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A Review on Thermal and Acoustic Insulation Materials of Wall Multi-Layered Building

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Abstract. The energy performance of a building is significantly influenced by the quality of materials utilized in its construction. In the building industry, exterior walls play a crucial role in optimizing efficiency. Thermal insulation emerges as an effective strategy for reducing energy consumption, providing benefits during both hot and cold seasons. In this context, the selection of insulation material, its thickness, and its placement within the building structure are vital for maintaining optimal indoor temperatures throughout the year. Furthermore, sound insulation is equally important in ensuring acoustic comfort within a space and should not be disregarded when constructing a building envelope. This article aims to review the extant literature on thermal and sound insulation and provide an overview of notable commercial insulation materials.

INTRODUCTION

The energy and environmental concerns have gained significant traction in recent years, prompting the establishment of various national and international regulations to promote global sustainability. The European Union has taken a leading role in this regard [1].

The construction sector, accounting for 40% of Europe's consumption of energy, has become a focal point for improvement. The construction industry presents substantial opportunities for enhancing energy efficiency, with the potential for widespread implementation of energy-saving techniques to significantly reduce emissions of greenhouse gas [2].

A construction exterior plays a vital role in shaping the surrounding microclimate [3]. The building envelope, acting as a barrier between indoor and outdoor environments, influences occupants' thermal comfort [4] and contributes to considerable energy losses during operation.

This research aims to explain a deep review of existing research on material selection for wall thermal and acoustic insulation in the construction industry, followed by a description of wall insulation design for future research purposes.

THE INSULATION MATERIALS PROPERTIES

In this paragraph, insulation materials will be presented in two groups, one group will be thermal insulation, and the other group will be acoustic insulation.

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Introduction of thermal insulation characteristics

The transient thermal of diffusivity (D) and the steady-state thermal conductivity (λ) are the key metrics used to measure the thermal efficiency of insulation. Thermal conductivity, measured in W/(m K), represents the heat transfer rate through a unit of a homogenous material, driven by a temperature gradient of one Kelvin [5]. Dynamic or transient conductions arise when the temperature fluctuates at the studied component's boundaries, requiring careful management [6]. The concept of thermal diffusivity is described as the thermal conductivity divided by the combined value of density (ρ) and representing a material's capacity to conduct thermal energy [7]

TABLE 1. Evaluation procedures for determining the thermal diffusion parameter and density [10]

Parameter	Evaluation Procedure	Note
λ [W/(m K)]	ASTM C518	Heat Flow Meter
	ASTM C177	Safe Hot Plate Equipment
	EN 12664	Min Heat Resistance
	EN 12667	Max Heat Resistance
	EN 12939	Dense Materials
ρ [kg/m^3]	ASTM C303	-
	EN 1602	-

TABLE 2. Comparison of thermal insulation effectiveness for commercial and non-traditional materials [10]

	ρ [kg/m^3]	λ [W/(m K)]	**Specific of Heat** [kJ/(kg K)]	**μ-value** (Water Vapor Diffusion Resistance Coefficient)
Commercially Available Material				
Mineral Wool	40–200	0.033–0.040	0.8–1.0	1.-1.3
Fiberglass	15–75	0.031–0.037	0.9–1.0	1.1.1
EPS	15–35	0.031–0.038	1.25	20-70
XPS	32–40	0.032–0.037	1.45-1.7	80-150
Foam of Phenolic	40–160	0.018–0.024	1.3-1.4	35
Polyurethane	15–45	0.022–0.040	1.3-1.45	30-170
Polyisocyanurate	30-45	0.018–0.028	1.4-1.4	55-150
Cellulose	30-80	0.037–0.042	1.3-1.5	1.7-3.0
Non-traditional Materials				
Bagasse	70–350	0.046–0.055	-	-
Cotton of Recycled Denim	-	0.036-0.038	-	-
Cotton Fiber from Stalks	150–450	0.059–0.082	-	-
Recycled Cotton	25–45	0.039–0.044	1.6	1.2

The characteristics of acoustics

The construction material can be acoustically characterized by their sound transmission impedance and sound wave absorption properties. The initial assessment evaluated both airborne and structural sound insulation characteristics [8].

On the other hand, sound absorption measures the amount of acoustic energy that is dissipated within a medium, which happens through resonance effects, heat dissipation in porous substances, or frictional forces [9].

Although porous sound barriers often demonstrate exceptional thermal insulation characteristics, this relationship is not universally true. There are various techniques for assessing the sound absorption properties of materials. These methods include the use of diffuse sound fields in reverberant chambers and the application of impedance tubes in plane wave environments.

Table 2 presents the thermal insulation performance of both commercial and unconventional products, providing a basis for comparing the effectiveness of different insulation materials.

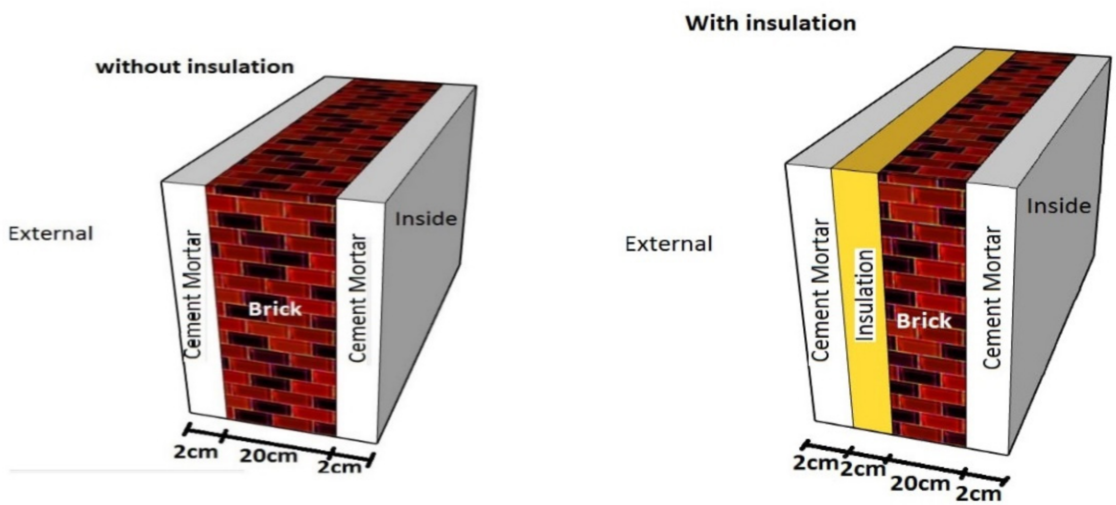
This comparison will help in identifying which materials offer superior thermal efficiency, allowing for informed decision-making in selecting the most appropriate insulation solutions for various applications.

DESIGN OF MULTILAYER WALL

The design and structure of a building's walls, coupled with the thoughtful choice of materials for thermal and sound insulation, are crucial in creating comfortable indoor environments. Effective insulation helps maintain a steady and pleasant room temperature while also boosting energy efficiency by lessening the demand for extensive heating during cold months and air conditioning in hot periods. This approach leads to consistent and comfortable indoor conditions throughout the year.

Additionally, effective soundproofing materials help to minimize noise transmission from both external and internal sources, contributing to a more peaceful and quieter environment.

A comprehensive diagram of thermal and acoustic insulation in a multi-layered wall construction is depicted in Figure 1. This illustration demonstrates the integration of various insulation layers, highlighting their combined effectiveness in providing both temperature control and noise reduction.



(a) (b)

FIGURE 1. (a) Wall Multilayer Building Plan without Insulation, (b) Wall Multilayer Building Plan with Insulation

When designing walls, the primary considerations are cost-effectiveness and long-term durability. Our goal is to explore, through both numerical and analytical methods, the sound and heat transfer properties of insulating layers that can fulfill these requirements. Specifically, we aim to identify insulating materials that are capable of efficiently managing both thermal and acoustic insulation within a single layer. This approach could streamline construction processes and reduce material costs while ensuring that the insulation performs effectively in both areas.

SUMMARY AND FUTURE PLAN

This investigation centers concerning the contemporary landscape of thermal insulation solutions employed in the construction field, encompassing both traditional and innovative materials. By adhering to international standards, various materials can be utilized to enhance thermal efficiency and reduce noise transmission in multi-layered building walls.

These materials offer effective solutions for maintaining stable indoor temperatures and minimizing sound pollution. As part of this research, Additionally, this study presents a comprehensive design strategy for enhancing the thermal and acoustic insulation properties of structures with multiple layers, which will serve as the foundation for future studies aimed at improving insulation strategies in construction.

Our future plan involves a detailed numerical and analytical investigation of thermal and acoustic insulation in walls with various layered structures. Through this research, we aim to assess the performance of different insulation configurations to optimize energy efficiency and soundproofing.

Based on the findings, we intend to offer practical recommendations to designers on how to develop new building structures that strike a balance between economic efficiency and environmental sustainability. These insights will contribute to creating more energy-conscious and cost-effective construction solutions for future projects.

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