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Original Article

Reed and Straw-Based Thermally Insulating Panels

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Abstract

Since the dawn of time, the need for an abode and ensuring a certain thermal comfort have been one of man's primary instincts. The original contributions of this paper consist of new types of thermally insulating materials made of ground straw, ground reed and reed strips. The original recipes were tested according to standardised methods for the determination of physical characteristics and thermal conductivity. Building materials such as reed and straw have been used since the dawn of time, but once new materials and producers appeared, they became marginalised. The tests performed have proven that using reed strips or ground reed and ground wheat straw mixed with ordinary commercial binders can have numerous advantages and form thermally insulating panels which, in terms of thermal conductivity, come close to the most commonly used thermally insulating panels employed in construction today, as proven through the experimental activities presented in this study.

Keywords: reed, straw, ecology, natural building materials, thermal conductivity

1. Introduction

The exact origin of the science concerned with thermal insulation is difficult to pin down in history, as, in the past, the thermal comfort of homes was ensured by means of various organic materials. People would cover the walls of their homes with fur from various wild animals, with cotton or straw, to later end up building homes out of wood, stone or earth, having noticed that these materials provide better thermal protection in winter and maintain cool temperatures during the warm season. [1]

Since the dawn of time, the need for an abode and ensuring a certain thermal comfort have been one of man's primary instincts. Prehistoric man withdrew into caves in order to find protection against the elements, as well as against winter's cold and summer's heat. Today, thermal comfort is ensured by means of modern thermal insulation materials and technologies. [1]

The main purpose of using thermally insulating materials is to provide a thermal climate which is as pleasant as possible to the inhabitants of a building by maintaining the air indoors as warm as possible during cold periods and as cool as possible during warm periods by means of keeping the heat flow through the exterior elements of the building down to a minimum.

The main purpose of thermal insulation is improving the living conditions of the people inhabiting a building; at the same time, there is the equally important issue of reducing energy consumption.

One must not forget that the materials employed have an impact on the environment throughout the building's life cycle. [2]

Thermally insulating materials can have a negative impact on the environment during their life cycle, especially due to their chemical composition or to expanded materials.

This can affect the air, the quality of the water and human health in a negative way. [2]

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One solution is increasing the use of renewable (wind, thermal, solar etc) energy, using natural, eco-friendly materials and reducing the demand for fossil fuels, which will contribute substantially to the decrease of carbon dioxide emissions.

When evaluating the impact of thermally insulating materials on the environment, several aspects must be taken into consideration: the necessary resources for production and fabrication, the pollutants emitted during their life cycle and during recycling, as well as the impact on the quality of the air [3].

The raw materials used for thermal insulation vary widely, from the sand in glass fibre to petrochemical products used in polystyrene thermal insulators or the recycled paper used to produce cellulose-based thermal insulators.

Acquiring or obtaining the raw materials needed to make thermally insulating products is another aspect to be taken into account, as there is the downside that these resources may be limited or polluting.

One positive aspect would be the use of as many natural, eco-friendly or recyclable materials as possible [3].

The most obvious limited resource used in producing thermal insulators is the one employing plastics, namely natural gas.

Polystyrene is made of ethylene, a component of natural gas, and benzene, a petroleum derivative.

Another chemical element used as raw material for producing thermally insulating materials which is on the brink of depletion is boron. It is used in the composition of glass fibre and as a fireproofing agent for cellulose insulators.

Boron improves glass fibre flexibility and reduces energy consumption during fabrication. Boron constitutes about 6-8% of the total weight of glass fibre [3].

Many of the substances used in some thermally insulating materials are carcinogens and can also harm people with respiratory disorders.

This paper is part of a more ample project which seeks to promote traditional, eco-friendly materials such as wheat straw and reed, which, mixed with organic or inorganic binders, can result in thermally insulating panels which can serve as good temperature and humidity regulators, thus ensuring a pleasant environment and having a positive impact on human health.

The main goal of the study is to obtain new types of thermally insulating materials by using ground wheat straw and reed – ground or in the form of strips – bound together by various organic or inorganic binders to create panels.

2. Material and Method

2.1. Materials

Buildings with a negative carbon footprint can be erected by using natural, eco-friendly materials, such as wheat straw, reed, wood, hemp. Since these materials grow straight out of the earth and do not require any processing, like any other plants, they have the capacity to absorb carbon dioxide and release oxygen, thus having a negative carbon footprint [1].

Due to lack of funding, researchers have turned their attention to unconventional building materials, such as fibres, which have similar properties to those of traditional materials used in civil engineering.

Vegetable fibres are available in most countries. They are proper materials for reinforcement, even though they perform poorly in terms of durability.

Given their mechanical properties, as well as the fact that they come in a wide range, they can make it possible to develop building materials with adequate properties [1].

While the seeds of cereal are the main objective of agricultural activities, there is high interest in the development of uses for the residues, which are currently burnt or returned into the earth.

Wheat straw makes for the most widespread agricultural waste; most of the time it is burnt out in the fields, thus contributing to carbon dioxide emissions.

This happens every year and has come to be a reason for concern for the competent authorities. In order for the straw to find its way back into the earth as a fertiliser, it has to be minced and spread, which entails a mechanised process, which is energy consuming and emits carbon dioxide. This is why straw has become a material recommended for construction [1].

Straw-bale construction constitutes a new building method which uses (wheat, rice, barley, etc.) straw bales as structural elements, loose fill or insulation (figure 1). This method is very common in natural, green building projects. Research has shown that this building method is sustainable all the way from the materials used to the energy required to heat the building. [1]

Another eco-friendly, 100% natural material is reed.

It makes for one of the vastest compact surfaces in the Danube Delta, covering over 1,500 km² of its total surface, but it can also grow in other parts of the country, such as the marshlands in the Romanian Plain, the Jijia Plain, the Transylvanian Plain (figure 2) and the Tisa Plain.

Figure 1. Straw bales used for thermal insulation in the Transylvanian Plain

Figure 2. Reed in the Transylvanian Plain, near Geaca commune

Phragmites australis (reed) is a perennial herbaceous plant with a crawling rhizome (the root of the reed), a rigid erect stem that grows 1-4 m tall (in exceptional cases even 7m), green-blue 40-50 cm long lanceolate leaves and flowers arranged in terminal panicles (panicle = a type of inflorescence in the shape of a complex cluster, in which each secondary branch branches out into multiple flowers).

The flowers are produced in July – September **[**4]. Reed forms reed beds, made up of intertwined reed rhizomes (over 80%) and the roots of other aquatic plants, mixed with organic debris and soil, resulting in 0.5 – 1.7 m thick layers. Reed beds can become detached from the bottom of marshes and ponds, turning into small islands of varying sizes [5]. Its physical characteristics make reed the ideal building material: it is light, yet stable.

The air inside and in between reed straws ensures remarkable thermal and acoustic insulation, thus creating high comfort. Moreover, it can be easily combined with other building materials such as lime, plaster, polyvinyl alcohol and cement [5].

These qualities have earned appreciation for it in modern architecture as well. In this context reed-based materials – prefabricated and otherwise – have proven their efficacy by combining physical and ecological qualities. Producing these materials requires reduced energy consumption and can be done without the use of chemical components and with no carbon dioxide emissions or residues.

Given that the price of building materials has risen in the last few years, using eco-friendly materials has become a constant engineering challenge, as attention is turned towards natural materials with similar characteristics to those of traditional ones and considerably lower production costs. In order to obtain thermally insulating panels, the vegetable fibres (straw and reed) were bound together by means of traditional organic and inorganic binders. Polyvinyl alcohol and cement (mixed with water, as expected) were used to make a paste that could cover the vegetable fibres and turn them into a unitary whole, thus forming the proposed thermally insulating materials.

2.1 Preparing the composites

The straw and reed used in the experimental programme were harvested in Cluj county, near Geaca commune, which is located at the centre of the Transylvanian Plain and harbors part of the chain of lakes that make up the ‘Fizeș Valley Lake Complex’.

After harvesting, those parts of the reed which were not in optimal condition, i.e. exhibited traces of mould, rot or any other imperfections caused by various insects or by storage, was removed.

Then the reed was cut into 15 cm pieces in order to be poured into original 150x150x30 mm moulds which would fit the dimensions of the machine for the determination of the thermal conductivity coefficient λ, as well as in 20 to 40 cm pieces in order to fit in the MC22 hammer mill, the productivity of which is 1-1.8 t/h for reed and 0.8-1.5 t/h for straw (Fig. 3).

Figure 3. The fibres used in the experimental activity from left to right: ground straw, ground reed and reed strips

Five types of panels were made (Fig. 4) according to original recipes, in which the presence of fibres (the total amount of fibres) consisting in ground reed, ground straw and reed strips remained constant, while the amount of each type of fibre was changed with each recipe. Thus, the first panel (A1) contains polyvinyl alcohol and reed strips, the second panel (A2) contains cement, water and reed strips, the third panel (A3) polyvinyl alcohol, ground straw and reed strips, the fourth (A4) polyvinyl alcohol, ground reed and reed strips, and the fifth (A5) polyvinyl alcohol, reed strips and ground straw (table 1)

Figure 4. Straw and reed-based thermally insulating panels

Table 1. The components of the five original recipes

Sample	Binder		Water	Ground reed	Ground straw	Reed strips
	Ciment (g)	Polyvinyl Alcohol (g)	(ml)	(g)	(g)	(g)
A1		450				178
A2	1000		380			178
A3		450			100	78
A4		450		89		89
A5		450			89	89

2.3 Test methods

Determination of bulk density

The fresh material was poured into original moulds sized 150x150x30 mm to fit the dimensions of the machine for the determination of the thermal conductivity coefficient λ.

The panels were weighed, measured for L, l and h, then their volume and subsequently their bulk density were calculated. Table 2 contains the average values obtained for each recipe [6]:

Table 2. The bulk density of each of the five samples

Recipe	A1	A2	A3	A4	A5
$\rho_{a\ avg}$ [g/ cm^3]	0.295	1.030	0.36	0.35	0.286

Determination of thermal conductivity through the heat flow meter method

The determination of thermal conductivity through the heat flow meter method was performed in accordance with SR EN 12667. Fox 200/300 (Fig. 5) is an accurate, easy-to-use instrument for the determination of thermal conductivity in accordance with ISO 8301. It provides quick and precise results, which are shown in table 3.

The FOX 200/300 instrument consists of two basic parts: the upper part and the base. The upper part of the instrument is the actual test chamber. Once the door has been opened, the sample can be placed in the test stack, between the two plates. The upper plate is stationary. The lower plate can move up and down. The upper side of the sample will have a temperature of 20 °C, while the temperature of the lower side will be of 0 °C [7].

Figure 5. The thermal conductivity measuring device

Table 3. The thermal conductivity of the five samples, λ [w/mk]

Recipe	Thermal conductivity λ [w/mk]
A1	0.096
A2	0.191
A3	0.070
A4	0.074
A5	0.071

3. Results and Discussions

Following the determination of thermal conductivity – figure 5 – by means of the heat flow meter method, it becames apparent that the results obtained following the determination of bulk density (Fig. 6), and those of thermal conductivity measurements (Fig. 7), were proportional for each panel.

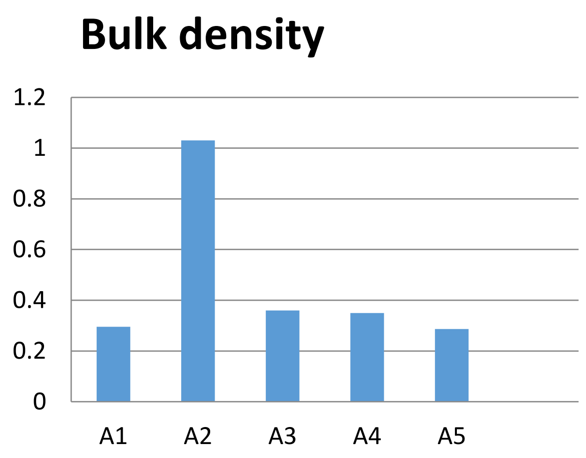

Figure 6. Bulk density [g/ cm^3]

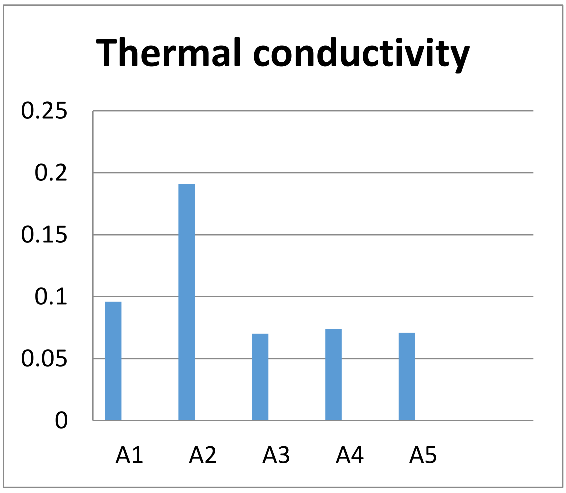

Figure 7. Thermal conductivity [w/mk]

As far as thermal resistance, determined with the aid of the Fox 200/300 machine available in the Building Materials Laboratory of the Faculty of Civil Engineering is concerned, the 5 samples registered results which were at least promising: 4 out of 5 samples of original recipes registered thermal conductivity results under 0.01 [w/mk].

As it is well known, a material is considered to be thermally insulating if its thermal conductivity is under 0.01 [w/mk]. The first batch of tests yielded good results, as four of the moulded panels can be said to meet the basic condition in order to be considered thermally insulating panels.

We will subsequently optimise the recipes by increasing the amount of fibres in an attempt to reduce conductivity as much as possible and obtain a good thermally insulating material.

At the same time, the mechanical strengths of the new panels obtained must be carefully monitored. In the next stage of the experimental programme, the manner of adhesion of the new panels to the support layer and their behaviour under the influence of fire will be monitored as well.

4. Conclusions

The original contributions of this paper consist of new types of thermally insulating materials made of ground straw, ground reed and reed strips.

The original recipes were tested according to standardised methods for the determination of physical characteristics and thermal conductivity.

Building materials such as reed and straw have been used since the dawn of time, but once new materials and producers appeared, they became marginalised.

It has been proven that the environment in a building insulated with natural materials is much more pleasant and welcoming. Both reed and straw bales, either ground or in the form they were harvested in, mixed with certain binders in well established proportions, make for good temperature and humidity regulators, thus ensuring a pleasant environment.

The tests performed have proven that using reed strips or ground reed and ground wheat straw mixed with ordinary commercial binders can have numerous advantages and form thermally insulating panels which, in terms of thermal conductivity, come close to the most commonly used thermally insulating panels employed in construction today, as proven through the experimental activities presented in this study.

The main difference between the thermally insulating panels presented in this study and the ones currently used in civil engineering is that the former are made of natural, eco-friendly materials and their production was characterised by low energy consumption and negative carbon dioxide emissions.

The conclusions above show these materials, made of natural ingredients – in this case, reed and straw – to be genuine building materials which can be used for thermal insulation in the form of panels, but also for closures.

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