Keepin' it Cool (or Hot)

This challenge focuses on developing an innovative solution for thermal energy storage for buildings to optimize energy utilization, enhance sustainability, and increase resilience. The solutions could involve (but are not limited to) integration of materials, systems, and controls for the storage and release of energy.

Background

Climate change is an immediate global concern, evident from the melting ice caps, sea-level rise, increasing frequency of extreme weather events, and shifts in ecosystems and wildlife patterns.[1] This change is driven by the excessive release of greenhouse gases into the atmosphere, particularly from burning fossil fuels, which absorb most of the outgoing infrared radiation (i.e., heat) from Earth's surface and emit in the atmosphere and contribute to global warming.[2] To combat climate change, it is crucial to reduce fossil fuel usage and transition to clean, renewable energy sources.[3] Electrification and decarbonization aim to replace fossil fuel-based systems for power generation, heating, and transportation with electric alternatives powered by renewable energy, such as solar, wind, and hydro.[4] However, the intermittent nature of renewable energy poses challenges for the electric power grid in maintaining a stable supply and demand balance.[5] Energy storage technologies balance energy supply and demand by enabling storage of surplus energy during periods with high renewable generation, which can be dispatched later during times with low renewable generation, while also reducing peak demand through load shifting to off-peak periods.[6] Energy storage systems can also enhance resilience by providing a backup energy source during emergencies for essential services like heating, cooling, and powering critical infrastructure.[7]

Thermal energy storage (TES) technologies store energy in the form of heat or cooling for later use. Based on the application or purpose, TES can be categorized as building-scale, district-level, or grid-scale TES. Building-scale TES involves the use of storage systems, such as water tanks or phase change materials, to store and release thermal energy within individual buildings, providing energy management and load-shifting capabilities for heating, cooling, and other thermal applications.[8] District-level TES involves the storage and distribution of thermal energy for heating and cooling purposes across multiple buildings or facilities.[9] Grid-scale TES technologies are integrated into the electrical grid infrastructure for electricity generation, typically at the utility or regional level.[10]

Depending on the mechanism used to store and release thermal energy, building-scale TES systems can be categorized as sensible heat, latent heat, and thermochemical storage. Sensible heat storage involves storing and releasing energy by changing the temperature of the storage medium, such as water or rocks. Latent heat storage utilizes phase change materials that absorb and release heat during the transition between solid and liquid states. Thermochemical storage involves the storage and release of heat via chemical bonds in reversible chemical reactions.[6,11]

The use of TES in buildings has a long history. Ancient civilizations utilized natural sources of heat and cold, including sunlight, ambient air, the sky and ground, and the evaporation of water, and stored energy using rocks, water, and the ground, as well as in building mass and phase change materials. Early TES systems in buildings included water-based storage tanks and ice storage systems, where storage of excess energy in the form of heated or chilled water or ice could be utilized later for heating, cooling, or other energy needs. [11,12]

Over time, technological advancements led to the development of more sophisticated TES solutions for buildings.[13] Advanced materials, such as high-performance phase change materials and high-density ceramics, offer enhanced energy storage capacities and more precise control over the charging and discharging processes. These materials can be charged and discharged at different time scales.[14] The integration of TES systems with renewable energy sources, such as solar and wind power, allows for the efficient storage of excess energy during periods of high renewable generation and its utilization during times of low generation or high demand.[15] Advanced control and monitoring technologies enable better management and optimization of TES operations. This includes real-time monitoring, predictive modeling, and intelligent control algorithms that optimize energy storage and release based on dynamic conditions and demand patterns.[16] Hybrid TES systems combine different storage technologies and leverage their strengths to achieve optimal performance in terms of enhanced flexibility, improved efficiency, and expanded operating ranges.[17]

TES has the potential to address energy challenges faced by communities that need affordable and reliable energy sources. TES can provide affordable, efficient, sustainable, and reliable solutions for heating, cooling, and power generation.[18] To fully realize the benefits of TES in a community, it is crucial to encourage community engagement, provide education, and support policies that enable successful implementation. Collaboration between government entities, community organizations, and industry stakeholders can foster innovative approaches and funding mechanisms that address the specific needs and challenges, ultimately leading to improved energy access, affordability, and sustainability.[19]

The Challenge

This challenge asks student teams to develop an innovative solution for thermal energy storage for buildings to optimize energy utilization, enhance sustainability, and increase resilience. Furthermore, the cost for implementing TES should be affordable or recoverable from the benefits provided by the TES. The solutions could involve (but are not limited to) integration of materials, systems, and controls for the storage and release of energy. Teams should first develop a focused problem statement for a specific stakeholder group and then develop a technical solution or process.

Suggestions for student teams include (but are not limited to) the following:

- Create innovative building type and climate specific design strategies and practices aimed at integrating TES in buildings.
- Develop TES solutions utilizing building materials, structure, and/or building's heating, cooling or water heating systems, and potentially, recovering waste heat in buildings.
- Present solutions with advanced controls, or innovative business models, for utilizing TES that can maximize the benefits of TES (e.g., reducing energy cost, shedding electric demand during peak periods, and/or utilizing more available renewable power) with acceptable cost to consumers.

Student submissions should:

- Describe the scope and context of the chosen problem.
- Identify affected stakeholders, making sure to research stakeholder backgrounds and understand the stakeholders' needs, especially regarding the problem.

- Develop a technical solution to the chosen problem for the targeted stakeholder group. The solution may also include policy and economic solutions, codes and standards, or other aspects critical to identified stakeholder barriers. However, a technical solution must be proposed.
- Discuss appropriate and expected impacts and benefits of the proposed solution. This should include an analysis of TES performance, expected benefits (e.g., electricity demand reduction, energy cost savings, and carbon emission reduction), a cost/benefit analysis, and a market adoption analysis.
- Discuss limitations and challenges of the proposed solution (e.g., technical, policy-related, code-compliance, etc.).
- Develop a commercialization plan that describes how the team envisions bringing its idea to scale in the market, outreach mechanisms, stakeholder engagement, and other relevant details.

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