

New Perspective on Designing Climate-responsive Latent Energy Storage Systems

Osman, O., Yehya, A., Maalouf, E.

Department of Mechanical Engineering

American University of Beirut, Lebanon

This study addresses a critical challenge in energy-efficient building design and the urgent need to reduce energy consumption and carbon emissions by proposing a climate-responsive phase-change materials (PCM) system. By dynamically optimizing the phase transition behavior of PCMs in response to external weather conditions, the system directly supports Sustainable Development Goal (SDG) 7, particularly the target to improve energy efficiency, and aligns with SDG 13 by enabling adaptive thermal management, reducing energy demand, and contributing to climate action. The optimal melting temperatures (T_m) and phase-transition temperature ranges (ΔT_{PCM}) are selected to maximize PCM effectiveness under varying climatic conditions. Through simulations across diverse weather profiles, the study evaluates three optimization strategies: (1) achieving continuous PCM activity with minimal ΔT_{PCM} , (2) minimizing total thermal load (Q_{Load}), and (3) maintaining stable indoor wall temperatures. Results reveal that Hypothesis 2 most effectively reduces Q_{Load} , offering the greatest potential for energy savings, while Hypothesis 3 prioritizes thermal comfort by ensuring temperature stability. Hypothesis 1 provides a balanced approach, sustaining consistent PCM activity with moderate temperature variations. Additionally, dynamically adjusting T_m over time while keeping ΔT_{PCM} constant significantly enhances PCM performance, demonstrating the value of adaptive control strategies. This research not only offers systematic methodologies for PCM optimization tailored to specific climatic conditions but also introduces a novel mechanism for temporal control of phase transitions. By supporting efficient energy use and lower carbon footprints in buildings, this work provides actionable insights for advancing energy storage technologies aligned with global sustainability and emissions reduction goals.