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ENHANCEMENT OF FIRE PROPERTIES IN WOOD FIBER-BASED THERMAL INSULATION FOR ECOLOGICAL NEW CONSTRUCTION AND RENOVATION PROJECTS

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ABSTRACT: The growing emphasis on sustainability in construction has led to increased demand for ecological and renewable building materials. Wood fiber-based thermal insulation offers a promising alternative to conventional mineral wool insulation, which is energy- and emission-intensive to produce. However, its broader adoption is hindered by strict fire regulations, particularly in buildings over two stories. This study explores advancements in fire-resistant wood fiber insulation, demonstrating that fire-retardant treatments can elevate its classification to Euroclass B while maintaining its environmental benefits. Expert interviews reveal that, despite misconceptions about its fire safety and moisture performance, wood fiber insulation exhibits favorable charring behavior, reducing fire spread compared to synthetic alternatives. Regulatory frameworks, however, often overlook these advantages. The study highlights the need for updated fire testing methodologies and policies that assess insulation performance at the structural level rather than focusing solely on material combustibility. By addressing these challenges, wood fiber insulation can play a crucial role in sustainable, low-carbon construction.

KEYWORDS: wood fiber insulation, fire safety, sustainability, thermal insulation, regulatory challenges, ecological construction

1 – INTRODUCTION

The construction industry faces a significant challenge in addressing the environmental impact of synthetic materials [1]. Widely used materials like polystyrene, commonly employed as thermal insulation, are problematic due to their long decomposition times and reliance on fossil-based raw materials [2]. Additionally, inefficiencies in recycling infrastructure and energy-intensive processes often result in synthetic materials ending up in landfills or natural environments. These issues highlight the urgent need to reduce the production of synthetic materials and to develop ecological alternatives.

The growing emphasis on sustainability in European construction regulations has increased demand for ecological building materials. This shift has driven the adoption of renewable materials and energy-efficient solutions, including advanced thermal insulations. In countries such as Austria, France, Germany, and Japan, the use of wood fiber-based insulation has become more common [3,4]. However, widespread adoption remains limited by high initial production costs and stringent fire safety regulations, particularly in multi-story buildings.

Currently, the most prevalent thermal insulations, such as mineral wools (glass wool and stone wool), belong to the A2 fire class but are associated with energy-intensive production processes and significant emissions [5]. Advances in fire-retardant treatments have allowed wood fiber insulation to achieve a B fire class rating, opening promising opportunities for broader application [6]. In Finland, with its abundant forestry resources and strong commitment to sustainable building practices, wood fiber insulation holds considerable potential. However, unlocking this potential requires reducing production

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costs and adapting regulatory frameworks to support its use in a wider range of building types.

Overall, wood fiber insulation represents a promising solution to the abovementioned challenges. Made from renewable resources, it offers excellent thermal performance and significant ecological benefits. However, its broader adoption is hindered by high production costs and regulatory limitations related to fire safety. This paper examines the potential of fire-resistant wood fiber insulation in promoting low-carbon construction by expert interviews. Particular attention is given to understanding the prerequisites for its broader adoption in low-carbon construction and renovation projects. The findings will contribute to the growing body of knowledge on ecological construction and support efforts to integrate renewable materials into mainstream building practices.

2 – RESEARCH METHOD

The study's scope extends across multiple European countries where the use of wood fiber insulation has seen notable progress. By incorporating diverse perspectives from manufacturing, research, and fire safety, it aims to provide comprehensive insights into the development, implementation, and performance of these materials.

To gain in-depth and multifaceted insights into the use and adoption of wood fiber insulation, semi-structured expert interviews were selected as the primary data collection method. This approach allowed for an in-depth exploration of key topics, providing flexibility for follow-up questions and enabling the discovery of unexpected perspectives and experiential knowledge. These informal yet critical insights were essential for understanding both the current applications and the evolving role of wood fiber insulation in construction.

Participants were selected from a diverse group of experts across multiple European countries where advancements in wood fiber insulation have been observed. The sample included professionals from manufacturing companies, research institutions, and fire safety specialists with expertise in bio-based building materials.

A purposive sampling strategy ensured a broad representation of geographic and professional expertise (Table 1). This was complemented by snowball sampling, where initial participants recommended additional suitable experts to provide further insights. To ensure expertise relevance, company representatives were identified based on their experience with fire-resistant wood fiber insulation and their ability to provide informed perspectives on regulatory and market challenges.

Table 1: Interviewees' profile.

Interviewee	Position/Title	Country of Affiliation
R1	Company Representative	Finland
R2	Company Representative	Finland
R3	Company Representative	Finland
R4	Company Representative	Finland
R5	Fire Safety Expert	Finland
R6	Researcher	Finland
R7	Researcher	Finland
R8	Company Representative	Norway
R9	Fire Safety Expert	Norway
R10	Company Representative	Germany
R11	Researcher	Germany
R12	Researcher	Germany
R13	Researcher	Poland
R14	Fire Safety Expert	Sweden
R15	Fire Safety Expert	Denmark

All interviews were conducted remotely via Microsoft Teams to ensure accessibility and flexibility across different geographic locations. To facilitate meaningful discussions, participants were provided with an overview of the interview themes in advance. Interviews were recorded with prior consent, and automatic transcription was utilized to streamline data processing.

The qualitative data were analyzed using ATLAS.ti, a qualitative analysis software that enabled systematic coding, categorization, and theme identification. The analytical process was based on the principles of grounded theory, following a three-phase approach: (1) open coding, (2) axial coding, and (3) selective coding as detailed below:

During the open coding phase, interview transcripts were systematically reviewed to identify recurring topics and expert insights. This initial categorization formed the foundation for deeper analysis. The primary categories and their respective subcodes are presented in Table 2.

Table 2: Open Coding

Category (Theme)	Codes (key concepts from the interviews)
Knowledge of Wood Fiber Insulation	Awareness level misconceptions comparison with other insulation materials research, education and awareness projects learning curve for professionals
Regulatory Landscape	Fire safety requirements environmental standards other technical regulation
Material Performance & Safety	Fire resistance moisture durability thermal efficiency air quality impact health concerns ease of installation
Adoption Barriers	Cost concerns lack of awareness resistance from industry professionals challenges in circular economy compliance challenges
Market Demand & Industry Growth	Customer interest market competition government incentives
Sustainable Development	Circular economy opportunities sustainability benefits influence of sustainability trends
Future Expectations & Innovations	Desired improvements research and development needs new innovations scalability potential

Following open coding, identified themes were grouped into broader axial coding categories to reveal interconnections between key factors influencing wood fiber insulation adoption. The relationships among themes are summarized in Table 3.

Table 3. Axial Coding Categories and Linked Open Coding Categories Forming the Core Themes

Core Theme	Subcategories	Linked Open Coding Categories
Deficiencies in the Assessment of Technical Performance and Safety	Awareness level, misconceptions, fire resistance, moisture durability, thermal efficiency, fire safety requirement, other technical regulation, desired improvements	Material Performance & Safety Regulatory Landscape Knowledge of Wood Fiber Insulation Future Expectations & Innovations
Sustainability As a Driver for Adoption and Innovation	Challenges in circular economy, sustainability benefits, influence of sustainability trends, circular economy opportunities, environmental standards, cost concerns, new innovations, desired improvements, research and development needs	Sustainable Development Adoption Barriers Regulatory Landscape Future Expectations & Innovations
Consumer Education and Regulatory Guidance as Guiding Factors	Fire safety requirements, desired improvements, government incentives, environmental standards, awareness level, misconceptions, learning curve for professionals	Knowledge of Wood Fiber Insulation Regulatory Landscape Market Demand & Industry Growth

This coding process allowed for the identification of relationships between different factors, structuring the expert interview insights into a coherent framework.

While this paper presents findings based on open, axial, and selective coding, further research will deepen the analysis by refining this framework. The next phase will focus on synthesizing these insights into a theoretical model that captures the most critical influences on wood fiber insulation adoption, providing guidance for industry stakeholders and policymakers.

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3 – RESULTS

3.1 Deficiencies in the Assessment of Technical Performance and Safety

3.1.1 Fire Safety

The fire safety of wood fiber insulation and its potential to improve structural fire resistance remain key areas of research. Typically, wood fiber insulation meets Euroclass E requirements, but fire retardants can elevate it to classes D or B. However, the benefits of increasing fire classification beyond Euroclass E are debatable as in full-scale fire tests the structure itself provides sufficient protection (R9). Variability in fire retardant formulations, their long-term durability, and potential health risks further complicate their use (R6, R14, R15).

A key advantage of wood fiber insulation is its ability to char instead of melt, unlike plastic-based insulation (R5, R8, R9). This prevents the formation of cavities that could accelerate fire spread (R5). Some studies suggest that the fire resistance performance of structures using wood fiber insulation is comparable to that of non-combustible insulation (R5, R15), with superior thermal insulation performance in fire conditions in some cases (R5, R9). However, current fire testing standards do not fully account for these protective effects, highlighting the need for revised methodologies (R8, R9).

Smoldering combustion, particularly in roof structures, remains a concern (R5, R10). While it progresses slowly, allowing more evacuation time (R2), standardized regulations addressing smoldering risk, could provide additional safety measures (R5). Structural solutions, such as board-type insulation, can enhance fire resistance by reducing settlement risks in wall structures (R5).

3.1.2 Thermal Efficiency

Interview findings indicate that wood fiber insulation does not exhibit the strong natural convection observed in mineral wool, contributing to stable indoor temperatures (R1, R2). Its high specific heat capacity further regulates temperature fluctuations (R1, R2, R10). However, due to the structural limitations of natural fibers, optimizing thermal conductivity remains a challenge (R2, R11, R12). Compared to mineral wools and especially plastic-based insulations (EPS, PU, XPS), wood fiber insulation requires a higher density to maintain stability, which affects its thermal efficiency (R2, R12, R13). Additionally, moisture absorption can increase thermal conductivity and reduce insulation performance over time (R12).

European standards do not fully account for natural convection, which can result in significant heat loss in open-porous insulation materials (R1, R2). Studies indicate that under certain conditions, heat loss from convection can be up to 70% higher than what is measured in standard thermal conductivity tests. Addressing these discrepancies in thermal performance assessments could improve the accuracy of energy efficiency evaluations for bio-based insulation materials. (R1)

3.1.3 Moisture Performance

Wood fiber insulation's hygroscopicity and vapor permeability help regulate moisture levels within structures, reducing the risk of damage while supporting healthy indoor air quality (R2, R6, R10, R11, R13) Compared to mineral wool, its ability to manage moisture fluctuations provides a significant advantage, particularly as climate change increases moisture-related stress on buildings (R6).

Misconceptions persist regarding wood fiber insulation. Moisture issues typically stem from improper installation or unsuitable applications rather than the material itself (R8, R11, R10). Wet-sprayed variants may risk mold in cold climates if drying is inadequate, while dry-installed options are more reliable (R6). Mold growth usually occurs only if the material remains wet post-construction, with risks diminishing once dried properly (R11). Misleading terms like 'breathable' structures have led to construction errors; maintaining airtightness with a proper air barrier is crucial to prevent unintended air movement (R6).

3.2 Sustainability As a Driver for Adoption and Innovation

3.2.1 Sustainability benefits

Wood fiber insulation is gaining popularity for its environmental benefits (R2, R3-5, R9, R13, R11, R14). As a renewable and biodegradable material, it offers a sustainable alternative to polystyrene and mineral wool (R1, R2, R4, R8, R10, R11, R13). Its manufacturing process has a low carbon footprint, and the material acts as a long-term carbon sink (R1-4, R7, R8, R10, R12, R13). Wood fiber insulation can also be produced without synthetic binders, and the use of bio-based binders is continuously being researched, further enhancing the sustainability of these products (R8, R11).

3.2.2 Challenges in circularity

The availability of raw materials poses challenges to widespread adoption (R4, R8, R11-13). A significant portion of wood industry by-products is currently used for energy production, a trend that has intensified in Finland due to the discontinuation of Russian energy wood imports (R4). However, as wood burning declines in energy production, alternative uses for these by-products—such as insulation manufacturing—are expected to increase (R3, R4). Additionally, recycled paper and cardboard are becoming more viable raw materials, particularly as newspaper production decreases and e-commerce drives higher cardboard production (R1, R2).

3.2.3 Circular economy opportunities

Recycling and reusing wood fiber insulation offer key opportunities. Waste from production, construction, and demolition can be repurposed for new insulation, with recycled content under investigation (R1, R3, R8, R10). Improved collection and sorting would enhance recovery (R8, R10). Used insulation can serve industrial applications like asphalt binder or pellet production (R2, R8). Biochar from wood fiber insulation could support carbon storage and soil improvement, while boron-treated insulation recycling may create new business opportunities in biochar and fertilizers (R1, R2, R3, R10).

3.3 Consumer Education and Regulatory Guidance as Guiding Factors

3.3.1 Regulatory Landscape

Regulations significantly influence wood fiber insulation adoption, particularly in fire safety, thermal performance, and sustainability. Growing consumer demand, stricter energy regulations, and green certifications drive interest in bio-based insulation (R2-4, R8, R13). However, many LCA models overlook biogenic carbon storage, underestimating its environmental benefits (R1, R2, R4, R7, R8). A dynamic approach could better reflect its carbon sequestration potential and enhance market positioning (R1, R7). Establishing standardized carbon footprint limits for small-scale residential buildings would further support adoption (R1, R15).

Fire safety regulations remain a major barrier, especially in large-scale construction (R1–R10, R13, R15). Current classifications favor non-combustible insulation (Euroclass A1/A2) without fully considering whole-building fire resistance (R1, R2, R4, R5, R8, R9). Sweden’s approach assesses fire performance at the structural level, offering more flexibility (R14). Upcoming Eurocode 5 revisions will introduce a "protection level" classification, recognizing insulation’s role in shielding wooden frameworks. Full-scale tests suggest wood fiber insulation can match mineral wool in structural fire resistance (R1, R2, R5). Standardized fire testing for prefabricated wood-based elements could further support market integration (R1).

The removal of Finland’s national insulation regulation in 2017 has led to reliance on EN standards, which do not fully consider local conditions (R1, R2). This has been particularly disadvantageous for wood fiber insulation, as its naturally low convective heat transfer is not recognized, leading to potential underestimation of its energy efficiency (R1, R2). Reintroducing an insulation-specific regulation could establish a clearer legislative framework, enhance market oversight, and ensure that key performance indicators, such as air resistance affecting convection, are included in product specifications (R1).

3.3.2 Consumer Awareness and Industry Collaboration

Consumer education and regulatory guidance are critical in advancing the market position of wood fiber insulation (R1, R4, R8, R10, R13). EU regulatory developments supporting carbon sequestration and sustainability metrics have a potential to improve competitiveness (R1, R8). Industry-wide advocacy and collaboration among bio-based material manufacturers are necessary to promote testing methods and regulations tailored to these products (R1, R3, R8, R15).

Misinformation about fire safety, moisture resistance, and proper installation remains a challenge (R1, R2, R4-6 R8, R10, R13-15). Targeted education for builders, designers, and consumers can be used to help dispel misconceptions and promote correct usage (R1, R5, R8, R10, R13). Financial incentives for sustainable construction could further accelerate market growth and new innovations (R3, R10, R13). Strengthening market trust through transparent fire safety data, international collaboration on testing standards, and public awareness campaigns are also used to drive adoption (R1, R9, R,13, R15). Ensuring that wood fiber insulation is recognized as a safe, sustainable, and high-performing material will be essential in securing its long-term place in the construction industry (R5, R8, R15).

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4 – CONCLUSIONS

Wood fiber insulation offers advantages in fire safety, thermal efficiency, moisture regulation, and sustainability but faces regulatory and market barriers. While it chars rather than melts, providing structural protection, current fire classifications overlook these benefits. Similarly, thermal regulations underestimate its low convective heat transfer. Standardized testing and updated regulations reflecting real-world performance are needed for fair market positioning.

Sustainability drives its adoption, with low-carbon production, biogenic carbon storage, and recyclability making it a key material. However, challenges include raw material availability, regulatory inconsistencies, and moisture misconceptions. Expanding recycled content, improving waste management, and aligning LCA with biogenic carbon accounting could boost competitiveness.

Consumer awareness and regulatory adjustments are crucial. EU-wide standardization, industry collaboration, and education for designers, builders, and consumers can dispel misconceptions and improve installation practices. Incentives for sustainable construction, especially in housing, could further drive market growth.

Future research should focus on optimizing fire safety, refining material processing, and improving regulations to support bio-based insulation. Addressing these challenges will enable wood fiber insulation to advance sustainable, energy-efficient, and fire-safe construction.

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