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THERMO-PHYSICAL PERFORMANCE ENHANCEMENT OF WALL MATERIALS USING ADVANCED ADDITIVES AND COMPOSITE SYSTEMS

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Abstract This paper presents a concise analysis of modern approaches for improving the thermal conductivity and thermal resistance of wall-building materials, including concrete, bricks, blocks, and composite systems. While low thermal conductivity is generally preferred for insulation purposes, certain engineering applications such as radiant heating systems, thermal energy storage, and PCM-based structures require enhanced heat transfer properties. At the same time, thermal resistance remains a critical parameter for ensuring fire safety and structural stability at elevated temperatures. The study examines the influence of advanced additives such as silicon carbide (SiC), carbon nanotubes (CNT), expanded graphite (EG), magnetite (Fe_3O_4), vermiculite, and basalt fibers. The results indicate that conductive additives significantly increase thermal conductivity, while mineral fillers and fiber reinforcements improve thermal resistance up to 300–1000°C depending on the composition.

Keywords: wall materials, thermal conductivity, thermal resistance, composites, nano-additives.

1. Introduction Improving the thermo-physical properties of construction materials is essential for achieving energy-efficient and durable buildings. Wall materials act as the primary barrier for heat exchange between indoor and outdoor environments, directly influencing energy consumption and thermal comfort.

Thermal conductivity (λ, W/m·K) defines the ability of a material to transfer heat. Although in conventional insulation systems lower λ values are desirable, in applications such as underfloor heating, thermal storage walls, and PCM-integrated systems, higher thermal conductivity is beneficial for efficient heat distribution.

According to Fourier's law:

q=−λ∇Tq = -\lambda \nabla Tq=−λ∇T

an increase in λ results in higher heat flux, enhancing thermal performance in specific applications.

Thermal resistance refers to the ability of a material to withstand high temperatures while maintaining its structural integrity. It is particularly important for fire-resistant construction and industrial environments.

2. Materials and Methods Overview

Modern strategies for improving thermal and thermo-physical properties include:

- Incorporation of high thermal conductivity additives
- Use of porous and lightweight mineral fillers
- Application of nanomaterials such as CNT and graphene
- Development of hybrid composite systems
- Utilization of locally available raw materials

Additives such as SiC, CNT, and expanded graphite (EG) form conductive networks that enhance heat transfer, while mineral fillers like vermiculite and basalt improve thermal stability.

3. Results and Discussion

The influence of various additives on both thermal conductivity and thermal resistance is summarized in Table 1.

Combined Effect of Additives on Thermal Conductivity and Thermal Resistance of Wall Materials

Table 1

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Material Composition	Additive Type	Thermal Conductivity λ (W/m·K)	Improvement Factor	Temperature Resistance (°C)
Conventional concrete	None	0.8 – 1.0	1.0	~300
Concrete + SiC	Silicon carbide (10–25%)	1.3 – 2.3	1.5 – 2.5	~400–600
Concrete + CNT	Carbon nanotubes (0.5–2%)	1.1 – 1.9	1.3 – 2.0	~400–600
PCM + Expanded Graphite	EG (5–10%)	0.2 → 6.0–7.0	6 – 8	~300–400
Cement + Magnetite	Fe_3O_4 (10–20%)	1.0 – 1.6	1.2 – 1.6	~400
Vermiculite-based composite	Vermiculite (20–40%)	Low–moderate	—	350–400
Basalt fiber composite	Basalt fibers	Moderate	—	400–600
Geopolymer composite	Alkali + slag	Moderate	—	800–1000

Silicon carbide and carbon nanotubes significantly enhance thermal conductivity by forming continuous heat-conducting pathways. Expanded graphite is particularly effective in PCM-based systems, enabling both heat storage and transfer. On the other hand, vermiculite, basalt fibers, and geopolymer matrices improve thermal resistance due to their mineral stability and structural integrity at elevated temperatures.

4. Discussion

The combined use of conductive and insulating additives allows tailoring material properties for specific applications. Hybrid systems such as CNT + vermiculite or SiC + basalt fibers provide a balance between thermal conductivity and thermal resistance.

However, several challenges remain, including:

- Increased density associated with conductive additives
- Dispersion difficulties of nanomaterials
- Higher cost of advanced additives
- Need for optimization of composite ratios

The use of locally available mineral resources such as vermiculite and basalt, along with industrial by-products, offers a cost-effective and sustainable approach.

5. Conclusion

The study shows that the thermo-physical performance of wall-building materials can be significantly improved through the incorporation of advanced additives and composite design strategies. Conductive materials such as SiC, CNT, and expanded graphite enhance thermal conductivity, while mineral fillers and geopolymer systems improve thermal resistance.

Hybrid composite systems provide the most effective solution by combining both properties in a single material. Future research should focus on optimizing compositions, improving nanomaterial dispersion, and expanding the use of local raw materials to develop efficient and sustainable construction materials.

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