Thermal Characterization of Textile Waste Materials for Reuse in the Energy Refurbishing of Buildings

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Abstract: - The study's findings suggest new applications for End-of-Life Household Materials (EoLHMs), with a focus on new materials derived from textile wastes. The aim is twofold: explore innovative methods to promote the circular economy by reusing EoLHMs in the building sector and refurbishing buildings with particular attention to home-made panels, to favour disadvantaged contexts. Three different materials were tested, and their thermal conductivity was measured according to the ISO 8301 standard. The thermal conductivity as a function of the density was also investigated for a material derived from hemp. Comparisons with other textile materials are presented as well. As a result, the thermal conductivity of the materials ranged from 0.035 to 0.049 W/(m K), typical for insulating materials used in refurbishing applications.

Key-Words: - Reuse, thermal conductivity, thermal insulation, circular economy, energy efficiency, textiles.

Received: March 19, 2024. Revised: August 21, 2024. Accepted: September 13, 2024. Published: October 18, 2024.

1 Introduction

An important aspect is supporting sustainable development, promoted by the United Nations through one of its 17 goals, [1]. This includes reducing inequalities, improving health and education, and protecting the environment. Europe faces the challenge of energy poverty, where many people can't afford adequate heating, cooling, and lighting, leading to disease, death, and social isolation. Reusing waste materials, such as surgical masks [2], or new materials, is particularly beneficial as it allows people in disadvantaged contexts to self-produce and install panels in their homes. This not only improves indoor comfort but also enhances human capital.

In the literature, thermal insulating materials made from recycled waste are now widespread, including those derived from textiles [3], [4], rubber [5], cigarettes [6], agriculture [7], [8], [9], and construction elements [10], [11]. By leveraging local labor, EoLHMs can be transformed into building components, promoting social inclusion.

The context of energy retrofitting of buildings is of great interest because, as is well known, buildings are responsible for a significant percentage of energy consumption [12], especially in light of the recent variability in energy costs, [13]. In this framework, in the literature, attention has been paid to green walls [14] and to their impact on energy consumption and indoor comfort [15] and mainly to the building envelope retrofit [16], [17], [18] as a strategy to provide comfort coupled with energy savings, without compromising functional needs.

In this framework, in the present work, we aim to present the experimental thermal characterization of new materials coming from textile wastes, from the perspective of possible reuse as thermal insulants.

2 Problem Formulation

The materials analyzed are produced from textile waste. In this preliminary analysis, to calibrate laboratory activities, we present data related to three different samples, presented in Figure 1 and named A, B, and C. Samples B and C are made of the same material but with two different densities.

The A panel is made from mixed fibers recycled from various types and colors of yarns. These fibers are thermally bonded, a thermal cohesion process that produces the material without adding any chemical components. Moreover, this process makes the material very stable over time and resistant to moisture and infiltration. This material is also easily workable and suitable for thermal and acoustic insulation of walls, floors, and roofs.

The panels will be attached with mechanical fasteners or gypsum-based adhesives on a brick support. A notable feature of this product is its complete recyclability during dismantling.

(a)

(b)

(c)

Fig. 1: Materials A (a), B (b) and C (c)

The B and C panels are made from thermally fixed hemp and kenaf fibers. This production process gives these panels lasting thermal and acoustic performance and makes them resistant to the effects of moisture. They can be used for external or internal insulation or with dry systems, and their installation involves the use of mechanical dowels or lime-based adhesives on brick support. This material is also completely recyclable during dismantling. Additionally, this material promotes the breathing cycle, retaining excess moisture in the cold months and releasing it in the warm months.

3 Experimental Measures

The measured density is reported in Table 1.

Table 1. Density of the samples

Test specimen	**Density** $(kg\ m^{-3})$
A	31.3
B	33.7
C	64.9

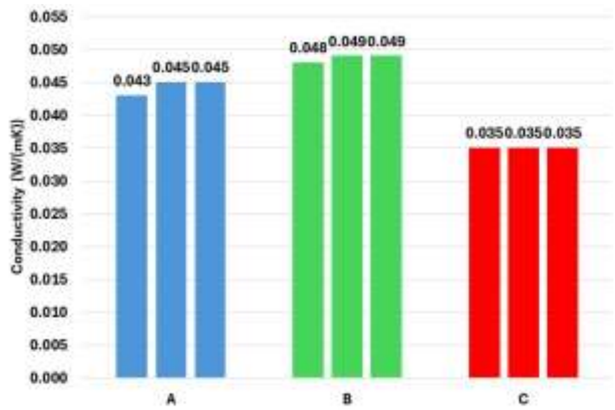

Fig. 2: Thermal conductivity of the panels obtained by experimental measurements. For each panel, three different test repetitions were performed

Thermal conductivity tests were conducted at the University of Bologna (Italy). After weighting and conditioning, a heat flow meter, designed to analyze materials with a thermal conductivity of less than 5 W/(m·K), was used following the ISO 8301 standard, [19]. During the test, the sample was placed between a hot and a cold plate, each maintained at constant temperatures by two thermostatic baths, with an insulating layer to minimize lateral heat losses. Data acquisition was carried out using a multimeter, a switch control unit, and an ice point reference.

Each measure was repeated, and the results are summarized in Figure 2. Figure 2 also delves into the dependence of the thermal conductivity on density: indeed, two different densities are considered concerning the material constituting sample B and sample C. Analogously to the findings concerning face masks [2], also for this new material higher density had lower thermal conductivity.

To better understand and contextualize the obtained data, we will now evaluate the thermal conductivity of raw textile materials, using samples from reuse reported in Figure 3. The analyses were performed employing the same heat flow meter located at the University of Bologna (Italy).

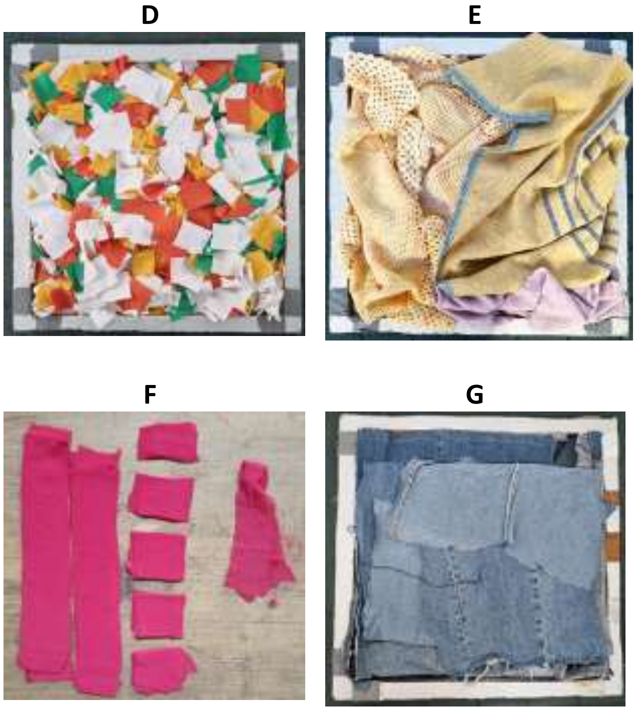

Fig. 3: Materials D (cotton crumped in ordered arrangement), E (wool in disordered arrangement), F (polyester in crumped in ordered arrangement), and G (Jeans in ordered arrangement)

The materials are given by cotton (D); wool (E); polyester (F) and Jeans (G), and their thermal conductivity and density are reported in Figure 4. This figure shows that thermal conductivity varies with material type, with cotton exhibiting higher conductivity than wool and polyester despite similar densities. Cotton and denim, both cellulose-based, differ in fiber density due to the manufacturing process, affecting conductivity. This confirms that density influences thermal conductivity, as previously noted.

After having tested the materials layered in an orderly manner, we decided to rearrange them in a disordered manner and cut them into small bites.

Results are reported in Figure 5, showing that the variation in arrangement within the sample generally yields an improvement in the thermal performance of the materials, except in the case of wool. In this case, the fabrics already provide ample air spaces: a disordered distribution likely increased these spaces to the point of allowing the formation of convection currents inside, as shown in Figure 5. For cotton, polyester, and jeans, however, the introduction of these air spaces improved thermal performance, especially for the first of the three.

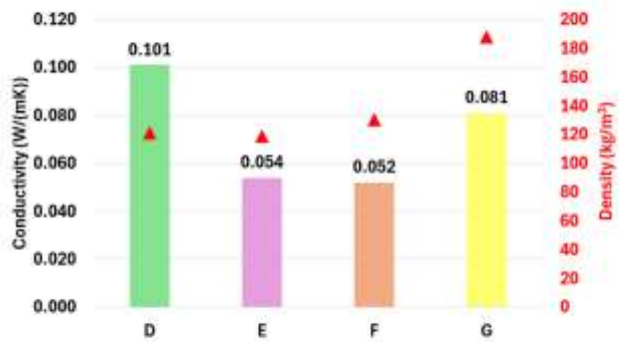

Fig. 4: Thermal conductivity and density of samples made of cotton (D), wool (E), polyester (F), and Jeans (G). Data refers to materials disposed in ordered arrangement within the test specimen

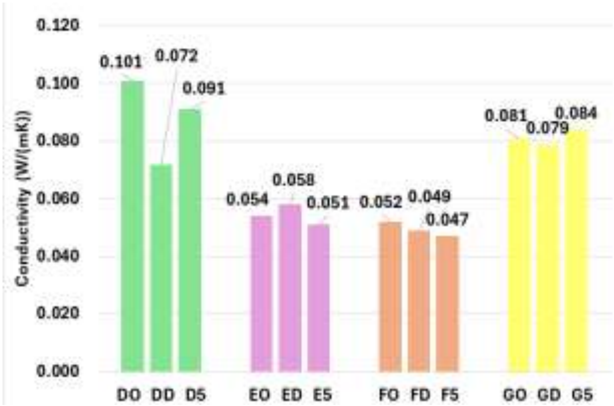

Fig. 5: Effect of an ordered arrangement (O), disordered rearrangement (D), and of 5 cm bite (5) on the thermal conductivity of samples C, D, F, and G. (For example, DO refers to the test specimen D in ordered arrangement)

Figure 5 shows that the measured thermal conductivity varies between 0.047 and 0.101 W/mK, typical values for fibrous materials objects, [2]. However, thermal conductivity depends not only on the material but also on the arrangement and size of the elements. Different relationships were observed among these three factors for the various materials. For cotton, polyester, and jeans, thermal conductivity decreased when the fabrics were arranged in a disordered manner, while cutting the fabrics improved conditions for wool and polyester.

Finally, a comparison with other reuse materials can then be performed. The benchmark is reported in Figure 6, where data from the literature are employed, [2], [20]. The figure shows that the lowest thermal conductivity values are reached for face masks placed inside cardboard boxes and that values of the same order of magnitude of the materials measured in the present paper are reached. Indeed, a comparison with insulating materials typically employed in building refurbishing is reported in Figure 7, showing that mainly high-density material C displays very interesting features.

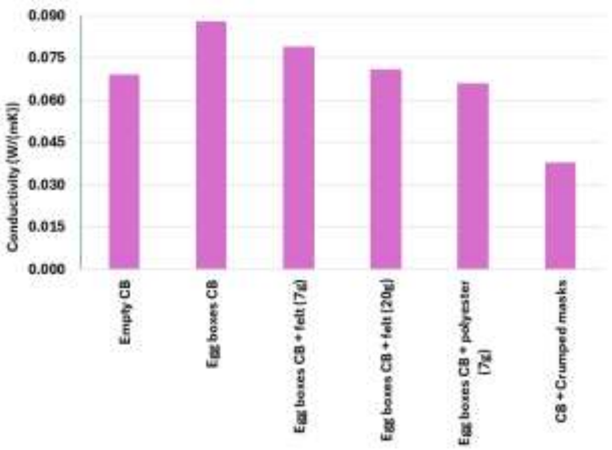

Fig. 6: Comparison of the thermal conductivity of insulating panels made of reusable materials placed inside cardboard boxes (CB) [2], [20], in various configurations: for polyester and felt, a variable amount of material (7 or 20 g) was considered based on the position inside each egg box

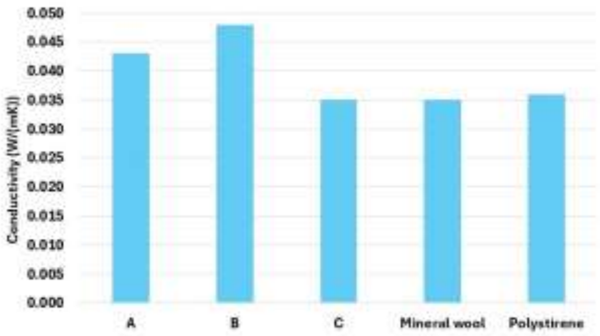

Fig. 7: Comparison between the experimental results obtained (best values) and the values of typical commercial insulant. It is observed that the "C" panel has a conductivity close to that of commercial insulants

4 Conclusion

This study investigated innovative methods to promote the circular economy by reusing End-of-Life Healthcare Materials (EoLHMs) in the building sector, focusing on panels built from textile wastes. Three different materials were tested, and the thermal conductivity was experimentally measured according to the ISO 8301 standard.

The thermal conductivity of the tested materials ranged from 0.035 to 0.049 W/(m K), typical for insulating materials in refurbishing applications. Concerning a material derived from hemp, the dependence of the thermal conductivity on density was deepened. Analogous to the findings concerning face masks, higher density had lower thermal conductivity for this new material.

Future analyses will focus on different materials, as well as on the acoustic performances of those materials.

Acknowledgement:
The authors are grateful to Mr. Matteo D'Orazi and Mr. Dario Zanghirati for their cooperation in the experimental activities.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)
The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself
We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 104 published on 2.2.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU– Project "Sustainable Thermal and Acoustic self-made solutions for buildings refurbishment in disadvantaged social contexts by Reusing poor materials (STAR)" – CUP J53D23002280006 - Grant Assignment Decree No. 961 adopted on June 30, 2023 by the Italian Ministry of Ministry of University and Research (MUR).

Conflict of Interest
The authors have no conflicts of interest to declare.