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THERMAL CONDUCTIVITY OF SOLID WOOD PANELS MADE FROM HEAT-TREATED SPRUCE AND LIME WOOD STRIPS

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Abstract

The paper presents the results of an experimental research performed with spruce (Picea abies L.) and lime (Tilia cordata) wood originating from the Stroesti-Arges region in Romania. Solid wood panels were manufactured from heat-treated strips, and also from untreated strips, as controls. The thermal conductivity (λ) of the panels was measured on a HFM 436/6/1 Lambda equipment at a temperature difference of 30°C between the cold and the hot plate. The results showed that the panels made from heat-treated wood strips had by 13% lower values of λ in case of spruce and by 6% lower values in case of lime and thus better heat-insulating properties than the panels made from untreated wood of the same species. With λ values around 0.07-0.08 W/m·K, 20mm thick solid wood panels made from heat-treated spruce and lime strips are comparable to wool from the viewpoint of the thermal insulating capacity.

Key words: *solid wood panels; thermal insulation; thermal conductivity; heat-treatd spruce; heat-treated lime.*

BACKGROUND

The heat treatment of wood causes a number of chemical and physical changes that lead to an increased dimensional stability, lower hygroscopicity and an improved biological durability of this material. These property modifications give the opportunity to employ heat-treated wood for outdoor uses.

Solid wood panels made from heat-treated wood are suitable for outoor claddings. For this purpose, beside shape-, color- and dimensional stability, thermal conductivity is also an important property.

The degradation of the wood structure components during the heat treatment results in lower density and more air in the material. This determines lower thermal conductivity of the heat-treated material, which means better insulation properties (Forsman 2008). According to the ThermoWood Handbook (2003), the thermal conductivity of softwoods is reduced by 20-25% through the heat treatment in superheated steam at 230°C.

The significance of the thermal conductivity reduction varies from one species to another and it also depends on the applied heat treatment parameters and method. A very good reference size is the mass loss, because it characterizes best the aggresivity (degree of decomposition) of the given heat treatment and it enhances to compare the results obtained on the same species with different methods/parameters. Unfortunately, most authors indicate in their works only the treating conditions (treating agent, temperature, time) applied, without mentioning the mass loss caused by these treating conditions.

Table 1 summarizes some results from reference literature concerning the heat conductivity values obtained by different researchers, with different wood species, by using different heat-treatment methods.

Table 1

Thermal conductivity values of heat-treated wood

Reference	Heat treatment method	Wood species	Treatment conditions	Mass loss,%	Thermal conductivity of heat-treated wood (λ_*), W/mK	Thermal conductivity reduction compared to untreated wood of the same species, %
ThermoWood Handbook (2003)	ThermoWood	Spruce	230°C/3h	5.8	λ_{10} 0.097	11.8
			230°C/5h	9.3	0.082	25.0
		Pine	230°C/3h	8.7	0.107	17.7
			230°C/5h	12.1	0.101	22.3
Kol and Sefil (2011)	ThermoWood	Fir	170°C/2h	Not specified.	0.127	2.0
			212°C/2h		0.119	9.0
		Beech	170°C/2h		0.179	2.0
			212°C/2h		0.155	16.0
Korkut et al (2013) Korkut and Aytin (2015)	ThermoWood	Wild cherry	212°C/1.5h	12.42	λ_{20} 0.115	18.4
			212°C/2.5h	18.7	0.110	29.0
Niemz et al (2010)	Vacuum-press dewatering method (Vacu^3), Opel Therm (Timura)	Ash	240°C/80mbar	Not specified.	λ_{10} 0.128	6.5
					0.123	10.2
		Beech			0.122	12.2
					0.109	21.6

*Temperature difference (Δt) at which the value of λ was determined.

OBJECTIVE

Within the present research, the thermal conductivity (λ) of solid wood panels made from heat-treated spruce and lime wood strips, respectively, was evaluated. The heat treatment was carried out at atmospheric pressure. The obtained values were compared to the thermal conductivity of other materials, traditionally used as heat insulators in buildings.

MATERIAL, METHOD, EQUIPMENT

The wooden material used in the present research consisted of 1100 x 110…170 x 30mm boards, cut from 3 mature logs (Φ = 30 ... 35cm) of spruce (*Picea abies*) and lime (*Tilia cordata*), all originating from the same forestry areal: Stroesti – Arges (45° 8' 0" North, 24° 47' 0" East). The boards were kiln-dried down to a moisture content of 12%. These were then planed and sectioned down to 340x110…170x28mm. Hereinafter, half of the samples were heat-treated in a BINDER electric oven in air, at atmospheric pressure, according to the schedules presented in Table 1. The other half of samples were kept untreated, as controls.

The parameters for the actual heat-treatment phase (Table 2) were established based on some preliminary experiments with various combinations of temperature and time so as to reach a 5%

mass loss (*ML*) of the strips. This criterion was grounded on Viitaniemi et al. (1997), who found that *ML*=5% is a threshold value, which ensures maximum efficiency of the heat treatment in case of spruce wood, without affecting its mechanical strengths.

Table 2

Heat-treating conditions

Phases	**Parameters for:**	
	Spruce	**Lime**
Oven-drying	103°C	103°C
Heating	180°C/8h	180°C/8h
Actual heat treatment	200°C/10h	200°C/3h
Cooling	20°C/12h	20°C/12h

Both the heat-treated wood strips and the untreated controls were conditioned for 2 weeks, in order to reach a moisture content of 12%. Hereinafter, 300x300x20mm panels were manufactured. Six panels of each species (half made of heat-treated strips and half made of untreated strips) were tested by means of a HFM 436/6/1 Lambda equipment (by NETSCH) (Fig. 1).

The measurement principle of this equipment is based on Fourier's equation (1): the thermal conductivity coefficient (λ) of the panel is automatically calculated by the machine software as function of the heat flux generated by the temperature difference beteen the two surfaces of the tested panel (one surface is in contact with the „cold" platen of the machine having temperature t_1 and the other one is in contact with the „hot" platen with temperature t_2)(Table 3).

$$q = \frac{\lambda}{\delta} \cdot \Delta t \quad \rightarrow \quad \lambda = \frac{q \cdot \delta}{\Delta t} \qquad (1)$$

where:

q – heat flux, in W/m^2.

λ - heat conductivity coefficient, in W/m·K

δ – panel thickness, in m;

Δt – temperature difference (t_2 - t_1) between the two surfaces of the sample, in K.

Both the thermal conductivity coefficient (λ) and the panel density (ρ) were measured in eight points and then, the equipment software automatically calculated the average for each parameter.

Fig. 1.
HFM 436/6/1 Lambda equipment (by NETSCH)** used **for measuring the thermal conductivity of the panels

Table 3

Temperature differences for thermal conductivity measurements

Number of tests	Temperature t_1 [°C]	Temperature t_2 [°C]	Δt (t_2-t_1) [°C]	Average (t_1+t_2)/2 [°C]
1	-25	5	30	-10
2	-20	10	30	-5
3	-15	15	30	0
4	-10	20	30	5
5	-5	25	30	10
6	0	30	30	15

RESULTS AND DISCUSSION

The average values of the density and thermal conductivity coeffcients obtained for the panels made of heat-treated wood strips compared to the untreated controls, for different temperature combinations between the hot and the cold platen, are given in Table 4.

Table 4

Density and heat conductivity of panels made from heat-treated and untreated spruce and lime wood strips

Panel sample	Cold platen temperature [°C]	Hot platen temperature [°C]	Density [kg/m³], sample N°:			Thermal conductivity [W/mK], sample N°:		
			1	2	3	1	2	3
Heat-treated spruce	-25	5	389	383	385	0.074	0.071	0.075
	-20	10				0.077	0.073	0.071
	-15	15				0.075	0.073	0.076
	-10	20				0.075	0.073	0.074
	-5	25				0.077	0.074	0.072
	0	30				0.077	0.075	0.076
						0.076	**0.073**	**0.074**
		Average:	**385.6**			**0.074**		
Untreated spruce	-25	5	441	439	424	0.089	0.093	0.075
	-20	10				0.086	0.089	0.078
	-15	15				0.084	0.088	0.084
	-10	20				0.085	0.088	0.084
	-5	25				0.086	0.090	0.086
	0	30				0.087	0.091	0.086
						0.086	**0.090**	**0.082**
		Average:	**434.6**			**0.086**		
Heat-treated lime	-25	5	484	491	457	0.086	0.095	0.078
	-20	10				0.083	0.091	0.078
	-15	15				0.081	0.089	0.078
	-10	20				0.081	0.089	0.078
	-5	25				0.082	0.090	0.078
	0	30				0.083	0.091	0.079
						0.083	**0.091**	**0.078**
		Average:	**477.3**			**0.084**		
Untreated lime	-25	5	546	510	537	0.095	0.094	0.084
	-20	10				0.092	0.090	0.089
	-15	15				0.090	0.088	0.089
	-10	20				0.090	0.089	0.091
	-5	25				0.091	0.090	0.090
	0	30				0.092	0.092	0.091
						0.092	**0.091**	**0.089**
		Average:	**531.0**			**0.090**		

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It can be noticed that the panels made of heat-treated wood strips are characterized by a lower thermal conductivity than the untreated ones, which confirms that the heat insulating capacity is improved by the heat treatment: by 13% in case of the spruce wood panels and by 6% in case of the lime wood panels.

With λ=0,074 W/m·K and λ=0,084 W/m·K, the 20mm thick panels made from heat-treated spruce and lime wood strips, respectively, are better heat insulators than chipboards, plywood, hardboards, gypsum (plaster) boards or PVC. Their heat insulation capacity is comparable to that of wool and low-density particleboards (http://www.engineeringtoolbox.com/__thermal-conductivity-d_429.html). The graph in Fig. 2 presents a comparison between the thermal conductivity of the panels under study and other materials frequently used as insulating materials in buildings (www.engineering.com/Library/ArticlesPage/tabid/85/ ArticleID/152/ Thermal-Conductivity.aspx).

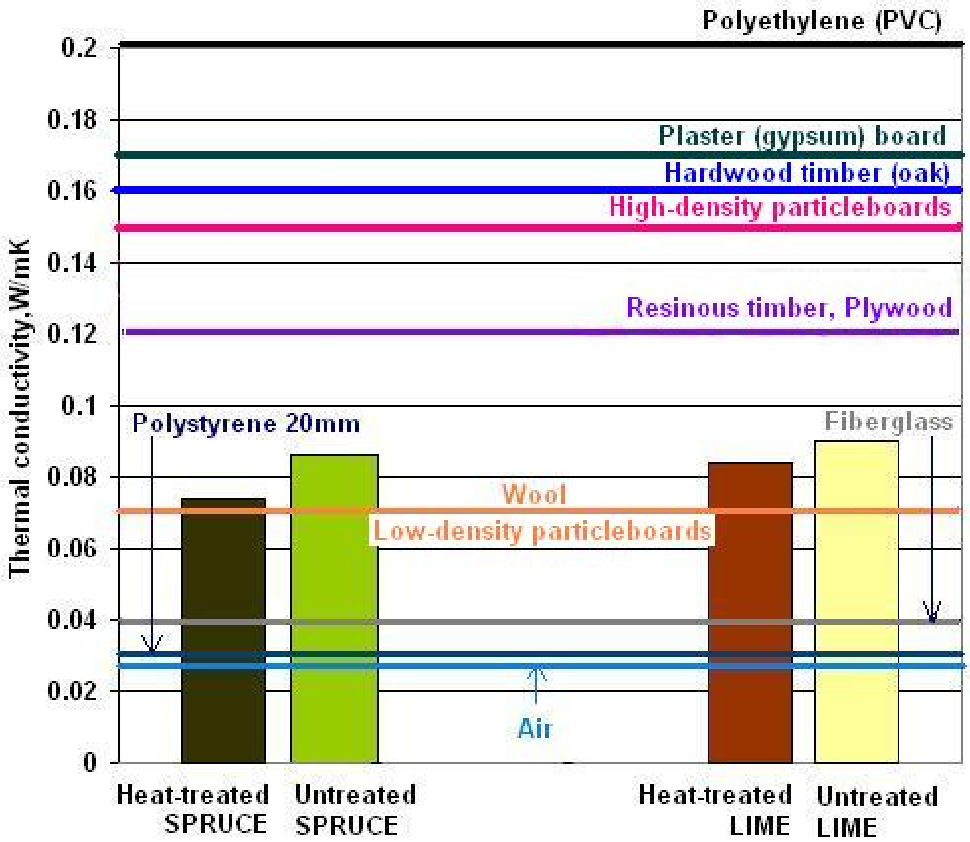

Fig. 2.
Thermal conductivity of 20mm thick experimental panels made from heat-treated spruce and lime wood, as compared to other building materials.

CONCLUSIONS

The heat treatment in air at atmospheric pressure also reduces the thermal conductivity of wood, even if not to such great extent as the ThermoWood process.

Spruce wood strips were heat-treated at 200°C for 10h until they reached a mass loss of 5%. They were assembled into 20mm thick solid wood panels and then tested at a temperature difference of 30°C. The thermal conductivity of the panels made from heat-treated spruce strips ranged between 0.071 and 0.077 W/m·K. The average value ($\lambda_{heat\text{-}treated\ spruce}$ = 0.074 W/m·K) resulted by ca. 13% lower than that of the panels made from untreated spruce wood strips.

Within the same research, lime wood strips were heat treated at 200°C for 3h until they reached a mass loss of 5%. They were also assembled into 20mm thick solid wood panels and then tested. The thermal conductivity of the panels made from heat-treated lime strips ranged between 0.078 and 0.085 W/m·K. The average value ($\lambda_{heat\text{-}treated\ lime}$ = 0.084 W/m·K) resulted by ca. 6% lower than that of the panels made from untreated lime wood strips.

For both species, the values of λ are smaller than given in reference literature (see Table 1) for wood that was heat-treated in an inert atmosphere.

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