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AN INDUSTRY PRIORITISED SURVEY OF THERMAL, MECHANICAL, HYDRO AND DECAY PROPERTIES OF NATURAL FIBRE INSULATION MATERIALS

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INTRODUCTION

Global warming has become a major world concern over the last 50 years, with the IPCC (2013) suggesting that the cause of climate change is an imbalance in the global atmospheric carbon pool, mainly created by anthropogenic factors. For most of the world's history carbon has been in a steady state cycle between the earth, living matter, the ocean and the atmosphere with only extreme weathering of rocks and volcanic events having destabilising influences (Cox et al., 2000). Currently, the carbon cycle is in a destabilized state, with carbon being moved from the earth and vegetation to the atmosphere. This is largely due to the increasing need for energy, with primary sources such as oil and coal being sourced from the earth and converted into appropriate energy through combustion, with a release of long-term stored carbon into the atmosphere. It is the responsibility of all industries to address their contribution to climate change and each industry has taken up this challenge in many individual ways (Stefanowski et al., 2015, 2016). The construction industry is no exception with numerous technical and material innovations as well legislative changes. It is these legislations that have resulted in the development European and British Standards for performance of insulation and natural fibre based insulation. Existing and developing insulations must meet these standard requirements if they are to be used in service. Natural fibre insulation is the 'catch all' name for insulation that is derived from plant and animal sources. The industry is predominantly based around cellulosic materials as a source of fibre (e.g. hemp, flax, wood), whilst there is an increasing use of protein-based fibre, predominantly sheep's wool. Research has been undertaken in this area, however, this generally focuses on one specific property, on one novel fibre source or novel applications.

Hill et al. (2009a & 2009b) undertook work to analyse the hydroscopic nature of natural fibre insulation. The analysis of the water sorption and desorption of jute, flax, Sitka spruce, hemp and cotton was analysed and compared. It was demonstrated that there were large differences in the different cellulosic materials in terms of their behavior in varying moisture environments, which in turn effects their performance as insulation materials.

Research has been undertaken to assess secondary properties of sheep's wool insulation in respect to the capture and storage of volatile organic compounds from the atmosphere and the improvement of indoor air quality. Curling et al. (2012) assessed the ability of sheep's wool to absorb formaldehyde from an atmosphere. They concluded that the wool both chemi- and physi-sorbed the formaldehyde, thus acting both as a scavenger and a buffer that would release the formaldehyde back into the atmosphere when levels were low. The research into this area was expanded by Mansour et al. (2016a & 2016b) in which different varieties of sheep's wool were assessed for their use as a VOC absorbent. The experiments used limonene, dodecane

and toluene as model compounds, representing VOCs with different polarities. It was shown that wool from different breeds of sheep absorbed the VOCs at differing rates.

As part of the ECOSEE project, it was agreed with industrial partners that materials used within domestic building construction, must perform sufficiently in a number of properties. Thermal performance is the primary function of an insulation material, however, the hygric, mechanical and decay susceptibility properties are also important to consider to ensure a material can endure. This paper reports a prioritised survey of the properties of natural fibre insulation products currently available on the market. Properties analysed include thermal properties (as its primary purpose), hygroscopic adsorption and basidiomycete decay susceptibility.

METHODS

Specific heat capacity was determined following the standard ISO 11357-4, 2005Determination of specific heat capacity.
Thermal conductivity was conducted following the testing standard BS EN 12664:2001 - Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods: Dry and moist products with medium and low thermal resistance
The hygroscopic adsorption of the insulation materials was determined following the standard method BS EN ISO 12571:2013 (Published August 2013 replacing 2000 version) Hygrothermal performance of building materials and products. Determination of hygroscopic sorption properties
The water absorption coefficient was determined using standard BS EN ISO 12572:2001. Hygrothermal performance of building materials and products. Determination of water vapour transmission properties
The decay susceptibility of the insulation materials was determined follow BSEN: 12038, 2002 Durability of wood and wood-based products – Wood-based panels – Method of test for determining the resistance against wood-destroying basidiomycetes.

RESULTS AND DISCUSSION

Thermal properties

Table 1 shows a summary of the two thermal properties tested; specific heat capacity and thermal conductivity. Figure 1 depicts the change in specific heat capacity of the insulation materials with increasing temperature.

Figure 1 shows that insulation produced from mineral material has a relatively steady specific heat capacity that does not change with increasing temperature. However, insulation materials produced from agricultural source (lignocellulosic based) or protein based (wool) the specific heat capacity decreases with increasing temperature beyond 60°C.

Both the hemp-lime insulation was found to have the highest thermal conductivity, the denser insulation 330 kg/m^3 had a slightly lower thermal conductivity of 0.07011 W/mK than the less dense hemp-lime insulation, 0.07851 W/mK . The lowest thermal conductivity was observed in mineral wool insulation, 0.03387 W/mK. Data for cellulose flasks could not be determined as this material is a loose flake material that is pumped into the cavity of walls and sufficient density of the material could not be achieved for the equipment used.

Table 1: Specific Heat Capacity and Thermal conductivity of insulation materials

Insulation	Specific Heat Capacity (dry) [J/kgK]				Thermal conductivity (dry)
	27°C	60°C	109°C	175°C	[W/mK]
Mineral Wool	760	780	760	842	0.03387
Cellulose flakes	1270	2560	1830	1410	Could not reach required density
Hemp-lime 275kg/m^3	1560	3480	2660	1610	0.07851
Hemp-lime 330 kg/m^3	1090	2060	2080	1930	0.07011
Wool	1600	3360	1810	1120	0.03754
Hemp	1560	3480	2660	1610	0.04025
Dense wood fibre (DWF)	1360	3420	1980	1060	0.04557
Carded wood fibre (CWF)	1560	3220	1420		0.03816

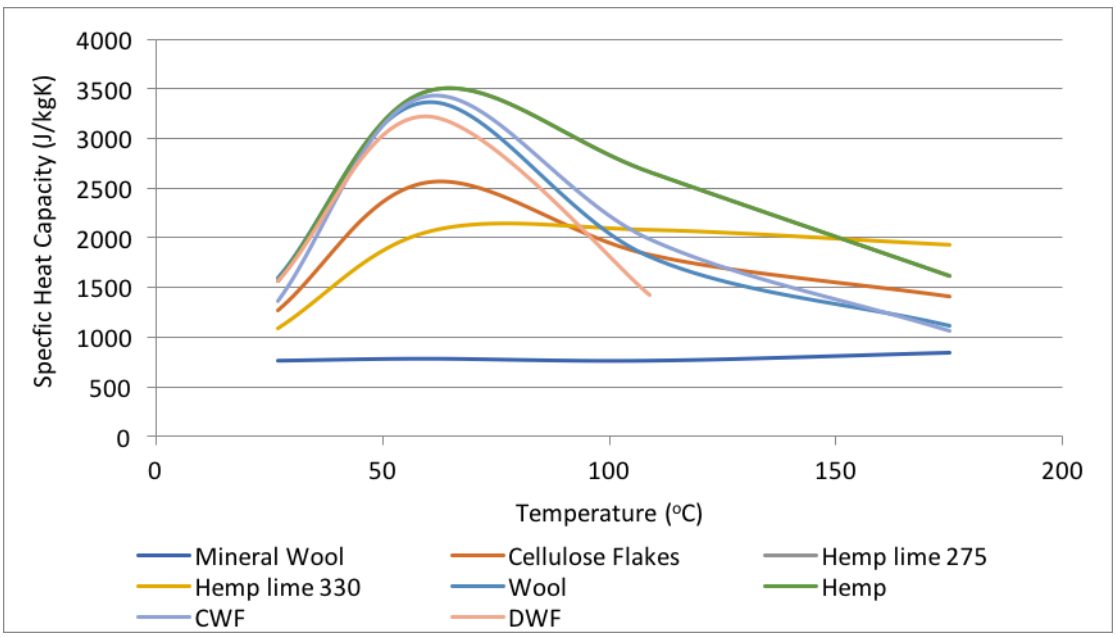

Figure 1: Specific heat capacity of insulation materials with increasing temperature

Hygric properties

Table 2 summaries the two hygric properties tested; hygroscopic adsorption and water absorption coefficient. The results show that the wool and lignocellulosic based insulation materials have an increasing hygroscopic adsorption of moisture, with increasing RH, whereas, mineral wool insulation does not significantly increase moisture uptake with increasing RH.

Table 2: Hygrscopic adsorption at different relative humidities and water absorption coefficient of insulation materials

Insulation	Hygroscopic adsorption					Water absorption coefficient
	[kg/m³]					[kg/m²/hr]
	0.3%	0.5%	0.6%	0.8%	0.95%	
Mineral Wool	0.1	0.15	0.16	0.2	0.28	0.46
Cellulose flakes	1.69	2.33	2.81	4.26	7.09	6.61
Hemp-lime 275kg/m3	9.87	13.22	15.06	22.04	42.4	1.05
Hemp-lime 330 kg/m3	6.09	7.86	9.05	13.91	27.37	0.89
Wool	1.17	1.6	1.8	2.5	4.34	4.5
Hemp	1.79	2.65	3.09	4.9	9.15	5.28
Dense wood fibre (DWF)	12.52	17.56	20.36	28.76	44.63	2.5
Carded wood fibre (CWF)	3.28	4.65	5.44	11.55	28.08	6.51

The water absorption coefficient of the mineral wool is also very low compared to the other types of insulation. The differences observed in the hygric properties of the insulation material are a direct result of their composition. Natural fibres absorb a lot of moisture and are able to expand to accommodate liquid uptake (Xie et al., 2010), whereas mineral wool insulation largely absorbed moisture into its physical structure and pores within the insulation, rather than the fibres/strands which comprise it. The physical structure of the insulation also influences the hygric properties of the lignocellulosic and wool based insulations. For example, hemp lime insulation produced at a lower density absorbs greater quantities moisture and liquid water than a hemp lime product with a higher density.

Basidiomycete Susceptibility

Figure 2 shows the insulation materials' mass loss after 16 weeks exposure to white rotting fungi *Pleurotus ostreatus* and *Coriolus versicolor.* The greatest mass loss and least susceptible to white rot decay was observed in hemp insulation. Mineral wool and wool fibre had a mass loss of zero. This is not surprising as the material comprises of material that is not decomposable by white rot fungi. Result for the hemp-lime and mineral wool insulations are not included as brown rot or white rot fungi were not found to be growing on the samples. It should be noted that virulence control mass losses for the *P. ostreatus* and *G. trabeum* strains were relatively low, suggesting that there may have been a problem with the decay capability of these strains.

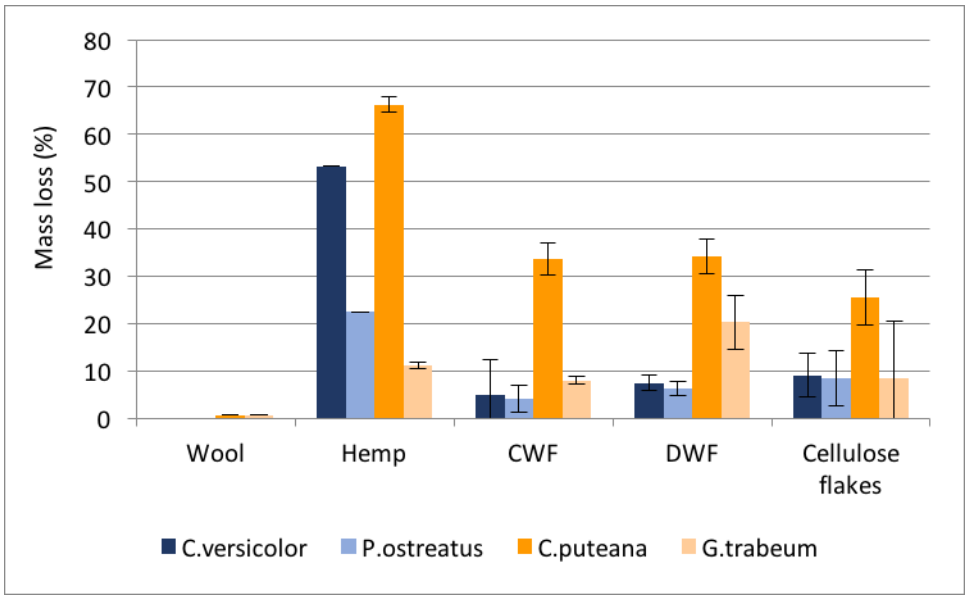

Figure 2: Mass loss of insulation materials exposed to white rot fungi

Figure 2 also shows the insulation materials' mass loss after 16 week exposure to brown fungi, *Gloeophyllum trabeum* and *Coniophora puteana.* The greatest mass loss was observed in hemp insulation exposed to *C. puteana.* The lowest mass loss was observed in wool insulation. Brown rot fungi can decay lignin (protein based) within the substrate material, hence the greatest mass loss of each of the insulation materials was caused by a brown rot fungi.

CONCLUSIONS

This paper reports a prioritised survey of the properties of natural fibre insulation currently available on the market. As is evident from this study, the thermal properties of the insulation material is dependent on the material it comprises of, be it protein based, inorganic based or lignocellulosic. The composition of the material also significantly influences the insulation materials other properties such as hygric and decay susceptibility. It is important to understand these other, secondary properties, as they will have direct effect on each other, and subsequently influence the material's thermal properties and performance as an insulation when used in buildings.

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REFERENCES

Cox, P.M., Betts, R.A., Jones, C.D., Spall, S.A. and Totterdell, I.J. (2000). Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature*. 408, 184–187. doi:10.1038/35041539

Curling, S.F., Loxton, C. and Ormondroyd, G.A. (2012). A rapid method for investigating the absorption of formaldehyde from air by wool. *J. Mater. Sci.* 47, 3248–3251. doi:10.1007/s10853-011-6163-7

Hill, C.A.S., Norton, A. and Newman, G. (2009a). The water vapor sorption behavior of natural fibers. *J. Appl. Polym. Sci*. 112, 1524–1537. doi:10.1002/app.29725

Hill, C.A.S, Norton, A. and Newman, G. (2009b) Natural Fibre Insulation Materials – The Importance of Hydroscopicity in Providing Indoor Climate Control. In: *Proceedings of the 11th International Conference on Non-Conventional Materials and Technologies* 6-9 September (2009), Bath, UK

IPPC Climate Change (2013) The Physical Science Basis – Summary for Policy Makers, Observed Changes in the Climate System IPCC

Mansour, E., Curling, S., Stéphan, A. and Ormondroyd, G. (2016a). Absorption of volatile organic compounds by different wool types. *Green Mater*. 4, 1–7. doi:10.1680/jgrma.15.00031

Mansour, E. Marriott, R. and Ormondroyd G. (2016b) Sheep wool insulation for the absorption of volatile organic compounds In: *Proceedings from the Young Researchers' Forum III – Innovation in Construction Materials,* London, U.K. 12th April 2016

Stefanowski, B.K., Curling, S.F., Mansour, E. and Ormondroyd, G.A. (2015). The sorption of volatile organic compounds (VOCs) by modified MDF panels and the effects on mould colonisation and growth. In: *Proceedings of the International Panel Products Symposium 2015*, 8-9th October, Llandudno, UK.

Stefanowski, B.K., Curling, S.F. and Ormondroyd, G.A. (2016). Evaluating mould colonisation and growth on MDF panels modified to sequester volatile organic compounds: International Wood Products Journal: Vol 7, No 4. *Int. Wood Prod. J*. 7, 188–194.

Xie, Y., Hill, C.A.S., Jalaludin, Z., Curling, S.F., Anandjiwala, R.D., Norton, A.J. and Newman, G. (2010). The dynamic water vapour sorption behaviour of natural fibres and kinetic analysis using the parallel exponential kinetics model. *J. Mater. Sci*. 46, 479–489. doi:10.1007/s10853-010-4935-0