HVAC: Cool Thermal Storage

Thermal storage systems offer building owners the potential for substantial operating cost savings by using offpeak electricity to produce chilled water or ice for use in cooling during peak hours. The storage systems are most likely to be cost-effective in situations where

• A facility's maximum cooling load is much greater than the average load;

• The utility rate structure has high demand charges, ratchet charges, or a high differential between on- and offpeak energy rates;

• An existing cooling system is being expanded;

• An existing tank is available;

• Limited electric power is available at the site;

• Backup cooling capacity is desirable; or

• Cold air distribution would be advantageous.

It's difficult to generalize about when cool storage systems will be cost-effective, but if you meet one or more of the above criteria, it may be worth doing a detailed analysis.

What Are the Options?

If you're considering a cool storage system, you'll need to make choices: which medium and tank you'll use for storage and what strategy you'll use to dispatch the system.

Storage Medium

The storage medium determines how large the storage tank will be and the size and configuration of the HVAC system and components. The options include chilled water, ice, and eutectic salts (see **Table 1**, next page). Overall, ice systems offer the densest storage capacity but the most complex charge and discharge equipment. Water systems offer the lowest storage density but are the least complex. Eutectic salts fall somewhere in between.

Chilled water. Chilled-water storage systems use the sensible heat capacity of water—1 Btu per pound (lb) per degree Fahrenheit (F)—to store cooling capacity. They operate at temperature ranges compatible with standard chiller systems and are most economical for systems greater than 2,000 ton-hours in capacity. The capacity of a chilled-water thermal energy storage (TES) system is increased by storing the coldest water possible and by extracting as much heat from the chilled water as practical (thus raising the temperature of the return water). For a given tank volume, increasing the temperature differential from 10° to 20°F will double the cooling capacity.

Table 1: Comparing storage media

Chilled water systems require the largest tanks, but they can easily interface with existing chiller systems. Ice systems use smaller tanks and offer the potential for the use of low-temperature air systems, but they require more complex chiller systems. Eutectic salts can use existing chillers but usually operate at the warmest temperatures.

Storage medium	Volume (feet^3/ton-hour)	Storage temperature (degrees F)	Discharge temperature (degrees F)	Strengths
Chilled water	10.7-21	39-44	41-46	Can use existing chillers; water in storage tank can do double duty for fire protection
Ice	2.4-3.3	32	34-36	High discharge rates; potential for low temperature air system
Eutectic salts	6	47	48-50	Can use existing chillers

Source: E SOURCE

Ice. Ice thermal storage systems use the latent heat of fusion of water—144 Btu/lb—to store cooling capacity. Storing energy at the temperature of ice requires refrigeration equipment that can cool the charging fluid (typically, a water/glycol mixture) to temperatures below the normal operating range of conventional air-conditioning equipment. Special ice-making equipment or standard chillers modified for low-temperature service are used. When ice thermal storage is incorporated into a new building system (or a major retrofit) the low temperatures of the chilled-water supply allow the use of low-temperature air distribution (usually calling for Fahrenheit temperatures in the mid-40s, versus the mid-50s for conventional systems), meaning smaller fans and ducts are needed.

When ice is the storage medium, there are several technologies available for charging (creating ice) and discharging (using the ice to cool circulated fluid) storage:

- Ice harvesting systems feature an evaporator surface on which ice is formed; it is then periodically released into a storage tank that is partially filled with water.

- External melt ice-on-coil systems use submerged pipes through which a refrigerant or secondary coolant is circulated, causing ice to accumulate on the outside of the pipes. Storage is discharged by circulating the warm return water over the pipes, melting the ice from the outside.

- Internal melt ice-on-coil systems also feature submerged pipes on which ice is formed. Storage is discharged by circulating warm coolant through the pipes, melting the ice from the inside. The now-cold coolant is then pumped through the building cooling system or used to cool a secondary coolant that goes through the building's cooling system. Pre-engineered tanks that can be easily configured for different applications are available from several manufacturers, including Calmac, Baltimore Air Coil, and FAFCO. Tanks are most commonly available in capacities ranging from 50 to 500 ton-hours (Calmac has the low side of this market, between 50 and 150 ton-hours); multiple tanks are used to meet the required cooling load. One advantage of multiple tanks is flexible location, particularly for retrofit projects where space is limited—tanks can be spread throughout available space in parking structures, mechanical rooms, or other locations. The tanks are then piped together to form a single cooling system.

- Ice slurry systems store water or water/glycol solutions in a slurry state—a partially frozen mixture of liquid and ice crystals that looks much like a frozen fruit smoothie. To meet cooling demand, the slurry may be pumped directly to the load or to a heat exchanger that cools a secondary fluid that circulates through the building's chilled-water system.

Internal melt ice-on-coil systems are the most commonly used type of ice storage technology in commercial applications. External melt and ice harvesting systems are more common in industrial applications, although they can also be applied in commercial buildings and district cooling systems. Ice slurry systems have not been widely used in commercial applications.

Eutectic salts. Eutectic salts, also known as phase-change materials, use a combination of inorganic salts, water, and other elements to create a mixture that freezes at a desired temperature. The material is encapsulated in plastic containers that are stacked in a storage tank through which water is circulated. The most commonly used mixture for thermal storage freezes at 47°F, which allows the use of standard chilling equipment to charge storage, but leads to higher discharge temperatures. That in turn limits the operating strategies that may be applied. For example, eutectic salts may only be used in full storage operation if dehumidification requirements are low.

Tank Type

Storage tanks must have the strength to withstand the pressure of the storage medium, and they must be watertight and corrosion-resistant. Aboveground outdoor tanks must be weather-resistant. Buried tanks must withstand the weight of their soil covering and any other loads that might occur above the tank, such as parked cars. Tanks may also be insulated to minimize external condensation and thermal losses, which typically run 1 to 5 percent per day. Options for tank materials include steel, concrete, and plastic.

Steel. Large steel tanks, with capacity of up to several million gallons, are typically cylindrical in shape and field-erected of welded plate steel. They are then tightly wrapped in taut steel cable to pre-stress the tank walls. Some kind of corrosion protection, such as an epoxy coating, is usually required to protect the tank interior. Cylindrical pressurized tanks are generally used to hold between 3,000 and 56,000 gallons.

Concrete. Concrete tanks may be precast or cast in place. Precast tanks are most economical in sizes of one million gallons or more. Cast-in-place tanks can often be integrated with building foundations to reduce costs, but cast-in-place tanks are more sensitive to thermal shock. Large tanks are usually cylindrical in shape, while smaller tanks may be rectangular or cylindrical.

Plastic. Plastic tanks are typically delivered as prefabricated modular units. Plastic tanks that are used outdoors require ultraviolet (UV) stabilizers or an opaque covering to protect against the UV radiation in sunlight. Cylindrical tanks come in sizes as small as six feet in diameter, enabling them to be located in congested building spaces. Rectangular tanks are commonly available in sizes up to 8 x 8 x 20 feet.

Steel and concrete are the most commonly used types of tanks for chilled-water storage. Most ice harvesting systems use site-built concrete, external-melt systems usually use concrete or steel tanks, internal melt systems usually use plastic or steel, and eutectic salt systems commonly use concrete tanks with polyurethane.

Operating Strategies

Several strategies are available for charging and discharging storage to meet cooling demand during peak hours.

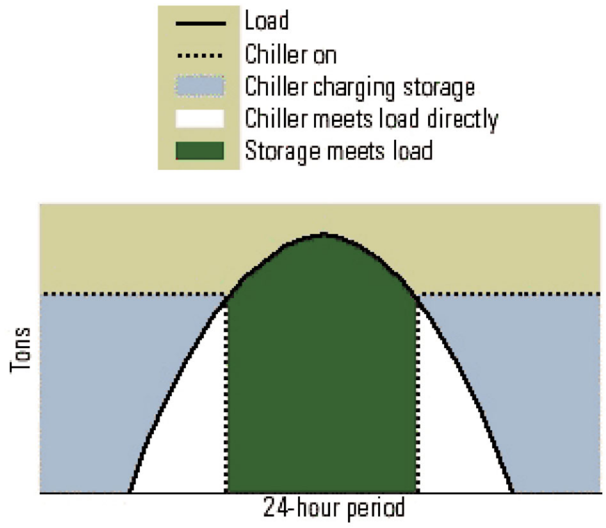
These are:

Full storage. A full-storage strategy, also called load shifting, shifts the entire on-peak cooling load to off-peak hours (see **Figure 1**). The system is typically designed to operate at full capacity during all nonpeak hours to charge storage on the hottest anticipated days. This strategy is most attractive where on-peak demand charges are high or the on-peak period is short.

Partial storage. In the partial-storage approach, the chiller runs to meet part of the peak period cooling load, and the remainder is met by drawing from storage. The chiller is sized at a smaller capacity than the design load. Partial storage systems may be run as load-leveling or demand-limiting operations.

Figure 1: Full-storage operating strategy

A full-storage, or load-shifting, strategy shifts the entire on-peak cooling load to off-peak hours. This strategy is most attractive where on-peak demand charges are high or the on-peak period is short.



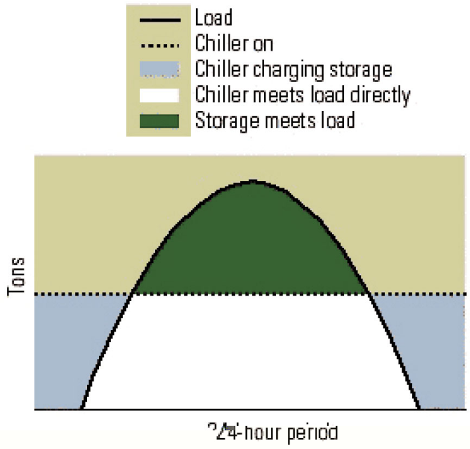
Source: *ASHRAE Design Guide for Cool Thermal Storage*

In a load-leveling system (see **Figure 2**), the chiller is sized to run at its full capacity for 24 hours on the hottest days. The strategy is most effective where the peak cooling load is much higher than the average load.

In a demand-limiting system, the chiller runs at reduced capacity during on-peak hours and is often controlled to limit the facility's peak demand charge (see **Figure 3**). Demand savings and equipment costs are higher than they would be for a load-leveling system and lower than for a full-storage system.

Figure 2: Partial storage load-leveling operating strategy

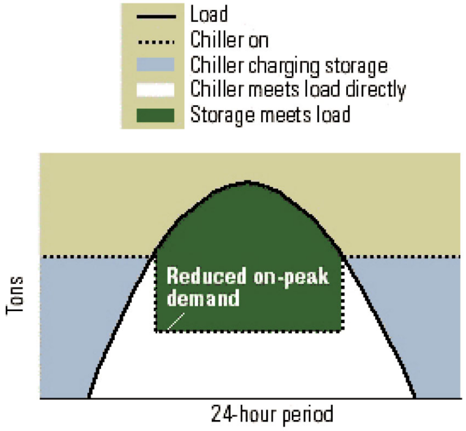
In a load-leveling system the chiller runs at its full capacity for 24 hours on the design day. When the load is less than the chiller output, the surplus cooling is stored. When the load exceeds the chiller capacity, the additional requirement is discharged from storage. A load-leveling approach minimizes the required chiller and storage capacities for a given load.



Source: *ASHRAE Design Guide for Cool Thermal Storage*

Figure 2: Partial-storage load-leveling operating strategy

A demand-limiting system operates the chiller at a reduced capacity during on-peak hours. Demand savings and equipment costs are higher than for a load-leveling system and lower than for a load-shifting system.



Source: *ASHRAE Design Guide for Cool Thermal Storage*

How to Make the Best Choice

Perform a detailed feasibility study. The analysis required is involved, and it is best accomplished by following an established procedure. A good source for feasibility analysis is the *Design Guide for Cool Thermal Storage*, published by ASHRAE (the American Society of Heating, Refrigerating and Air-Conditioning Engineers—order it at www.ashrae.org). To perform the study, you'll need the following information:

- An hour-by-hour 24-hour building load profile for the design day.

- Description of a baseline nonstorage system, including chiller capacity, operating conditions, and efficiency.

- Description of the proposed storage system, including:

—Sizing basis (full storage, load leveling, or demand limiting);

—Sizing calculations showing chiller capacity and storage capacity, and considering required supply temperature;

—Design operating profile showing load, chiller output, and amount added to or taken from storage for each hour of the design day;

—Chiller operating conditions while charging storage, and if applicable, when meeting the load directly;

—Chiller efficiency under each operating condition; and

—Description of the system control strategy, for design-day and part-load operation.

- Operating cost analysis, including:

—Demand savings,

—Changes in energy consumption and cost, and

—Description and justification of assumptions used for annual demand and energy estimates.

Storage equipment manufacturers will provide simulations of storage performance for a given load profile and chiller temperature.

What's on the Horizon?

Some manufacturers are offering freeze-point depressants, which lower the temperature at which the cooling medium will freeze. This enables chilled-water thermal storage systems to provide greater cooling capacity by lowering the freezing point and by improving low-temperature fluid stratification. Pure water reaches maximum density at 39.4°F, so it will not stratify at lower temperatures, which reduces the cooling capacity that can be extracted from a charged TES tank. One freeze-point depressant product is called "SoCool" and is offered by Chicago Bridge & Iron Co. (a manufacturer of storage tanks). This product is added to the water in the TES loop. The TES tank design must account for the presence of this additive in order to prevent corrosion (the product contains sodium nitrate and sodium nitrite, along with other additives).

Ice slurry systems are a priority research area for ASHRAE, so look for new developments in that technology. The primary advantage of ice slurries comes from their high latent cooling capacity. A slurry that contains about 20 percent ice can triple the cooling capacity of a conventional 40°F supply/55°F return chilled-water distribution system. The higher cooling capacity, in turn, leads to significant reductions in the cost of piping and in the pumping energy required. The challenge lies in controlling the behavior of the slurry—as pumps push it around the piping system, ice can congeal and block flow at valves, joints, and pumps.