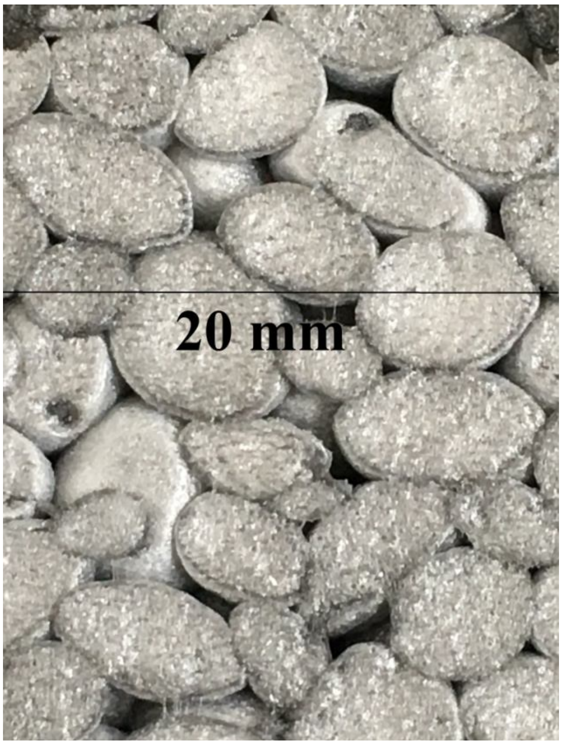

Figure 2. The pore structure of the tested GEPS

From Fig. 2 a pore size an approximate pore size analysis was done. 13 pores were chosen to measure their diagonal length. In Table 1 the measured lengths of the pores are highlighted. Besides each measurement results the averages and the absolute deviances in (±) are indicated too. From Fig. 2 pore diameter with approximately 4 mm can be estimated (3.98±0.27 mm)

	Pore size (mm)	Deviance (mm)
	4.57	0.59
	3.91	0.06
	3.91	0.06
	3.43	0.55
	3.91	0.06
	3.43	0.55
	5.48	1.50
	3.43	0.55
	3.43	0.55
	4.57	0.59
	4.57	0.59
	3.43	0.55
	4.89	0.92
Average	**3.98**	**±0.27**

Table 1. The pore sizes of the sample

C. Thermal transmittance measurements with calibrated chamber/hot box method

The measurement orders were previously clearly written in Ref. [7-9] but some completion regarding the measurement method should also be given. For the measurement of the thermal resistance of a building structure in the Building Physics Laboratory of the University of Debrecen, Faculty of Engineering an adiabatic test room is available. The test room is surrounded, as well as it is divided into two rooms cold and warm, with 6 m^2 areas each, built from a 0.3 and divided with a 0.5 m thick expanded polystyrene (EPS) 200 insulation material. The test room is nearly adiabatic. In a previous paper, it was showed that only 2 W/m^2 heat loss can be expected through the surrounding EPS walls. The cold room can be cooled down to 250 K by three separated cryogenics. The warm room can be heated up by a basic portable electric radiator. In the middle of the EPS dividing-wall at 0.35 m parapet high over the ground a brick wall window, with 0.29 m thickness and 1.44 m^2 surface area can be found. This 0.25 m thick brick wall is covered with 0.02 m thick plaster both on the warm and on the cold side. Furthermore, the brick wall was covered with 0.1 m thick graphite enhanced polystyrene insulation blanket on the cold side. Four slabs with 0.6 m x 0.6 m geometries were fixed on the wall only with conventional polystyrene glue. The measurements in the laboratory test room were carried out by calibrated chamber (CC) method according to the ISO 8990 Standard. The hot box is surrounded by air with fixed temperature (equal with inside) parallel to its own, so that zero heat transfer is expected through the wall of the box. Moreover, the box is made of 0.1 m thick EPS 200 enclosed between two sheets of OSB wood board with 0.02 m thickness. The temperature outside the hot box is kept constant by basic portable radiator. For measuring the temperatures of both the air and the surfaces of the wall on either side Pt-100 type thermocouples were used these thermocouples were calibrated by the Energotest Ltd. Hungary. The temperatures on the surface of the wall at both sides were measured at 16 points arranged in equal distances from each other, as a 4x4 matrix; while the air temperatures were measured with 4-4 pieces of

Pt-100 type thermocouples. It is noticeable that the results were stored on a tablet with data storage in 60 s steps. The average value of the temperatures (air and wall) was calculated both on the warm and the cold sides from the measurement data. Than the average values of the absolute deviances were calculated belonging to the temperatures. Inside the hot 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 separately. From the measured electric power the heat flux (ϕ) can be calculated. On the cold side one fan as well as two air baffles were used in order to reach a good air temperature homogenization. From the measured surface and air temperatures of the wall, moreover, from the calculated heat fluxes by using the area the thermal resistance (R) furthermore the thermal transmittance (U) can be calculated:

$$R = \frac{\Delta T}{\Phi} \tag{2}$$

The thermal transmittance from the measured total thermal resistance according to the ISO 6946 standard is defined as [16]:

$$U = \frac{1}{R} \tag{3}$$

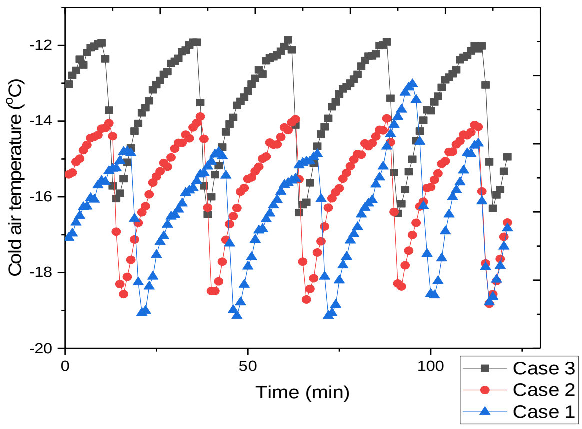

Figure 3. The profiles of the air temperature.

III. RESULTS AND DISCUSSION

During the laboratory measurements three cases were investigated. The main aim of the analysis was to show the effect of the change in the temperature difference in the thermal resistances of the wall structure. Firstly, the temperature on the thermostat in the cold side was set to -16.5 than to -15.5 and after to -13.5 °C. The resulted cold air temperature profiles are indicated in Fig.3. In the picture one can see the sinusoidal shape of the air temperatures due to the continuously changing on/off mode of the thermostat.

In Table 2 and 3 the measurement results are collected. During the measurements the temperatures of the wall surfaces, the temperatures of the air (at both sides) and the heat flux through the wall were measured.

	Temperature cold wall [°C]	Temp. warm wall [°C]	Temp. cold air [°C]	Temp. warm air [°C]
1	-14.78	21.83	-16.41	22.26
2	-14.01	22.83	-15.6	23.34
3	-11.85	22.76	-13.55	23.2

Table 2. The measurement results 1.

From the results both the overall resistances ($R_{overall}$) and the resistances of the wall (R_{wall}) were calculated by using the modified type of Eq. 2:

$$R_{overall} = \frac{\Delta T_{air}}{\Phi} \tag{4}$$

$$R_{wall} = \frac{\Delta T_{wall}}{\Phi} \tag{5}$$

	ΔT Wall [°C]	ΔT Air [°C]	Heat flux (W/m²)	Thermal resistance of the wall (m²K/W)	Overall thermal resistance (m²K/W)
1	36.61	38.67	19.73	1.86	1.96
2	36.84	38.94	22.29	1.65	1.75
3	34.61	36.75	22.28	1.55	1.65

Table 3. The measurement results 2.

The temperature differences for the overall resistances were reached from the temperatures of the cold and warm air, furthermore the thermal resistances of the air were reached from the surface temperatures of the air measured both on the cold and on the warm side. From the differences of the overall and wall resistances the surface heat transfer resistance can be deduced.

$$R_s = R_{overall} - R_{wall} \tag{6}$$

It is observable that it is 0.1 m^2K/W for all the three cases. The explanation for this is nearly trivial, because the speed of the air both at the cold and the warm side was not changed.

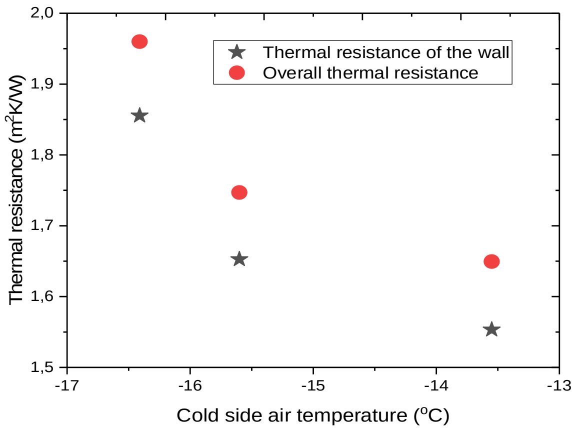

Figure 4. The measured resistances

From Figure 4 one can see the calculated (total) overall as well the wall thermal resistances. It is observable that the thermal resistances both the wall and the total is decreasing with increasing external temperature. From the results by using Eq. 3 the overall thermal transmittance (U-value) of the wall were calculated. Following the results above, upon the reciprocal function between "R" and "U" values an increasing thermal transmittance in function of the increasing cold temperature was manifested (see Table 4).

	U-value (W/m^2K)
1	0.51
2	0.57
3	0.61

Table 4. The calculated U-values

CONCLUSION

The presentation of the results of laboratory measurements of the building and structural materials are also important when one designs a building.

In this article the measurement results carried out an in-built wall structure were presented. The measurements were done on a 0.25 m thick solid brick masonry wall covered both sides with a conventional plaster, moreover it was insulated with a 0.1 m thick graphite expanded polystyrene insulation. At first, in the article the used insulation material was characterized from the pore structure point of view. The diagonals of the pores were measured and an average pore size was estimated. Than laboratory measurements were done with calibrated chamber method in order to see the potential changes of the thermal transmittance by increasing the temperature of the air at the cold side. It was manifested that the increasing temperature decreases the thermal resistance, while increases the overall thermal transmittance. It can be concluded that as a result of the measurements one can reach the real and correct resistance values, however computations and calculations give us "safe" (higher) values. This method should be very useful for building scientists working in energy conservation and savings, and for designers building nearly zero energy or passive houses as well, independently from place and residence.

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