

Thermal and moisture adsorption/desorption properties for a selection of vegetal insulation materials

Stanislavs Gendelis^{1,*}, Andris Jakovičs¹, and Max Engelhardt²

¹ The Faculty of Physics, Mathematics and Optometry, University of Latvia, Latvia

² Department of Research and Development², Forschungsinstitut für Wärmeschutz e.V. München, Germany

Abstract. Natural, or ‘green’ insulation materials, have become more popular for the ‘ecologisation’ of construction activities. The ecological aspects for such materials are being widely analysed, but experimental data about their physical properties when installed in building constructions remains lacking. In this study, pressed samples of three locally wild grown agricultural materials – rye, reed, and hemp – are analysed. Thermal conductivity measurements were carried out using the hot plate device. Comparison with widely used mineral insulation materials shows that thermal conductivity for simple pressed materials are roughly three times higher, and are comparable to plywood and cross-laminated timber insulation properties. Additional experiments regarding such materials include measurements of hygroscopic sorption properties (adsorption/desorption), determined using the dynamic gravimetric method at different temperatures and a wide, relative humidity range. The results obtained show that the difference in all studied materials appeared only at high humidity values; the rye straw and reed spikelets adsorbed more water than other materials, which is important for potential indoor air humidity assessment.

1 Introduction

In recent years, the EU adopted several directives related to energy efficiency, e.g. the Energy Efficiency Directive 2012/27/EU [1], which requires a significant reduction in buildings’ energy consumption through, e.g. the introduction of nearly zero energy buildings (nZEBs). To meet these requirements, the industry will need to improve the efficiency of existing materials, optimise their use as building structures, as well as develop novel, sustainable, and ecological construction materials [2].

Natural, or ‘green’ materials, produced from natural sources, were historically used in the construction of houses and farm buildings. The easiest and cheapest approach for using these materials is to make them into blocks by pressing together the raw materials (without

* Corresponding author: stanislavs.gendelis@lu.lv

any additives). A more complicated method involves the combination of green materials with denser base materials such as lime mortar, in order to provide a sufficient load-carrying capacity, which is necessary for wall construction. Generally, materials sourced from natural raw materials have a negative CO₂ emission; this occurs due to locking more carbon dioxide within the material than is unlocked during the production process [3]. Other factors that are important for these unconventional materials, but that are not analysed in this research include sustainability, acoustic performance, and the life cycle assessment of sustainability [4].

In general, natural insulation materials can be made from vegetal or animal sources. The bulk of primary vegetal insulation materials are made of wood or agricultural products. Animal-origin insulation materials are primarily made from hair, e.g. sheep's wool. The ecological aspects of such materials have been widely analysed, but experimental data about their physical properties when installed in building constructions remain lacking.

In this study thermal and hygroscopic sorption properties for three locally wild grown agricultural materials, rye, reed, and hemp (Fig. 1), are analysed. No additives were used during the manufacturing of products; they were simply mechanically pressed raw materials. Information about the thermal properties of other unconventional building insulation materials can be found in [4, 5].



Fig. 1. Fibres of pressed rye (left), reed (centre), and hemp (right).

2 Methods and results

2.1 Thermal conductivity

The efficiency of insulation materials is described by thermal conductivity λ (W/(m·K)). One approach for the measurement of this parameter in steady-state conditions is the guarded hot plate method [6]. The measurement principle is simple: a specimen is placed between two surfaces that are kept at constant temperatures, and the heat flow passing through the plates is registered after stationary conditions are reached; a so-called ‘compensations zone’ with the same temperatures surrounds the flow meters to avoid heat losses in other directions. Dependence of thermal conductivity on mean temperature can be estimated by conducting the measurements with different surface temperatures.

Insulation materials made from agricultural and plant products are mostly soft and easily compressible; therefore, it is very important to choose the optimal pressure on a specimen in the hot plate device, a too-high compression pressure will squeeze out the air, which will lead to incorrect results, due to increasing thermal conductivity. For the measurement of such materials, 100 N of force is experimentally approved as being good.

The measurement results for rye, reed and hemp, which in this instance represent simply mechanically pressed raw materials, are summarised in Table 1. The thermal conductivities for these materials were very close within the range 0.08...0.1 W/(m·K). An example of temperature dependence is shown on Fig. 2, where line slope for all the materials is practically the same. The key aspects in this instances are fibre orientation and compression, which impact the thermal resistance of air inclusions.

A comparison with mineral insulation materials shows that thermal insulation properties for simply pressed materials are roughly three times higher, and they are comparable to plywood or cross-laminated timber insulation properties. Thermal conductivity for similar unconventional natural raw materials like sunflower stalks, corn cobs or hemp shives is in range 0.9...1.1 W/(m·K) [4, 7], which is very close to the measured values.

Table 1. Summary of densities and thermal conductivity results for measured materials.

Material	Density (kg/m ³)	Thermal conductivity λ_{10} (W/(m·K))
Pressed rye straw	690	0.09
Pressed reed straw	740	0.10
Pressed hemp shives	630	0.08

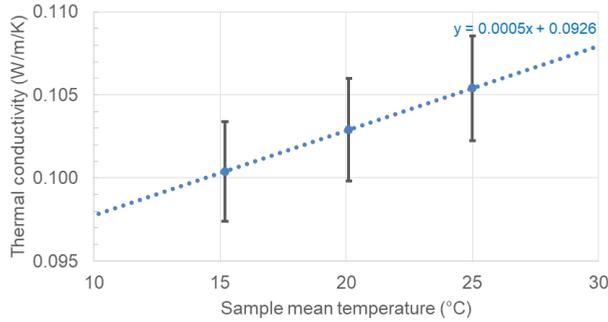


Fig. 2. An example of thermal conductivity dependence on mean temperature (reeds).

2.2 Hygroscopic sorption properties

Experiments were made for rye, reed, and hemp raw materials, where measurements of water vapour adsorption and desorption was determined using the dynamic gravimetric method, according to the ISO 12571 standard [8]. While taking the measurements, samples were firstly dried to minimise their initial water content. Afterwards, samples were held at a temperature of 23°C, and successively in 50% and 80% air relative humidity, until the water content stabilised, which was determined by periodically weighing the samples (Fig. 3). After these measurements were finished, samples were dried again at 70°C and 110°C temperatures for control purposes (in the last case, all water had evaporated from samples). Unfortunately, data measured at only two air humidity values are not sufficient for characterising water content dependence (sorption) in the full relative humidity range up to the saturated vapour condition. However, such dependencies are necessary for use in the numerical modelling of humidity dynamics in building construction, and to analyse the sustainability of composite constructions in real climatic conditions, to ensure that water will not accumulate in the construction over the long-term, and facilitate mould growth.

The results of equilibrium moisture content in the researched natural materials obtained for adsorption and desorption processes are summarised in Table 2. It can be seen that all materials behaved very similarly, except in the case of high humidity values (98%), where the rye straw and reed spikelets were able to adsorb more water than another materials (32% and 37% moisture content by mass, compared to the 25% to 27%). This is an

extremely significant finding, and is important for potential indoor air humidity assessment. Unfortunately, due to technical problems, desorption measurement was not carried out. It is clearly visible (Fig. 4), that increasing (adsorption) and decreasing (desorption) processes creates a hysteresis curve, which is typical for porous wood-based materials [9].

Visually, equilibrium moisture content at 23°C depended on relative air humidity for all the studied materials, shown in Fig. 4. The smallest difference between adsorption and desorption curves was determined for reed spikelets; for the other materials, the difference was larger, and very similar to one another. Results are close to the bulk wood properties with moisture content of 27% at the temperature 21°C and relative humidity of 98% [9].



Fig. 3. Samples during the measurement of hygroscopic sorption properties.

Table 2. Equilibrium moisture content at 23°C.

	RH [%]	Moisture content [% by mass]				
		Rye straw	Reed	Reed (spikelets only)	Reed (stems only)	Hemp shives
Adsorption	0	0.0	0.0	0.0	0.0	0.0
	10	2.8	3.5	3.4	2.6	3.0
	20	4.3	5.0	5.2	4.1	4.5
	30	5.6	6.4	6.7	5.4	5.9
	40	6.9	7.7	8.3	6.7	7.2
	50	8.4	9.2	10.0	8.2	8.7
	60	10.2	10.8	11.9	9.8	10.4
	70	12.6	13.0	14.5	11.9	12.6
	80	15.6	15.8	18.0	14.5	15.3
	90	21.5	20.1	23.5	19.0	19.6
	98	32.0	26.6	37.1	25.1	26.0
Desorption	90	-	22.6	23.2	21.6	22.5
	80	-	18.9	18.0	18.1	18.8
	70	-	15.5	15.1	14.8	15.4
	60	-	13.1	12.8	12.8	13.3
	50	-	11.1	10.8	10.7	11.2
	40	-	9.3	9.2	8.9	9.4
	30	-	7.6	7.7	7.2	7.7
	20	-	6.7	5.8	5.5	5.8
	10	-	4.7	4.1	3.6	3.8
	0	-	0.0	0.0	0.0	0.0

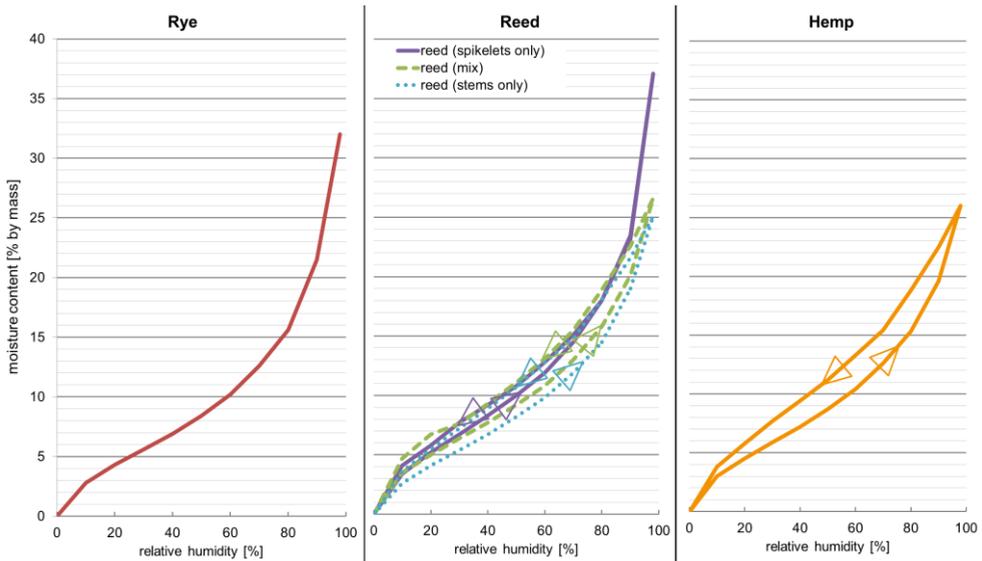


Fig. 4. Samples during the measurement of hygroscopic sorption properties.

3 Conclusions

The measurements carried out show that the thermal properties of vegetal-origin renewable materials without any additives or processing, i.e. simply pressed rye, reed, and hemp, are similar to wood-based materials (e.g. plywood, cross-laminated timber). This means that when these materials are used as thermal insulation materials, a significant material layer thickness is needed to fulfil their objectives.

Another advantage of these materials is the ability to adsorb and retain water vapour, thereby stabilising humidity changes and improving thermal comfort indoors (e.g. after a large number of people enter a small room). At the same time, it should be noted that increased moisture content also causes increased thermal conductivity, and creates good conditions for mould to grow; thus, without special antifungal additives, the studied materials cannot be used in environments with increased air humidity.

The key factor for researched vegetal-origin materials are fibre orientation and compression rate, which influence the thermal resistance of air inclusions and the water sorption properties.

The main advantage of these materials is sustainability, which is linked to their availability. They should preferably be used where they are harvested, produced, or manufactured, thereby radically reducing transportation and storage costs, which constitute a significant part of the final price of most common thermal insulation materials. Another important advantage of such materials is their low embodied energy.

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