


CALMAC


A TECHNICAL INTRODUCTION
TO THERMAL ENERGY STORAGE
COMMERCIAL APPLICATIONS

THERMAL ENERGY STORAGE (TES) IS A NEW APPLICATION OF AN OLD IDEA THAT CAN CUT AIR CONDITIONING ENERGY COSTS IN HALF

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 Ice Bank® Thermal Energy Storage (TES) System 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.

THERMAL ENERGY STORAGE

SAVES...

Building Owners
Money and Energy

Utility Companies
Energy and Assets

PROTECTS...

The Environment's Resources
By Lowering Emissions

TES is a proven method of reducing operating costs with over 6000 installations worldwide. TES 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, TES systems are electric suppliers' best option for increasing load factors on their generating equipment and avoiding the costs of new generating plants.

Ice Bank Systems not only can cut operating costs in half 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 Ice Bank TES System can often provide cooling for an addition or increased loads to a building without adding chiller capacity.

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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." TES 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.

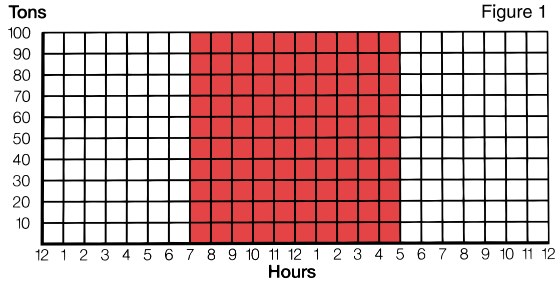
As you can see, the full 100-ton chiller capacity is needed for only two hours in the cooling cycle. For the other eight hours, less than the total chiller capacity is required. If you count the tinted squares, you will total 75, each representing 10 ton-hours. A 100-ton chiller must be specified, however,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

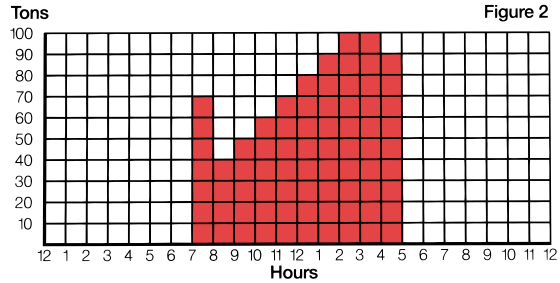
"Diversity Factor" is defined as the ratio of the actual cooling load to the total potential chiller capacity, or:

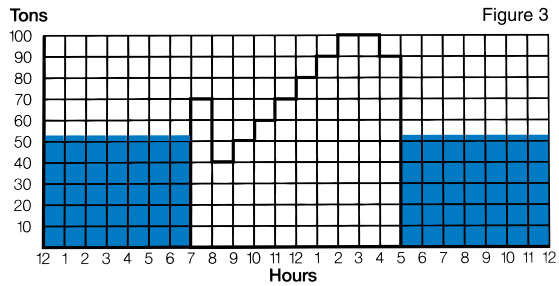
$$\text{Diversity Factor (\%)} = \frac{\text{Actual Ton-Hr.}}{\text{Total Potential Ton-Hr.}} = \frac{750}{1000}$$

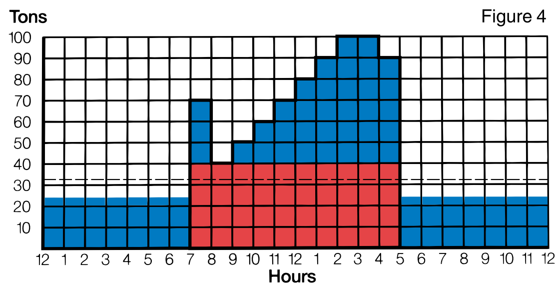
This chiller, then, has a Diversity Factor of 75 percent. It is capable of providing 1000 ton-hours when only 750 ton-hours are required. If the Diversity Factor is low, the system's cost efficiency is also low. (The lower the Diversity Factor, the greater the potential benefit from a TES system.)

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 TES, 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 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 Ice Bank 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 ICE BANK SYSTEM WORKS

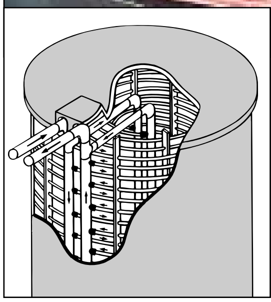


Figure 5

The essential element of the Calmac Ice Bank System is a modular, insulated, polyethylene tank containing a spiral-wound 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 temperature-averaging 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

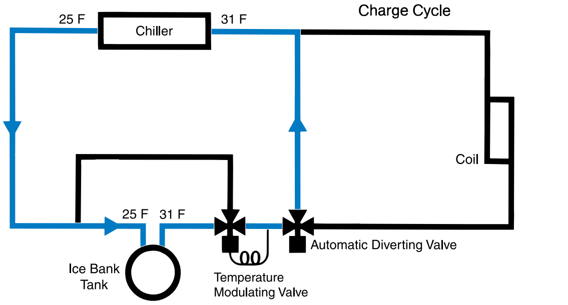


Figure 7

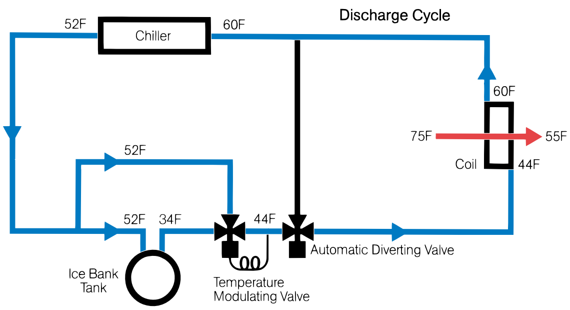
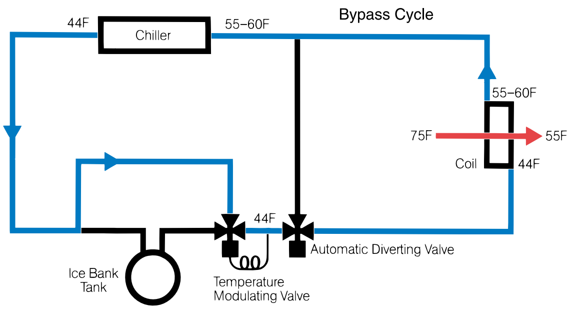


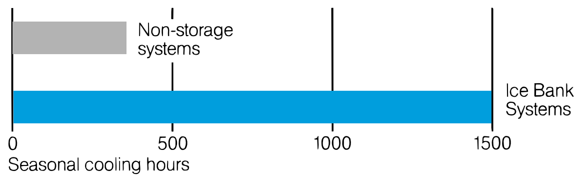
Figure 8



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, TES 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.

Annual hours of full-load operation Figure 9



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.

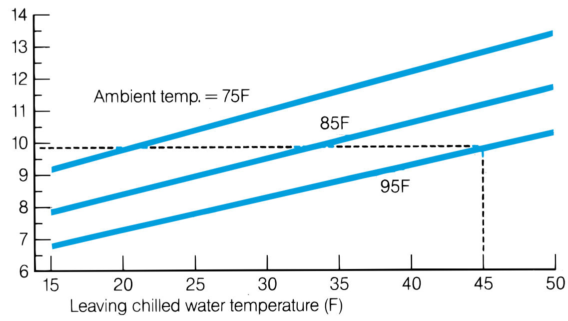
Nighttime condensing temperatures

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).

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

EER Efficiency of air-cooled screw compressor Figure 10



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 recent 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 TES 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.

New Model 1500C with over 500 ton/hrs.

A SMALL SAMPLING OF SOME OF OUR INSTALLATIONS AROUND THE GLOBE

Ice Bank Systems are cutting demand charges and operating costs in over 2000 office buildings, schools, churches, hospitals, hotels and shopping malls throughout the world.

NATIONAL

ALABAMA
Children's Hospital, Birmingham
Alabama Power, Montgomery

ARIZONA
Civic Performing Arts, Chandler
Parker Hannifan Corp., Glendale
American West Terminal, Phoenix
Paradise Valley High School, Phoenix

CALIFORNIA
Culver Studios, Culver City
Grossmont Hospital, La Mesa
El Capitan Office Building, Los Angeles
Tri-City Medical Center, Oceanside
West Valley Detn. Center, Rancho Cucamonga
Utilities Operations Center, Riverside
Doubletree Hotel, San Diego
Kaiser Hospital, San Diego
Qualcomm, San Diego
Channing House Assisted Living, Palo Alto

CONNECTICUT
Wright Office Building, Bridgeport
U.S. Repeating Arms, New Haven

DELAWARE
Delmarva Power & Light, Newark
DuPont Company, Newark

DISTRICT OF COLUMBIA
Intelstat
Market Square

FLORIDA
Sarasota County Schools, Sarasota (12)
Port of Miami, Miami
State Office Building, Ft. Myers
Brevard County Schools (9)
Broward County Schools (2)
Florida Atlantic University, Jupiter
Florida Gulf Coast Univ., Ft. Myers
Kravis Perf. Arts Center, West Palm Beach
Embry Riddle University, Daytona Beach (2)
AAA Headquarters, Lake Mary

GEORGIA
Athens Regional Medical Center, Athens

HAWAII
Inter-Island Terminal, Honolulu

IDAHO
Idaho State University, Pocatello
Ricks College, Rexburg (3)

ILLINOIS
Elk Grove High School, Elk Grove
Motorola Training, Schaumberg

INDIANA
First Presbyterian Church, Elkhart
Indiana State University, Terre Haute

IOWA
Sacred Heart Cathedral, Davenport

KANSAS
Woodland Methodist Church, Wichita

KENTUCKY
South End Medical Clinic, Louisville

MAINE
Scovil Building, Presque Isle

MARYLAND
Ft. Meade Def. Info. Sch., Ft. Meade
IBM Office Building, Gaithersburg

MASSACHUSETTS
John Hancock Institute, Boston
Wang Center, Boston
United States Court House, S. Boston
Raytheon Company, Waltham

MICHIGAN
NBD Technical Center, Belleville
Standard Federal Bank Building, Troy

MINNESOTA
Northern States Power, Maple Grove

MISSOURI
Maritz Inc. South Campus, Fenton
Mel Tillis Theater, Branson

NEVADA
American West Air Lines, Reno

NEW HAMPSHIRE
Hitchcock Medical Center, Lebanon

NEW JERSEY
ETS, Princeton
Carnegie Center, Princeton
Raritan Community College, Raritan
ITT Corporation, Clifton

NEW MEXICO
Albuquerque Plaza, Albuquerque

NEW YORK
Buffalo Memorial Auditorium, Buffalo
Swissair Headquarters, Melville
100 Century N. Office Bldg., Mt. Pleasant
Consumers Union Inc., Yonkers

NORTH CAROLINA
Johnston County Schools (3)
Wake County Schools

OHIO
First National Bank, Akron
Ohio University, Akron
General Electric Co., Cincinnati
Heritage Museum Center, Cincinnati

OKLAHOMA
Lazy E Arena, Guthrie
Deaconess Hospital, Oklahoma City
50 Penn Plaza, Oklahoma City

OREGON
Fleming Foods, McMinnville,
PENNSYLVANIA
General Public Utilities, Reading
Villanova University, Villanova
Messiah College, Grantham
RHODE ISLAND
Roger Williams College, Bristol
Swarovski Crystal Office Bldg., Providence
SOUTH CAROLINA
Baptist Medical Center, Columbia
Lexington Medical Center, Lexington
TENNESSEE
Northeast High School, Clarksville
TEXAS
The Centex Building,* Dallas
JC Penny, Plano
Ford Motor Company, Carrollton
Baylor Hospital Bush Bldg., Dallas
First Baptist Church, Dallas
BP Plaza, Houston
Texas Instruments Inc., McKinney
MCI Corporation, Richardson
NCR Corporation, Fort Worth
EDS Corporation, Plano
El Paso Community College, El Paso (3)
UTAH
Brigham Young University, Provo
Utah State Retirement Bldg., Salt Lake City
VIRGINIA
Xerox Central Services, Leesburg
Army National Guard, Manassas
Christian Broadcast Center, Virginia Beach
WASHINGTON
Bellevue Place, Bellevue
WISCONSIN
The Trane Company, LaCrosse
First Interstate Bank, Milwaukee

INTERNATIONAL

ARGENTINA
Luna Park, Buenos Aires
AUSTRALIA
James Cook Univ. Med. Ctr., Brisbane
Grovesnar Place, Melbourne
AUSTRIA
Sparkassendatendienst, Vienna
BELGIUM
Upjohn, Antwerpen
BERMUDA
Bermuda Underwater Exploration, Hamilton
BRAZIL
B M & F Stock Exchange, Rio de Janiero
Credicard - Hall Theater
Banco Bradesco SA
Shopping Jardim Sul (Expansion)

**Named the most energy efficient building in the US, according to the DOE & EPA.*

CANADA
General Motors Building, Oshawa
Metro Centre, Toronto
Shipp Centre, Toronto
Place des Arts, Montreal
CHINA
Shaoxing Yue Do Hotel, Shaoxing
Shenzen Min Gin Square, Shenzen
Tianjian Li Da Hotel, Tianjian
Shanghai Jiahua Mansion, Shanghai
Ningbo Power Company, Ningbo
COLOMBIA
Lamitech, Bogota
DENMARK
Copenhagen Airport, Copenhagen
FRANCE
Cheese Dairy, Lyon
GERMANY
Palast Hotel, Berlin
Hansedom, Straslund
Kaufhof, Rostock
Deutsche Bank, Bremen
Airport, Hamburg
Siemens, Cologne
Bayrische Vereinsbank, Munich
Hannover Messe, Hannover
GREECE
Olympic Complex, Athens
Esperos Hotel, Rhodes
HUNGARY
Radio Budapest, Budapest
IRELAND
Antigen, Dublin
ISRAEL
Israeli Electric Corp., Haifa
ITALY
Phillips, Saranno
RAI Radio-Television, Rome
JAPAN
Christa Nagahori, Tokyo
Kita-Aoyama D.H.C., Tokyo (2)
Sumitomo Building No. (2)
JORDAN
Dairy Factory, Amman
KOREA
Hyundai Department Store (Chun-Hoo)
Hyundai Grand Tower
Pusan City Core, Pusan
Pusan Officetel, Pusan
Jinju Department Store
Kookmin Bank Head Office
LIECHTENSTEIN
Hilti, Schann
LUXEMBOURG
Banque Internationale
MEXICO
Ideal Standard, Monterrey
Ideal Standard, Guadalajara

NETHERLANDS
De Nederlandsche Bank, Amsterdam
NEW ZEALAND
Palerston North Hospital, Wellington
NORWAY
Gunnar Karlson, Oslo
PORTUGAL
Airport, Lisbon
Feira Nova, Sintra
PUERTO RICO
American International Plaza, San Juan
SAUDI ARABIA
Saudi French Bank, Riyadh
Saudi American Bank, Dammam
SLOVAKIA
Siemens, Bratislava
SKB Bank, Kopper
DuPont, Geneva
SPAIN
Continento Mostolos, Madrid
Malage Airport, Malage
SWEDEN
Stockholm Energi, Stockholm
SWITZERLAND
Emmi, Dagemrsellen
Muba, Basel
Swiss Re, Zurich
TAIWAN
MRTS General Office Building, Taipei
Customs Building, Taipei
T/C Tower, Taipei
Taipei County World Trading Center
Ma-Kai Hospital, Taipei
THAILAND
Thairath Press, Bangkok
TURKEY
Afra Shopping Center, Tarsus
UNITED KINGDOM
British Aerospace, Preston
National History Museum, London

ECONOMIC ANALYSIS OF TYPICAL PARTIAL AND FULL STORAGE INSTALLATIONS

Partial Storage

Assume: 400-ton peak cooling load, 10-hour cooling day, 75% diversity factor, $8.00/month kW demand charge, 12-month ratchet.*

Conventional chilled water air conditioning system:

400-ton air cooled chiller @ $650/ton, installed**	$260,000
Air Distribution system	240,000
Total	**$500,000**

Partial storage (40% size chiller with Ice Bank System):

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

160-ton air cooled chiller @ $750/ton (higher than the 400-ton unit because of smaller size), installed**	$120,000
Stored cooling @ $85/ton hour, installed	119,000
Air Distribution system	$ 240,000†
Total	**$479,000**
Purchase savings:	**$21,000**

Demand savings:

240 tons x 1.3 kW/ton‡ x 12 mos. x $8.00 = **$29,952/year**

Full storage

Assume: 400-ton peak cooling load, 10-hour cooling day, 75 percent diversity factor, 1000-hour cooling system, $8.00/mo./kW demand charge, 12-month ratchet, $0.04/kWh off-peak differential. Storage chiller size will be reduced by 70 tons to 330 tons.

Full Storage: 10 hrs. x 400 tons x 75% x

$75/ton-hour, installed	$225,000
Saving on chiller size, 70 ton x $650/ton	-45,500
Total addition for storage system	$179,500

Demand savings: 400 tons x 1.3 kW/ton‡ x 12mos. x $8.00 — $49,920/year

Energy savings: $0.04/kWh x 1000 hrs. x 400 tons x 1.1 Avg.Kw/ton — $17,600/year

Total savings: **$67,520/year**

Simple payback: $179,500 ÷ $67,520 = 2.66 years

*Utility term for a monthly electrical bill surcharge based on a previous month's higher peak demand.
** The $650-750/ton for air-cooled chillers includes all accessories such as pumps, piping, controls, etc.
† Figure shown is for conventional temperature system. This cost could be reduced by 40% by using a cold air system.
‡ The 1.3 KW/ton is figured at the peak summer demand conditions.

SUB-ICE low temperature storage solutions

Non-toxic eutectic salts are available to lower the freezing point of the water in Ice Bank tanks to either 28 F or 12 F and, consequently, the temperature of the "salt ice". 28 degree ice, for example, can provide cold, dry primary air for extra-low temperature airside applications. 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.

CALMAC

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