A Technical Introduction to Cool Thermal Energy Storage Commercial Applications

Cool Thermal Energy Storage is a new application of an old idea that can cut air conditioning energy costs in half while preparing your building for the future.

Air conditioning of commercial buildings during summer daytime hours is the largest single contributor to electrical peak demand. In the afternoon, as more air conditioning is needed to maintain comfortable temperatures, the increased demand for electricity adds to the load already created by lighting, operating equipment, computers and many other sources. This requires the electric suppliers to bring additional, more costly generating equipment on line to handle this increased demand. Commercial users, whose large air conditioning loads greatly contribute to the need for these seldomly used generating stations, are charged more for this "On Peak" energy, either in the form of higher energy charges (kWh) or a "Demand Charge" which is based on their highest on-peak demand (kW) for electricity. The "On-Peak" demand charge is normally based on the electricity required (in kW) over a specified time period, usually 15 or 30 minutes, assessed on a monthly or yearly basis.

An IceBank® Cool Storage System, commonly called Thermal Energy Storage, is a technology which shifts electric load to off-peak hours which will not only significantly lower energy and demand charges during the air conditioning season, but can also lower total energy usage (kWh) as well. It uses a standard chiller to produce solid ice at night during off-peak periods when the building's electrical loads are at a minimum. The electric supplier's generating capacity is also typically under-utilized at night and, consequently, its rates are lowest then. The ice is built and stored in modular ice tanks to provide cooling to help meet the building's air conditioning load requirement the following day allowing chillers to be downsized or turned off.

Cool Storage is a proven method of reducing operating costs with over 6000 installations worldwide. Cool Storage improves a user's negotiating position with energy suppliers in the deregulated environment, because it increases a building's "Load Factor"

(Average Load ÷ Peak Demand). The higher the load factor the more attractive the customer. In fact, Cool Storage systems are one of the electric suppliers' best option for increasing load factors on their generating equipment and avoiding the costs of new generating plants.

IceBank Systems not only can cut operating costs but they can also substantially reduce capital outlays when systems are suitably designed for new commercial and industrial buildings. Engineers can specify half-size chillers operating 20-24 hours a day rather than full-size chillers operating only 10 or 12 hours per day. In retrofit applications, an IceBank Cool Storage System can often provide cooling for an addition or increased loads to a building without adding chiller capacity.

COOL STORAGE

SAVES...

Building Owners
Money and Energy

Utility Companies
Energy and Assets

PROTECTS...

The Environment's Resources
By Lowering Emissions

The Concept of Stored Cooling Systems

In conventional air conditioning system design, cooling loads are measured in terms of "Tons of Refrigeration" (or kW's) required, or more simply "Tons." Cool Storage systems, however, are measured by the term "Ton-Hours" (or kW-h). Figure 1 represents a theoretical cooling load of 100 tons maintained for 10 hours, or a 1000 ton-hour cooling load. Each of the 100 squares in the diagram represents 10 ton-hours.

Realistically, no building air conditioning system operates at 100% capacity for the entire daily cooling cycle. Air conditioning loads peak in the afternoon -- generally from 2 to 4 PM -- when ambient temperatures are highest. Figure 2 represents a typical building air conditioning load profile during a design day.

As you can see, the full 100-ton chiller capacity is needed for only two hours in the cooling cycle. For the other eight hours, less than the total chiller capacity is required. If you count the tinted squares, you will total 75, each representing 10 ton-hours. A 100-ton chiller must be specified, however, to handle the peak 100-ton cooling load.

"Diversity Factor" is defined as the ratio of the actual cooling load to the total potential chiller capacity, or:
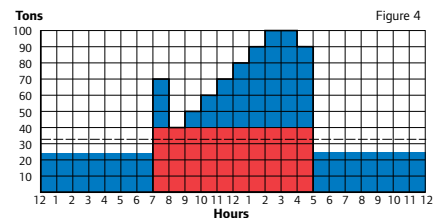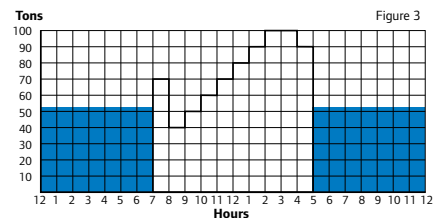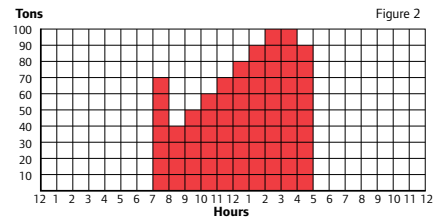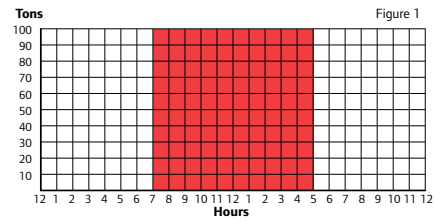
$$\text{Diversity Factor (\%)} = \frac{\text{Actual Ton-Hr.}}{\text{Total Potential Ton-Hr.}} = \frac{750}{1000}$$

This chiller, then, has a Diversity Factor of 75 percent. It is capable of providing 1000 ton-hours when only 750 ton-hours are required. If the Diversity Factor is low, the system's cost efficiency is also low. (The lower the Diversity Factor, the greater the potential benefit from a Cool Storage system.)

Dividing the total ton-hours of the building by the number of hours the chiller is in operation gives the building's average load throughout the cooling period. If the air conditioning load could be shifted to the off-peak hours or leveled to the average load, less chiller capacity would be needed, 100 percent diversity would be achieved, and better cost efficiency would result.

Full Storage or Partial Storage?

There are any number of control strategies that can be utilized to take advantage of the benefit of Cool Storage, however, there are two basic approaches that define the common limits of the system design. The electric rates will determine which control strategies are best for the project. When electric rates justify a complete shifting of air-conditioning loads, a conventionally sized chiller can be used with enough energy storage to shift the entire load into off-peak hours. This is called a Full Storage system and is used most often in retrofit applications using existing chiller capacity. Figure 3

Figure 1

Figure 2

Figure 3

Figure 4

shows the same building air conditioning load profile but with the cooling load completely shifted into 14 off-peak hours. The chiller is used to store ice in IceBank tanks during the night. The 32 F energy stored in the ice then provides the required 750 ton-hours of cooling during the day. The average load has been lowered to 53.6 tons (750 ton-hours ÷ 14 = 53.6). The chiller does not run at all during the day, which results in significantly reduced demand charges. In new construction, a Partial Storage system is usually the most practical and cost-effective load management strategy. In this case, a much smaller chiller is allowed to run any hour of the day. It charges the ice storage tanks at night and cools the load during the day with help from stored cooling. Extending the hours of operation from 14 to 24 results in the lowest possible average load (750 ton-hours ÷ 24 = 31.25), as illustrated by the dotted line in Figure 4. Demand charges are greatly reduced and chiller capacity can often be decreased by 50 to 60 percent or more.

Note that although the building's average 24-hour load is 31.25 tons, the chiller's actual capacity is slightly higher during the day and lower at night. This is because of the chiller's 30 to 35 percent derated capacity for ice making, described on the following page. (This is not to be mistaken for an efficiency de-rating.)
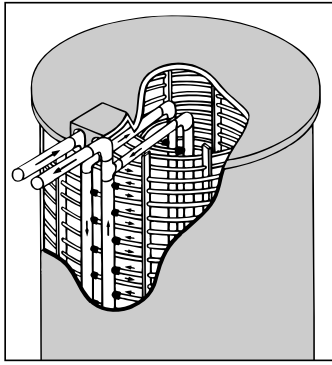
How the IceBank® System Works

Figure 5

The essential element of the CALMAC® IceBank System is a modular, insulated, polyethylene tank containing a spiralwound plastic tube heat exchanger surrounded with water. The tank is available in many sizes ranging from 45 to over 500 ton-hours. At night, water containing 25% ethylene glycol, is cooled by a chiller and is circulated through the heat exchanger, extracting heat until eventually about 95% of the water in the tank is frozen solid. The ice is built uniformly throughout the tank by the patented temperatureaveraging effect of closely spaced counter-flow heat exchanger tubes, (Figure 5). Water does not become surrounded by ice during the freezing process and can move freely as ice forms, preventing damage to the tank.

Typical flow diagrams for a Partial Storage system are shown in Figures 6 and 7. At night, the water-glycol solution circulates through the chiller and the tank's heat exchanger, bypassing the air handler coil. The fluid is 25 F and freezes the water surrounding the heat exchanger.

The following day, the stored ice cools the solution from 52 F to 34 F. A temperature modulating valve set at 44 F in a bypass loop around the tank permits a sufficient quantity of 52 F fluid to bypass the tank, mix with 34 F fluid, and achieve the desired 44 F temperature. The 44 F fluid enters the coil, where it cools air typically from 75 F to 55 F . The fluid leaves the coil at 60 F, enters the chiller and is cooled to 52 F.

It should be noted that, while making ice at night, the chiller must cool the water-glycol solution to 25 F, rather than produce 44 F or 45 F water temperatures required for conventional air conditioning systems. This has the effect of "de-rating" the nominal chiller capacity by approximately 30 to 35 percent. Compressor efficiency, however, will vary only slightly (either better or worse) because lower nighttime temperatures result in cooler condenser temperatures and help keep the unit operating efficiently.

The temperature-modulating valve in the bypass loop has the added advantage of providing unlimited capacity control. During many mild temperature days in the spring and fall, the chiller will be capable of providing all the necessary cooling for the building without assistance from stored cooling. When the building's actual cooling load is equal to or lower than the chiller's capacity, all of the system coolant flows through the bypass loop, (Figure 8).

Please note that the glycol recommended for the solution is an ethylene glycol-based industrial coolant, which is specially formulated for low viscosity and superior heat transfer properties. These contain a multi-component corrosion inhibitor system which permits the use of standard system pumps, seals and air handler coils. Because of the slight difference in heat transfer coefficient between water-glycol and plain water, the supply liquid temperature may have to be lowered by one or two degrees. This is easily achieved by the ice.
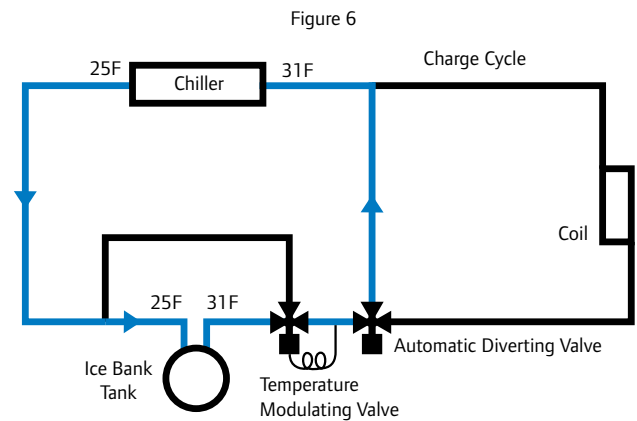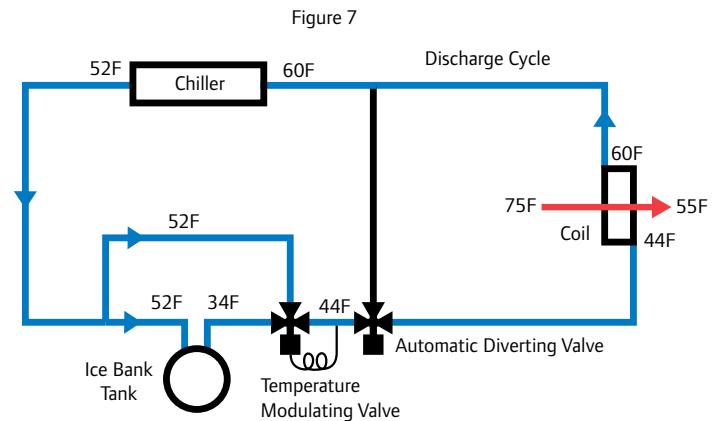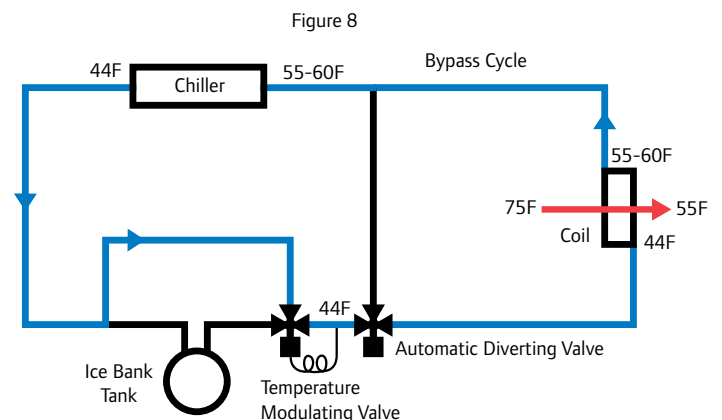

Figure 6
Charge Cycle

Figure 7
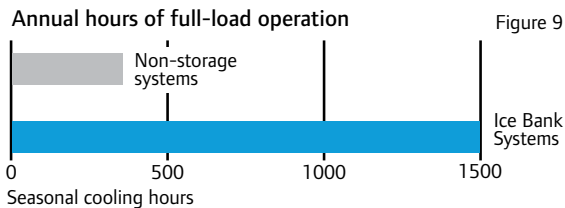Discharge Cycle

Figure 8
Bypass Cycle

Why It Can Reduce Air Conditioning Costs and Energy Use

Off-peak operation

Running the chiller at night substantially reduces electrical costs since energy is used off-peak when electric generating facilities are typically under-utilized by 50 percent or more. Many suppliers offer time-of use rates that include a 20 to 90 percent reduction in electrical energy prices at night specifically to encourage load shifting. This, with the reduction of all or part of the demand charges, results in a substantial saving in operating costs. In general, Cool Storage increases a building's load factor, which significantly reduces operating costs and increases a user's ability to negotiate favorable rates. In essence the customer becomes a Preferred Power User.
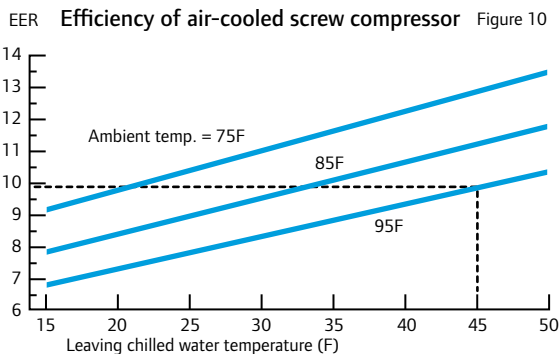
Constant full-load operation

On-off cycling and capacity modulation occurs throughout the day in most air conditioning systems in response to the cooling load of the building. Therefore, most air conditioning systems operate within their most efficient range less than 25 percent of the time, (Figure 9). With the Ice Bank® System, the chiller runs at or near full load (peak efficiency) continuously, eliminating the inefficient cycling that accompanies part-load operation.

Annual hours of full-load operation   Figure 9

Non-storage systems

Ice Bank Systems

| 0 | 500 | 1000 | 1500 |

Seasonal cooling hours

Nighttime condensing temperatures

Air-cooled chillers perform most efficiently when the outdoor temperatures are relatively low, as naturally occurs during cooler nighttime hours. Operation at night with 20 degree lower condensing temperatures can improve energy efficiency typically by 2 to 8 percent over non-storage systems operating during the day, (Figure 10).

EER   **Efficiency of air-cooled screw compressor**   Figure 10

Ambient temp. = 75F

85F

95F

Leaving chilled water temperature (F)

Cold air distribution

The use of 44 F air in the duct system rather than the usual 55 F air permits further huge savings in initial and operating costs. This colder air is achieved by piping low temperature (36-38 F) water-glycol solution from the Ice Bank tanks to the air handler coil. The 44 F air is used as primary air and is distributed to a high induction rate diffuser or a fan-powered mixing box where it is fully mixed with room air to obtain the desired room temperature. The 44 F primary air requires much lower airflow than 55 F air. Consequently the size and cost of the air handlers, motors, ducts and pumps may be cut 20 to 40 percent. Colder air also lowers relative humidity, therefore occupants feel comfortable at higher, energy-saving thermostat settings. The Electric Power Research Institute reports that "overall HVAC operating costs can be lowered by 20 to 60 percent by using ice storage and cold air distribution." (EPRI brochure CU-2038 "Cold Air Distribution with Ice Storage," July 1991.)

Fast Installation, low maintenance

Ice Bank tanks are compact, factory made modular units, easily shipped and installed. They contain no moving parts, have no corrodible materials and are backed by a 10-year limited warranty. The tanks can be located indoors or outdoors, even stacked or buried to save space. They can also be easily moved if required in future building expansions.

Benefits electric suppliers and the environment

The Ice Bank system is a technology that conserves energy for the generators of electricity as well as the customer. Generation plants operating on-peak have much higher heat rates (fuel BTUs required per kW-h generated) than energy generated at night. A 1996 report by the California Energy Commission (CEC), revealed that summer peak heat rate of a large west coast utility was 11,744 BTUs per kWh as opposed to its off-peak heat rate of 7,900 BTUs per kWh.* This means that during the summer months, off-peak generation of electricity consumes up to 30 percent less fossil fuel per kWh than during peak periods. The CEC report further concluded that Cool Storage could save enough energy in California to supply over a third of the new air conditioning load projected for the next decade. Fewer BTUs per kWh also means reduced air emissions, a feature that can contribute significantly to our environmental quality.

Economic Analysis of "Right Sizing" Partial Storage Design

Cool Storage Strategies

Full and Partial storage are two common Cool Storage strategies used today. The most cost effective and flexible strategy is partial storage. Partial storage can help with cost effective growth as facilities fill up or build out. An effective partial storage method can be applied with "right sizing." This partial storage strategy minimizes risk and maximizes operational savings and simplicity. A simple inexpensive control strategy using chilled water reset can enable the Cool Storage system to shift from chiller priority to ice priority as rates, seasons, and occupancy change.

Facility and Rate Description

Assume: 400-ton peak cooling load, 10-hour cooling day, 75% diversity factor, $13.00 / kW / month utility demand charge, and an 7 month cooling season.

Conventional chilled water air conditioning system sizing and installed costs:

(2) 240-ton air cooled chiller @ $1,000/ton, installed*	**$480,000**
Air Distribution system	**$240,000**

Two chillers are installed, as is common practice, to provide cooling should one chiller or chiller ancillary be off line. The total installed capacity is 20% higher than peak cooling design loads to provide a safety factor for unexpected loads and higher cooling capacity should one chiller be off line.

Total	**$720,000**

Right Sizing with Partial storage (80% size chiller with IceBank System) installed costs:

At 75 percent diversity factor, the true cooling load translates into 3,000 ton-hours with the one chiller providing 1,600 ton-hours and stored cooling the balance, or 1,400 ton-hours. Therefore right sizing uses:

(2) 160-ton air cooled chiller @ $1,000/ton, installed*	**$320,000**
Stored cooling @ $150/ton hour, installed**	**$210,000**
Air Distribution system	**$240,000**

(Right sizing with partial storage allows one or both chillers to make ice and requires only one chiller to augment stored cooling during daytime operation. However, the storage design gives more safety factor (peak capacity of 580 tons with both chiller and storage vs. 480 for non-storage system) as well as more redundancy in the event of a component failure. **Thermal energy storage is simply a different, more valuable safety factor.**

Total	**$770,000**
Purchase premium for ice:	**$50,000**
Investment simple Payback from demand savings:	
Annual Savings	
(400-160) tons x 1.2 kW/ton x 7 months x $13/kW =	**$26,208**
Payback	
Purchase premium / annual savings = $50,000 / $26,208 per year =	**1.9 years**

* The $1,000 / ton for air-cooled chillers includes all accessories such as pumps, piping, controls, etc.
** The $150 / ton-hour for the ice tank installation is outdoors on a pad, with glycol, piping, controls, etc.

Related CALMAC® Products

SUB-ICE low temperature storage solutions

Non-toxic eutectic salts are available to lower the freezing point of the water in IceBank tanks to 12 F and, consequently, the temperature of the "salt ice". 12 degree ice can be used for on-ground aircraft cooling, and for industrial process applications requiring colder liquids.

Liquid pressurization systems for optimal cooling system performance

Managing the liquid in your cooling system is easy with CALMAC's GMS. Comprised of a pump coupled to a 68 gallon vented reservoir, a CALMAC GMS incorporates a series of alarms to monitor high or low liquid levels, low system pressure, loss of power, or the need to add additional solution to the system. When a pressure below a specified level is detected, solution from the reservoir is pumped into the system maintaining its proper pressure. Installs easily indoors or out and provides a simple, cost-effective solution to a potentially costly problem.

LET'S GO BEYOND™

To find out more about IceBank® energy storage visit calmac.com *or* trane.com/energystorage

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Club Car® **IR** Ingersoll Rand® **TK** THERMO KING® TRANE®

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