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Original Research Article

EFFECT OF TEMPERATURE AND HUMIDITY ON THE THERMAL CONDUCTIVITY Λ OF INSULATION MATERIALS

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Abstract

The aim of this article is to address the influence of air humidity and testing temperature on the thermal conductivity coefficient (λ) of various thermal insulation materials. This group includes wood-based materials, rock wools, heat-insulating renders, climate boards, and lightweight cellular concretes. These materials are used both indoors and outdoors in buildings. Over the course of several years, data were collected from laboratory tests to determine the thermal conductivity coefficient (λ) in relation to increases in temperature and humidity. The obtained results were compared with values provided by the manufacturers of the insulation materials. The aforementioned research was carried out due to the rather high sorption of most materials and thus the possibility of them becoming humid at high air humidity. Because of the very large difference in the thermal conductivity coefficient of water and air, a relatively small increase in the mass moisture content of the materials results in a loss of insulation.

Keywords: thermal insulation materials, thermal conductivity coefficient, thermal insulation, interior thermal insulation

1. INTRODUCTION

The thermal conductivity coefficient is the fundamental parameter characterizing the properties of thermal insulation materials. The value of this coefficient depends on, among other things: the density of the material, the porosity and pore structure of the material substance constituting the framework, temperature and humidity[2][10].

This article analyses the results of insulation materials research conducted over the last few years [5][6][7][8]. The group of materials studied includes wood-based materials, perlite plasters, climatic

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boards, lightweight cellular concrete and rock wools. In each group, 2 or 3 products were selected. The thermal conductivity coefficient λ was determined based on air temperature in 4 ranges and air humidity in 5 ranges. The results obtained were compared with the data declared by the insulation material manufacturers. The data is presented in tables and graphs.

2. CHARACTERISTICS OF THE MATERIALS ANALYSED

The materials analysed include a group of wood-based materials, in detail the particleboard analysed. These boards are used for both thermal and acoustic insulation. They are known for their lightness, high compressive strength and ease of processing. The comparison includes results for three particleboards: thermal insulation, insulation and porous[5].

Another group analysed is perlite plasters. The plasters containing perlite show excellent thermal insulation properties. In addition, they are non-combustible, vapour-permeable and resistant to chemicals, weathering and biological corrosion. Replacing sand with perlite reduces the strength properties of the render in favour of a reduction in the thermal conductivity value λ. The analysis includes results for two types of thermal insulation plasters [7][4][9].

The next group of insulation materials tested were climatic boards. This material has the ability to absorb and release significant amounts of moisture in the form of water vapour. This ability allows it to regulate the indoor climate and prevent condensation and mould formation in rooms. In addition, it acts as a sound insulator and is non-combustible. It can be used as internal insulation for walls or lattice structures, as well as in the dry lining of building installations. Two boards produced on the basis of calcium silicate were included in the analysis [8].

In the fourth group of materials, the thermal properties of lightweight cellular concretes were analysed, which can provide an alternative to the previous group of climate panels. In addition, they are frost resistant, non-combustible, resistant to biological corrosion and easy to work with. Three types of cellular concrete, differing in material density, have been investigated [6][8][1].

The last group included rock wools. These have excellent thermal insulation properties and are commonly used for insulating buildings. Mineral wool is non-combustible, non-absorbent, vapour-permeable, resistant to mechanical stress and organic substances. In addition, the fibre structure of wool has a positive effect on the acoustic insulation of partitions. Three types of stone wool were analysed, differing in material density.

3. EFFECT OF TEMPERATURE

Tests of the thermal conductivity coefficient (λ) in relation to the temperature of thermal insulation materials were carried out using a Laser Comp FOX 314 [3]. The method used for the tests was the steady-state heat flux method, which involves passing a heat flux through a material sample. The flux maintains a constant value while the sample maintains a constant temperature at each point. The thermal conductivity coefficient of the test material is determined by measuring the heat flux density and the temperature difference on both sides of the sample. The course of the test was monitored using WinTherm32v3 software.

Materials dried to a humidity oscillating around 0% were analysed. Four of the five groups were tested at four temperature levels: 12.5°C, 22.5°C, 32.5°C and 42.5°C. The remaining group, the perlite plasters, was tested at three temperature ranges: 12.5°C, 22.5°C and 32.5°C. Table 1 shows the results of the analysis, while Fig. 1 illustrates the dependence of the λ coefficient on air temperature for selected materials from each group.

Table 1. The value of the λ coefficient depending on the test temperature

MATERIAL		DISCLAIMER	MATERIAL DENSITY [kg/m3]	FACTOR λ [W/mK] - EXAMINED TEMPERATURE [°C] 12,5	22,5	32,5	42,5
WOOD-BASED MATERIAL	HEAT-INSULATING FIBERBOARD	*WB-110*	110	0,03790	0,03906	0,04010	0,04102
	INSULATING FIBERBOARD	*WB-240*	240	0,04498	0,04622	0,04749	0,04811
	POROUS FIBERBOARD	*WB-290*	290	0,04814	0,04937	0,05040	0,05131
PERLITE PLASTER	PERLITE THERMAL PLASTER	*PP-400*	400	0,08546	0,08748	0,08968	
	PERLITE THERMAL PLASTER	*PP-350*	350	0,08325	0,08501	0,08677	
CLIMATE PANEL	LIME SILICATE PANEL	*CP-220*	220	0,06780	0,06984	0,07026	0,07121
	LIME SILICATE PANEL	*CP-230*	230	0,07209	0,07307	0,07449	0,07548
CELLULAR CONCRETE	CELLULAR CONCRETE	*CC-350*	350	0,09400	0,09570	0,09740	0,09870
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-115*	115	0,04863	0,04998	0,05152	0,05319
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-100*	100	0,04497	0,04628	0,04766	0,04919
ROCK WOOL	ROCK WOOL	*RW-95*	95	0,03795	0,03858	0,03941	0,04034
	ROCK WOOL	*RW-110*	110	0,03965	0,04135	0,04252	0,04336
	ROCK WOOL	*RW-135*	135	0,03928	0,04051	0,04164	0,04273

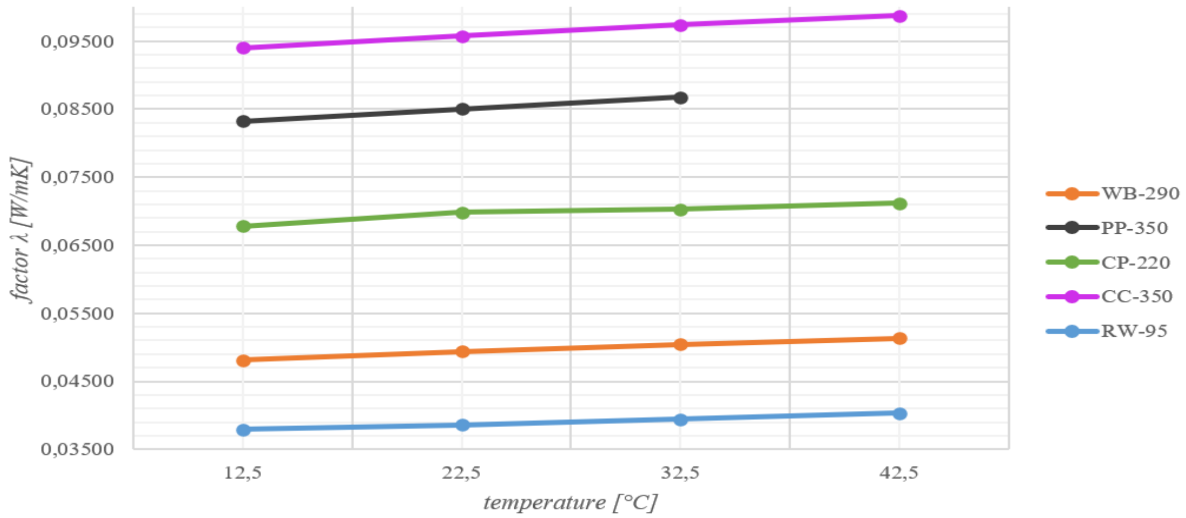

Fig. 1. The coefficient of thermal conductivity of selected materials at different temperatures [°C]

From the table and graph above, the thermal conductivity coefficient λ was found to increase with increasing temperature in all of the materials tested. The increase is linear, with no peaks.

In purpose of comparing the effect of temperature on the thermal conductivity of each of the materials, the percentage increase in the coefficient value was calculated. The value tested at an average temperature of 12.5°C was taken as the initial value. The results are presented using the bar charts below. As the perlite plasters were tested over 3 temperature ranges, the change in the material is presented in the form of 2 bar graphs.

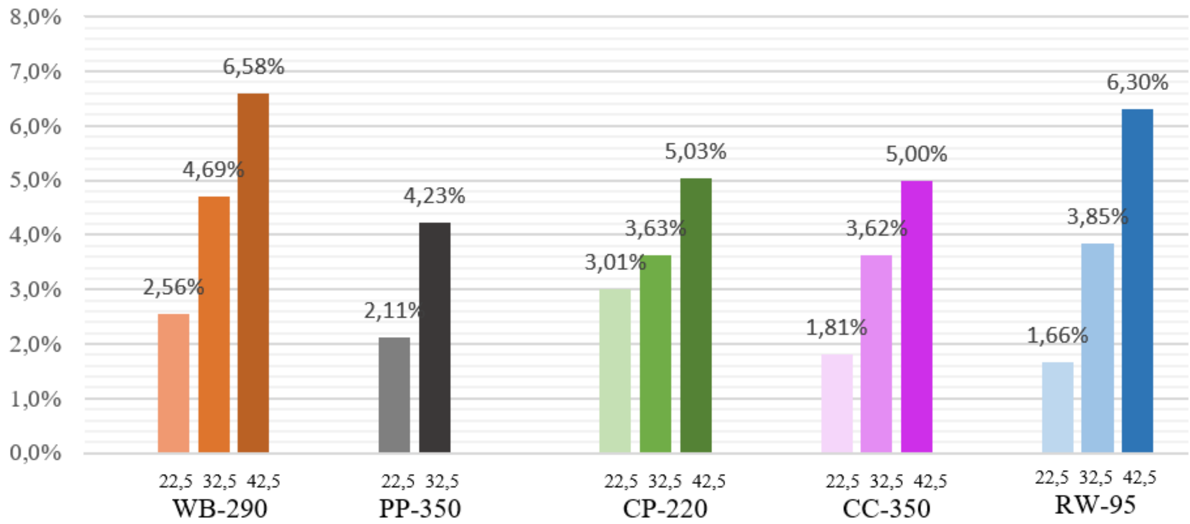

Fig. 2. Percentage increase coefficient of thermal conductivity of selected materials at different temperatures - 22.5°C, 32.5°C and 42.5°C

With a temperature increase from 12.5°C to 42.5°C, the differences in value changes range from 4.23% to a maximum of 6.58%. Similar increases are noticeable for wood-based materials and mineral wool, where the largest changes in coefficient values occurred, at 6.58% for *WB-290* and 6.30% for *RW-95*.

In contrast, a smaller difference (almost identical in both cases) was observed for lightweight cellular concrete *CC-350* - 5.00% and climatic board *CP-220* - 5.03%. *PP-350* perlite plaster was tested in the temperature range from 12.5°C to 32.5°C, showing a difference in value change of 4.23%.

4. EFFECT OF HUMIDITY

To investigate the impact of air humidity on the lambda coefficient value, samples were conditioned using the Laser Comp FOX 314 device [4]. Before the analysis, the samples were conditioned in laboratory conditions in a climatic chamber at five humidity ranges: 0%, 35-40%, 70-75%, 80-85%, and 90-95%. The sample conditioning was carried out in the ToRoPol chamber, and the humidity was controlled using a thermo-hygrometer. Each time, the samples were conditioned until their mass stabilized. Table 2 presents the analysis results, while Fig. 2 illustrates the relationship between the λ coefficient and humidity for selected materials from the respective groups.

Table 2. The value of the λ coefficient depending on the humidity of the air

MATERIAL		DISCLAIMER	MATERIAL DENSITY [kg/m3]	FACTOR λ [W/mK] - *EXAMINED* AIR HUMIDITY				
				0%	35-40%	70-75%	80-85%	90-95%
WOOD-BASED MATERIAL	HEAT-INSULATING FIBERBOARD	*WB-110*	110	0,03779	0,04423	0,05219	0,05538	0,05913
	INSULATING FIBERBOARD	*WB-240*	240	0,04498	0,04907	0,05398	0,05648	0,05873
	POROUS FIBERBOARD	*WB-290*	290	0,04814	0,05231	0,05638	0,06050	0,06408
PERLITE PLASTER	PERLITE THERMAL PLASTER	*PP-400*	400	0,08546	0,08746	0,09319	0,09478	0,09571
	PERLITE THERMAL PLASTER	*PP-350*	350	0,08325	0,08497	0,08623	0,08624	0,08660
CLIMATE PANEL	LIME SILICATE PANEL	*CP-220*	220	0,06984	0,07337	0,07683	0,08571	0,08898
	LIME SILICATE PANEL	*CP-230*	230	0,07307	0,07685	0,07891	0,08858	0,09455
CELLULAR CONCRETE	CELLULAR CONCRETE	*CC-350*	350	0,0957	0,1011	0,1076	0,1162	0,1391
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-115*	115	0,04998	0,0551	0,06299	0,07185	0,08893
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-100*	100	0,04628	0,04741	0,05367	0,06840	0,07430
ROCK WOOL	ROCK WOOL	*RW-95*	95	0,03790	0,03806	0,03828	0,03851	0,03862
	ROCK WOOL	*RW-110*	110	0,03994	0,04004	0,04021	0,04032	0,04034
	ROCK WOOL	*RW-135*	135	0,04000	0,04047	0,04071	0,04092	0,0410

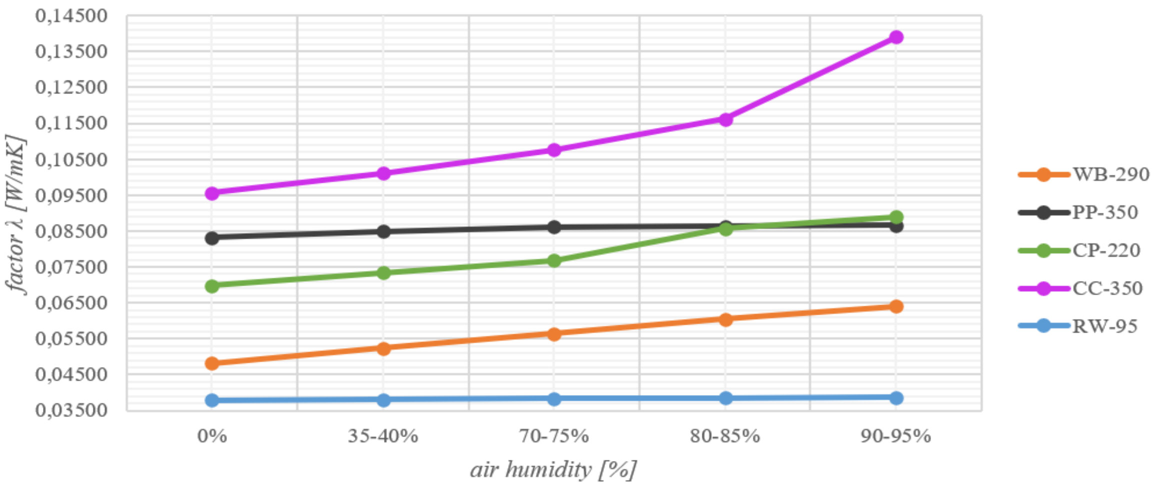

Fig. 3. The coefficient of thermal conductivity of selected materials at different humidity [%]

The results show the dependence of the thermal conductivity coefficient λ on air humidity. For each material tested, as the humidity increases, the value of the coefficient also increases. The increase is minimal for mineral wool *RW-95* and perlite plaster *PP-350*. The graph for wood-based material *WB-110* shows an almost linear trend. However, in the case of climate board *CP-220*, the graph does not show a linear pattern, the change in value at a moisture level of 80-85% is noticeable. The graph for lightweight cellular concrete *CC-350* shows a clear increase in the conductivity coefficient value at the highest moisture content tested, reaching 95%.

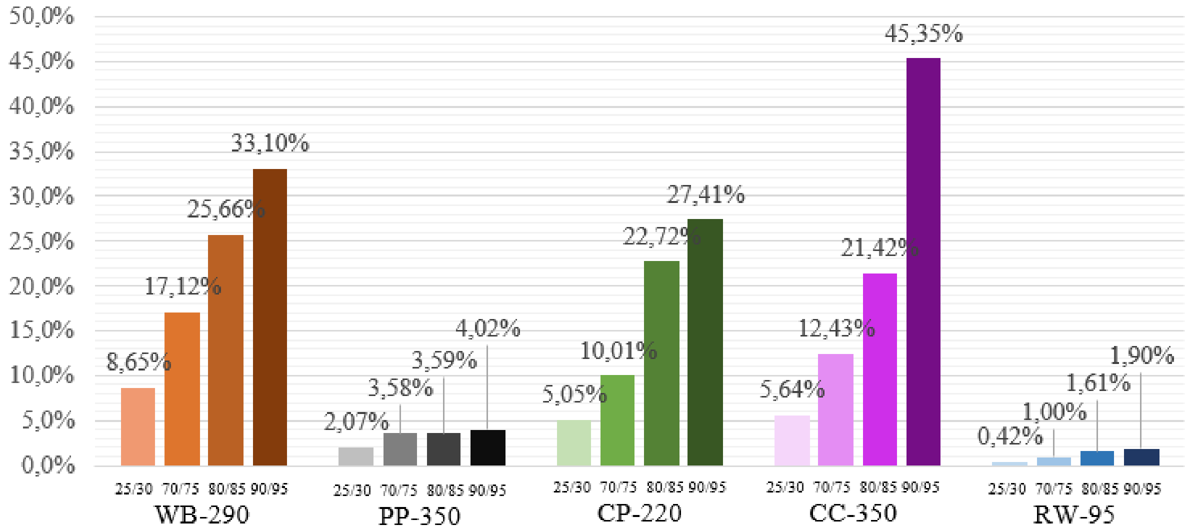

Fig. 4. Percentage increase coefficient of thermal conductivity of selected materials at different humidity: 25-30%, 70-75%, 80-85% and 90-95%

In an effort to compare the effect of humidity on the thermal conductivity coefficient of the selected materials, a chart was created to illustrate the percentage increase in the thermal conductivity coefficient λ, taking λ at 0% humidity as the base value.

After analyzing this graph, a relatively small effect of humidity on adverse changes in the conductivity coefficient was observed for two materials. The increase in value at 95% humidity ranged from 1.9% for *RW-95* mineral wool to 4.02% for *PP-350* perlite plaster. A significant increase in the thermal conductivity coefficient was observed for *CP-220* climate panels - 27.41%, *WB-290* wood-based materials - 33.10% and *CC-350* lightweight cellular concrete - 45.35%.

The different increases in thermal conductivity λ for materials determined at similar moisture levels may be due to different material structures, densities and sorption capacities.

A comparison of the effects of temperature and humidity on thermal conductivity indicates that humidity has a leading effect on the value of the thermal conductivity coefficient λ. This is due to the fact that the increase in this coefficient caused by an increase in humidity is much greater, several times greater, than the increase caused by changes in ambient temperature.

5. COMPARISON OF THE TESTED VALUES OF THE THERMAL CONDUCTIVITY COEFFICIENT Λ WITH THE VALUES GIVEN BY THE MANUFACTURERS

An analysis of the technical documentation of the tested products showed that it contained an insufficient number of parameters. In most cases, information on the temperature and humidity at which the thermal conductivity coefficient determination was performed is missing. In order to compare the declared values with the tested ones, the conditions most favorable to the manufacturers were assumed. In-house tests were conducted at 0% humidity of materials and in the lowest temperature range (0°C - 25°C).

Table 3. Comparison of the tested values of the thermal conductivity coefficient λ with the values given by the manufacturers

MATERIAL		DISCLAIMER	MATERIAL DENSITY [kg/m3]	FACTOR λ [W/mK]		DIFFERENCE [%]
				EXAMINED *temp. 12,5°C air humidity 0%*	DECLARED	
WOOD-BASED MATERIAL	HEAT-INSULATING FIBERBOARD	*WB-110*	109	0,03790	0,0370	-2,4
	INSULATING FIBERBOARD	*WB-240*	239	0,04498	0,0480	6,3
	POROUS FIBERBOARD	*WB-290*	288	0,04814	0,0500	3,7
PERLITE PLASTER	PERLITE THERMAL PLASTER	*PP-400*	401	0,08546	0,06400	-33,5
	PERLITE THERMAL PLASTER	*PP-350*	351	0,08325	0,12000	30,6
CLIMATE PANEL	LIME SILICATE PANEL	*CP-220*	220	0,06780	0,05900	-14,9
	LIME SILICATE PANEL	*CP-230*	230	0,07209	0,05900	-22,2
CELLULAR CONCRETE	CELLULAR CONCRETE	*CC-350*	350	0,09400	0,0950	1,1
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-115*	115	0,04863	0,04200	-15,8
	LIGHTWEIGHT CELLULAR CONCRETE	*CC-100*	100	0,04497	0,04200	-7,1
ROCK WOOL	ROCK WOOL	*RW-95*	95	0,03795	0,03600	-5,4
	ROCK WOOL	*RW-110*	110	0,03965	0,04000	0,9
	ROCK WOOL	*RW-135*	135	0,03928	0,03900	-0,7

The above comparison compares the tested values to those declared by manufacturers. In this analysis, a deviation of ±5% was allowed. It was observed that only in 5 cases the λ coefficient was close to the value declared by the manufacturer (results shown in yellow). This includes CC-350 cellular concrete, as well as two types of mineral wool, *RW-110* and *RW-135*, and two wood-based materials, *WB-240* and *WB-290*.

In two cases, the results were lower than guaranteed, indicating that WB-240 wood-based material and PP-350 perlite plaster are better insulators than assumed. This group showed the greatest discrepancy in results, reaching 30.6% for perlite plaster (indicated in green).

The remaining 6 materials show worse thermal insulation than initially assumed. Differences ranging from 5.4% to 33.5% indicate a significant deterioration in their thermal insulation properties (marked in red).

6. CONCLUSIONS

- There is too limited information in the technical specifications. In most cases, there is no information about the temperature and humidity at which the thermal conductivity coefficient determination was performed.
- The λ coefficient determined at 0% humidity of the samples and a temperature of 12.5°C in all tested samples was close to the declared (±5%) by the manufacturers only in the case of 5 materials. In the remaining materials, the differences were much higher, most often unfavorable (greater than declared).
- Regardless of the type of material, as the test temperature increases, the thermal conductivity coefficient increases. With an increase from 12.5°C to 42.5°C, the percentage increase in the value of the thermal conductivity coefficient ranges from 4.23% to 6.58%. The increases are linear.
- As the humidity of the air in which the samples were seasoned increases, the thermal conductivity coefficient increases. With an increase in air humidity from 0% to 95%, the percentage increase in the value of the thermal conductivity coefficient reached values of more than 45%.

- A relatively small effect on the adverse changes in the thermal conductivity coefficient was noted for rock wool and perlite plasters. The increase in values at 95% humidity ranged in the range from 1.9% for wool to 4.02% for perlite plasters.
- Significant increases in the thermal conductivity coefficient were recorded for climate panels (27.41%), wood-based materials (33.10%) and lightweight cellular concrete (45.35%).

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