Development of Thermal Energy Storage Measure by the Using Thermodynamic Analysis

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Abstract: The comparison between compressed air energy storage, batteries, and thermal energy storage is crucial in understanding their respective roles in meeting heating and cooling demands in an energy-efficient and cost-effective manner. This study aims to quantify the impact of Thermal Energy Storage (TES) measures on a building's heating and cooling demands, particularly focusing on system efficiency and boiler cycling. Through thermodynamic analysis and modeling of TES systems with varying storage capacities, this research aims to showcase the potential of TES in optimizing peak thermal loads, consequently reducing the required boiler or chiller capacity and enhancing overall thermal system efficiency.

Keywords: Thermodynamic Analysis, Thermal Energy, heat transfer fluid, DSM, MECS.

1. INTRODUCTION

The pervasive use of heating, cooling, and HVAC systems across diverse sectors highlights the significance of advancing energy efficiency in this domain. Thermal Energy Storage (TES) has emerged as a promising technology in this context, aiming to enhance energy efficiency. For instance, in 2012, approximately 20% of the energy consumption in commercial buildings, equating to around 1,650 million MMBtus, was attributed to space heating alone (CBECS E1)[3]. According to a Manufacturing Energy Consumption Survey (MECS) in 2014, within the American manufacturing sector, 22% of the total fuel consumption was allocated for heating purposes, while 15% was utilized for cooling and facility HVAC (MECS 5.1) [1].

The demand for heating, cooling, or power is rarely consistent and can fluctuate over time. During periods of lower demand, excess generation capacity can be employed to charge Thermal Energy Storage, effectively increasing the generation capacity during high-demand periods. This approach enables a smaller production component to be utilized or capacity to be added without acquiring additional units, resulting in a higher load factor for the component.

A noteworthy advantage of a Thermal Energy Storage system lies in its capacity to reduce electric costs by utilizing off-peak electricity to generate and store energy for daytime cooling. Thermal Energy Storage systems have proven successful in various settings, including offices, schools, hospitals, airports, and universities across many countries, effectively shifting energy consumption from peak electricity rate periods to off-peak ones. This advantage is compounded by the reduction in demand charges. While energy efficiency is a commonly used metric to evaluate Thermal Energy Storage performance, it is inadequate in assessing the system comprehensively, as it overlooks factors such as performance proximity to ideality, storage duration, and environmental temperatures during thermal energy input and retrieval.

Energy analysis emerges as a comprehensive and insightful alternative for assessing and comparing Thermal Energy Storage systems. Energy analysis provides efficiencies that offer a true reflection of how closely the actual performance aligns with the ideal scenario. Additionally, it allows for a clearer understanding of the magnitudes, causes, and locations of thermodynamic losses compared to traditional energy analysis. Consequently, energy analysis proves instrumental in refining and optimizing Thermal Energy Storage system designs.

Potential Benefits of TES

The energy consumption for end users can significantly fluctuate throughout the day or year due to variations in fuel supply and demand. Thermal Energy Storage offers an accessible means to implement Demand Side Management (DSM) in a system. DSM plays a crucial role in reducing energy costs within a thermal system by managing peak demands and aligning loads with energy price fluctuations [5]. In order to encourage a reduction in peak demand by end users, facilities are often billed based on their highest monthly peak demand by energy providers. This serves as an incentive for users to shift their energy usage away from peak periods. By doing so, utilities can delay the necessity for additional generation capacity, thereby optimizing the utilization of base load plants.

2. METHODOLOGY

The constructed models have been streamlined to their fundamental elements, aiming to generate a comprehensive evaluation of Thermal Energy Storage sizing that can be swiftly applied across a diverse range of thermal systems. With the models' uncomplicated controls and a minimal set of user-required input parameters, the model can be promptly adjusted to offer a qualitative assessment of the integration of Thermal Energy Storage. This involves modifying the input load data and boiler capacity in line with the envisioned system.

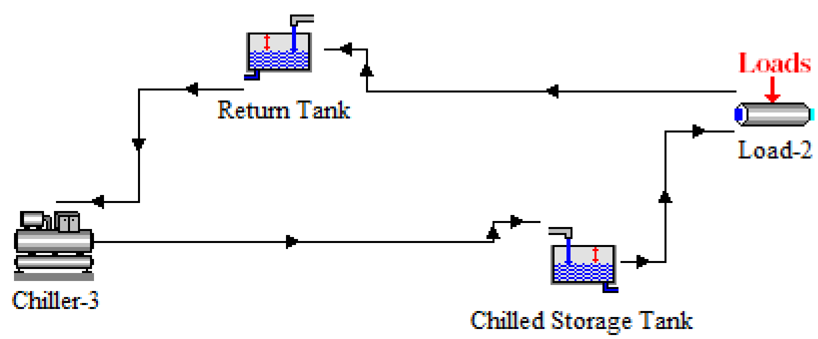

Figure 1: The preliminary heating and cooling models

The simulation utilized heating and cooling load data, representing the thermal output of the boiler or chiller. Initial models for each system were introduced to give insight into the ultimate design of the heating and cooling model. In both preliminary models, a stratified storage tank was employed, but after careful consideration, it was determined that a separate return and supply tank would be more effective. This decision was based on factors such as simplified controls and enhanced management of supply and return temperatures.

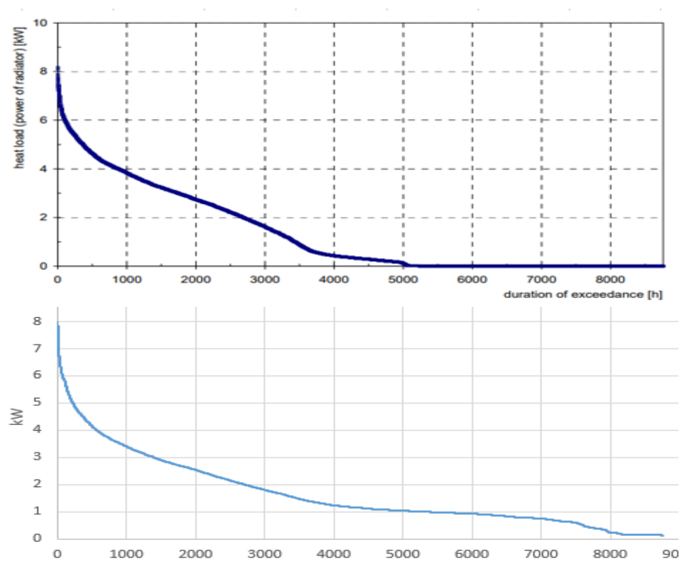

Figure 2: Graph of heat load

3. EXPERIMENTAL RESULTS

This performance metric expression offers a concise means to compare Thermal Energy Storage against electrical storage technologies from an electrical energy standpoint. The concept of round trip efficiency and/or turn around efficiency is encapsulated in this draft as storage efficiency. The thermodynamic model encompasses governing equations concerning heat transfer between the heat transfer fluid (HTF) and molten salt storage, losses in the heat exchanger, and losses in the molten salt storage tank. For the heating model simulation, the original hourly unscaled heating load tied to the retirement community energy model heating load data was utilized. The load data peaks at approximately 0.69 MM Btu/h. During this simulation, the boiler was allowed to modulate its capacity from 100% to 35% of its rated capacity, which is dimensioned to cover the annual peak heating load.

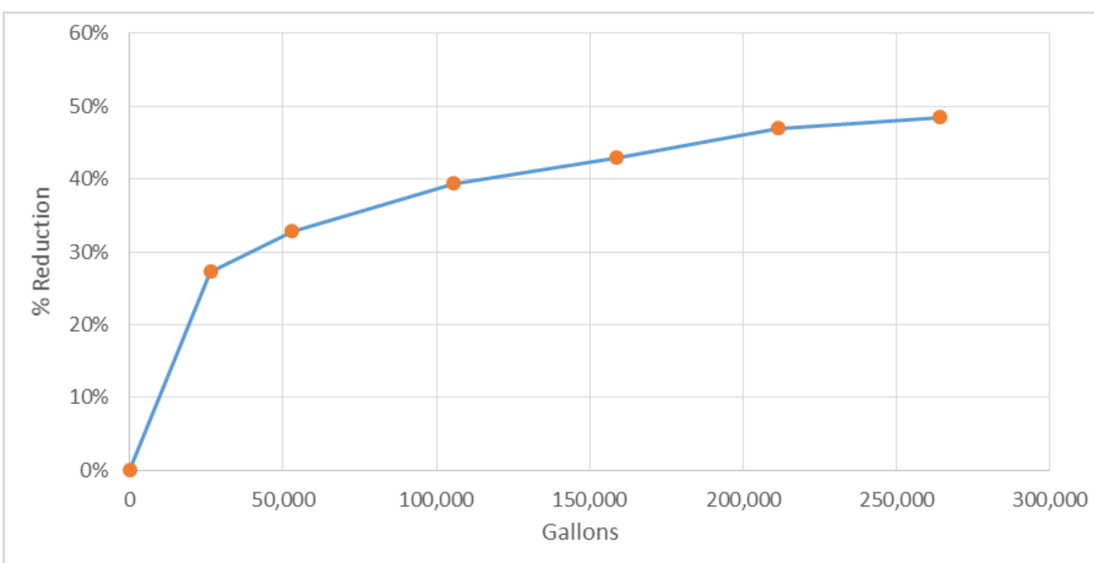

Figure 3: Reduction Ratio during heat fluid

The addition of 263,126 gallons (1,000 m3) of total storage volume led to a notable 45% reduction in the required boiler capacity, diminishing it from 698 kBtu to 356 kBtu/hr. This translates to a reduction of approximately 0.123 kBtu/hundred gallons of added storage. The most significant reduction in boiler capacity was observed with the initial 26,425 gallons (100 m3) of added storage, resulting in a remarkable 27% decrease in boiler capacity, equivalent to a capacity reduction of 0.698 kBtu/hundred gallons. Subsequent increases in storage volume yielded diminishing returns in reducing the required boiler capacity. An increase from 211,336 gallons (800 m3) to 264,162 gallons (1,000 m3) merely led to a 1.4% decrease in necessary boiler capacity.

CONCLUSION

This research aimed to investigate the influence of varying thermal energy storage (TES) capacity on heating and cooling system design and operation. This was achieved by modeling separate heating and cooling water storage systems using simulation software, TRNSYS. The models were designed to be easily adaptable to any inputted hourly load to provide an initial assessment of Thermal Energy Storage feasibility. Simulations were conducted with different storage capacities to examine the relationship between storage size, boiler cycling, and chiller load shaping. In the heating model, the addition of 13,203 gallons (50 m3) of total storage reduced boiler cycling by 56%. As storage volume increased, the decrease in boiler cycles per hundred gallons of storage volume became less significant. The cooling model demonstrated that peak energy usage could be reduced from 40% to 22% with the addition of 52,864 gallons (200 m3) of storage. Furthermore, 99% of on-peak loads could be shifted to the off-peak period with 211,398 gallons (800 m3) of storage.

An in-depth exploration of varying Thermal Energy Storage volumes included utilizing Thermal Energy Storage to enhance the effective capacity of heating and cooling systems. The models were simulated with reduced boiler and chiller capacities compared to what would conventionally be necessary to satisfy annual peak loads. This was done to assess how Thermal Energy Storage might enable boilers and chillers to meet demands above their peak capacities. The results indicated that 26,419 gallons (100 m3) of storage volume allowed for a 7.5% reduction in minimum chiller capacity and a 27.6% reduction in minimum boiler capacity, assuming that the minimum capacity for each matches their respective peak thermal load without storage.

Future Work

In this study, we deliberately treat Thermal Energy Storage capacity as a collective amount of thermal energy without imposing specific constraints on its storage or deployment. However, to enhance the applicability of the models developed in this study, it is essential to delve into greater detail regarding the integration and controls of Thermal Energy Storage. This will ensure a more precise depiction of system efficiency resulting from Thermal Energy Storage at varying capacities. Such details should encompass aspects like the maximum heat transfer rate of Thermal Energy Storage, additional pump energy consumption due to Thermal Energy Storage, standby losses, demand reduction in the system, the potential use of multiple boilers or chillers, and the influence of Thermal Energy Storage on the operating efficiencies of boilers and chillers. This is particularly crucial when considering how Thermal Energy Storage can enhance boiler and chiller capacity. By incorporating these features of varied Thermal Energy Storage volumes into the simulation control scheme, it becomes possible to estimate annual energy consumption, cost, and emissions. Utilizing the proposed models in conjunction with a contemporary exploration of Thermal Energy Storage technology and cost data would provide an invaluable tool for potential users of this technology.

REFERENCE

[1] “Residential Energy Consumption Survey (RECS) - Data - U.S. Energy Information Administration (EIA).” n.d. Accessed January 23, 2019. https://www.eia.gov/consumption/residential/data/2015/.

[2] “Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS) Data.” n.d. Accessed January 23, 2019. https://www.eia.gov/ consumption/ commercial/ data/ 2012/ index.php?view=consumption#e1-e11.

[3] McDaniel, Benjamin, and Dragoljub Kosanovic. 2016. “Modeling of Combined Heat and Power Plant Performance with Seasonal Thermal Energy Storage.” Journal of Energy Storage 7 (Supplement C): 13–23. https://doi.org/10.1016/j.est.2016.04.006.

[4] Zhang, Zhiqin, William D. Turner, Qiang Chen, Chen Xu, and Song Deng. 2011. “Tank Size and Operating Strategy Optimization of a Stratified Chilled Water Storage System.” Applied Thermal Engineering 31 (14): 2656–64. https://doi.org/ 10.1016/j.applthermaleng.2011.04.035.

[5] DeForest, Nicolas. 2014. “Optimal Deployment of Thermal Energy Storage under Diverse Economic and Climate Conditions,” April. http://www.sciencedirect.com/science/art.

[6] Seo, Byeong Mo, and Kwang Ho Lee. 2016. “Detailed Analysis on Part Load Ratio Characteristics and Cooling Energy Saving of Chiller Staging in an Office Building.” Energy and Building (Supplement C): 309–22. https://doi.org/10.1016/j.enbuild.2016.03.067.

[7] “Steam Systems | Department of Energy.” n.d. Accessed January 23, 2019. https://www.energy. gov/ eere/amo/steam-systems.

[8] Win, Kaung Myat, Tomas Persson, and Chris Bales. 2012. “Particles and Gaseous Emissions from Realistic Operation of Residential Wood Pellet Heating Systems.” Atmospheric Environment 59: 320–327.

[9] Heinz, Andreas, and Wolfgang Streicher. 2006. “Application of Phase Change Materials and PCM-Slurries for Thermal Energy Storage.” In Proceedings of the ECOSTOC Conference, Session 12B–Transportation of Energy, New Jersey.

[10] Schreiber, Heike & Graf, Stefan & Lanzerath, Franz & Bardow, André. (2015). Adsorption thermal energy storage for cogeneration in industrial batch processes: Experiment, dynamic modeling and system analysis. Applied Thermal Engineering. 89. 485 - 493. 10.1016/j.applthermaleng.2015.06.016.

[11] Pelay, Ugo, Lingai Luo, Yilin Fan, Driss Stitou, and Mark Rood. 2017. “Thermal Energy Storage Systems for Concentrated Solar Power Plants.” Renewable and Sustainable Energy Reviews 79 (Supplement C): 82–100. https://doi. org/10.1016/j.rser.2017.03.139.

[12] Amini, Amir, Jeremy Miller, and Hussam Jouhara. 2017. “An Investigation into the Use of the Heat Pipe Technology in Thermal Energy Storage Heat Exchangers.” Energy, Renewable Energy and Energy Storage Systems, 136 (Supplement C): 163–72. https://doi.org/10.1016/j.energy.2016.02.089.

[13] Comodi, Gabriele, Francesco Carducci, Balamurugan Nagarajan, and Alessandro Romagnoli. 2016. “Application of Cold Thermal Energy Storage (CTES) for Building Demand Management in Hot Climates.” Applied Thermal Engineering 103 (Supplement C): 1186–95. https://doi.org/ 10.1016/ j.applthermaleng. 2016.02.035.

DOI: https://doi.org/10.15379/ijmst.v10i4.3442