

Extended Abstract
(For PhD open seminar)

**Experimental and Numerical Study on Performance
Optimization and Scalability of Salt Hydrate-Based Phase
Change Materials for Thermal Energy Storage in Buildings**



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Abstract

The growing global energy demand and the need for sustainable building cooling solutions have intensified interest in thermal energy storage (TES) systems using phase change materials (PCMs). This study presents an experimental and numerical investigation on the performance optimization and scalability of sodium sulfate decahydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$)-based PCMs for building applications. A polyurethane–PCM (PU-PCM) composite, incorporating Na_2SO_4 aqueous solution, Laponite® Gel, and borax, was developed to mitigate supercooling, phase separation, and thermal instability. The composite was characterized by differential scanning calorimetry (DSC) to determine latent heat, transition temperature, and cycling stability.

Experimental and COMSOL Multiphysics simulations on 600 mL to 5 L thermal storage models evaluated heat transfer, phase change kinetics, and system performance across scales. The results indicated stable operation with minimal thermal stratification and effective heat storage–release behavior. Optimized PU-PCM composites were integrated into building wall assemblies to assess passive cooling performance. Both experimental cubicle tests and numerical building energy simulations confirmed reductions in peak indoor temperature and cooling load under hot climatic conditions. Overall, the study demonstrates that $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ -based PU-PCM composites offer high latent heat capacity, scalability, and energy-saving potential for sustainable building cooling.

Chapter 1: Introduction

This chapter introduces the need for efficient thermal energy storage (TES) systems in the context of rising global energy demand and shift toward sustainable energy solutions. It emphasizes the role of phase change materials (PCMs) in storing and releasing latent heat for building cooling, load shifting, and renewable energy integration. The chapter establishes sodium sulfate decahydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) as a promising salt hydrate PCM due to its high latent heat capacity, cost-effectiveness, and wide availability. However, challenges such as supercooling, phase separation, and thermal cycling instability are highlighted.

Chapter 2: Literature Review

This chapter reviews research on phase change materials (PCMs), focusing on salt hydrates in comparison to organic and other inorganic systems. It discusses the thermal properties and challenges of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, including phase segregation, and examines stabilization strategies such as thickeners, nucleating agents, and polymer composites. TES configurations from lab-scale to building applications and numerical modeling methods are outlined, while key gaps are identified in large-scale evaluation and realistic building integration. The review highlights the novelty of this thesis in linking material development, scalability, and practical application.

Chapter 3: Experimental Evaluation of Thermal Performance of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ Salt Hydrate-Based Phase Change Materials

This chapter presents the experimental and numerical investigation of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ -based phase change materials (PCMs). A polyurethane–PCM (PU-PCM) composite was developed,

incorporating a Na_2SO_4 aqueous solution, polyurethane foam, and LAPONITE® Gel as a stabilizing agent. A 600 mL physical model was fabricated to evaluate the cooling and heating cycles, and the experimental data were used to construct and validate a computational model in COMSOL Multiphysics. Differential scanning calorimetry (DSC), was carried out to determine the phase transition temperature, latent heat storage capacity, and long-term stability. The findings demonstrate that the PU-PCM composite can be effectively integrated into building wall assemblies, offering valuable insights into its energy-saving potential, thermal performance, and contribution to sustainable building applications.

Chapter 4: Performance Analysis of a Multi-Scale Scaled Thermal Energy Storage System with Varying Volumes

This chapter presents the scalability analysis of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ -based thermal energy storage (TES) systems using polyurethane–PCM (PU-PCM) composites. Physical model ranging from 600 mL to 5 L were developed to evaluate thermal charging and discharging performance, with experimental results validated through COMSOL Multiphysics simulations capturing transient heat transfer, phase change kinetics, and system efficiency. The PU-PCM composite, prepared with Na_2SO_4 aqueous solution, polyurethane foam, Laponite® Gel, and borax, demonstrated improved stability by mitigating supercooling and phase segregation. Differential scanning calorimetry confirmed thermal stability across repeated cycles. Scale-up analysis identified key challenges such as heat transfer limitations, non-uniform melting/solidification, and thermal stratification, while simulations determined the optimum composite thickness for 2 L and 5 L reactors. The influence of phase change temperature range (ΔT) and latent heat (L) on temperature difference profiles was also examined. Results highlight that the PU-PCM system maintains effective thermal management across scales and holds strong potential for integration into building and industrial applications to enhance energy efficiency and thermal comfort.

Chapter 5: Performance Evaluation and Integration of Salt Hydrate-Based PCMs with Wall Materials for Cooling of Buildings (Application)

This chapter applies the optimized PCM formulations to building envelope integration for passive cooling. Wall panels embedded with $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ -based PCM composites are fabricated and tested under simulated climatic conditions. Both experimental cubicle tests and numerical building energy simulations are conducted to evaluate the reduction in indoor peak temperatures, delay in heat transfer through walls, and overall thermal comfort improvement. Results show that PCM-integrated walls can significantly reduce cooling loads and improve energy efficiency in buildings located in hot climates. A parametric study investigates the effect of wall thickness, PCM loading fraction, and ambient conditions. The findings demonstrate the practical applicability of salt hydrate-based PCMs in real-world building cooling, thereby linking laboratory-scale studies to large-scale energy-saving applications.

Chapter 6: Conclusions and Future Work

This chapter summarizes the experimental findings and outlines future research opportunities. The study concludes that $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ -based PCMs exhibit high latent heat, but require stabilization using additives or eutectic formulations. Scale-up experiments revealed thermal

inhomogeneities, highlighting the need for improved heat exchanger designs. Building integration studies confirmed their energy-saving potential, recognizing salt hydrates as effective materials for sustainable cooling. Future work will focus on the development of micro-encapsulated and hybrid salt hydrate-organic PCMs, long-term field evaluation, and improved thermal and mechanical stability. Overall, this dissertation combines material development, scalability, and practical application, providing a robust framework for advancing thermal energy storage technologies.

Research Publication:

Journals Papers

1. Published paper “*Disodium Phosphate Dodecahydrate Salt Hydrate-Based Approach for Thermal Energy Storage Systems*”, **Journal of Technical Education Science**, Issue 74, Pages 1-7, 2023. <https://doi.org/10.54644/jte.74.2023.1330>.
2. Published paper “*Performance analysis of a multi-scale thermal energy storage system with varying volumes using polyurethane-encapsulated sodium sulphate decahydrate for building applications*” in **Energy and Building** (IF=7.1). <https://doi.org/10.1016/j.enbuild.2025.116390>.
3. Published paper “*Na₂SO₄·10H₂O Salt hydrates-based Phase Change Materials for Thermal energy storage: A scale-up approach*” in **ChemistrySelect** (IF=2). <https://doi.org/10.1002/slct.202504616>.
4. Submitted manuscript on the title “**Performance Evaluation and Integration of Salt Hydrate-Based PCMs with Wall Materials for Passive Cooling of Buildings**” in **Journal of Building Engineering** (IF=7.4). (Under Review).
5. Manuscript under preparation on the title “*Effect of a Thickening Agent on Eutectic Salt Hydrate-Based Phase Change Materials (Na₂SO₄·10H₂O and MgSO₄·7H₂O) for Thermal Energy Storage*”.

Conferences

1. Oral presented my work on “*Disodium Phosphate Dodecahydrate Salt Hydrate-Based Approach for Thermal Energy Storage Systems*” at the 6th International Conference on Green Technology and Sustainable Development held at **Vietnam** in online mode.