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Influence of air humidity and temperature on thermal conductivity of wood-based materials

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Abstract: The aim of this paper is to approximate the issues related to the influence of air humidity and test temperature on the thermal conductivity coefficient λ of wood-based materials. During the laboratory tests, the λ coefficient was determined depending on the test temperature and air humidity, material density and sorption were also tested.
Keywords: wood-based materials, thermal conductivity coefficient, thermal insulation.

1. Introduction

The paper aims to familiarize the research on thermal conductivity in wood-based materials. During the tests, the values of thermal conductivity coefficient were determined for various types of wood-based panels used in the construction industry.

During the laboratory tests, the thermal conductivity coefficient was determined depending on the test temperature and air humidity. The temperature-dependent coefficient was determined on 29 samples. 5 types of plates were selected for further research. Each type was tested in three temperature ranges. The next group of tests included the determination of the λ thermal conductivity coefficient for different air humidity of the sample tested. The test was done on samples at five different air humidity values. The tests were carried out on five types of fibreboards. On the basis of the results, the graphs were created on which the relationships between the λ coefficients, test temperature, air humidity, and material density are shown. The sorption curves have also been determined. The obtained test results are presented in the form of tables and graphs.

2. Test stand

The tests were carried out using the Laser Comp FOX314 device, which consists of a base and a measuring chamber. The base includes a display with a keyboard to operate the device. The sample can be placed in the device after opening the door of the measuring chamber. The top plate of the instrument is fixed, the lower one has the ability to move up and down with the help of four stepper motors. After taking the sample through the plates, an average height value is read from four sensors with an accuracy of ±0.025 mm.

To remove the radial temperature gradient in the plates, they were equipped with a heating and cooling system, which consist of groups of thermoelectric elements, monitored separately for each of the plates. When the coolant temperature is maintained at 18°C, the plates can reach independent temperatures in the range of 0°C to 95°C with an accuracy of ± 0.02°C. [1]

To check the accuracy of measurements, the device was calibrated using a mineral wool sample numbered as S117, density equal to 76.7 kg/m^3, and dimensions of 301 mm x 301 mm x 34.2 mm (length x width x thickness). Due to the possibility of crushing the sample with automatic thickness measurement, the thickness was entered manually. A temperature range of 10–30°C was selected for the measurements, which corresponds to the range included in the instrument's manual. [2] The error of the calibration measurement was 0.22%, with a maximum permissible error of 2%, which means that the calibration of the device was carried out correctly.

3. Specimens tests

The plates collected were dried to a constant weight in an oven at 70 °C. The determination of the thermal conductivity coefficient was carried out on 29 samples. The measurements were made using a stationary method in the Laser Comp FOX 314 device. The course of the study was controlled using the WinTherm32v3 software. Each of the samples was tested in one range, at a temperature of 12.5°C (lower plate temperature L=0°C, upper U=25°C). The results obtained are presented in Table 1.

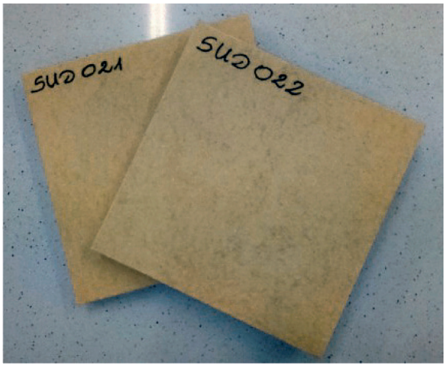


Fig. 1. Identification of the SUD 021 and SUD 022 samples. Thermo-insulating fibreboard – 200 kg/m^3

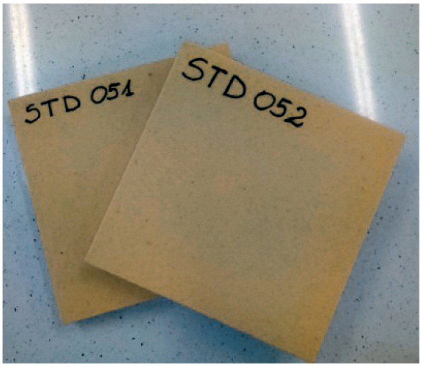


Fig. 2. Identification of the STD 051 and STD 052 samples. Insulating fibreboard – 210 kg/m^3

Fig. 3. Identification of the SB 061 and SB 062 samples. Insulating fibreboard – 240 kg/m^3

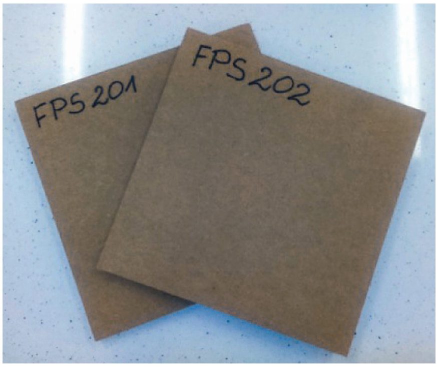


Fig. 4. Identification of the FPS 201 and FPS 202 samples. Porous fibreboard – 290 kg/m^3

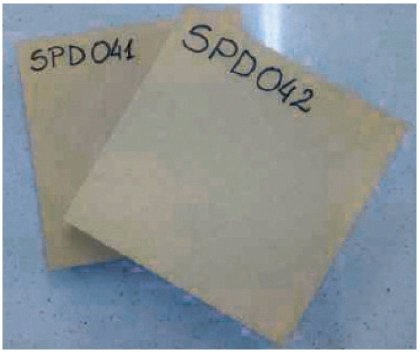


Fig. 5. Identification of the SPD 041 and SPD 042 samples. Insulating fibreboard – 160 kg/m³

Fig. 6. Identification of the OSB 1 sample – 560 kg/m³

Table 1. Results of the thermal conductivity coefficient of samples at 12.5°C

The desigantion of the sample	Type of material	Density [kg/m³]	λ [W/mK] Temperature range $U1=0$; $L1=25$	λ average examined [W/mK]	Manufacturer's λ [W/mK]
SP011	Insulating fibreboard	256	0.04751	0.048	0.050
SP012		257	0.04765		
SUD021	Thermo-insulating fibreboard	198	0.04392	0.044	0.045
SUD022		200	0.04410		
ST031	Insulating fibreboard	147	0.03800	0.038	0.038
ST032		147	0.03799		
SPD041	Insulating fibreboard	161	0.04151	0.041	0.043
SPD042		160	0.04141		
STD051	Thermo-insulating fibreboard	109	0.03772	0.038	0.037
STD052		108	0.03786		
SB061	Insulating fibreboard	240	0.04512	0.045	0.048
SB062		238	0.04484		
SU071	Thermo-insulating fibreboard	266	0.04691	0.047	0.048
SU072		266	0.04704		
SPH081	Insulating fibreboard	344	0.05344	0.053	0.050
FI091	Fibreboard	309	0.04504	0.045	0.05
FPT101	Hard fibreboard	905	0.07295	0.073	–
FPS201	Porous fibreboard	289	0.04815	0.048	0.05
FPS202		288	0.04813		
FW301	Porous fibreboard	290	0.04880	0.049	0.050
FW302		289	0.04870		
FT401	Fibreboard	168	0.03808	0.038	0.040
FT402		169	0.03808		
Chipboard 1	Chipboard	635	0.10220	0.102	–
Chipboard 2		590	0.09561	0.096	–
Chipboard 3		643	0.10130	0.101	–
OSB 1	OSB	561	0.08816	0.088	–
Plywood 1	Plywood	710	0.12730	0.127	–
Plywood 2		629	0.11640	0.116	–

After analyzing the results obtained for further research, five types of fibreboards with different densities were selected, two pieces from each density. Ten samples selected were dried at 70°C to a humidity of about 0%. The tests were carried out for three temperature levels: 22.5°C, 32.5°C, and 42.5°C.

Table 2. Temperature ranges used to the *λ* examination, using the Laser Comp FOX314 device

The temperature of the upper plate	The temperature of the lower plate	The temperature inside the sample
*U*1=0°C	*L*1=25°C	Tavrg=12.5°C
*U*2=10°C	*L*2=35°C	Tavrg=22.5°C
*U*3=20°C	*L*3=45°C	Tavrg=32.5°C
*U*4=30°C	*L*4=55°C	Tavrg=42.5°C

After each test, the samples were placed in the dryer so that the humidity was kept within 0% with each subsequent test. Below a table with results (Table 3) is placed, an exemplary graph with the relation of the *λ* coefficient and the test temperature (Fig. 7), a collective plot of the average values of the fibreboards tested (Fig. 8), and a bar graph of the average values of the *λ* coefficient.

Table 3. The values of the *λ* thermal conductivity coefficient depending on the test temperature

The designation of the sample	Producer's *λ*	*λ* [W/mK]			
		Temperature range			
	[W/(mK)]	*U*1=0; *L*1=25	*U*2=10; *L*2=35	*U*3=20; *L*3=45	*U*4=30; *L*4=55
SUD021	0.045	0.04392	0.04608	0.04591	0.04731
SUD022		0.04410	0.04523	0.04661	0.04770
STD051	(0.037	0.03772	0.03901	0.04011	0.04090
STD052		0.03786	0.0391	0.04011	0.04114
SB061	0.048	0.04512	0.04647	0.04797	0.04857
SB062		0.04484	0.04597	0.04700	0.04764
FPS201	0.05	0.04815	0.04938	0.05040	0.05127
FPS202		0.04813	0.04936	0.05040	0.05135
FT401	0.040	0.03808	0.03925	0.04029	0.04115
FT402		0.03808	0.03932	0.04032	0.04107

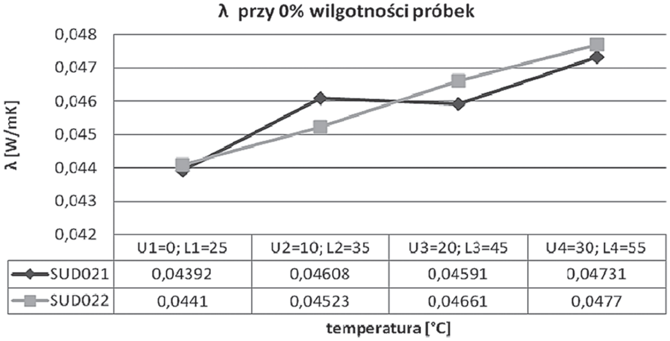


Fig. 7. The dependence of the *λ* thermal conductivity coefficient and the test temperature – the SUD02 material SUD02, samples 1 and 2

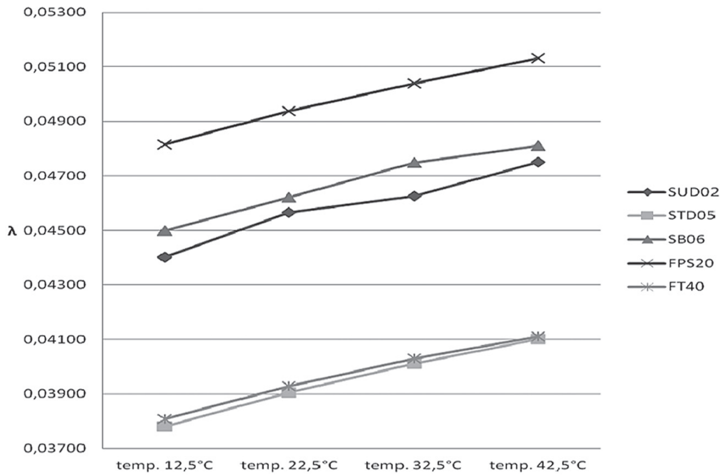
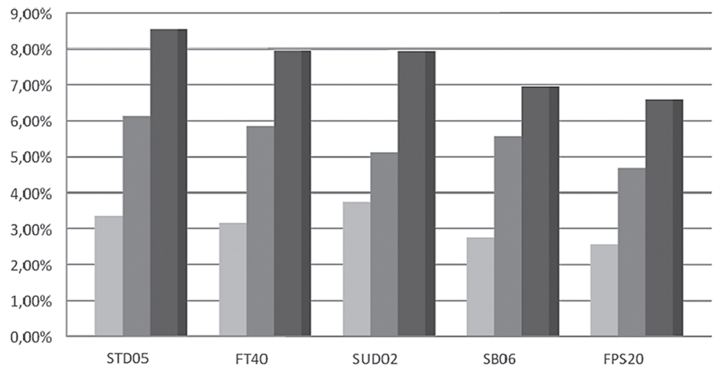


Fig. 8. A collective graph of the dependence between of the λ thermal conductivity coefficient and the temperature. Graph was developed for the average of two samples

In all studied wood-based panels, the diagrams show a course close to linear. To compare the influence of the test temperature on the thermal conductivity of selected materials, a graph of the percentage increase in the λ coefficient was made, assuming that the base value is the value of λ determined at an average temperature of 12.5°C. From the results obtained, it can be seen that for all materials, the percentage increase in λ was similar.



	STD05	FT40	SUD02	SB06	FPS20
U2=10; L2=35	3,35%	3,16%	3,74%	2,76%	2,56%
U3=20; L3=45	6,14%	5,84%	5,11%	5,57%	4,69%
U4=30; L4=55	8,55%	7,96%	7,94%	6,95%	6,58%

Fig. 9. The percentage increase in the λ thermal conductivity coefficient depending on the temperature range. The reference level is the value of the λ coefficient at a temperature of 12.5°C.

4. Study of sorption properties

The purpose of the analysis was to investigate the amount of water that can be absorbed by the samples under the particular climatic conditions. For this test, the samples were dried to a constant mass, then placed in a climatic chamber in which the humidity was gradually raised without changing the temperature (25ºC). Initially, the lowest of the humidity selected for testing was set. Samples were weighed periodically until their weight was settled. The amount of water absorbed was determined at the moment when the sample mass stabilized. Correlation between air humidity and sorption humidity is shown by the sorption curves. A table with results (Table 4) and an example of a sorption curve chart are shown below (Fig. 10).

Table 4. The values of the equivalent sorption humidity of the materials tested in different air humidity

The designation of the sample	Air humidity				
	0%	32–33%	70–75%	80–85%	90–95%
	Sorption [%]				
SUD02	0.00	5.80	11.14	13.37	16.53
STD05	0.00	5.70	11.37	13.27	16.34
SB06	0.00	6.03	12.81	15.47	19.10
FPS20	0.00	5.42	10.75	14.02	17.32
FT40	0.00	5.70	12.20	15.73	19.64

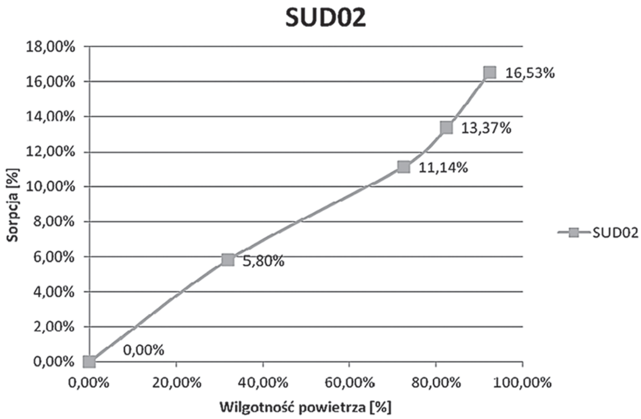


Fig. 10. Sorption curve of the SUD02 sample

There is no information on the size of sorption in the manufacturers' technical sheets, therefore the values obtained can not be compared and assessed of compliance with the declared values.

5. Effect of air humidity

To determine the effect of air humidity on the thermal conductivity coefficient, five types of wood-based panels of varying density were selected and placed in a climatic chamber. Samples were seasoned at air humidity equal to 32–33%, 70–75%, 80–85%, and 90–95% to stabilize the sample mass. Each time, the humidity in the climatic chamber was controlled using a hytherograph.

All materials were tested in a one temperature of 12.5°C. Each of the samples was weighed at 0% moisture and at each subsequent in which it was seasoned. Below is an example of a table with results (Tab. 5), a graph showing the dependence of the λ coefficient and air humidity for two samples from the same material (Fig. 11), a collective plot of the λ coefficient and the air humidity of the fibreboards tested (Fig. 12), and bar graph for average results of the λ coefficient. The types of boards were arranged in order of increasing density. (Fig. 13).

Table 5. The results of the impact of air humidity on the λ coefficient for five selected materials

The designation of the sample	λ [W/mK]				
	U1=0; L1=25				
	0%	32–33%	70–75%	80–85%	90–95%
SUD02	0.04401	0.050170	0.057360	0.059740	0.063575
STD05	0.03779	0.044230	0.052185	0.055380	0.059125
SB06	0.04498	0.049065	0.053975	0.056480	0.058730
FPS20	0.04814	0.052305	0.056380	0.060495	0.064075
FT40	0.03808	0.042395	0.048225	0.052065	0.056235

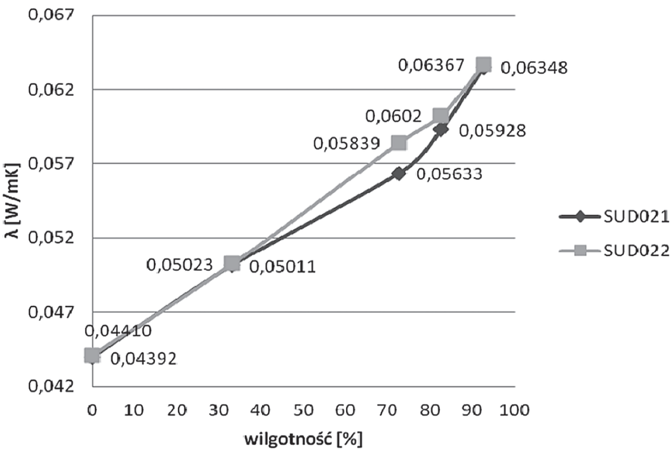


Fig. 11. The dependence of the λ coefficient and the air humidity for SUD02

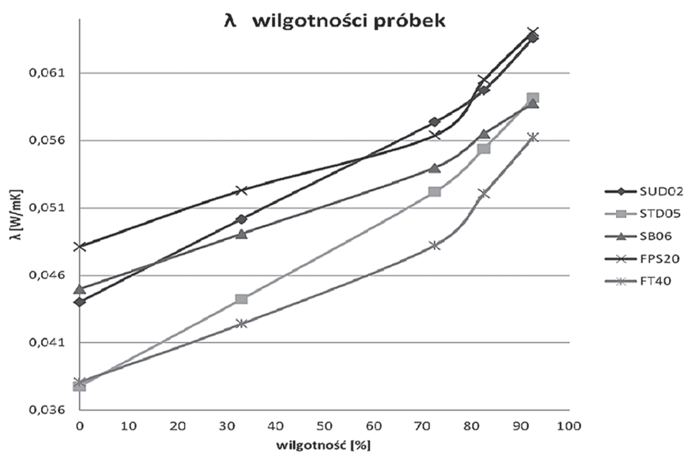
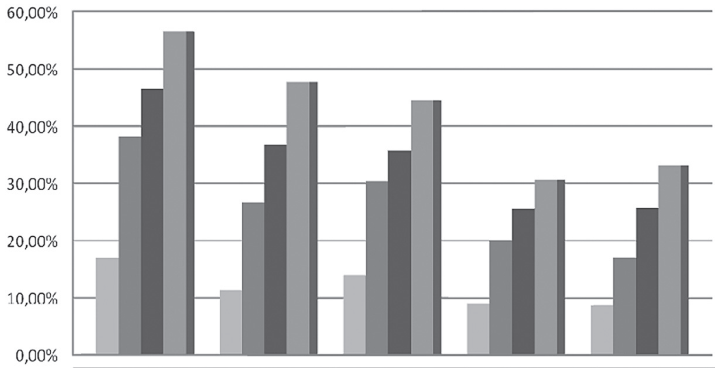


Fig. 12. Average dependence of the λ coefficient and air humidity of all samples

The graphs show a non-linear course of the dependencies. With each material examined, it was observed that the thermal conductivity coefficient increases with increasing humidity.

I order to compare the impact of air humidity on the thermal conductivity of selected materials, a graph of the percentage increase in the λ coefficient was made, assuming that the base value is the value of λ determined at 0% humidity. Different sizes of the increase in the λ thermal conductivity coefficient for materials determined at similar humidity may result from the different structure of the material, density, and sorption capacity.



	STD05	FT40	SUD02	SB06	FPS20
32-33%	17,04%	11,33%	14,00%	9,08%	8,65%
70-75%	38,09%	26,64%	30,33%	20,00%	17,12%
80-85%	46,55%	36,73%	35,74%	25,57%	25,66%
90-95%	56,46%	47,68%	44,46%	30,57%	33,10%

Fig. 13. The percentage increase in the λ coefficient value depending on the air humidity

6. Effect of density of materials

In order to determine the effect of density of wood-based materials on the thermal conductivity coefficient, the table presents the results of samples density and the λ coefficient values obtained from tests carried out on samples with 0% moisture and tested at 12.5°C.

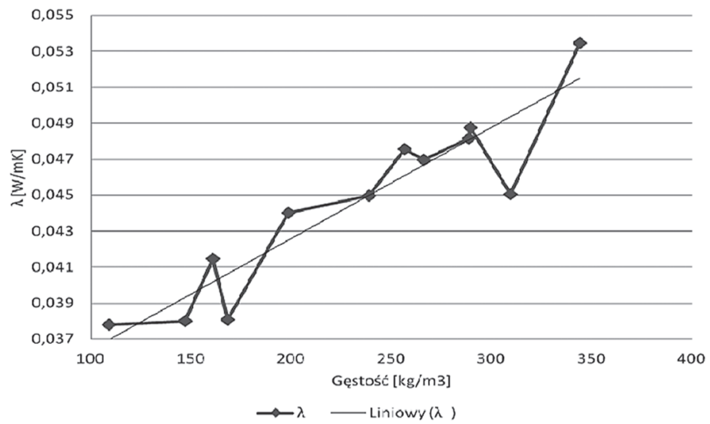


Fig. 14. Graph of dependence of the thermal conductivity coefficient and the density of materials tested

Table 6. The values of the thermal conductivity coefficient in terms of materials' density

The designation of the sample	Density (average) [kg/m³]	λ tested (average) [W/m·K]
SP01	256	0.04758
SUD02	199	0.04401
ST03	147	0.03800
SPD04	161	0.04146
STD05	109	0.03779
SB06	239	0.04498
SU07	266	0.04698
SPH081	344	0.05344
FI091	309	0.04504
FPT101	905	0.07295
FPS20	288	0.04814
FW30	289	0.04875
FT40	168	0.03808
Chipboard 1	635	0.10220
Chipboard 2	590	0.09561
Chipboard 3	643	0.10130
OSB 1	561	0.08816
Plywood 1	710	0.12730
Plywood 2	629	0.11640

The trend line shows an increase in the thermal conductivity coefficient with increasing density. The graph obtained does not illustrate the actual situation, because the values should be more similar to the trend line, such a discrepancy may be related to various methods and the specificity of the process of fibreboards production.

7. Conclusions

- There is too little information in the technical specifications.. The information on the temperature and air humidity in which the thermal conductivity coefficient was determined has not been included,
- The λ coefficient determined at 0% moisture of the samples and the temperature of 12.5°C in all tested samples was close to the one declared by the producers, which may mean that this coefficient was determined by the manufacturers in similar conditions.
- For most materials the thermal conductivity coefficient value declared by the manufacturer was higher than that obtained in the laboratory.
- Regardless of the type of wood-based boards, as the temperature of the test rises, the thermal conductivity coefficient also increases. When the test temperature increased from 12.5°C to 42.5°C, the percentage increase in the thermal conductivity coefficient ranged from 2.56% to 8.55%.
- There is no information on the value of sorption in the manufacturers' technical sheets, therefore the values obtained can not be compared and assessed of compliance with the values declared.

– The thermal conductivity coefficient increases with increasing humidity. With an increase in air humidity from 0% to 95%, the percentage increase in the thermal conductivity coefficient ranged from 8.65% to 56.46%.
– When testing the effect of density on the thermal conductivity coefficient, a graph that does not show the actual situation was obtained, the values should be closer to the trend line. Such a discrepancy may be related to various methods and the specificity of the manufacturing process of wood-based materials.

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