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# Chilled Water Thermal Energy Storage and Management Systems Provide Opportunities to Optimize Renewables

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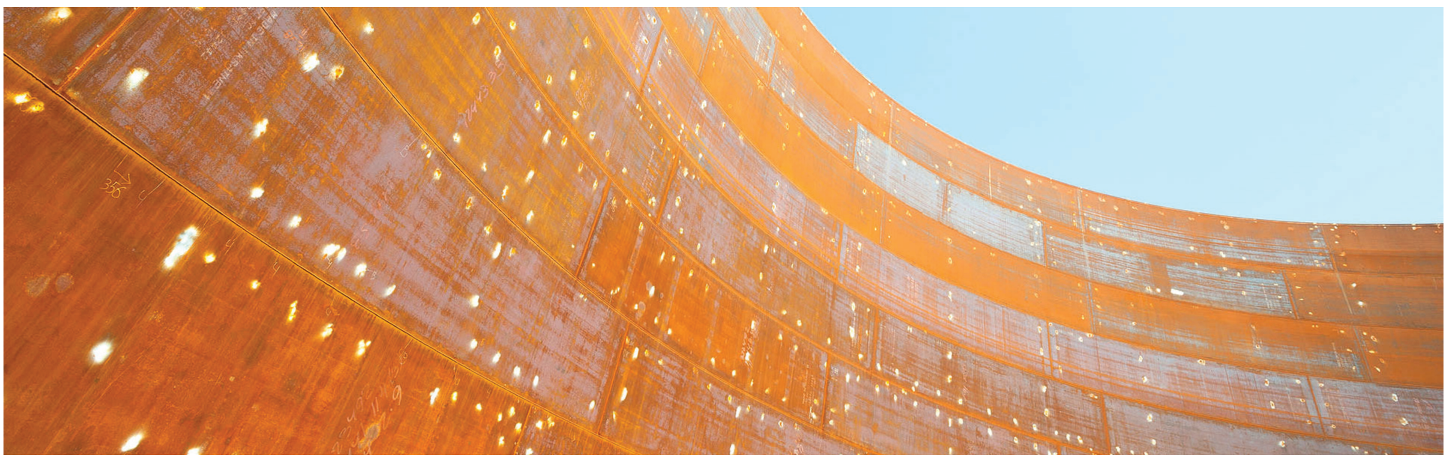
**Employing thermal energy storage (TES) technologies can improve flexibility when auxiliary power associated with energy storage is utilized. This can optimize battery performance, resulting in longer life cycles.**



The renewable energy industry — primarily wind, solar, hydro, biomass and geothermal — has grown every year since 2015. Moreover, it was the only power generation sector that increased its net share of capacity from 2019 to 2020, according to the U.S. Energy Information Administration (EIA). As generation capacity increases for these renewable solutions, so too does the demand for systems that store this often-intermittent energy. By storing excess energy produced during peak production periods, renewable energy can be made available for longer periods extending into off-peak times.

Batteries have been around since the 1800s, but those capable of cost effectively storing the energy necessary to power a hospital or an entire city are relatively new. One need only look back to 2012, when lithium-ion battery technology was just a U.S. Department of Energy demonstration project to see how far the technology has come. Today, due to a decadelong focus by the electric vehicle industry on lithium-ion battery development and steady drops in production cost, this technology has become a preferred method of energy storage supporting the renewable sector.

Increasing battery energy storage capacity results in heightened thermal demand required by these systems. In addition, as the energy density of batteries increases, so does heat density. More stringent requirements are then placed on thermal management designs implemented to support the operation and life of these batteries, which typically function in a narrow-preferred temperature range between 65°F and 85°F. Traditional direct expansion (DX) packaged air handling units (AHU) use a condensed refrigerant liquid to produce a cooling effect on the coils in direct contact with the conditioned air. DX units cool batteries inexpensively at the front end of the life cycle, but over time they become increasingly inefficient, resulting in higher energy usage and operations and maintenance (O&M) costs.

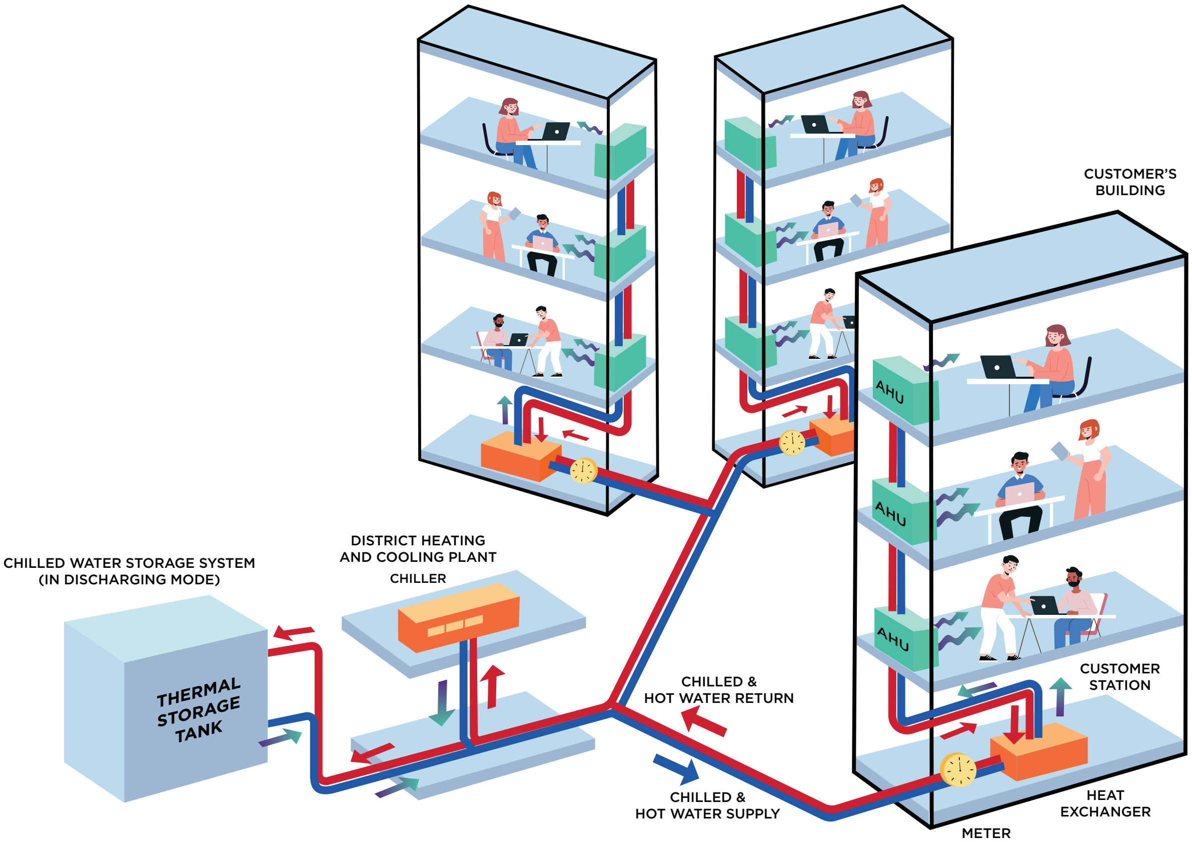



***Figure 1:** District energy systems can be scaled for cost-efficient heating and cooling over large campus settings.*

An existing technology utilized in many different systems provides another more energy-efficient option. Multiple cooling and heating systems for downtown districts, large college or hospital campuses, and manufacturing facilities rely on central utility plants (CUPs) that employ large centrifugal chillers to distribute chilled water throughout multiple buildings to handle their heat loads. Heat can be exhausted to ambient using evaporative cooling. Other benefits of these systems include the ability to add redundancy to the system to reduce potential downtime. Thermal storage can be used and extra capacity for future loads can be added relatively easily. Centralized cooling for battery storage can be deployed in a similar manner for both containerized or building solutions. This type of system has been proven over years of utilization to be robust and energy efficient, while also making maintenance easier due to centralized centrifugal equipment and a reduced frequency of maintenance activities.

## Technologies to Cool Lithium-Ion Batteries

A variety of temperature-controlling technologies are available depending upon the battery system size.

**Variable refrigerant flow (VRF):** Energy storage systems up to 2 megawatts (MW), with enclosures handling up to 20 tons of cooling, are adequately served by VRF systems. A VRF system transfers heat by circulating refrigerant to evaporator coils. This split-unit technology houses distributed fan coil units, which heat and cool inside the battery enclosure, while a condensing unit exhausts heat outside, away from the battery container.

**DX air handling units:** Cooling systems employing packaged DX air handling units can sufficiently handle battery energy storage systems (BESS) requiring up to 1,000 tons of cooling. However, system inefficiencies begin to increase costs as the auxiliary power required to energize the cooling systems grows. In addition to paying a penalty on system efficiencies when compared to chilled water, O&M expenses increase when DX units are used for large cooling systems, when compared to more centralized cooling systems.

Many companies with large (100-MW+) battery storage systems select containerized DX unit solutions based on upfront cost. However, that choice often does not consider O&M expenditures over the life expectancy of the battery system. A 100-MW system, for example, requires roughly 50 enclosures, each of which typically contains two to four DX packaged units. This results in up to 200 separate refrigerant systems. Every loop contains at least one compressor, filters that must be constantly replaced, condenser fan(s), supply fan(s), dampers, and other mechanical components that require consistent upkeep. The result is not only higher maintenance costs, but also undue burdens on operations staff to sustain and monitor many individually operating mechanical pieces of equipment.

**Chilled water systems and thermal energy storage (TES):** Adding a centralized chilled water system can be a solution for battery storage requiring 500 tons of cooling or more. This technology can provide cooling at an approximate demand of 0.6 kilowatts (kW) per ton or less, compared to DX units using an average 1.2 to 1.4 kW per ton. Adding a thermal storage solution to a chilled water plant may not increase the overall efficiency of the system, but it can provide flexibility to the operator to energize compressors and cooling equipment during off-peak times when energy can be cheaper. This often means fewer air handling units are needed, resulting in a drastic reduction in auxiliary power load during times when batteries are discharging energy. Although the chilled water and thermal storage system approach may result in higher front-end costs for materials and labor, thermal management program savings over the longer term may exceed initial expenditures. TES can also provide the ability to offset enough auxiliary power to reduce the number of batteries, inverters and containers needed, as well as the labor associated with manufacturing and installing equipment required to meet the BESS capacity requirements. Economic analysis tools that incorporate TES solutions demonstrate the potential cost savings of this approach, though the exact savings depends on variables like overall capacity, dispatch strategies, and auxiliary power demand goals, such as off-peak power usage or load leveling.

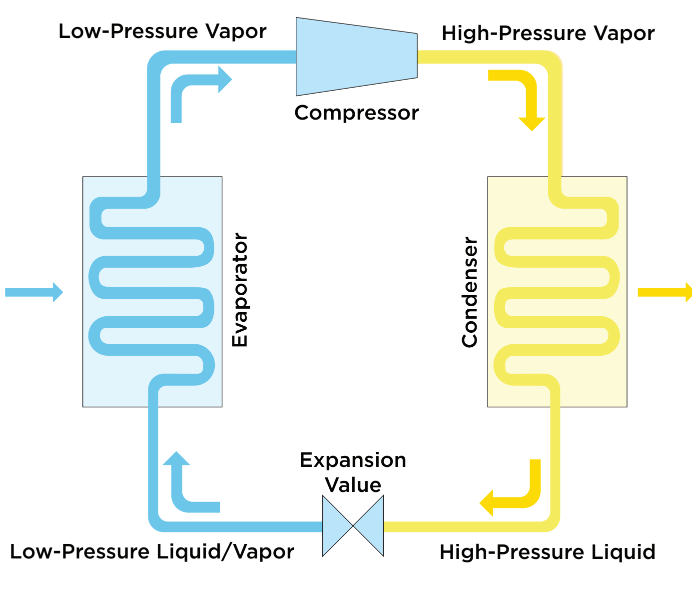



***Figure 2:** Heat transfer in VRF systems.*

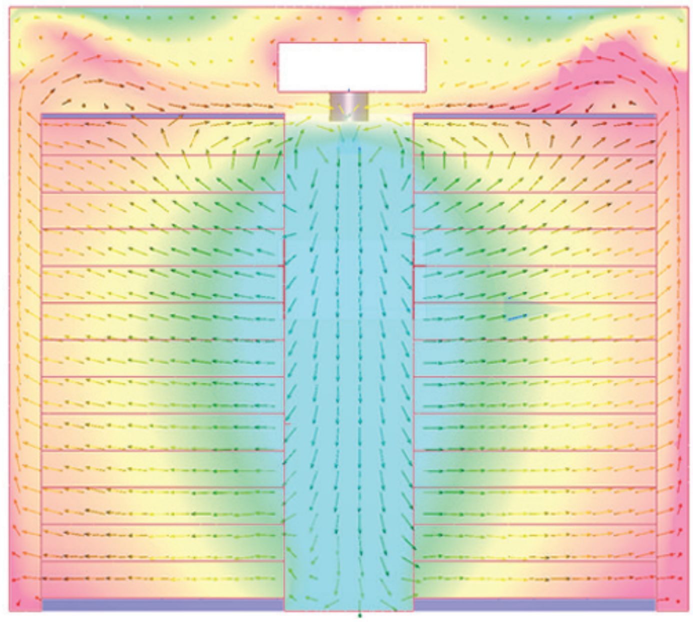


***Figure 3:** CFD model temperature with velocity vectors.*

## Computational Fluid Dynamics As a Design Tool

When the ability to deliver consistent power depends on the long-term, efficient storage capacity of temperature-sensitive battery systems, measures must be taken to confirm that a given HVAC system can perform as required daily in all conditions. Computational fluid dynamics (CFD) is a technique used to create a three-dimensional model of the temperature distribution in a battery enclosure, allowing designers to visualize system performance in a wide variety of real-world conditions. Model simulations applied to an HVAC design predict temperature distribution throughout the battery storage area, providing a high degree of confidence over battery operating cycles. Rapid iteration of alternatives results in a design that keeps batteries within the required temperature range. System performance at installation is then predictable at the scale of individual battery racks, which minimizes costs, maximizes speed, and increases confidence in the final design.

## Benefits of Thermal Storage Management Approaches

On a grander scale of renewable energy operations, TES solutions can offer enormous benefits. This approach allows entities to choose when to expend their stored energy. For instance, without TES, thermal management equipment is tied directly to the heat load. Therefore, when heat is generated by batteries, the cooling equipment must be energized. This creates auxiliary power peaks during times when the batteries are discharging and energy is at a premium. Implementing TES solutions, a utility can decouple centrifugal cooling equipment and compressors from the heat load and utilize stored thermal energy to cool batteries during discharge at a fraction of the power. Once the batteries have been discharged and are cooled, the operator can choose when to charge the thermal storage system, which can be during off-peak times when energy can be less expensive.

Materials used in cooling towers and TES systems are keys to long-term efficiencies. Circular compressed concrete tanks are commonly used for large-capacity chilled water storage. Warm water circulates through chillers and then recirculates to the tank after being cooled. These insulated tanks keep water at low temperatures for many weeks. Tank design provides warm water to the tank that rests on top of the cold water, capitalizing on differences in water density. Water is introduced and removed from the tank in an almost completely laminar method, which maintains separation of warm and cold water, except for a thin layer called the thermocline, which is typically one to three feet in height.

## Maintenance Cost and Waste Material

The chilled water system can be a centralized system contained within a small footprint. Because it incorporates fewer and larger mechanical pieces of equipment, less time may be required to maintain a chilled water system, compared to distributed DX AHUs. Maintaining hundreds of DX AHUs can be cumbersome. Operations crew members may be required to be on-site weekly or even daily for routine maintenance. Upkeep expenses for a large BESS facility can be considerable, requiring multiple employees. When utilizing smaller DX AHUs for containerized solutions, filter replacement for more sizable systems can cost hundreds of thousands of dollars annually. The financial and environmental burden of throwing away non-reusable items like filters is also higher with these DX unit systems. More cooling loops mean potential for additional refrigerant leaks, which also results in battery downtime. With a centralized cooling system, redundancy and robustness is easily improved, resulting in fewer potential cooling system-induced outages during peak production times.

### Life Span and Performance of Battery System

Extended battery life ultimately means purchasing fewer replacements. When applying thermal management design standards, the goal is to maintain air temperatures surrounding the batteries at around 73°F. If the battery operates for long periods of time above or below that temperature, then performance and battery life expectancy is reduced. Chilled water systems can have tighter temperature control and may better fit the thermal needs of batteries.

## Design Implications Due to Location

Because many renewable energy projects are developed in desert environments, DX units must be designed to withstand temperatures that can reach 115°F. Instead of installing a typical nominal 10-ton unit, 14- to 15-ton units are required to protect battery integrity due to the reductions in system cooling capacity caused by high-ambient conditions. In more moderate climates, however, thermal management systems of similar sized BESS may employ smaller AHUs due to the lack of derating that occurs when systems are not exposed to extreme temperatures.

In humid coastal regions where salt-laden air is common, proper air filtration and moisture removal are additional considerations to make sure optimal battery life is not compromised. Salt can corrode conductor terminals and several other components critical to battery functionality, which requires particular types and efficiencies of filtration.

## Conclusion

Upgrading or designing new battery energy storage systems can be a highly complex endeavor. Incorporating systems to keep them cool, efficient and profitable is a basic requirement, though technology options are improving. While the market tries to keep up with equipment demands, understanding of the requirements and variability of each component and solution often lags. For instance, prefabricated battery, purpose-built systems, with a pre-installed chiller are now available. Yet, these solutions have not been designed to maximize performance for a specific project location or size. These purpose-built enclosures have become a popular technology for BESS due to potentially lower installation costs. However, for larger systems, employing many small chiller systems to handle the heat loads is very inefficient and extremely burdensome for the O&M crews. With these smaller thermal systems, it is generally more economical to replace the entire chiller rather than diagnose the problem and repair the individual components of a chiller when it fails. This provides other complications such as large material waste and transportation of said waste. For smaller BESS, however, this solution may be a good option, because small systems won't suffer from quickly escalating maintenance costs associated with hundreds, or even thousands, of individual racks each with its own cooling system.

It is important that energy storage systems have functionally tested designs that optimize project efficiency and longevity. Working with professionals that have experience with a variety of different options for managing battery thermal loads can result in more optimal solutions that minimize auxiliary load and maintenance costs while, at the same time, maximizing battery longevity and availability.

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