

Controlled ventilated phase change material façades for climate-responsive buildings

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Enhancing the thermal performance of phase change materials (PCM) has become an essential strategy for improving building envelope efficiency; however, effectively managing the charging and discharging cycles of PCM remains critical to maximizing their benefits. This study explores a promising novel solution, which is the use of controlled ventilation within PCM-enhanced wall assemblies (VPCM). Results demonstrated that the VPCM system consistently maintained inner surface temperatures between 23 and 24 °C, significantly outperforming conventional wall designs, which fluctuated from 23.5 to 26.5 °C. Cooling efficiency was notably improved, with gains of up to 75 % compared to traditional PCM-based walls. A detailed parametric analysis further highlighted key factors such as inlet air temperature, airflow velocity, pipe dimension, PCM melting temperature, PCM thickness, and PCM positioning that strongly influence overall system performance. Specifically, reducing inlet air temperature from 24 °C to 18 °C increased cooling efficiency from approximately 50 % to 77 %, and optimal pipe sizing boosted total efficiency from 18 % to 63 %. Alternative wall configurations, including dual inlet-outlet setups and pre-insulation placement, further increased total efficiency to 84 %, though these enhancements were accompanied by a cooling efficiency decline from 76 % to 63 %. Overall, the results underscore the substantial benefits of actively ventilated PCM systems, emphasizing the critical role of controlled ventilation in optimizing thermal comfort and energy performance within building envelopes. This work provides a scalable pathway toward climate-responsive and low-energy building envelopes, offering practical design strategies that can be integrated into sustainable construction and retrofit practices.