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USE OF ANNUAL AND PERENNIAL PLANTS FOR DIMENSIONALLY STABLE INSULATION PANELS

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Abstract
In the future the awareness of the people for sustainable building and insulation materials might increase, therefore the need for developing standardized natural based insulation systems with defined properties occurs. This study analyses the possibility that culm parts from annual or perennial cultivated plants are suitable for the manufacturing of insulation materials with a low specific gravity (<300kg/m³). Hemp, corn, and wheat straw as well as miscanthus were used as raw material. The boards were hot pressed under comparable conditions. Besides the boards thermal conductivity, the bulk density and the particle distribution for each raw material were analysed. First results show that the thermal conductivity of boards produced from annual and perennial cultivated plants are in range with other available natural based insulates. Nevertheless additional research is required before an industrial production can be realized.

Key words: *straw based insulates; straw based board thermal conductivity; lab light boards.*

INTRODUCTION

The use of natural resources for building materials has been known for a long time. Wood is a versatile building material but also parts (e.g. fibers or humps) from annual and perennial plants are used as insulation material. For the past years research on this topic focusing on alternative materials and usage has been intensified (Barbu et al. 2014, Kymäläinen and Sjöberg 2008, Vogel 1999). Natural based insulants can bear some advantages at possible building certification following different guidelines and standards (ÖGNB - Österreichische Gesellschaft für Nachhaltiges Bauen, DGNB - Deutsche Gesellschaft für Nachhaltiges Bauen, BREEAM - Building Research Establishment Environmental Assessment Methodology).

Straw as stating material is locally available, inexpensive, fast growing and has been used as building material for centuries. Besides wheat straw as building material for straw-bale houses (Ashour et al. 2001) hemp and flax fibers can be used for thermal insulation. Treml (2011) also determined the usability of grass as raw material for insulation purposes. Not only research on this topic has been intensified, moreover annual plant based insulants (e.g. hemp) are already available at the market

(Paulitsch and Barbu 2015, Pfundstein et al. 2007). Gellert (2010) concludes that insulants based on herbal or animalistic raw materials have a market share in Europe of about 4 to 6%.

The objective of this research was the production of boards with a low specific gravity (<300kg/m³) using shredded parts of annual and perennial agricultural plans in traditional production steps of the wood processing industry and determining there suitability as insulation materials. Therefor two main questions have been worked out:

1. What is the range for the specific gravity in which dimensionally stable boards can be produced using a lab hot press?

2. Which thermal conductivity can be reached using straw at different specific gravity?

Through comparison with other available insulantion materials the suitability of the manufactured boards as insulant should be determined. The results should give indication of further research topics.

MATERIALS AND METHODS

Materials used in this study

Straw of hemp (*Cannabis L.*), corn (*Zea mays L.*), miscanthus (*Miscanthus A.*) and wheat (*Triticum L.*) have been used in this study. The air dried hemp, corn and miscanthus have been shredded using a customary shredder (Fig. 1). Wheat straw has been mulched. Especially hemp created a wooly-fibrous material when shredded.

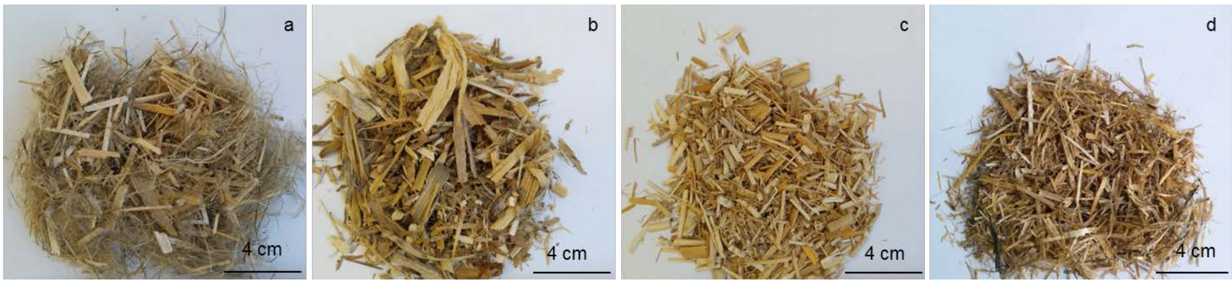

Fig. 1.
Raw materials from various plant species: a) hemp, b) corn, c) miscanthus and d) wheat

Research methods

Particle size distribution was determined using a shaking- or vibrating procedure according to European standard EN 15149-1/2 (2011). The particles were graded in decreasing size classes in the automatic sieve AS 200 (Retsch) within 15 minutes shaking time and an amplitude of 50.

Determination of bulk density was done according to European standard EN 15103 (2009) and was used to compare the different bulk densities. These values cannot be used in regarding the ability to settle in the structural element.

The insulation boards have been manufactured with a dimension of 450mm x 450mm x 39mm, while the different material was used without fractionation of the material. The adhesive amount of 10% urea formaldehyde (UF)resin and 4% hardener has been held constant for all materials. Mixing and gluing was made simultaneously using a lab blender which was equipped with a spray nozzle that measures 2.3mm in diameter and has a supply pressure of 2 bar. Following the glued rods and particle scattered manually, with no separation of fine and coarse material was carried out. The press temperature of 180°C, and the pressing cycle and the pressing time were kept constant for all manufacturing attempts. Determination of thermal conductivity was done according to European standard EN 12667 (2001) using a thermal conductivity gauge λ-Meter EP500e (Lambda-Messtechnik GmbH Dresden). The thermal conductivity was determined at the temperatures 10, 25 and 40°C.

CONCLUSIONS AND DISCUSSIONS

Distribution of particle size

Fig. 2 shows the particle size distribution of the materials used, based on weight which varies significantly. While chopped hemp and corn <4mm are more heavy, have miscanthus and mulched wheat significantly lower values in this fraction. This behavior changes when smaller particle sizes occur.

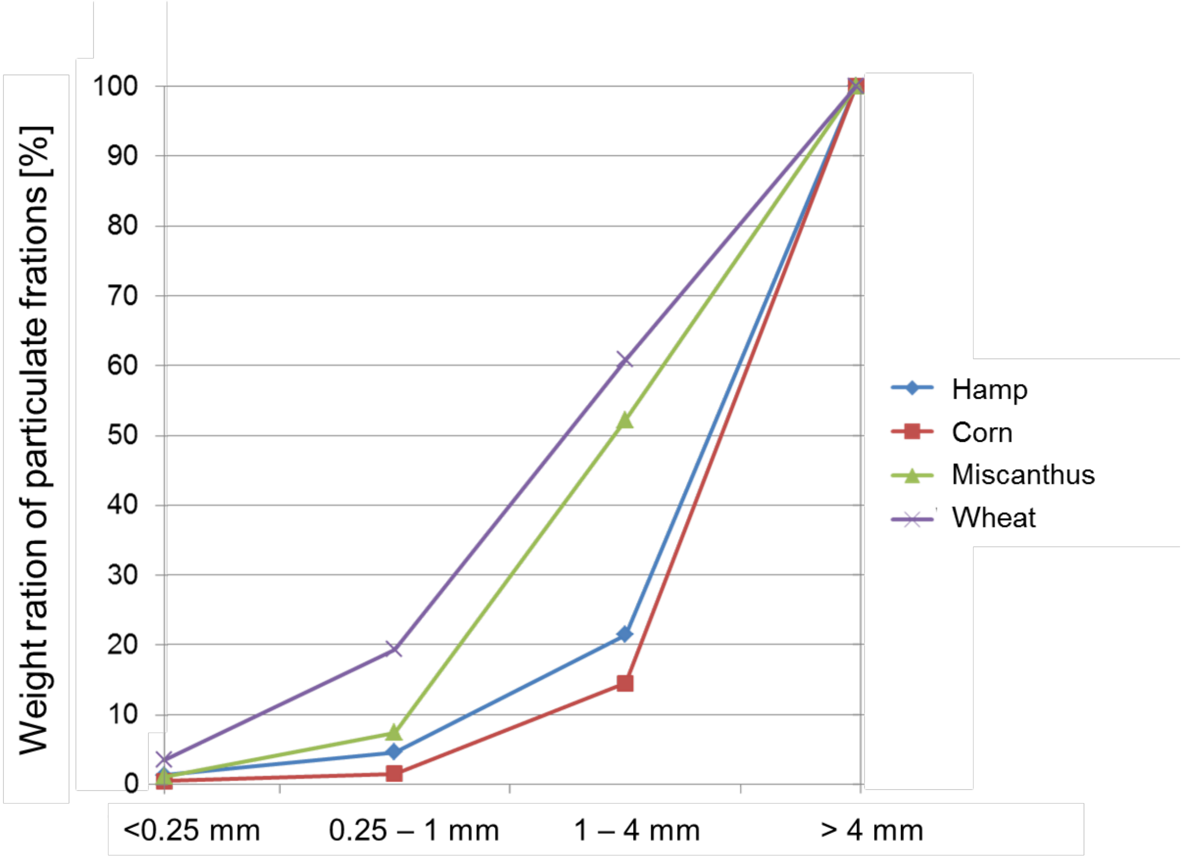

Fig. 2.
Weight of the various graded material vs. particulate fractions

Chipped wheat straw contains the highest amount of fine particles (> 0.25mm), followed by hemp and miscanthus. The thermal conductivity of the produced insulation materials is influenced by the particle size distribution (Nagl et al. 2015, Treml 2011).

Bulk density

Fig. 3 represents that the bulk density of the investigated raw materials varies. The chipping process developed a wooly fine material, thus hemp shows the lowest bulk density, followed by corn and wheat straw.

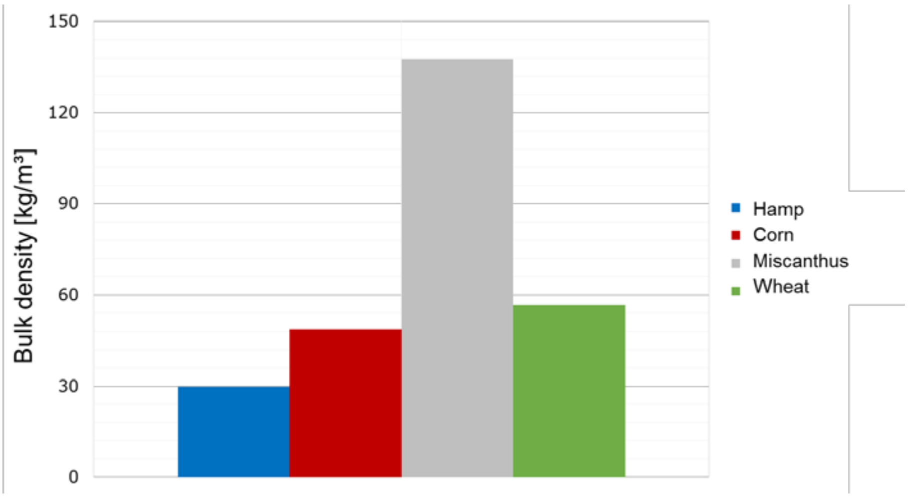

Fig. 3.
Bulk density of the chopped straw

The average moisture content of the material was 9.9% with a standard deviation of 3%. The bulk density also influences the properties of the panels as there wasn't produced a dimensionally stable panel with lower density than the bulk density during hot pressing (see Fig. 4).

Thermal conductivity of the insulating material

The objective of the study was the production of a dimensionally stable panel with a density of less than 300kg/m³ and to analyze the thermal conductivity. Therefore insulating panels out of different raw materials and different densities were produced (Fig. 4). Before the measurement of the thermal conductivity was determined, all panels were conditioned at 20°C and 65% relative air humidity until a constant weight was reached.

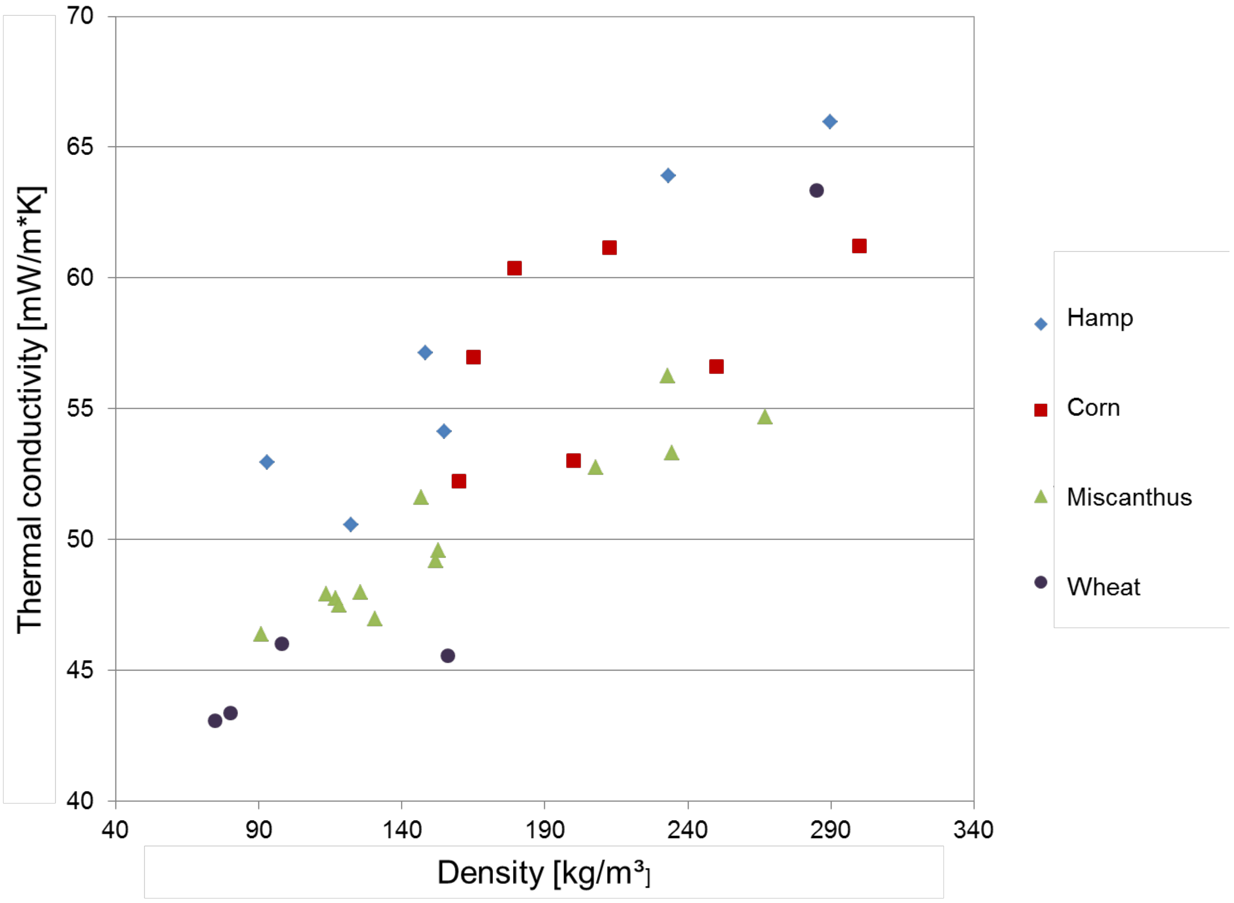

Fig. 4.
Thermal conductivity of the used panels subject to the density at a measurement temperature of 10°C and a temperature difference of 15 K

Except for the hemp material there were no problems reported during the production of the panels.

In order to blend the hemp fibers successfully with the resin, the plows of the lab blender have to be removed. The lowest density of 80kg/m³ was reached only for a single panel made of corn straw. A dimensionally stable panel with a lower density could not be produced under the available lab conditions. For a stable panel made of miscanthus a density of at least 160kg/m³ is needed. Even wheat straw panels with a density of 90kg/m³ and more could be produced in the lab, as wheat is considered to be extremely challenging to agglutinate (Barbu et al. 2014, Bouillon et al. 2004, Zhang et al. 2003). For future studies of UF adhesive used could be replaced by a tannin/hexamine binder. The feasibility was confirmed for hemp fiber by Theis and Grohe (2002).

All materials show a correlation of thermal conductivity and panel density in the investigated density range (Fig. 4). A reduction of the bulk density has a positive effect on the thermal conductivity. Low thermal conductivity values mean a higher thermal insulation. Pfundstein et al. (2007) lead the good thermal insulation properties at low densities back to a large cavity volume and thus a high proportion of air in the pores of the insulating material. The lowest thermal conductivity values at comparable densities were found for the panels made of wheat and corn.

Table 1

Comparison with other insulation materials according to Pfundstein et al. (2007)

Insulation material (mats or loose)	Density [kg/m³]	Thermal conductivity [mW/(mK)]
Glas wool	15-150	35-45
Mineral wool	20-200	35-45
Glas foam	115-220	40-60
$CaSiO_3$ foam	115-300	45-65
Perlite	150-210	45-70
Polystyrenel	15-45	30-40
PUR hard foam	30-100	24-30
PF resin foam	40	22-40
Wood wool	350-600	90
Wood fiber	30-60	40-90
Cork expanded	100-200	45-60
Hemp	20-68	40-50
Wool	25-30	40-45
Coconut fiber	70-120	40-50

The high scattering of miscanthus panels could derive from the high weight proportion of the 1 to 4mm fraction. Due to the variable orientation of the rods caused by bulking respectively in the panel (parallel or length to panel surface), the thermal conductivity is subjected to severe variations. The phenomenon that the alignment of the straw influences the thermal conductivity is also known from straw bales (Ashoura et al. 2011).

All produced panels had a density between 80 to 300kg/m³ and achieved thermal conductivity values from 43 to 66mW/(m*K). Table 1 shows that the panels offer similar densities compared to rock wool, glass wool, foam glass, Calcium silicate foam or expanded perlite panels. Sub-areas are comparable to polyurethane (PU) foam, wood wool boards, expanded cork or coconut fiber. Regardless of the densities of the panels is clear that the thermal conductivities of them are placed in the area of natural organic insulating materials. Comparable values of wood wool boards and wood fiber boards could be even lower. This obviously shows the high potential of annual and multi-annual plants. Panels which are already offered on the market have partly higher thermal conductivities. The thermal conductivity of hemp, wool and coconut fibers is slightly below the thermal conductivity of the studied panels, which are usually present in hemp, wool and coconut fibers lower densities.

CONCLUSION

All in all it can be stated that the boards made out of untreated annual and perennial plants can keep up with conventional boards concerning the thermal conductivity. Although mineral wool, polystyrene, PU and phenolic foam are able to achieve lower thermal conductivity the aspect of sustainability and the fact of economical and local acquirable recourses are good reasons for the use of annual and perennial plants. Nowadays these materials are used mainly as natural fertilizer, litter or thermal fuel. But a lot of potential is involved in these materials. In this study only the reachable thermal conductivity of the produced boards has been analyzed. Nevertheless some more properties are necessary to gain an impression of the possibilities for insulation materials made out of annual and perennial plants. Besides the burning behavior and the water absorption, tests concerning the strength of the boards will be made in the future.

The variety of natural insulants will increase in the future, as current studies show. The use of natural resources results in a very sustainable insulant, which indicates a big potential.

If a competitive product can be produced in the near future is unsure, but just the ecological awareness and the endeavor for a sustainable handling of resources should be reason enough for continuative studies and research.

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