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Advancing Timber for the Future Built Environment

OAK TREE BARK AS A SUSTAINABLE MATERIAL FOR THERMAL INSULATION

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ABSTRACT: The increasing demand for sustainable and natural building materials has driven significant interest in alternative, new, eco-friendly insulation solutions. Using wood residues for insulation is a promising yet under-researched topic. According to green policies at the EU level, wood and its components, e.g., bark, should be used for long-lasting products and not as an energy source. Oak wood bark offers a renewable and natural resource with several advantageous properties for insulation. The study aimed to investigate the thermal properties of Oak tree bark embedded in the exterior walls and compare the U-values of the exterior walls with mineral wool (MW), a standardised and well-known insulating material. Preliminary results show that the U-values of experimental wall compositions were 0.22 W/m^{2}K for the wall with mineral wool (MW) and 0.29 W/m^{2}K for the wall with Oak tree bark. According to the Technical Regulation on the Rational Use of Energy and Thermal Insulation in Buildings, the maximum U-value for external walls in Croatia is 0.30 W/m^{2}K. However, the U value was 24% higher with bark; according to the environmental impact assessment, the economic value and sustainability of using Oak tree bark as insulation are still promising.

KEYWORDS: oak wood, veneer, paneling, cladding, bark insulation

1 – INTRODUCTION

Global energy demand continues rising, driven by population growth and economic and technological development. This increasing energy consumption has significant environmental implications, primarily due to the greenhouse gas emissions associated with energy production and use (1). The industrial, building, transportation, and agriculture sectors are the key contributors to energy consumption. Much of this energy usage can be attributed to construction and day-to-day operations. The growing investment in nearly zero energy buildings (nZEB) leads to greater use of passive envelope solutions, resulting in thicker insulation or using a material with better thermal properties in buildings worldwide (2).

The market for insulation materials is primarily dominated by a limited range of materials, such as mineral wool (MW), expanded polystyrene (EPS), extruded polystyrene (XPS), and glass fiber [3, 4], some of which cause significant environmental impacts at one or more lifecycle stages [5]. Insulation materials available today can be classified based on various factors, including structure, chemical composition, origin, specific weight, thermal conductivity, density, resistance to physical agents, and resistance to chemical factors.[6]

The overall environmental impact of different thermal insulation types across various life cycle stages (production, construction, use, and end-of-life) is generally most significant during the production stage [4].

As a result, the environmental impact of these materials throughout the building's life cycle is also becoming more important (2). This has led to increased interest in finding new natural insulation materials with low carbon footprints for the building industry. Sustainability

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efforts are not limited to the building industry, as other sectors also aim to minimise waste during production and maximise the use of input materials to achieve zero waste and preserve the environment.

The bark serves multiple functions: it shields the tree from insects, animals, and weather conditions, transports water and dissolved minerals from the roots to the rest of the plant, and offers physical support to the trunk [7]. In the wood industry, tree bark is often regarded as a byproduct. During wood processing, bark removal is typically the first step in sawmill production, and in general, oak bark is excluded from log diameter measurements. Reducing the total diameter of oak logs by up to 4 cm effectively turns the bark into an additional raw material without incurring extra costs. Bark has several advantages, including relatively high resistance to microorganisms, low density, low thermal conductivity, and a high heat storage capacity [8]. Tree bark contains higher levels of protective substances (such as tannin and suberin) than wood, giving it natural resistance to decay. As a result, it is reasonable to expect that bark used as an insulation material would require less chemical treatment than other materials, potentially reducing costs [9].

As various authors [10, 11] have detailed, bark has historically been used for various purposes: its fibrous structure makes it suitable for spinning ropes and fabrics, it's used in paper production, and it even had medicinal applications.

Bark, due to its high tannin content, can also be utilized to produce tanning agents. Additionally, it is used as mulch, helping retain soil moisture during dry periods. There were even attempts to manufacture bark-based particle boards; however, these were unsuccessful due to various contaminants in the bark, which negatively impacted the longevity of tools used in wood processing.

Nowadays, residuals such as tree bark are used in timber production for bioenergy production or for even less value-added purposes like composting and incinerating [7] , which is not in line with green policies.

2 – BACKGROUND

Research on bark insulation is not new; however, limited data are available on this topic. According to previous investigations by Kain et al. [8], tree bark was used for many purposes, including for thermal insulation. One of the most significant advantages of using tree bark as insulation is its environmental impact. As a natural and renewable resource, tree bark insulation has a lower carbon footprint than synthetic insulation materials. Furthermore, utilising tree bark helps mitigate waste in the timber industry. By repurposing a byproduct often discarded or used for low-value applications, tree bark insulation contributes to a circular economy and promotes resource efficiency.

3 – PROJECT DESCRIPTION

During this research, one of the main objectives was to explore the potential of using oak bark as an insulation material, aiming to provide an eco-friendly alternative to traditional insulating panels. In the initial stages of wood processing, bark is produced as a byproduct of the log debarking process, an essential first step in log processing. The raw material obtained, bark chips, has primarily been used for thermal energy production. Given the large potential quantities of bark available, its favourable thermal properties, ecological benefits, and the low cost of this byproduct from log processing, we found it worthwhile to investigate its feasibility.

Two experiments were conducted. The first experiment, outlined in this paper, involved using tree bark to prepare samples for thermal conductivity testing. Three samples were produced and tested in the laboratory. The same procedure was followed for other common wall materials: mineral wool, veneer plywood, and OSB panels. Three samples from each of the wall materials were tested to determine the thermal conductivity values of each material. Thermal conductivity is a critical property for thermal insulation materials. A material with low thermal conductivity (measured in W/mK) allows for the design of thinner walls while still providing high thermal resistance (R-value, measured in m^2K/W) and low thermal transmittance (U-value, measured in $W/m^2 \cdot K$).

The second part of the research involved installing tree bark as an insulation material in experimental external prefabricated walls. Some sections of the walls were insulated with mineral wool as a reference. Both sections of the walls were subjected to in-situ measurements of thermal transmittance values (U-value, $W/m^2 \cdot K$).

3 – EXPERIMENTAL SETUP

In the first investigation, we used tree bark to prepare samples for thermal conductivity testing. Three samples were made and tested in the laboratory. The thermal conductivity (λ, W/mK) of the insulation material, MW and tree bark panel utilised for the external wall of the

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bungalow (experimental house) was assessed in a laboratory using a heat flow meter instrument, specifically the Fox200 instrument employed in this study for determining the thermal conductivity of materials. The raw material for preparing the insulation, oak tree bark, was shredded and sterilised at 65°C for 25 hours. The dimension of the raw material composition was determined by granulometric analysis. For the experimental material for testing, we used material with 6.66% moisture content, Vinavil XA V 500 mPas water dispersion adhesives, and a pressing pressure of 150 bar at a dimension of 250x250x50mm.

After preparing and calibrating the insulation material, thermal conductivity testing was conducted by placing the samples between two plates in the test stack, and a temperature gradient was established across the material's thickness. The plates were positioned to adjust the thickness of the samples automatically. Each material used in constructing the external wall - veneer plywood, mineral wool, OSB panel, and tree bark - was tested using the same test setup, with three samples of each material being analysed. Figure 1 shows the Tree Bark sample and MW in the Fox200 instrument before conducting the measurement.

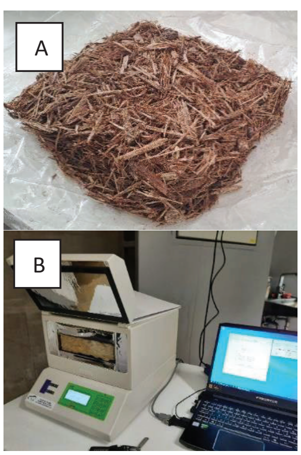

Figure 1 A) Preparation of tree bark insulating material for measurement with Fox200 machine, B) Tested sample of MW

The Heat Flow Method (HFM) and Temperature-Based Method (TBM), as shown in Figure 3, were used to determine the U-values of the walls. Both methods are described in detail in [12]. HFM is a widely used, non-destructive, and standardised technique for estimating the thermal transmission properties of flat building components. It relies on creating a sufficient temperature gradient between the indoor and outdoor environments to ensure an adequate heat flow is present [12]. The Temperature-Based Method (TBM) is a recent, yet non-standardised approach for performing in-situ U-value measurements. It is based on Newton's law of cooling, which states that the heat transfer rate is proportional to the temperature difference between an object and its surrounding environment and the surface area involved [13].

U-values of the examined wall assemblies were determined based on measurements between December 1 and December 8, 2023, with data recorded at 10-minute intervals. Following ISO 9869-1:2014 (Thermal insulation—Building elements—In-situ measurement of thermal resistance and thermal transmittance), all measurements were performed under conditions where the indoor–outdoor temperature differential exceeded 10 °C.

Both measurement approaches were used in this study to enable comparison and validate the results, serving as a control and to evaluate the performance of the Temperature-Based Method (TBM), which remains a non-standardised technique for in-situ thermal assessment. Figure 2 presents the experimental setup, showing Wall A (insulated with mineral wool) on the left and Wall B (insulated with tree bark) on the right. As shown in Figure 3, sensors for the Heat Flow Method (HFM) and TBM were installed nearby on both wall sections.

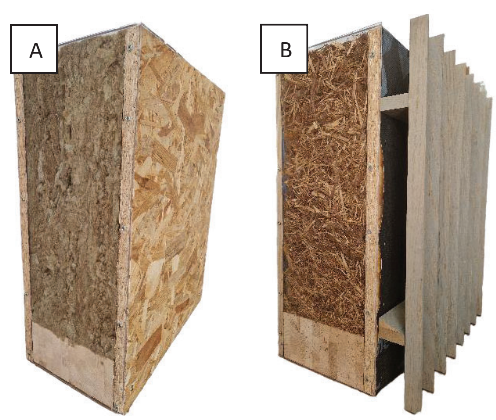

Figure 2 Experimental wall cross section A) wall insulated with MW B) wall insulated with experimental Oak tree bark (from outside to inside: veneer plywood 1.4cm, steam dam 0.017cm, MW or tree oak bark 20cm, vapour-permeable film 0.038cm, OSB panel 2.4cm

Figure 3 Heat Flow Method (HFM - https://www.hukseflux.com/products/heat-flux-sensors/heat-flux-meters/hfp01-heat-flux-sensor) and Temperature Based Method (TBM) instruments setup

Table 1. An overview of in-situ U-values obtained through measurements, compared with theoretical U-values, alongside a comparison of theoretical U-values for uninsulated and insulated walls using various building materials

Wall	Layers	Thickness [cm]	Coefficient of thermal conductivity of layer [W/mK]	Wall Thermal transmittance [W/m^{2}K] - calculated value	Wall Thermal transmittance [W/m^{2}K] - measured value HFM	Wall Thermal transmittance [W/m^{2}K] - measured value TBM
Wall A (insulated with MW) 	Veneer plywood	1,4	0,1267	0,16	0,2017	0,2237
	Steam dam	0,017	-			
	Mineral Wool	20	0,0351			
	Vapor-permeable film	0,038	-			
	OSB panel	2,4	0,1068			
Wall B (insulated with Tree Bark) 	Veneer plywood	1,4	0,1267	0,32	0,2902	0,2984
	Steam dam	0,017	-			
	Tree bark layer	20	0,076			
	Vapor-permeable film	0,038	-			
	OSB panel	2,4	0,1068			

According to ISO 9869-1:2014 (Thermal insulation, Building elements, In-situ measurement of thermal resistance and thermal transmittance), U-value measurements were conducted under a temperature difference more significant than 10 °C between the indoor and outdoor environment. The heat flow method (HFM) and Temperature-based Method (TBM), were used to determine the U-values of the walls.

5 – RESULTS

Table 1 presents the results for the tested wall assemblies, comparing in-situ U-values obtained through measurements with calculated U-values derived by ISO 6946:2017. The calculated values are based on thermal conductivity coefficients [W/mK] determined through laboratory testing of each individual layer. Wall A's U-values obtained through in-situ measurements exceed the calculated values by approximately 26%. In contrast, the measured U-values for Wall B are slightly

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lower than those calculated, with a deviation of less than 10%. These deviations may be attributed to the exposure of the wall assemblies and their constituent layers to actual environmental conditions, including elevated indoor relative humidity levels, exceeding the recommended range of 40% to 60%, and the impact of material moisture content on thermal performance. Conversely, the measured coefficient of thermal conductivity of the experimental wall layer (W/mK) presented in Table 1 correlates well with previous investigations [14].

The results obtained using the standardised Heat Flow Method (HFM) and the non-standardised Temperature-Based Method (TBM) show a high level of consistency. This indicates that the TBM, despite its non-standard status, can be a reliable and effective approach for in-situ thermal transmittance assessment.

The maximum permissible U-value for external walls is 0.30 W/m²K. The measured U-values for both Wall A and Wall B fall below this limit. However, the calculated U-value for Wall B slightly exceeds the allowable maximum, suggesting that the tree bark insulation layer would need to be increased by approximately 2 cm to meet the requirements outlined in [14]

6 - CONCLUSIONS AND RECOMMENDATIONS

The plentiful availability of tree bark positions it as a highly attractive resource for developing building materials. Its application as a thermal insulation material represents a promising opportunity for creating durable, wood-based products and offers a sustainable alternative to its conventional use as an energy source. This study highlights the potential of oak bark as a sustainable and thermally efficient insulation material, particularly suitable for application in lightweight building constructions.

In conclusion, this research emphasizes the potential of tree bark as a viable, environmentally friendly insulation material, contributing to sustainable construction practices. Ongoing investigation into its applications, coupled with the establishment of standardized testing protocols, will facilitate its wider adoption and foster innovation in developing green building materials. Tree bark represents a promising raw material for producing insulation panels, offering a sustainable and effective alternative to conventional insulation products. Its favourable thermal properties and environmental benefits position it as a compelling option for the development of energy-efficient materials and the realization of nearly Zero Energy Buildings (nZEB).

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HRN ISO 9869-1:2022 Thermal insulation -- Building elements -- In-situ measurement of thermal resistance and thermal transmittance -- Part 1: Heat flow meter method (ISO 9869-1:2014)

HRN ISO 6946:2017 Building components and building elements -- Thermal resistance and thermal transmittance -- Calculation methods (ISO 6946:2017, Corrected version 2021-12; EN ISO 6946:2017)

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