

sensitivity analysis of the impact of system and material properties such as latent heat, PCM thickness, transition temperature and range, density, thermal conductivity, and DIMS switch ratio on load shifting. We examine a novel wall design, comprising of a layer of PCM between two layers of DIMS. The PCM-DIMS-integrated wall provides significantly higher energy saving potential than the DIMS-only integrated wall or the PCM-only integrated wall in all climates and wall orientations analyzed in this study. Depending on the climate, the PCM-DIMS-integrated wall could provide 15% to 72% reduction in annual heat gain and 7% to 38% reduction in annual heat loss. We also show that optimized properties can result in a 70% reduction the wall related heat gain during peak hours with only a minor increase in total-daily heat gain. The analysis presented in this study serves to encourage the development of scalable dynamic insulations combined with thermal energy storage systems for buildings.

11:00 AM EN11.10.05

Salt Hydrate Eutectics: Tailored Design of Equilibria, Reversibility, and Stability in Complex Phase Change Material Systems Sophia Ahmed, Anirban Chakraborty, Denali Ibbotson, Sarah Lak, Kartik Rajagopalan, Achutha Tamraparni, Charles Culp, Jonathan Felts, Emily Pentzer, Svetlana A. Sukhishvili, Choongho Yu and Patrick Shamberger; Texas A&M University, United States

A critical aspect of thermal energy storage systems for the built environment is the development of thermal energy storage media that will reversibly store and discharge thermal energy repeatedly within a defined temperature range. For example, to optimize efficiency, some environmental climate control and air conditioning systems require thermal energy storage between 5 to 25 °C. To address this need, eutectic salt hydrates have been identified as promising candidate systems that will allow for the tailoring of bespoke low cost thermal energy storage systems, due to the large number of potential eutectics distributed across a broad temperature range. However, these phase change materials are associated with a number of known limitations (undercooling, phase segregation, low heat transfer rate) which limit their practical use in energy storage systems. Individual strategies have been identified to overcome many of these challenges. For example, nucleation agents are utilized to decrease undercooling, while thickeners or polymers which form salogels are utilized to limit phase segregation. However, the interaction between these different strategies has not been systematically investigated.

Here, we present recent efforts to expand the palette of low cost high energy storage density salt hydrate eutectics developed for building thermal energy storage applications. We compare theoretical predictions against validated eutectic compositions and properties, and highlight some of the advantages and challenges associated with these materials. We specifically address efforts to overcome the known technical limitations of salt hydrates, and their relevance to salt hydrate eutectic systems, including 1) the introduction of specific nucleation agents to promote reversibility in salt hydrate systems, 2) the introduction of polymer salogels to stabilize systems from phase segregating, 3) the introduction of expanded graphite networks to improve heat transfer through these systems, 4) the use of encapsulants to encase PCM particles, and 5) the use of scaled testbeds to evaluate stability of systems under use conditions. Addressing all of these challenges results in a complex multi-phase material system which introduces additional interactions. Here, we will focus on both individual strategies and the resulting interactions, using development of zinc nitrate hexahydrate-based eutectic systems as an example model system. We will demonstrate successful implementation of tailored low-cost PCM systems, and will emphasize ongoing challenges in this area.

11:15 AM EN11.10.06

Thermal Conductivity of a Novel Salt-Hydrogel Complex as a Phase Change Material for Building Thermal Management Daniel Hsieh¹, Youngmun Lee¹, Mayur S. Prabhudesai¹, Sung Bum Kang¹, Ho Chan Chang¹, Wuchen Fu¹, Jay M. Taylor¹, Paul V. Braun^{1,2}, Nenad Miljkovic^{1,1,2} and Sanjiv Sinha¹; ¹University of Illinois at Urbana-Champaign, United States; ²Materials Research Laboratory, United States

Use of electricity for space heating, ventilation and air conditioning in buildings may be better managed through temporary energy storage. Compared with electrochemical storage, the leveled cost of thermal energy storage systems can be lower depending on geographical location and thermophysical properties [1]. In any phase change material (PCM), the rate of absorption and release of thermal energy increases with higher thermal conductivity [2]. However, leading PCMs like paraffin waxes have thermal conductivities on the order of 0.1 W/mK. Glauber's salt, a salt hydrate, possesses a relatively high thermal conductivity but suffers from supercooling and phase segregation. Research has shown that polymer-based composites with salt hydrates can prevent phase segregation and limit supercooling over hundreds of cycles [3] though the thermal conductivity of the composite may be reduced leading to low energy storage rates. Here, we report thermal conductivity measurements on polymer hydrogels which are stable in solutions of Glauber's salt. To measure thermal conductivity of soft gels, we use a 3-omega method [4] where heat flows bidirectionally through a substrate below and through a gel placed on top. This suits measurements of both gels and liquids unlike transient plane heat source or transient hot wire methods. We report measurements of thermal conductivity of salt-hydrogel complexes as a function of temperature, cross-linking and salt concentration. In addition, we present modeling of thermal conductivity of sodium sulfate solutions with available theories. We finally employ polarized optical microscopy to observe inside the transparent hydrogel networks, showing that precipitating crystals may influence thermal conductivity measurements for high salt concentrations. Our thermal conductivity results combined with enthalpy of phase change, mass density and specific heat are essential to accurately design thermal storage systems for energy-efficient buildings.

11:30 AM EN11.10.07

Role of Ba-containing Compounds in the Nucleation of Solid Calcium Chloride Hexahydrate Denali Ibbotson, Sophia Ahmed and Patrick Shamberger; Texas A&M University, United States

Currently, heating and cooling of commercial and residential buildings is one of the leading consumers of energy in the country, accounting for 40% of building energy demand and about 75% of all electricity use. One method used to increase HVAC system efficiency and to allow for more efficient load displacement, is to incorporate phase change materials (PCMs) into thermal energy storage systems, as PCMs are able to passively store and release heat, allowing for a pathway to displace peak energy load for buildings to better align with available excess energy generation. However, robust and economical phase change materials that are tailorable to a specific desired energy storage temperature are needed to accomplish this task. Salt hydrates represent one class of PCMs of interest due to their high volumetric energy densities, low cost, and the ability to tailor the energy storage temperature through the design of custom salt hydrate eutectics. However, they can also experience undercooling, a nucleation-limited phenomena which results in the existence of a metastable liquid below the melting point. This phenomena can lead to undesired issues, including incongruent melting and phase segregation. To induce nucleation, and thereby improve the reversibility of the thermal energy storage process, nucleation agents can be added to a PCM system to induce nucleation, and thereby suppress the formation of metastable phases. In many cases, the underlying mechanisms governing which nucleation agents introduce potent nucleation sites and which do not, are not well understood.

In this study, we investigated the dependence of undercooling in calcium chloride hexahydrate ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$), a low-cost salt hydrate that melts at 29°C, on the crystal structure, chemistry, and the solubility of a family of Ba-based compounds. We utilized calorimetric techniques to measure undercooling in small quantities of calcium chloride hexahydrate with different nucleation agents, and differing weight percentages of the nucleation agents. We observed in several cases that the addition of barium-based nucleation agents resulted in at least a 10°C reduction in the undercooling, enabling practical utilization of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$. However, some variability existed between different compounds, as nucleation agents such as barium carbonate and barium hydroxide were observed to be effective nucleators and resulted in a larger reduction of the undercooling, while nucleation agents such as barium iodide or barium chloride dihydrate had minimal effects on the reduction of the undercooling. Additionally, we observed that the presence of insoluble particles of the nucleation agents aided in reducing the undercooling of the system and also resulted in more consistent melting behavior. The structure of the nucleation