

Biocomposite based on corn cobs as an innovative thermal insulation material

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ABSTRACT

Under contemporary conditions of increasingly intensive climate change and growing energy demands, the role of renewable energy sources has become increasingly important. However, their availability and efficiency largely depend on variable meteorological conditions, which directly affect the stability and reliability of energy systems based on renewable energy sources. At the same time, climate change is altering energy consumption patterns, particularly through the growing need for adequate thermal insulation of buildings in order to maintain energy efficiency. Based on these facts, this research investigates the possibility of using ground corn cobs as an aggregate in the production of thermal insulation materials. The aim is to develop a composite material with satisfactory thermal insulation properties that could be applied in construction practice. This study contributes to the development of innovative materials that support the improvement of building energy efficiency.

KEYWORDS

Biocomposite; Thermal conductivity; Thermal insulator; Energy efficiency

1. INTRODUCTION

Increasing energy consumption in the building sector represents one of the key challenges of modern society, considering that the construction industry accounts for a significant share of global energy consumption and greenhouse gas emissions. Consequently, growing attention is being directed toward the development of materials that, in addition to possessing satisfactory technical characteristics, also exhibit a favorable environmental profile throughout their entire life cycle.

Materials produced from agricultural waste are of particular interest because they enable the efficient utilization of locally available resources while reducing the amount of waste generated in the environment. In this context, biocomposite thermal insulation materials represent an important direction in the development of sustainable construction, with significant potential for application in energy-efficient and environmentally friendly buildings. This research is specifically focused on investigating the feasibility of using corn cobs as a component of an innovative thermal insulation biocomposite.

2. THERMAL INSULATION MATERIALS

Thermal insulation is one of the key factors affecting the energy efficiency of buildings, as it directly contributes to reducing heat losses through the building envelope and lowering the overall energy consumption required for heating and cooling. Despite this, construction practice is still dominated by the use of synthetic thermal insulation materials such as expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PU), and mineral wool (Figure 1).

These materials exhibit excellent thermal insulation properties, with thermal conductivity coefficients typically ranging from 0.025 to 0.048 W/mK. However, their production requires substantial amounts of energy and the use of synthetic chemicals. Furthermore, at the end of their service life, they pose significant environmental challenges due to their limited biodegradability and the accumulation of waste.



Figure 1: Synthetic Thermal Insulation Materials

In addition, certain synthetic insulation materials may release harmful and toxic gases when exposed to high temperatures, posing risks to both human health and the environment. Although mineral wool demonstrates good fire resistance, its moisture absorption capacity may negatively affect the durability and thermal performance of building components. Due to these disadvantages, research in the field of construction materials is increasingly focused on the development of sustainable alternatives based on natural and renewable raw materials.

2.1. Natural Biocomposite Materials

Biomass-based materials represent one of the most promising groups of sustainable thermal insulation materials. Their main advantages include the renewability of raw materials, biodegradability, and lower energy requirements during the manufacturing process. Furthermore, the use of these materials contributes to waste reduction and lower carbon dioxide emissions, thereby supporting the principles of sustainable development in the construction industry.

Natural thermal insulation materials include reed boards, cork, sheep wool, straw bales, wood fibers, and corn-based materials (Figure 2). Although their thermal conductivity coefficients are generally higher than those of synthetic insulation materials, typically ranging from 0.037 to 0.145 W/mK, these materials offer significant environmental and health-related benefits. Their application is still relatively limited due to insufficient practical experience in the design and construction of such systems. However, recent research indicates a growing potential for their wider use in the construction sector.



Figure 2: Natural Thermal Insulation Materials

A particularly important area of development is represented by biocomposite materials, which are produced by combining natural fibers and natural binders. Biocomposites are defined as materials composed of at least two components of natural origin, where the fibers act as aggregates, while the binders enable the formation of a compact material structure. The analysis of heat transfer processes through such materials is of crucial importance for determining their thermal insulation properties and their potential application in building structures.

Numerous studies have confirmed the feasibility of using biocomposites for thermal insulation purposes. Cerezo et al. [1] analyzed the thermal and mechanical properties of hemp–lime biocomposites and demonstrated that increased porosity improves thermal insulation performance but may simultaneously reduce the mechanical strength of the material. Domenico Curto et al. [2] investigated the acoustic and thermal properties of the same type of biocomposite, confirming its suitability for application in energy-efficient and acoustically optimized buildings.

Similar studies were conducted by Maris Sinka and Genādijs Šahmenko [3], who examined the possibility of producing thermal insulation biocomposites from locally available raw materials, with particular emphasis on reducing CO₂ emissions throughout the material life cycle. Sophie Walker et al. [4] highlighted the significant influence of manufacturing processes and compaction levels on the internal structure and thermal insulation characteristics of hemp–lime composites. Bojković et al. [5] demonstrated that wood sawdust-based biocomposites can represent a sustainable alternative to conventional thermal insulation materials, offering satisfactory thermophysical properties and considerable environmental benefits. Florence Collet and Sylvie Pretot [6] further analyzed the effects of density and moisture content on thermal insulation performance and developed predictive models describing material behavior under different service conditions. Černý et al. [7] investigated the hygrothermal and physico-mechanical properties of flax shiv-based composite materials,

showing that agricultural waste can have significant potential for use in sustainable thermal insulation systems. Marín-Calvo et al. [8] explored the production of thermal insulation materials based on recycled cellulose and rice husks, concluding that agro-industrial waste can provide a sustainable alternative to conventional insulation materials while reducing environmental impacts.

Based on the available research, it can be concluded that natural and biocomposite thermal insulation materials represent a significant opportunity for the advancement of sustainable construction. Although certain limitations regarding their practical application still exist, ongoing research and technological development continue to improve their properties and expand their potential use in the energy-efficient buildings of the future.

3. METHODS FOR DETERMINING THE THERMAL TRANSMITTANCE COEFFICIENT

In accordance with modern requirements for sustainable and energy-efficient construction, building design must comply with current regulations that define minimum energy performance requirements and permissible levels of energy consumption. Compliance with energy-efficiency requirements is achieved through the application of relevant regulations that define the energy performance characteristics of buildings, methodologies for calculating the thermal properties of building components, and maximum allowable energy consumption values for heating, cooling, ventilation, domestic hot water preparation, and lighting.

In addition to requirements related to building energy consumption, special attention is given to the analysis of water vapor transmission through external building elements and structures adjacent to unheated spaces. Building assemblies must be designed to prevent both surface and interstitial condensation, since the presence of moisture can significantly affect structural durability and reduce the thermal insulation performance of materials. In cases where condensation occurs, it is necessary to determine the drying period required for the structure to regain its functionality and long-term stability.

Within this research, double-wall assemblies incorporating a biocomposite thermal insulation material were analyzed. The overall thermal transmittance coefficient (U-value) was determined using the URSA software package. As the thermal insulation layer, a biocomposite panel designated as K was used, produced from ground corn cobs, an agricultural waste material. In order to improve the thermal insulation properties of the material, expanded polystyrene (EPS) granules were incorporated into the biocomposite mixture, while a lime-gypsum paste in a 4:1 ratio was used as the binding component. In this way, a composite material with enhanced thermophysical characteristics and potential application in energy-efficient building structures was developed.

The percentage composition of the individual components of biocomposite K was as follows:

1. ground corn cobs – 53.5%
2. granules of expanded polystyrene (EPS) – 13.5%
3. lime-gypsum paste – 33%

Table 1 presents the particle size distribution of the aggregate used for the production of biocomposite K. The largest proportion consists of particles in the 4–8 mm size range (approximately 62%), while the 2–4 mm fraction accounts for about 28.8%. The particle size of the expanded polystyrene (EPS) granules was 0.3 cm. Figure 3 shows the appearance of the materials used in the composition of biocomposite K.

Table 1: Average Particle Size Distribution of the Aggregate

Biocomposite/size (mm)	<0,4	0,4-0,5	0,5-1	1-2	2-4	4-8	>8
Corn-cobs	3,1	0,5	9,4	3,6	28,8	62,3	8,9



Figure 3: Components of Biocomposite K

Methods for determining the physical and thermophysical characteristics of biocomposites were thoroughly analyzed in the study by Bojković et al. [9], where experimental testing on samples of identical composition was used to determine

the thermal conductivity coefficient of the biocomposite, K , which was then applied in the analysis of the energy performance of wall assemblies. To assess the energy efficiency of the analyzed constructions, the overall thermal transmittance coefficient (U-value) (1) was determined using the standard expression [10]:

$$U = \frac{1}{\frac{1}{\alpha_i} + \sum \frac{d_m}{\lambda_m} + \frac{1}{\alpha_e}} \quad (1)$$

where $R_{si} = 1/\alpha_i$ and $R_{se} = 1/\alpha_e$ are the thermal resistance coefficients for the inner and outer wall sides, λ_m is the coefficient of thermal conductivity, and d_m is the thickness of the m-th layer of the wall.

4. RESULTS AND DISCUSSION

The overall thermal transmittance coefficient (U-value) was determined for two types of wall assemblies: the first consisting of a ceramic block, and the second using a concrete panel as the primary structural layer. In both cases, a biocomposite K-based board was used as the thermal insulation layer. In addition to the calculation of the thermal transmittance coefficient, a water vapor diffusion analysis was also performed to assess the possibility of condensation occurring within the structure.

4.1. Wall Assembly 1 – Biocomposite K / Ceramic Block

The characteristics of the wall assembly incorporating a 50 mm thick thermal insulation layer made of biocomposite K and a ceramic block as the main structural material are presented in Table 2. The values of the thermal conductivity coefficient and the water vapor diffusion resistance factor for the remaining layers of the structure were taken from the relevant national regulation, while for biocomposite K, a thermal conductivity value of $\lambda = 0.125$ W/mK was used [10]. The water vapor diffusion resistance factor was determined using the dry cup method, as presented in the doctoral dissertation [11].

Table 2: Wall Assembly with Thermal Insulation Biocomposite K and Ceramic Block as the Base Material

Layers		d (m)	λ (W/mK)	μ	R (m ² K/W)
i					0.125
1	Extension plaster	0.02	0.85	15	0.024
2a	Ceramic block	0.19	0.61	6	0.311
2b	Cement–lime plaster	0.19	0.87	15	0.218
3	TI biocomposite K	0.05	0.125	7.8	0.400
4	External finishing plaster	0.03	0.87	15	0.034
e					0.04

The obtained value of the overall thermal transmittance coefficient for the analyzed assembly is:

$$U = 1.082 \text{ W/m}^2\text{K}$$

Compared with conventional thermal insulation materials, it was determined that when EPS of the same thickness is used, the U-value would be 0.572 W/m²K, while for mineral (rock) wool it would be 0.490 W/m²K. Based on these results, it can be concluded that the wall assembly incorporating biocomposite K exhibits approximately twice the poorer thermal insulation performance compared to assemblies with EPS and rock wool of the same thickness.

In order to achieve equivalent thermal transmittance values, it is necessary to increase the thickness of the biocomposite layer to approximately 0.16 m relative to EPS, or 0.19 m relative to rock wool.

Table 3: Water Vapor Diffusion Resistance Factor for Assembly 1 with Ceramic Block

Layers		d (m)	λ (W/mK)	μ	R (m ² K/W)	r (m)	t (°C)	p'(kPa)	p(kPa)
i					0.125		20.00	2.337	1.285
							15.36	1.749	1.285
1	Extension plaster	0.02	0.85	15	0.024	0.30	15.36	1.749	1.285
							14.48	1.650	1.136
2	Ceramic block	0.19	0.61	6	0.311	1.14	14.48	1.650	1.136
							2.92	0.752	0.570
3	TI biocomposite K	0.05	0.125	7.8	0.400	0.39	2.92	0.752	0.570
							-11.93	0.219	0.376
4	External finishing plaster	0.03	0.87	15	0.034	0.45	-11.93	0.219	0.376
							-13.21	0.195	0.152
e					0.04		-13.21	0.195	0.152
							-14.70	0.169	0.152

The vapor diffusion analysis was performed under design conditions: indoor temperature $t_i = 20^\circ\text{C}$, outdoor temperature $t_e = -14.7^\circ\text{C}$, indoor relative humidity $\phi_i = 55\%$, and outdoor relative humidity $\phi_e = 90\%$. Based on the results presented in Table 3, condensation was found to occur between the third and fourth layers of the construction. However, the structure's drying period is 15 days, which is acceptable under the applicable regulations.

4.2. Wall Assembly 2 – Biocomposite K / Concrete Panel

The characteristics of the second wall assembly, in which the primary structural element is a concrete panel, are presented in Table 4. The thermophysical parameters of the remaining layers were adopted in the same manner as for the previous assembly, while the thickness of the thermal insulation layer was kept unchanged.

Table 4: Wall Assembly 2 with Thermal Insulation Biocomposite K and Concrete Panel as the Base Material

Layers		d (m)	λ (W/mK)	μ	R (m ² K/W)
i					0.125
1	Extension plaster	0.02	0.85	15	0.024
2	Concrete panel	0.1	2.04	60	0.049
3	TI biocomposite K	0.05	0.125	7.8	0.400
4	External finishing plaster	0.03	0.87	15	0.034
e					0.04

The obtained value of the overall thermal transmittance coefficient is:

$$U = 1.488 \text{ W/m}^2\text{K}$$

In the case of EPS with the same thickness, the U-value would be 0.670 W/m²K, while for rock wool it would be 0.559 W/m²K. The results indicate that the wall assembly consisting of a concrete panel and biocomposite K exhibits approximately two and a half times poorer thermal insulation performance compared to assemblies with conventional thermal insulation materials. In order to achieve adequate thermal transmittance values, it would be necessary to increase the thickness of the biocomposite thermal insulation layer.

Table 5: Water Vapor Diffusion Resistance Factor for Assembly 2 with Concrete Panel

Layers		d (m)	λ (W/mK)	μ	R (m ² K/W)	r (m)	t(°C)	p'(kPa)	p(kPa)
i							20.00	2.337	1.285
					0.125		13.55	1.557	1.285
1	Extension plaster	0.02	0.85	15	0.024	0.30	13.55	1.557	1.285
							12.33	1.430	1.238
2	Concrete panel	0.1	2.04	60	0.049	6.00	12.33	1.430	1.238
							9.80	1.212	0.285
3	TI biocomposite K						9.80	1.212	0.285
		0.05	0.125	7.8	0.400	0.39	-10.85	0.240	0.224
4	External finishing plaster	0.03	0.87	15	0.034	0.45	-10.85	0.240	0.224
							-12.63	0.205	0.152
e					0.04		-12.63	0.205	0.152
							-14.70	0.169	0.152

The vapor diffusion analysis showed that no condensation occurs within this assembly. However, despite the more favorable moisture behavior, the assembly with the concrete panel exhibited less favorable thermal transmittance values compared to the assembly with the ceramic block.

5. CONCLUSION

Based on a comparison with reference cases using EPS and rock wool, it can be concluded that wall assemblies incorporating biocomposite thermal insulation material exhibit up to twice as high U-values, indicating poorer thermal insulation performance compared to conventional materials of the same thickness.

Nevertheless, despite these thermal limitations, the obtained results confirm that biocomposites based on corn cobs have potential for application in sustainable construction, particularly in buildings where environmental considerations and the use of renewable raw materials are of primary importance. Although their thermal insulation performance currently cannot fully compete with conventional insulation materials, opportunities for improving composition, density, and internal structure indicate significant potential for further development and application of these biocomposites in energy-efficient buildings of the future.

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