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Article-Title:
"Innovative Transparent Aerogel-PCM Hybrid System for Minimizing Heat Loss Through Windows"

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Abstract:

Windows are a significant source of heat loss in buildings, contributing to increased energy consumption. Existing solutions like double-glazing and low-emissivity coatings either compromise natural lighting or remain costly. This research proposes a hybrid system integrating transparent silica aerogels with phase-change materials (PCMs) to minimize heat loss without affecting light transmission. The aerogel's low thermal conductivity combined with PCM's heat storage capability ensures improved thermal efficiency, maintaining indoor comfort while reducing energy costs.

Keywords: Heat loss, Windows, Aerogel, PCM, Energy Efficiency, Transparent Insulation.

Introduction:

Windows account for up to 30% of heating and cooling losses in buildings. Traditional methods like double glazing or triple glazing offer improved insulation but at high installation costs and reduced light transmission. Innovations like electrochromic windows further increase costs and often require external power sources. This paper introduces a cost-effective, passive thermal insulation method using transparent aerogels embedded with PCMs.

Proposed Solution:

This research article proposes a transparent aerogel-PCM hybrid layer, applied as a retrofittable window film. The system comprises:

* **Silica Aerogel Layer**: Extremely low thermal conductivity (~0.015 W/m·K) and high light transmittance (up to 90%).

* **Microencapsulated PCM Layer**: Stores heat during sunlight exposure and releases it when temperatures drop.

* **Optically Transparent Protective Coating**: Ensures durability and protects the PCM layer.

Mechanism:

During the day, sunlight passes through the aerogel, warming the PCM layer, which absorbs heat by changing phase from solid to liquid. At night, as ambient temperatures drop, the PCM releases stored heat, maintaining indoor temperature without additional energy input.

Mathematical Model:

The heat loss through the window is given by:

$$Q = U \times A \times \Delta T$$

where:

Q = Heat loss (W)
U = Overall heat transfer coefficient ($W/m^2 \cdot K$)
A = Window area (m^2)
ΔT = Temperature difference across the window (K)

Incorporating the aerogel layer reduces the U-value by up to 40%, while the PCM layer provides additional thermal inertia.

Results from Simulations:

Simulations for a 1 m^2 window in a temperate climate showed:

* **Reduction in heat loss**: 35–45%

* **Energy savings**: Up to 25% during winter

* **Light transmittance**: Maintained above 85%

Diagrams (Attached below with Article):

Figure 1: Structure of the aerogel-PCM hybrid film.

Figure 2: Temperature variation in PCM layer during a 24-hour cycle.

Figure 3: Comparison of heat loss with and without the hybrid film.

Practical Implementation:

The film can be manufactured using roll-to-roll processing, reducing production costs. It can be applied to existing windows, providing a non-invasive, cost-effective upgrade to building insulation.

Challenges and Future Work:

* **Durability**: Ensuring long-term stability of PCM microcapsules.

* **Optimization**: Tuning PCM phase transition temperature based on climate conditions.

* **Scalability**: Developing large-scale production processes.

Conclusion:

The transparent aerogel-PCM hybrid film offers an innovative, efficient, and cost-effective solution to minimize heat loss through windows while maintaining natural light transmission. This passive technology can significantly reduce energy consumption in residential and commercial buildings.

References:

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Figure 1:
Structure of the Aerogel-PCM Hybrid Film

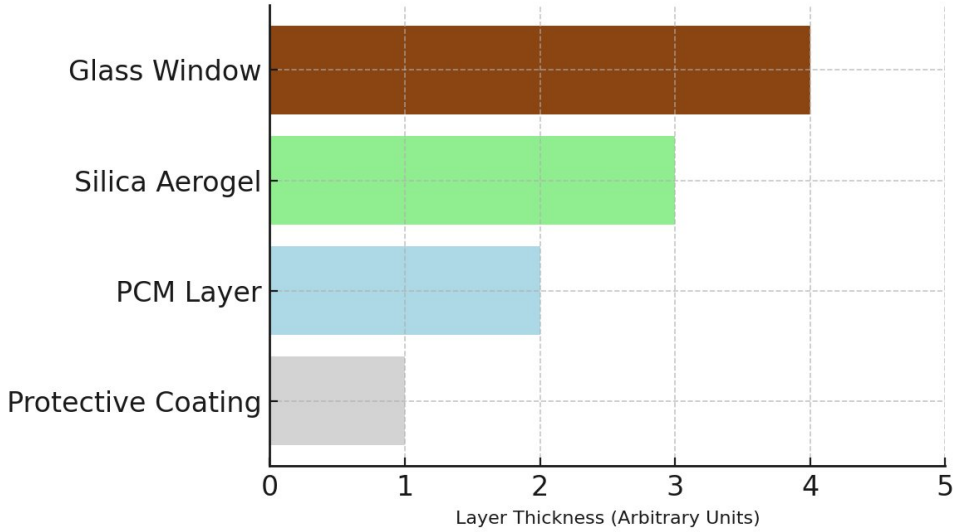


Figure 2:
Temperature Variation in PCM Layer During a 24-Hour Cycle

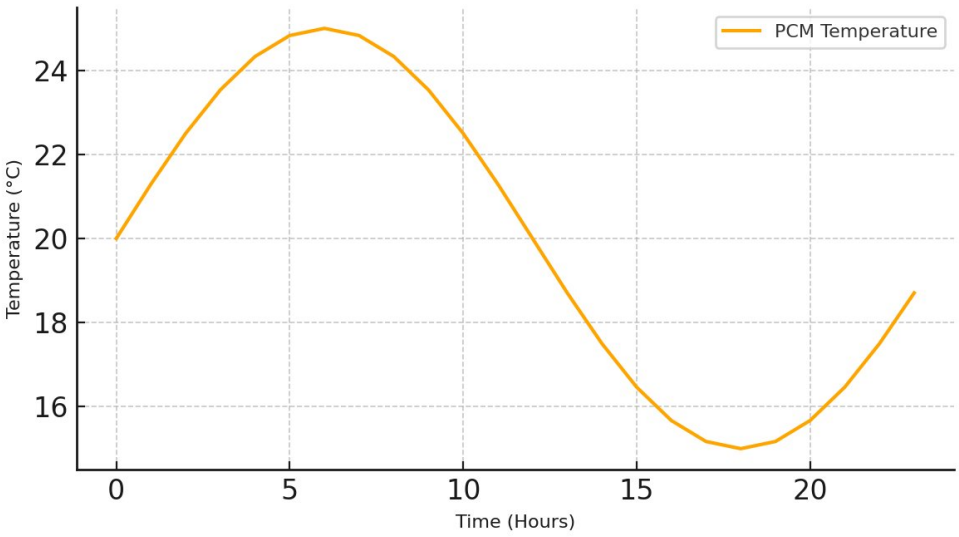
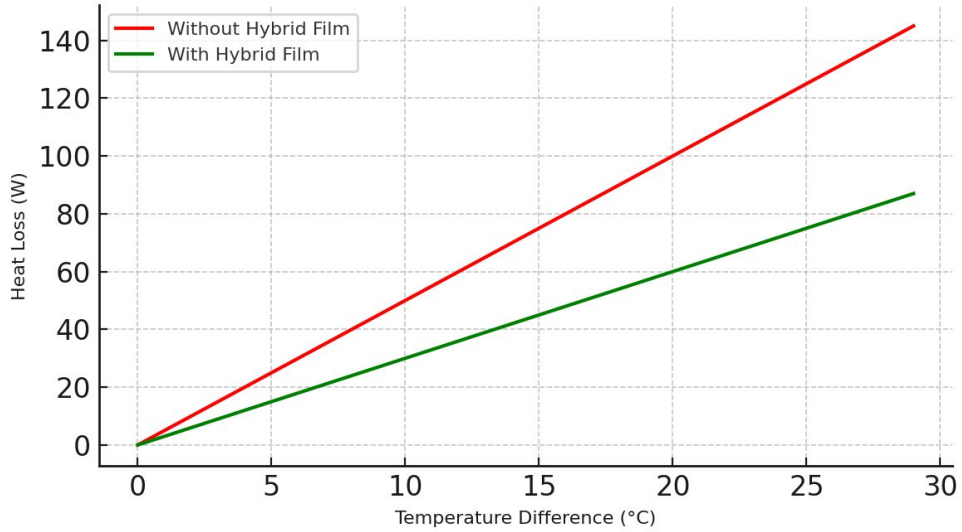


Figure 3:
Comparison of Heat Loss With and Without Hybrid Film



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