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Abstract Title: Inverse Design of Dynamic Low-Emissivity Solar-Control Films for Year-Round Window Energy Efficiency

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Introduction

Windows are among the weakest components of building envelopes, accounting for approximately 25% of total energy loss from buildings[1]. Conventional solar control films effectively reduce summer heat gain but limit beneficial winter heat gain, hindering year-round energy efficiency.

Objective

In this work, we present an inverse design methodology for a multilayer dynamic solar-control film that optimizes window performance year-round.

Methods

A hybrid optimization framework, integrating genetic algorithm2 and pattern search3, is used in conjunction with the transfer matrix method to determine the optimal material sequence and thicknesses.

Results

The resulting IHO/TiO_2/VO_2/TiO_2/MgF_2 multilayer structure achieves high luminous transmittance (> 0.6), low mid-infrared emissivity (~ 0.18), and a solar modulation ability of 0.11. The film dynamically adjusts solar heat gain based on ambient temperature, reducing heat loss in winter and cooling loads in summer. A validated one-dimensional (1D) coupled radiative-conductive model quantifies heat flux through windows in urban environments, confirming the inverse relationship between internal emissivity and energy loss. Energy analysis indicates that applying this film to windows can reduce energy consumption by 9.69% compared to uncoated single glazing windows and 1.15% compared to commercial low-E single glazing windows in medium office buildings across diverse climates. This study demonstrates a powerful inverse approach for tailoring multifunctional coatings, providing a scalable solution for building energy savings.

Significance

Our inverse design approach bridges materials optimization and building-scale energy performance, offering a cost-effective and passive strategy for smart building envelopes.

Acknowledgements

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References

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