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EFFECTIVE THERMAL PROPERTIES OF STRAW FOR BUILDING SYSTEM

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ABSTRACT

Sustainable materials derived from natural sources are often used to promote thermal comfort in buildings, which justifies their usage in formulating building mixes. The use of natural resources for construction dates back to antiquity; a combination of straw, clay, and sand is only one example of a material that may keep a house warm in the winter and cool in the summer. This piece aims to assess how adding clay, sand, and straw to a building's insulation improves thermal comfort. Straw was added to a clay and sand mixture in varying proportions to create several kinds of sample plates for the experiment. Using the infinite flat layer approach, the thermal conductivity coefficient was calculated based on the results of the trials. According to the findings, a sand-clay matrix with varying quantities of straw added might be thought of as excellent reinforcement. All new projects should have these values by code, and they may be attained by using thermal insulation to safeguard the construction budget and by fabricating envelope parts from high-thermal-resistance materials. The use of vegetable wastes as thermal insulation material and as a material used for building load-bearing and in-fill straw-bale construction is among the unconventional technologies and materials proposed as a replacement for conventional thermal insulations like mineral wool and expanded polystyrene, which are both significant consumers of energy. The experimentally determined thermal conductivity of this material is reported in the specialised literature. The research suggests a straightforward technique, one that is sufficient for determining straw bales' thermal conductivity.

Keywords: Straw, Thermal, Building, Properties, Material

INTRODUCTION

A large percentage of total carbon dioxide (CO2) emissions worldwide comes from the construction industry, associated transportation, and dependence on cooling and / or heating equipment. This has generated the idea of implementing environmentally friendly materials and thus mitigate the carbon footprint that conventional materials such as metal, synthetic, and ceramic produce in their elaboration and residual stage after being demolished. Natural organic products are of great potential to mitigate these problems, recognizing straw as one of the most valuable for its easy obtaining due to high agricultural activity locally and globally. In addition, to be an element that has the ability to absorb CO2 during its growth as well; 10 kg of wheat straw absorbs 14 kg of carbon dioxide, which they retain throughout their lifetime. The low environmental impact of straw as well as the high agricultural activity worldwide (wheat, rice, barley, etc.), it generates a large amount of waste, considering it as a suitable by-product for the field of construction, because the background makes evidence isolation and structural application showing thermal and acoustic characteristics. Due to the fact that antecedents show Table 1, that the straw physical properties confer structural and thermal insulation advantages due to its low conductivity, surpassing traditional and non-traditional materials. This research focuses on identifying these attributes, especially the physical-thermal ones of the material, to later implement them in the design of a sustainable panel-type construction system as an architectural dividing element. Taking into account studies that highlight the design of insulated products to optimize thermal efficiency, thus ensuring the internal comfort of the space.

Table 1. Physical-thermal properties of materials

Materi al	Density(Kg/m^3)	Conductivityλ(W/m K)
Compressedsoilwall	1.400	0.600
Compressedsoilblock	1.700	0.810
Adobe	1.200	0.460
Strawbales	60.00	0.067
Massconcretewithaggregates	2.400	1.630
Solidbrickwall	1.800	0.870

LITERATURE REVIEW

Mesa, Alessandra &Arenghi, Alberto (2019) Straw is an organic material with hygroscopical properties. The high capacity it has of storing moisture from the surroundings can furthermore influence the performance and lead to the possible degradation of the material thereof. The aim of this study was to assess the conductance C-value of a complex material such as straw. A climatic chamber was used to study a sample, which reproduces a traditional plastered straw bale wall. Tests were conducted under different boundary conditions, setting constant values for temperatures and relative humidity. The revision of the assessment's results allowed the calculation of conductance and conductivity values under different conditions. A numerical model was then designed starting from the laboratory data, which was used to characterize material properties. The match between software simulations and laboratory analyses will be a starting point for further tests. Determining the straw conductance C-value is a difficult task to achieve, due to the complexity and the unique properties of the material. In spite of all this, laboratory tests have shown encouraging results, which reflect the great potential of straw as a building material.

El Azhary, Karima&Chihab, Y. & Mansour, M. &Laaroussi, Najma&Garoum, Mohammed. (2017) Unfired clay is a sustainable building material resisting to the hard climatic conditions. In order to improve the energy efficiency of this ecological material, this work tries to develop the thermal properties of unfired clay as an insulation material by mixing it with straw. An experimental measurement of thermal properties of unfired clay mixed with straw was done by using the flash method to determine the thermal diffusivity and the state hot plate method to estimate the thermal conductivity in order to deduce the thermal capacity. A building was simulated using the unfired clay–straw envelope with the climate data of south Morocco region, for the purpose to establish its thermal inertia and its ability to bring a good comfort by limiting summer overheating and keeping the heat in winter without heating and cooling systems.

Lee, Kyu-In &Yeom, Dongwoo. (2014) The purpose of this research was to assess the performance of straw bales and carbonized rice hulls when used as natural insulation to regulate the indoor environment. Toward that end, specimens of straw bales and carbonized rice hulls were tested in the Korea Conformity Laboratories. Based on the results, real-scale mockup rooms insulated with these natural materials were constructed for cost analysis and performance evaluation. The cost analysis results showed that carbonized rice hulls are relatively cost effective and economically feasible. The thermal conductivity of carbonized rice hulls is lower than that of straw bales, and no difference in thermal performance was shown in relation to the different construction method used for each material. With regard to humidity, both mockup rooms built with each of the natural materials exhibited stable variations compared to the outside weather, and both materials sustained a general humidity within a comfortable 40-60% range. The straw bales mockup room was shown to produce a higher CO_2 emission possibly due to the bio-metabolism (anaerobic fermentation), suggesting that this material should be used with caution. Carbonized rice hulls were proven to be a good natural insulation material and a good regulator of indoor humidity and would not yield CO_2 due to bio-metabolism.

Sabapathy, Karthik&Gedupudi, Sateesh. (2020) Incorporating insulation material in the building envelope is one of the simple yet effective passive techniques aimed at mitigating the energy consumption in buildings. The development and utilization of sustainable materials with heat insulating capacity as an alternative to synthetic insulations is a promising path towards reduced carbon footprint of buildings. The insulation potential of straw, an agricultural waste, in the context of the wide-ranging climate of India is the focus of the current work. Cooling and/or heating load analysis over 24 h of a representative summer and winter day is performed through transient numerical analysis for five climatic zones of India. Three building envelope configurations possible with retrofitting straw insulation (placed on the outside or inside or equally on either side) over existing walls/roof are compared. Four different thicknesses (10, 20, 30 and 40 cm) of the straw insulation are considered for analysis. Recommendations of envelope configuration with insulation are proposed based on energy and cost savings for the different climatic zones. Overall, the case of insulation split on either side performs the best. Energy savings in the range of 67–96% is achievable with the addition of just 10 cm thick insulation across different climatic zones. Comparison of straw envelope performance against different envelope types found in literature was carried out.

Gallegos, Ricardo &Magaña-Guzmán, Tonatiuh& Reyes-Lopez, J. & Romero, Socorro. (2017) Building with natural materials brings benefits to the environment because their manufacture and use do not consume as much energy as conventional materials do. The use of natural materials has been regulated in some countries with regards to their structural capacities. In the thermal aspect, straw bales have the advantages of high thermal resistance, time lag and temperature damping, which are important to attain thermal comfort. This paper presents values of time lag and temperature damping obtained through the on-site monitoring of a straw bale wall in a building in Tecate, Baja California, Mexico. The floor area of the building is 35 m^2 and is made up entirely of load-bearing walls made with three-wire wheat straw bales. Monitoring was carried out for sixty-six days, taking temperature and heat flux measurements on the surfaces of one wall every 10 min. Additionally the indoor black globe temperature was monitored. The results showed a time lag of 9.12 h, a temperature damping of 93.6% and apparent thermal resistance equivalent to R39. The indoor black globe temperature on the inside of the building stood at 25.6 °C with a swing of 0.5°C. The method used in this study gives results that are comparable to those reported in laboratory tests. The data reported can be useful in the design of straw bale constructions in other parts with similar climate.

RESEARCH METHODOLOGY

There has been an effort to find a straightforward technique that is suitable for the measurement of thermal conductivity in bulk materials like straw and that can be used in any construction laboratory. The Romanian standard procedure is inapplicable since it is designed only for dry, board-shaped materials. The chosen experimental apparatus consists of two overlapping tubes. The outer tube has an inner diameter of D = 10.78 cm and an outside diameter of d = 0.72 cm and a length of L = 16 cm (5), while the inner tube is a glass tube with the same dimensions (2). A constantan wire (3) runs through the glass tube, which has been filled with fine glass sand to ensure surface temperature uniformity. Two layers of 3 cm thick extruded polystyrene (1) seal the plastic bottle's edges to prevent heat escape via the sides. Using a micro-voltmeter, the copper-constantan thermocouple (4) determines the difference in temperature between the outside surface of the glass tube (T1) and the interior surface of the plastic bottle (T2) (7). Straw fills the gaps between the tubes, and the whole thing rests on an extruded polystyrene base (6). All of these tools belong in the laboratory of any respectable construction firm.

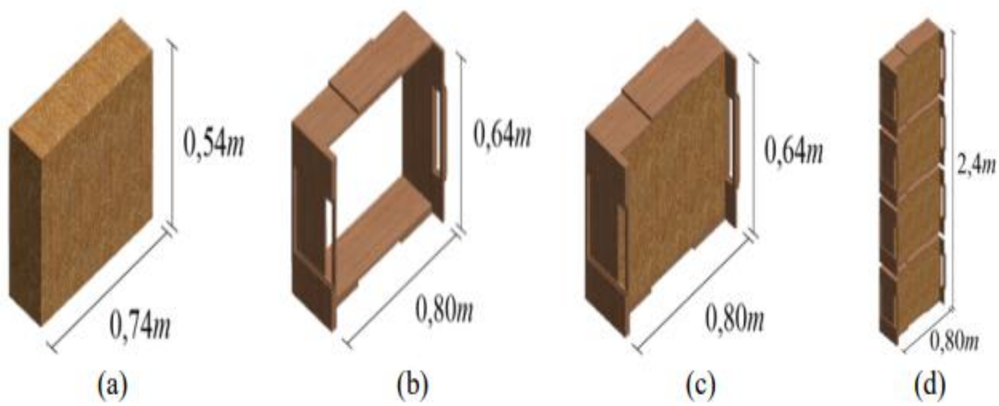
DATA ANALYSIS

In order to have a clear direction of what is most important to focus on, the EcoStraw panel model took into account the following criteria for the design elaboration. In Table 1, we see that the density and thermal conductivity of straw bales are specified, along with the expected dimensions in the design proposal. At the time of compression, the straw is assumed to have a density of about 60 kg/m3 and a thermal conductivity of around 0.067 W/mK. The air chamber acts as a support for the module's internal networks, which are situated between the straw bale and the outside cardboard layer, therefore further delaying the panel's heat transfer.

Table 1.EcoStraw panel module components and physical-thermal characteristics.

Material	Width (m)	Conductivity λ (W/mK)
Straw bale	0.200	0.067
Air chamber / installations	0.097	0.026
cardboard	0.003	0.065

Figure 1 shows the compression of straw in Figure 1(a), the wood structure in Figure 1(b), the final module in Figure 1(c), and the standard panel height in Figure 1(d). However, the panel measurements with regard to its height may change in terms of the arrangement of modules, suggesting four modules to complete a standard panel height of 2.4 m in this situation.



The mixture was homogenized to a reasonable degree. The plates were air-dried at room temperature for 48 hours with no sintering. We used sandpaper to get the final surface roughness, which allowed us to get rid of imperfections and take more accurate measurements. The thickness of the plates was measured using a dial indicator in order to exactly identify the density of the tested composite constructions and then to correctly compute thermo-physical parameters, specifically specific heat capacity. Table 2 displays the collected information.

Table 2: Physical data for test samples.

Type	δ [m]	m [kg]	ρ [kg/m^3]
1	0.0240	2.765	2000
2	0.0241	2.606	1877
3	0.0245	2.451	1737
4	0.0247	2.394	1683

To ensure the reliability of the TCi-analyser, we first measured the thermal conductivity of a material with well-established thermal properties. A 0.24-by-0.24-by-0.015-meter square plate of potassium float glass was used as the test specimen. kglass = 1.15 W/(m.K) is the value for the glass' thermal conductivity coefficient. The TCi-analyser reading was taken at room temperature (T = 23 oC) using the C-Therm technique.

The measurements were taken at three different locations on the specimen's surface in accordance with ISO 22007-2:2008. Processing the data yielded values for the thermal effusivity of glass of eglass = 1.556 W.s1/2/(m2 K (RSD = 0.5%) and the coefficient of thermal conductivity of glass of kglass = 1.18 W/(m.K) (RSD = 0.5%). Very little variation (2.6%) exists between the tabular and experimentally measured values of the thermal conductivity coefficient. This means that the analyzer's findings are solid and that testing on the composite materials may proceed.

Table 3: Experimental results for thermo-physical characteristics of the tested composite materials.

Experiment №	Sample	e	Δe	c_p	Δc_p	k	Δk
		W.s$^{1/2}$/(m^{2}K)	%	J/(kg.K)	%	W/(m.K)	%
1	0 % straw	648.72 (RSD=0.7%)	-	456.78	-	0.498	-
2	0.3 % straw	629.9 (RSD=0.6%)	-2.9	721.45	57.9	0.379	-23.9
3	0.4 % straw	616.3 (RSD=0.8%)	-4.9	907.21	98.6	0.241	-51.6
4	0.5 % straw	591.42 (RSD=0.7%)	-8.8	968.83	112.1	0.219	-56.0

Rising cp values indicate enhanced heat accumulation capacity of the tested composites. As the value of k goes down, it means the material is better at blocking heat transfer. Although these numbers aren't as low as those seen in the finest insulating materials, they are comparable to those of autoclaved lightweight concrete (k = 0.130-0.384 W/m.K, cp = 837 J/kg.K) and ceramic bricks (k = 0.72W/m.K, cp = 837 J/kg.K). Consequently, a clay-sand combination enhanced with straw may help bring about the aforementioned thermal comfort and energy efficiency in the built environment. Thermal properties obtained suggest the investigated environmentally friendly material might be utilised successfully in the application of passive ways of construction.

Straw thermal conductivity test

Straw is often employed as a thermal insulation material nowadays, as was previously indicated. Shredded triticale straw that was 50 mm in length and subjected to various pressing methods was used to determine the straw's heat conductivity. The straw had a certain dryness and humidity. Table 4 displays the findings of the analysis.

Table 4: Test results of thermal conductivity

Sample	Air-dry samples			Wet samples		
	Humidity %	Density kg·m^{-3}	Thermal conductivity W·m^{-1}·K^{-1}	Humidity %	Density kg·m^{-3}	Thermal conductivity W·m^{-1}·K^{-1}
1	1-1.5	46	0.048	22.1	57	0.058
2	1-1.5	63	0.048	18.8	79	0.067
3	1-1.5	53	0.046	44.3	91	0.071
4	1-1.5	128	0.048	21.6	151	0.057
5	1-1.5	139	0.049	13.0	209	0.061
6	1-1.5	134	0.053	-	-	-
7	1-1.5	425	0.061	3.6	694	0.081

The density of dry straw was shown to have an effect on its heat conductivity. Similar tendencies are seen in several other thermal insulation materials. The density and heat conductivity coefficient were both higher in the wet straw. The thermal conductivity coefficient rises by 0.0005–0.0011 Wm-1 K-1 for every 1% increase in humidity. At a maximum humidity of 20%, straw's thermal conductivity may rise to 0.01-0.02 Wm-1 K-1, an increase of 19-42%. The density of air-dry straw has a little effect on its thermal conductivity, but only in the range of 50 to 130 kgm-3. Beyond that point, the thermal conductivity of straw rises as its weight increases.

RESULT AND DISCUSSION

Many people have negative preconceptions about using straw as a construction material, believing that it may catch fire, decay, or be invaded by pests like mice and rats. In this post, we'll examine the scientific literature in an effort to dispel the concerns raised above. data from third-party conformity assessment labs and peer-reviewed academic papers are examples of such sources. There have been unified demands for building materials throughout the European Union as of late. A performance guarantee must accompany every product on the market. Typical procedures are being followed here. Once the National Technical Assessment (NTA) or European Technical Assessment (Eta) is established, validation of straw and produced building materials is feasible (ETA). In Germany, a technical evaluation was completed in 2006 per the Building from Pressed Straw Union order, and a Construction from Straw Directive (Strohbaurichtlinie, 2014) and certificate (Allgemeine, 2014) were also developed in 2014. Dimensions, density, thermal conductivity, humidity, and reactivity to fire are only few of the criteria mentioned in these texts as applicable to pressed straw bales. All the necessary information for building is outlined as well. The testing procedures, guidelines, and time intervals for straw bales are all included in the technical evaluation. The United States and Belarus both have set similar rules for pressed straw.

Mechanical qualities, especially strength, are crucial for evaluating pressed straw bales and building structures in light of the fundamental need for mechanical strength and stability. Insulation for walls, roofs, ceilings, and lofts in frame buildings is often provided using pressed straw. Wooden frames, ceiling beams, or rafters carry the weight here. German law mandates that there be no more than one metre between fence posts (Strohbaurichtlinie, 2014). Mechanical experiments reveal that wooden-framed walls can withstand considerable vertical and horizontal stresses. In order to legitimise timber frames stuffed with straw, a similar experiment was conducted in Lithuania (National, 2013). Results from the tests validated the viability of building using straw shades. This indicates that straw is an appropriate thermal insulator in wooden frame and shade buildings, when wooden parts serve as load bearing structures. Straw bales may be used to create frameless walls for inexpensive and simple housing (when the length between the walls is less than 6 m). Large straw bales allow for taller walls to be built. We assume further research is required before frameless buildings can be built using straw bales. Plaster must be applied over the straw during construction, thus a strong enough connection between the two materials is essential. The binding strength between straw and plaster must be at least 40 kPa in order to pass the Lithuanian National Technical Assessment (National, 2013).

CONCLUSION

The purpose of this overview is to draw attention to the positive findings from previous research on straw bale houses and to pinpoint the areas that have been left unexplored and thus need more study. Several of the reviewed studies—specifically those involving in-situ testing, which provides a quantitative evaluation of the physical and mechanical properties—mark a significant advance towards the adoption of straw-bale building methods as a recognised construction technology. Nonetheless, the great diversity of qualities that this substance displays explains why there is a lack of reliable data relating to certain areas. By reducing the possible range of numerical values for the material qualities, strict criteria for straw bales would aid in predicting the building envelope's behaviour and its reaction to certain environmental circumstances. Straw bales, for instance, would have a more narrowly defined range of usable sound and thermal insulation qualities if their density were regulated.

From the physical-thermal examination of the materials to the decision-making in terms of design, the EcoStraw panel's planned evolution combines multiple disciplines in order to conceive of a full notion of an architectural and sustainable constructive solution. The coefficient of thermal conductivity of the straw embedded in the wood panels is better, thus the previous study and the suggested design imply that the EcoStraw panel is less conductive of heat. The EcoStraw panel, on the other hand, eliminates the drawbacks of conventional Nebraska and Greb construction systems as well as some existing modular techniques by eliminating the need to drill straw bales for the installation and maintenance of internal networks; this is made possible by the panel's ventilated air camera, which also demonstrates minimal values in its U value. Because it is a reusable agricultural product with a low environmental impact and easy obtaining throughout much of our Colombian territory and the world, this element contributes to diversify and expand application opportunities to continue studying this rarely used material and to recognise the constructive options that it offers in housing projects based on sustainable principles. By validating the social, cultural, economic, and thermal comfort value of building using vernacular materials, the methodology used at the end of the process provides a foundation for design and innovation processes in the sustainable construction sector.

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