APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Thermal Energy Storage Strategies for Commercial HVAC Systems

Summary

Thermal energy storage (TES) systems shift cooling energy use to non-peak times. They chill storage media such as water, ice, or a phase-change material during periods of low cooling demand for use later to meet air-conditioning loads. Operating strategies are generally classified as either full storage or partial storage, referring to the amount of cooling load transferred from on-peak to off-peak.

TES systems are applicable in most commercial and industrial facilities, but certain criteria must be met for economic feasibility. A system can be appropriate when maximum cooling load is significantly higher than average load. High demand charges, and a significant differential between on-peak and off-peak rates, also help make TES systems economic. They may also be appropriate where more chiller capacity is needed for an existing system, or where back-up or redundant cooling capacity is desirable.

Besides shifting load, TES systems may also reduce energy consumption, depending on site-specific design, notably where chillers can be operated at full load during the night. Also, pumping energy and fan energy can be reduced by lowering the temperature of the water, and therefore the air temperature, affecting the quantity of air circulation required.

Capital costs tend to be higher than a conventional direct-cooling system, but other economic factors can reduce such costs. In new construction, ductwork

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could be smaller, allowing more usable space. Or a TES system may enable reduction in electrical capacity, reducing the cost of electrical service for a new or expanding facility.

How This Technology Saves Energy

In a TES system, a storage medium is chilled during periods of low cooling demand, and the stored cooling is used later to meet air-conditioning load or process cooling loads.

The system consists of a storage medium in a tank, a packaged chiller or built-up refrigeration system, and interconnecting piping, pumps, and controls. The storage medium is generally water, ice, or a ***phase-change***[1] material (sometimes called a eutectic salt); it is typically chilled to lower temperatures than would be required for direct cooling to keep the storage tank size within economic limits. Figure 1 illustrates the basic operation of a system that uses chilled water.

Load shifting is typically the main reason to install a TES system. Cool storage systems can significantly cut operating costs by cooling with cheaper ***off-peak*** energy, and reducing or eliminating ***on-peak demand charges***.

These systems have a reputation for consuming more energy than nonstorage systems. This has often been true where demand reduction was the primary design objective. Cool storage does require the chiller to work harder to cool the system down to the required lower temperatures (for ice storage); and energy is needed to pump fluids in and out of storage.

But a number of design options can make TES systems more energy-efficient than nonstorage systems. Storage systems let chillers operate at full load all night , versus operating at full or part load during the day.

Depending on the system configuration, the chiller may be smaller than would be required for direct cooling, allowing smaller auxiliaries such as cooling-tower fans, ***condenser*** water pumps, or condenser fans. Pumping energy can be reduced by increasing the chilled water temperature range; fan energy can be cut with colder air distribution. Storage systems can also make increased use of heat recovery and waterside economizer strategies.

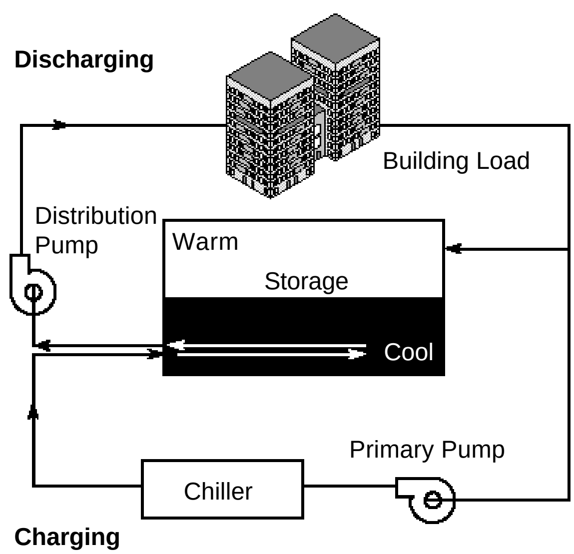

Figure 1: Thermal Energy Storage System with Stratified Chilled Water Storage *(Source: ASHRAE)**

[1] Bold italicized words are defined in the section title "Definition of Key Terms."

Types of Demand and Energy Efficiency Measures

TES systems can be characterized by storage medium and storage technology. Storage media include chilled water, ice, and phase-change materials, which differ in their operating characteristics and physical requirements for storing energy. Storage technologies include chilled water tanks, ice systems, and phase-change materials.

Chilled Water Storage

These systems use the ***sensible heat*** capacity of water (1 Btu per pound per degree Fahrenheit) to store cooling. Tank volume depends on the temperature difference between the water supplied from storage and the water returning from the load, and the degree of separation between warm and cold water in the storage tank. Where most conventional nonstorage HVAC systems operate on temperature differentials of 10° to 12°F, chilled water systems generally need a differential of at least 16°F to keep the storage tank size reasonable. A difference of 20°F is the practical maximum for most building cooling applications, although a few systems exceed 30°F.

Chilled water is generally stored at 39°F to 42°F, temperatures directly compatible with most conventional water chillers and distribution systems. Return temperatures of 58° to 60°F or higher are desirable to maximize the tank temperature difference and minimize tank volume.

Tank volume is affected by the separation maintained between the stored cold water and the warm return water. Natural stratification has emerged as the preferred approach, because of its low cost and superior performance. Colder water remains at the bottom and warmer, lighter water remains at the top. Specially designed diffusers transfer water into and out of a storage tank at a low velocity to minimize mixing.

The ***figure of merit*** (FOM) is a measure of a tank's ability to maintain such separation; it indicates the effective percentage of the total volume that will be available to provide usable cooling. Well-designed stratified tanks typically have FOMs of 85 to 95 percent.

The practical minimum storage volume for chilled water is approximately 10.7 cubic feet per ton-hour at a 20°F temperature difference.

Chilled Water System Example Application

Needing an additional 3,750 tons of peak cooling capacity for a 250,000-square-foot addition to its Dallas headquarters, Texas Instruments chose a chilled water thermal storage system: Adding chiller capacity would have cost about $10 million, while the TES system cost about $7 million—and a $200/kW utility rebate reduced this to about $5.75 million. The new system also has cut operating costs about $1.5 million per year and allowed postponement of an expansion of the facility's high-voltage substation.

The TES system uses a 5.2-million-gallon, thermally stratified chilled water storage tank, built under a parking lot.

This pre-stressed, cylindrical concrete reservoir, 140 feet in diameter and 45 feet in height, has a design discharge rate of 7,500 tons—delivering 40°F water at 12,000 gallons per minute (gpm) which returns to the tank at 55°F.

This system shifts 5.1 MW (35 percent) of existing electric chiller load to off-peak hours—about 8.5 percent of total facility demand. Five existing chillers with total capacity of 6,500 tons now remain off during the day. Mechanical cooling systems now operate more efficiently because they are more fully loaded (0.85 kW/ton versus the previous 0.95 kW/ton) and produce 13 percent more annual ton-hours of cooling.

Ice Storage

Ice thermal storage uses the latent heat of fusion of water (144 Btu per pound). Storage volume is generally in the range of 2.4 to 3.3 cubic feet per ton-hour, depending on the specific ice-storage technology.

Thermal energy is stored in ice at 32°F, the freezing point of water. The equipment must provide charging fluid at temperatures of 15° to 26°F, below the normal operating range of conventional cooling equipment for air-conditioning. Depending on the storage technology, special ice-making equipment is used or standard chillers are selected for low-temperature duty. The heat transfer fluid may be the refrigerant itself or a secondary coolant such as glycol with water or some other antifreeze solution.

The low temperature of ice can also provide lower temperature air for cooling. The lower-temperature chilled water supply available from ice storage allows

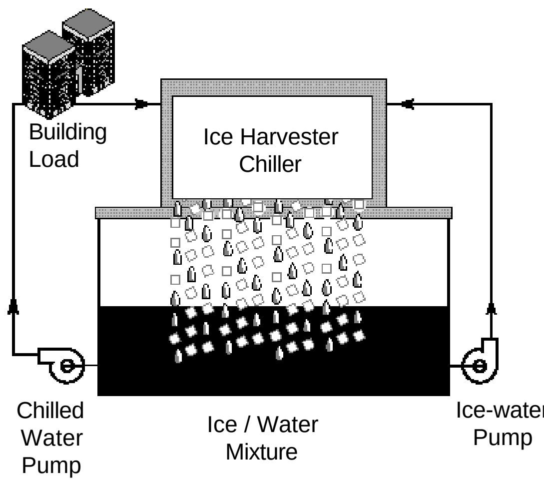

Figure 2: Ice Harvesting
*(Source: ASHRAE)**

a higher temperature rise at the load, up to 25°F. The following technologies are used:

- **Ice harvesting.** Ice is formed on an evaporator surface and periodically released into a tank partially filled with water. Cold water is pumped from the tank to meet the cooling load. Return water is then pumped over ice in the tank. Refer to Figure 2.

- **External melt ice-on-coil*.*** Ice is formed on submerged pipes or tubes through which a refrigerant or secondary fluid is circulated. Storage is discharged by circulating the water that surrounds the pipes, melting the ice from the outside.

- **Internal melt ice-on-coil.** Ice is formed on submerged pipes or tubes, as in the external melt system. Cooling is discharged by circulating warm coolant through the pipes, melting the ice from the inside.

- **Encapsulated ice.** Water inside submerged plastic containers freezes and thaws as cold or warm coolant is circulated through the tank holding the containers.

- **Ice slurry.** Water in a water/glycol solution is frozen into a slurry like the ice in a "Sno-Cone" and pumped to a storage tank. Slurries can be pumped from the tank to heat exchangers or directly to cooling coils, resulting in high energy transport rates.

The most common commercial technology today is internal melt ice-on-coil. External melt and ice-harvesting systems are more common in industrial applications, and can also be applied in commercial buildings. Encapsulated ice systems are also suitable for many commercial applications.

Ice Storage Example Application

The Seafirst Building in Bellevue, Washington uses an ice storage system and cold air distribution with smaller-than-typical ducting. An Electric Power Research Institute comparison showed that this increased gross construction costs but reduced construction cost per square foot by about $4, because reduced floor-to-floor heights allowed 21 stories within a height that would normally accommodate only 20—thus adding 13,000 square feet of rentable space. Smaller mechanical rooms added another 4,000 square feet. This provides about $340,000 per year of additional income.

Phase-Change Material Storage

Phase-change materials, or eutectic salts, are available to melt and freeze at selected temperatures. Most common is a mixture that stores 41 Btu per pound at its melting/freezing point of 47°F. This material is encapsulated in rectangular plastic containers, which are stacked in a storage tank through which water is circulated. The net storage volume of such a system is approximately six cubic feet per ton-hour.

The 47°F phase-change point of this material allows the use of standard chilling equipment. Discharge temperatures are higher than the supply temperatures of most conventional cooling systems, so operating strategies may be limited.

Phase-change materials are also available for lowering the storage temperatures of ice systems. Additives on the market reduce freezing temperatures to 28° and 12°F in ice storage tanks; they reduce the latent heat capacity of water, as well as lower the freezing point. The material is highly corrosive, so care must be used in applying it.

Operating and Control Strategies

TES operating strategies are generally classified as either ***full storage*** or ***partial storage***, referring to the amount of cooling load transferred from on-peak periods. Strategies for operation at less than design loads include chiller priority and storage priority control.

The period during which a system must reduce electric demand is generally called "on-peak," often but not necessarily synonymous with on-peak hours defined by the electric utility. In some facilities the period may actually be shorter than the utility on-peak period.

Peak electric demand from cooling also may not occur simultaneously with the peak facility demand.

Cool storage systems are usually sized to generate enough cooling in 24 hours to meet all the loads occurring during that period, but some applications use longer cycles.

Full Storage

Full-storage, or load-shifting (shown in Figure 3), shifts the entire on-peak cooling load to off-peak hours and usually operates at full capacity to charge storage during all non-peak hours. On-

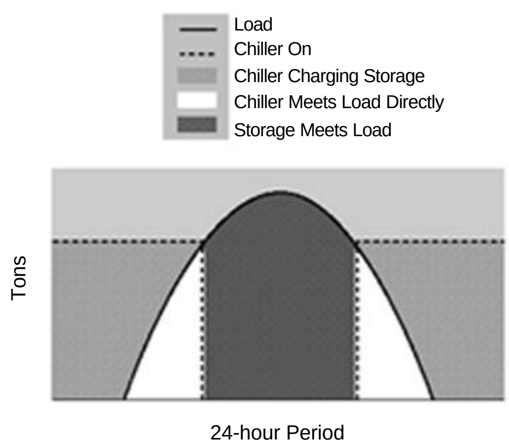

*Figure 3: Full Storage Operating Strategy (Source: ASHRAE)**

peak, all cooling loads are met from storage, and the chiller does not run. A full-storage system requires relatively large chiller and storage capacities and is most attractive where on-peak demand charges are high or the on-peak period is short.

Partial Storage

With this strategy chiller capacity is less than design load. The chiller meets part of the on-peak cooling load and storage

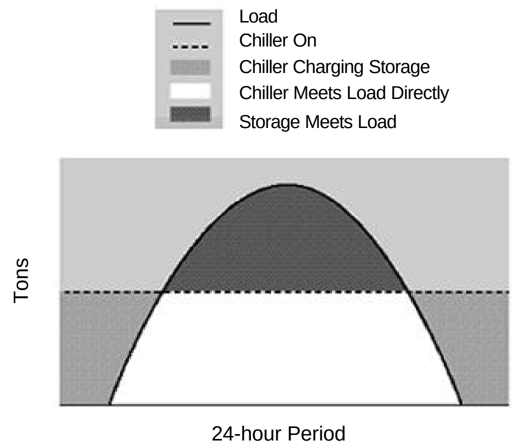

*Figure 4: Partial-storage Load-Leveling Operating Strategy (Source: ASHRAE)**

meets the rest. Such operating strategies can be further subdivided into load-leveling and demand-limiting, Figures 4 and 5.

In a load-leveling system, the chiller typically runs at full capacity for 24 hours on the design day. When the load is less than the chiller output, the excess charges storage. When the load exceeds chiller capacity, the additional requirement is discharged from storage.

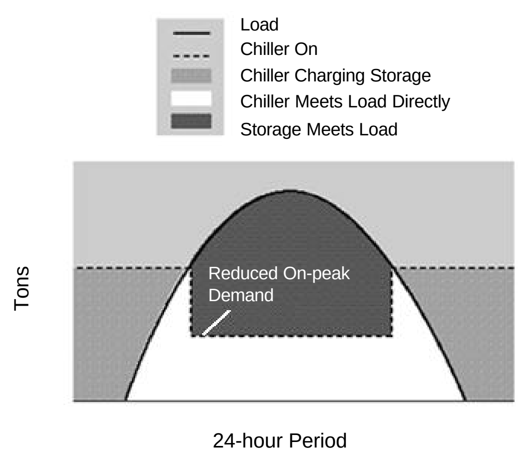

*Figure 5: Partial-storage Demand-Limiting Operating Strategy (Source: ASHRAE)**

This approach minimizes required chiller and storage capacities and is particularly attractive where peak cooling load is much higher than average load. In many systems, cooling loads during off-design periods are small enough that partial-storage systems may be operated as full-storage systems. This can increase savings but care must be taken to not deplete storage before the on-peak period is over.

A demand-limiting partial-storage system operates the chiller at reduced capacity on-peak. The chiller may be controlled to limit the facility demand at the billing meter. This strategy falls between load shifting and load leveling. Demand savings and equipment costs are higher than for load-leveling, and lower than for load-shifting. Here too care must be taken not to deplete storage before the end of the on-peak period.

Additional variations on the full- and partial-storage strategies are possible by scheduling the operation of multiple chillers.

Partial-storage systems use one of two control strategies to divide the load between chiller and storage. A chiller-priority strategy uses the chiller to directly meet as much of the load as possible. Cooling is supplied from storage only when load exceeds chiller capacity. Storage-priority meets as much of the load as possible from stored cooling, using the chiller only when daily load exceeds total stored cooling capacity. Some systems use combinations of these strategies. For example, chiller priority during off-peak daytime hours, and storage priority during on-peak hours.

Applicability

Thermal energy storage can be used in virtually any building; the merits are compelling in the right situations. The main issues are the type of storage system and the amount of cooling load to be shifted. Before embarking on a cool storage project, however, one should consider the field observation guidelines below. In addition, alternative approaches should be considered for each project.

Field Observations to Assess Feasibility

This section discusses observations and checks that can ensure a TES system is appropriate and is installed and working properly.

Related to Applicability

The many successful TES systems operating today demonstrate that the technology can provide significant benefits. However, many cool storage systems have failed to perform as predicted because they did not meet the criteria for applicability cited below.

Cool storage systems are most suitable where any of the following criteria apply:

- **The maximum cooling load of the facility is significantly higher than the average load.** The higher the ratio of peak load to average load, the greater the potential.

- **The electric utility rate structure includes high demand charges**, ratchet charges, or a high differential between on- and off-peak energy rates. The economics are particularly attractive where the cost of on-peak demand and energy is high.

- **An existing cooling system is being expanded.** The cost of adding cool storage capacity can be much less than the cost of adding new chillers.

- **An existing tank suitable for cool storage use is available*.*** In some retrofits, particularly in industrial applications, using existing tanks can reduce the cost of installing cool storage.

- **Electric power available at the site is limited*.*** Where expensive transformers or switchgear would otherwise have to be added, the reduction in electric demand through the use of cool storage can mean significant savings.

- **Backup or redundant cooling capacity is desirable*.*** Cool storage can provide short-term backup or reserve cooling capacity for computer rooms and other critical applications.

- **Cold air distribution can be used**, is necessary, or would be beneficial. Cool storage technologies using ice permit economical use of lower-temperature supply water and air. Engineers can downsize pumps, piping, air handlers, and ductwork, and realize substantial reductions in first cost.

If one or more of the following are true, TES may not be an appropriate technology:

- **The maximum cooling load of the facility is very close to the average load.** A TES system would offer little opportunity to downsize chilling equipment.

- **On-peak demand charges are low** and there is little or no difference between the costs of on- and off-peak energy. There is little economic value for customers to shift cooling to off-peak periods.

- **The space available for storage is limited**, there is no space available, the cost of making the space available is high, or the value of the space for some other use is high.

- **The cooling load is too small to justify the expense of a storage system*.*** Typically, a peak load of 100 tons or more has been necessary for cool storage to be feasible.

- **The design team lacks experience or funding to conduct a thorough design process.** The design team should be capable of TES design, which differs from standard HVAC system design. If this is not the case, or if funding for design fees is limited, the chances for a successful system are reduced.

Performance testing of a new thermal storage plant is particularly important. Each system should be tested for charge capacity, discharge capacity, and scheduling and control sequences.

The charge capacity test verifies that the system can fully charge storage within the available time. The discharge capacity test verifies its ability to provide the required cooling, at or below the maximum usable supply temperature, for each hour over the design load profile. Of primary concern is that stored thermal energy is used at a rate consistent with the design. Especially in chilled water systems, if oversized pumps circulate water at higher than design flow rates, a smaller supply-return temperature difference will reduce the capacity of the storage system.

A test of scheduling and control sequences confirms the proper operation of valves, resetting of setpoints, and starting and stopping of equipment, according to scheduled operating modes.

A TES system operates differently from a nonstorage system, in that the inventory of stored cooling must be properly managed. Operators of TES systems must receive training in basic concepts as well as the intended operating sequences and specific operating procedures for their systems. As operators gain experience they can improve system performance and minimize operating costs by refining the design operating strategies and control setpoints.

Related to Energy Savings

In new construction, TES systems can reduce overall energy consumption even though there may be increased use in the chiller: distribution of colder chilled water can allow use of smaller pumps and less fan horsepower to circulate a smaller quantity of air through the cooling coils.

In retrofits it also is possible to reduce energy consumption but generally less so than in new construction. Here energy savings result from chillers operating at full load nearly all the time, potentially at higher efficiency. And operation is generally at night when lower ambient temperatures make for cooler condenser temperatures, reducing energy use.

However, TES systems do not always save energy. A retrofit using ice storage that fails to take advantage of the colder water available from the ice system may consume more energy than a direct cooling system. Yet this system can make economic sense—consuming more off-peak, lower cost energy at night can still significantly reduce expensive electrical demand and expensive on-peak electricity use.

Related to Implementation Cost

Most TES systems cost more up front and (if cost-effective) pay off through reduced electricity bills. But carefully designed systems needn't cost more—or much more—than conventional HVAC systems.

Sometimes cool storage systems can cost less and save energy. The Texas Instruments' case study discussed earlier describes one of three chilled-water storage installations in Dallas that have reduced energy consumption by more than 10 percent compared to nonstorage alternatives. The TI installation also reduced capital costs millions of dollars by deferring the need for added chiller capacity. Other factors that may help reduce cost of implementation include:

- **Smaller air flows will provide adequate cooling** in new construction or major retrofits, especially for ice storage. This can decrease the duct diameter, reducing not only the cost of the ductwork, fans, and pumps but also the installation labor cost.

- **Smaller ducts may increase rentable space** in new construction.

- **System sizing is critical.** For example, a careful assessment of the number of hours that peak load must be met with stored cooling could show that a considerably smaller storage system may only minimally affect demand reduction.

Estimation of Energy Savings

Demand costs are the main consideration in determining the economics of a TES system. Energy savings may be achieved, particularly in new construction or major renovation projects, but typically are a small percentage of operating cost savings. In fact, energy consumption may increase and still allow for an economically viable project.

To determine economic feasibility, accurate cooling load data from the existing chiller plant is always best. If data are not available, not considered reliable or incomplete, or if only a short time period of data has been collected, an hourly computer simulation model must be developed by a reputable energy analysis professional. Available data, even for only a short period, can be used to help calibrate the simulated building model and improve its accuracy.

Back-of-the-envelope calculations can give a rough estimate of possible savings but must not be used for the final economic analysis, or chiller or storage tank sizing.

Standard Savings Calculation

The following equation can be used in estimating demand savings from TES systems. While energy consumption may increase or decrease, the change generally has only a minor impact on project economics. The time period when the energy is consumed has a significant impact; i.e. on-peak demand reduction or displacing expensive on-peak energy with less expensive off-peak energy use. In general, system economics depend heavily on the demand savings and/or on-peak/off-peak rate differential. Demand savings must be calculated for each month of chiller operation.

$$kW_{savings} = \#\ tons_{shifted} \times (kW/ton)_{chiller\ performance}$$

Energy shifted to off-peak is more difficult to calculate without monitored field data or a calibrated, hourly computer simulation. A rough estimate can be calculated as follows:

$$kWh_{shifted} = \#\ tons_{shifted} \times (kW/ton)_{chiller\ performance} \times \text{on-peak hours} \times \text{load shape factor}$$

The load shape factor is a needed multiplier because peak cooling load typically is not constant. This factor, used in the above equation, is for the on-peak period only (the time when cooling load will be shifted) and for the peak cooling load for that day. Typical load shape factors are in the range of 60 to 90 percent for a variety of building types and climates. Annual energy shifted is the sum of daily energy shifted. At this point, an estimate can be made using an average cooling load for each month and the number of cooling days in the month, then summing the monthly totals.

Cost and Service Life

Factors That Influence Service Life and First Cost

Typically, a TES system increases costs compared to those for a direct cooling system. But a much larger picture needs to be looked at. Additional issues include:

- **Floor Height:** In new construction, can low-temperature air distribution—which uses smaller, less expensive ductwork—reduce floor-to-floor height?

- **Electrical Capacity:** Can using TES reduce the capacity and therefore the cost of the electrical service to a new project, or avoid increasing the service in the case of a building expansion?

- **Useable Space:** Can using TES, with an underground storage tank, such as under a parking lot, free up space in an existing chiller plant or reduce the size of a new structure?

Costs given in Table 1 are general guidelines for initial economic evaluations of storage systems. They include the cost of storage tanks and any required internal diffusers, headers, or heat transfer surface. Costs will vary depending on the size of the project and site-specific considerations, among other things. Accurate cost estimates for a specific application can be obtained from contractors or vendors.

Costs for chilled water tanks are based on volume, so the cost per ton-hour depends on the chilled water temperature range. Unit storage costs decrease as tank size increases. The cost of chillers or refrigeration equipment must be considered along with the cost of storage capacity. Chilled water and phase-change material storage are compatible with typical conventional HVAC temperatures, and can often be added to existing systems with no chiller modifications. For ice-harvesting systems, low storage cost is offset by a relatively high cost for the ice-making equipment.

Typical Service Life

In addition to all equipment in a traditional cooling system, a TES system has a storage tank, pumps, piping and possibly an interface heat exchanger. The service life of each component (except the actual storage tank) has been estimated and can be found in Reference 1. All TES-specific components are rated at a 20-year minimum service life. Storage tanks, generally concrete or steel, also have service lives of at least 20 years.

Operation and Maintenance Requirements

Factors that tend to increase maintenance costs for cool storage systems compared to nonstorage systems include:

- **Annual tests** to ensure solutions contain proper coolant concentration, levels of corrosion inhibitors, and other

	Chilled Water	Ice Harvester	External Melt Ice	Internal Melt Ice	Encapsulated Ice	Phase-change Material
Chiller Cost	Standard water	Pre-packaged or built-up ice-making equipment	Low-temperature coolant or built-up refrigeration plant	Low-temperature secondary coolant	Low-temperature secondary coolant	Standard water
Chiller Cost[a] $/ton	200-300, or use existing	1,100-1,500 per ice-making ton	200-500	200-500	200-500	200-300, or use existing
$/kW	57-85	313-427	57-142	57-142	57-142	57-85
Tank Volume ft^3/ton-hr	11-21	3.0-3.3	2.8	2.4-2.8	2.4-2.8	6.0
Storage Installed Cost[b] $/ton-hr	30-100	20-30	50-70	50-70	50-70	100-150
$/kWh	8.50-28	5.70-8.50	14-20	14-20	14-20	48-43
Charging Temperature (°F)	39-42	15-24	15-25	22-26	22-26	40-42
Chiller Charging Efficiency kW/ton	0.60-0.70	0.95-1.3	0.85-1.4	0.85-1.2	0.85-1.2	0.60-0.70
COP	5.9-5.0	3.7-2.7	4.1-2.5	4.1-2.9	4.1-2.9	5.9-5.0
Discharge Temperature[c] **(°F)**	1-4 above charging temperature	34-36	34-36	34-38	34-38	48-50
Discharge Fluid	Water	Water	Water	Secondary coolant	Secondary coolant	Water
Tank Interface	Open tank	Open tank	Open tank	Closed system	Open or closed system	Open tank
Strengths	Use existing chillers; fire protection duty	High instantaneous discharge rates	High instantaneous discharge rates	Modular tanks good for small or large installations	Tank shape flexible	Use existing chillers
Comments	Storage capacity increases with larger temperature range.	Requires clearance above tank for ice maker.	Separate charge and discharge circuits. Charge with coolant or liquid refrigerant.			

Notes:

a: Costs are for chiller or refrigeration plant only, and do not include installation. All costs, except ice harvesters, are per nominal ton. Derating for actual operating conditions may be required.

b: Costs are for storage only, and include tank, internal diffusers, headers, and heat transfer surface.

c: Typical minimum temperatures, with appropriate sizing of storage capacity. Higher temperature can be obtained from each medium.

*Table 1: Comparative Costs and Performance of Cool Storage Systems (Source: ASHRAE)**

additives for ice storage systems using glycol or other secondary coolants. Some glycol manufacturers provide free laboratory analysis of samples. There may also be an expense associated with replacing glycol lost during maintenance procedures and through leaks.

- **Increased water treatment expense** in chilled water storage and some ice storage systems, which contain large volumes of chilled water in the tanks.

- **Added maintenance** for cool storage system components, such as additional pumps, heat exchangers, and control valves.

Factors that tend to decrease maintenance costs for cool storage systems include:

- **Smaller components,** such as chillers, pumps, and cooling towers, for typical systems.

- **Glycol or other secondary coolants in the system provide coil freeze protection**, and eliminate the need to drain the cooling system in the winter, or to use special controls to prevent coil freeze-ups.

- **Cooling loads can be met from storage** while some equipment is taken out of service for maintenance in some storage systems.

Laws, Codes, and Regulations

All equipment and components used for a TES system should conform with the same laws, codes, and regulations required for traditional cooling systems. Large tanks may pose a problem. Zoning requirements, particularly height restrictions, should be checked early. If height is an issue, it is possible to completely or partially bury it. It is also possible that a levee will be required around the tank in case of a rupture.

If a fire-protection storage tank is required on site, as it would be at some manufacturing facilities, it may be possible to use this tank to store chilled water for the cooling system. If this is available, it should be carefully checked to ensure code compliance.

Definitions of Key Terms

- **Condenser:** The container in a cooling system where gas changes phase to liquid, releasing heat to the surroundings.

- **Demand Charge:** A tariff added to a customer's electric bill that increases in proportion to maximum kilowatts used.

- **DX (direct expansion):** Refers to a heat exchanger that contains the refrigerant inside its tubing rather than water, antifreeze, or other fluid. Heat from the surroundings is directly absorbed into the refrigerant, which is "pumped" by the compressor.

- **Figure of Merit (FOM):** A measure of a storage tank's ability to maintain separation between warm and cool water.

- **Full Storage:** Refers to a TES system that stores sufficient cooling to meet an entire peak day cooling capacity, allowing chillers to be off during the on-peak period.

- **Off-Peak:** A time period, defined by the utility, when the cost of providing power is relatively low, because the system demand for power is low. The off-peak period is often characterized by lower costs to the customer for energy costs, and either no or low demand charges.

- **On-Peak:** A time period, defined by the utility, when the cost of providing power is high because the system demand for power is high. The on-peak period is typically characterized by higher costs to the customer for energy and/or demand charges.

- **Partial Storage:** Refers to a TES system that contains sufficient cool storage to meet part of the cooling load of a facility. Such systems are used in conjunction with a chiller system to provide required cooling capacity.

- **Phase Change:** As a substance changes between its solid, liquid, and gaseous forms, it is said to change phase. During transitions in phase—freezing, melting, condensing, boiling—the material releases or absorbs large amounts of thermal energy without changing temperature. The energy associated with this is called latent heat. A material that can store thermal energy as latent heat is called a phase-change material.

- **Sensible Heat:** Heat that can be perceived by the human senses, as opposed to latent heat (see phase change definition).

References to More Information

1. American Society of Heating Refrigeration, and Air-Conditioning Engineers, "ASHRAE Handbook HVAC Applications," June 1995.

2. American Society of Heating Refrigeration, and Air-Conditioning Engineers, "Design Guide for Cool Thermal Storage," 1994.

3. Electric Power Research Institute (EPRI) HVAC & R Center (formerly the Thermal Storage Air Conditioning Center), University of Wisconsin, 150 East Gilman Street, Suite 2200, Madison, WI 537093, Tel: (800) 858-3774, Fax: (608) 262-6209.

4. E Source, "State of the Art Technology Atlas: Commercial Space Cooling and Air Handling," Chapter 11, 1995.

5. International Thermal Storage Advisory Council (ITSAC), 3769 Eagle Street, San Diego, CA 92103, Tel: (619) 295-6267.

Major Manufacturers

Chicago Bridge & Iron Co.
1501 N. Division Street
Plainfield, IL 60544-8929
Tel (815) 439-6000
Fax (815) 439-6010
E-mail: www.chicago-bridge.com

San Luis Tank & Piping Co.
825 26th Street
Paso Robles, CA 93447
Tel (805) 238-0888
Fax (805) 238-5123

Cryogel
P.O. Box 910525
San Diego, CA 92191
Tel (619) 792-9003
Fax (619) 792-2743
E-mail: tes@cryogel.com

For more information on companies who make TES components see Reference 4 above. In addition, you may contact the International Thermal Storage Advisory Council (Reference 5) or the EPRI HVAC & R Center (Reference 3).