Saves Energy, Money

Thermal Energy Storage

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Thermal energy storage (TES) has been widely used in the commercial sector since the 1980s to shift HVAC cooling load out of the peak demand period of the day. By charging a chilled water or ice-based TES system overnight, a facility can take advantage of off-peak electricity prices and reduce any charges based on peak demand. Adding TES can also increase cooling capacity without installing more or larger chillers. TES is often viewed as a cost-savings measure, rather than as an energy-savings technology.

However, TES can save energy overall, sometimes at the site of use and usually at the electricity generation source. Current advances in TES include progressively tighter integration of distributed TES systems with regional power grids to reduce the cost of generation. This integration is facilitated by new control technologies, communication channels, and business models.

Technology Overview

The simplest form of cool TES uses chilled water as the storage medium. The water is typically stored in a large concrete or welded steel tank, with warm and cool layers stratified by the density difference between them. During system charge, warm water is removed from the top layer, chilled, and returned to the bottom layer through specialized diffusers that minimize mixing. Chilled water TES is simple, efficient and cost-effective, particularly at large scale as the cost per gallon decreases with tank size. Existing system capacities range from about 500 to more than 100,000 ton·hours.

The downside to chilled water TES is a large footprint; for a tank with a typical temperature differential (~15°F [8.3°C]), the storage volume is around 15 ft^3/ton·hour. The footprint of chilled water TES can be decreased by increasing the temperature differential. However, water reaches its maximum density at 39°F (4°C), so if the temperature of the cool layer drops below that point, it will disrupt the stratification. This destratification can be avoided by using commercially available salt additives that depress the temperature of maximum density, allowing a colder cool layer and thus a larger temperature differential. Aggressive temperature differentials can reduce the volume footprint by a factor of two or more.

Ice-based systems have a smaller footprint than chilled water TES systems, thanks to the high latent heat of fusion of water, with effective storage volumes usually in the range of 2 to 4 ft^3/ton·hour. In the most common configuration, ice is built around chilled coils; this is known as "static ice" or "ice-on-coil." The system is charged by passing cold fluid (usually glycol) through coils submerged in a tank of water, causing ice to accumulate around them. Static ice TES modules are offered by several well-established manufacturers, with per-module capacities generally in the high tens to low hundreds of ton·hours; larger capacities can be achieved by combining multiple modules in a central or distributed system.

One relatively recent development is the emergence of a 30 ton·hour, ~175 ft^3 (5 m^3) unitary static ice system, incorporating both a storage tank and an ice-making condenser, and designed for use with rooftop and other direct expansion (DX) systems (*Figure 1*). This unitary system uses gravity-fed liquid overfeed refrigerant loops to build ice (charge mode) and to pass cooling to the associated packaged DX system (discharge mode).[1]

Energy Savings

There are three main mechanisms through which cool thermal energy storage can contribute to site energy savings. First, cool storage is charged overnight, when ambient outdoor temperatures are lower. Particularly in the case of air-cooled chillers, this increases efficiency substantially compared to daytime operation. In addition, charging runs the chillers in an efficient mode, i.e., at or near full load, with reduced start/stop and off-design operation time. Finally, in new construction ice-based TES may suggest the use of low-temperature air distribution, with resulting reductions in air handler size and power.[2,3]

Using TES can result in system efficiency penalties, however. There is inevitably some degree of heat leakage into the cool storage. Also, in the case of ice-based TES, the chiller output temperature must be lower than in a conventional system, with commensurate efficiency reduction.

Depending on configuration and operational parameters, the bottom line energy consumption of a particular site may or may not be improved with the addition of cool TES. However, published case studies favorable to TES report that site energy savings on the order of 10% to 20% are achievable in some instances.[4]

Energy savings at the electricity source are independent of specific energy savings at the use site. In the electrical grid, demand must be continually matched by generation, ideally in the least expensive way possible. Generators with negligible fuel costs (nuclear, solar, and wind) are at the top of the dispatch list, followed by efficient coal and gas plants. As electricity demand rises, e.g., on a hot summer day, increasingly less-efficient plants may be dispatched to match it, requiring increasingly more primary energy (and more money) per kWh produced. Cool storage shifts demand out of the peak hours, where it would likely have to be met with an inefficient plant, into the off-peak hours, where it can be met with an efficient plant. A 1996 study by the California Energy Commission estimated the source primary energy savings from cool TES (compared to conventional cooling equipment) to be in the range of 8% to 43%, even assuming zero energy savings at site.[4]

The energy mix has shifted substantially since 1996, but the prevailing trends make cool TES even more important to energy sustainability.[5] Wind and solar generators are inherently intermittent, and as their penetration increases, the variability of the remaining demand that must be met with conventional generation ("net load") will likewise increase. Cool storage has the potential to smooth this minute-to-minute net load variation, just as it can smooth the diurnal demand variation that has traditionally been the driver for its use.

Electricity deregulation has in many areas meant the establishment of explicit markets for delivered and reserved energy on a variety of timescales; essentially, cool TES is a resource that has value in these markets, and there are models emerging to realize that value. In one model, facilities participate directly in the markets, buying electricity under real-time pricing. This involves the implementation of sophisticated HVAC control algorithms to optimize the use of the TES resource, but could reduce electricity costs by a few percent compared to a time-of-day control scheme under time-of-use pricing.[6]

In another model, a third-party demand response (DR) services company acts as a middleman between the markets and the facilities. For a fee, the DR service manages the optimization, quantifying the TES resource's value and controlling the HVAC systems to reduce electrical load when it is profitable to do so, through some combination of automated and manual channels.

In a third model, the utility owns and operates the TES resource outright. The unitary static ice TES system mentioned previously is currently marketed under this model; the Southern California Public Power Authority is an early adopter. By funding the deployment of a fleet of TES units, the utility reduces its peak demand and gains a directly controllable load-matching resource. The buildings involved save money on electricity due to off-peak pricing, with no capital investment or maintenance required.

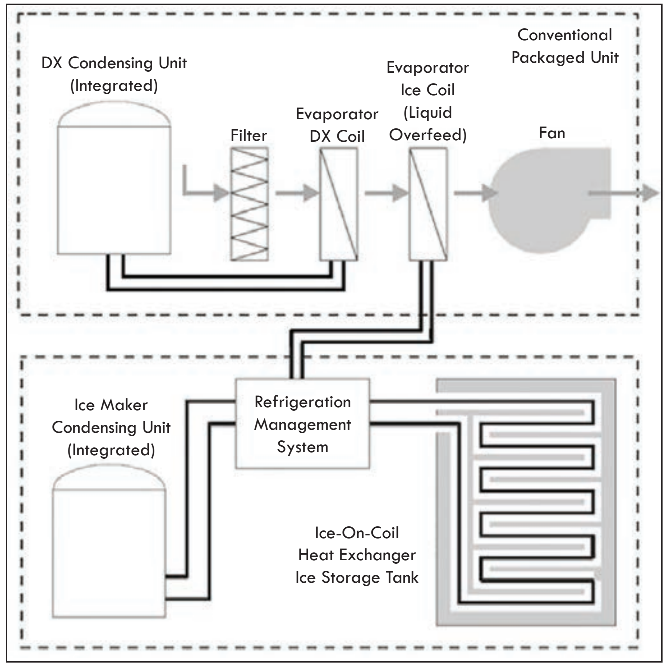

Figure 1: Diagram of unitary static ice TES system used in conjunction with packaged DX unit.[1]

Market Potential

Pike Research has estimated the 2011 installed cooling capacity of commercial TES in the United States to be about 1,000 MW for ice-based systems and 355 MW for chilled water. Commercial cooling applications account for about 50% of all installed TES in the U.S.; the remaining 50% consists of power plant applications and electric thermal storage.[7] Projected capacity additions for all forms of TES in North America by 2020 total 768 MW of cooling capacity.[7]

Data from the Commercial Building Energy Consumption Survey (CBECS)[8] can be helpful in developing an estimate of the addressable market for ice/chilled water forms of TES in commercial buildings. *Figure 2* is based on data from the 2003 CBECS and summarizes the total square footage in nonresidential, non-mall buildings that is cooled by one or more of the indicated types of cooling. Since buildings currently using central chillers and/or chilled water are actual or potential installation sites for TES, the addressable market for commercial applications of TES is about 15,000 million ft^2 (1.4 billion m^2). In addition, unitary systems may begin to penetrate the 40,000 million ft^2 (3.8 billion m^2) packaged/central direct expansion (DX) cooling market.

TES systems have already noticeably penetrated the Florida market for commercial building space cooling, particularly in schools.[9] Schools in Sarasota County, Hernando County, and Orange County have installed TES systems. The 450,000 ft^2 (41 805 m^2) Weeki Wachee high school campus in the Hernando County School District operates with one central energy plant that uses both ice storage tanks and chillers in a partial energy storage process. Benefits of this partial energy storage process includes downsizing of chillers and efficient operation at full load or near full load. The central plant/TES/chiller design contributed to the school district's selection for the Central Florida ASHRAE Chapter Institutional Building Technology Award, as well as certification at the LEED Silver level.[10]

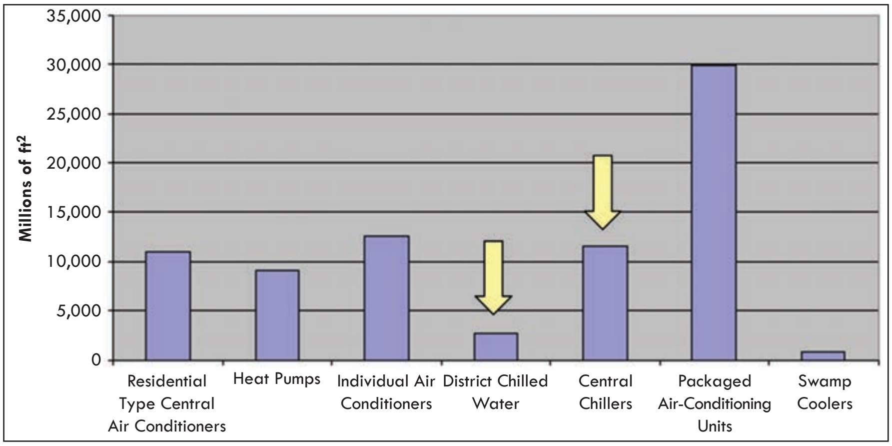

Figure 2: Total floor space versus major cooling type used.

Potentially favorable to increased market adoption of TES in regions where the cost of meeting peak demand is sufficiently high, TES technology can qualify for efficiency incentive programs for non-residential buildings offered at the state and/or local utility level. The Interior Building program of Florida Power and Light (FPL) includes financial incentives for TES equipment.[11] The energy efficiency rebates offered by Progress Energy includes thermal energy storage.[11] In Texas, Austin Energy offers non-residential customers a Data Center Efficiency Rebate up to $200,000 toward the cost of retrofitting energy efficiency technologies, including TES.[12] In Iowa, equipment that can qualify for MidAmerican Energy's Custom Systems rebate program includes TES.[13]

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