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ice storage as part of a
LEED® Building Design

The technology of ice storage has changed little in the last few decades. What *has* changed is the international demand for power, the availability of fuel to create power, and the subsequent cost and availability of that electrical power on taxed grid systems. Without a power technology shift, energy costs can be expected to continue their escalation well into the future.

A valid argument could be made that each of us in our trade or profession has the unwritten duty to not only design, install, commission, and maintain the most cost effective and reliable HVAC systems, but also to use electrical power wisely. One HVAC design option that can balance these criteria is *ice storage*. An ice-storage system may help the overall building design receive LEED Energy & Atmosphere credit 1 (EAc1) points based on the building energy cost savings beyond ASHRAE Standard 90.1-2004 (Table 1).

Figure 1. Hourly building energy cost contribution of a HVAC system

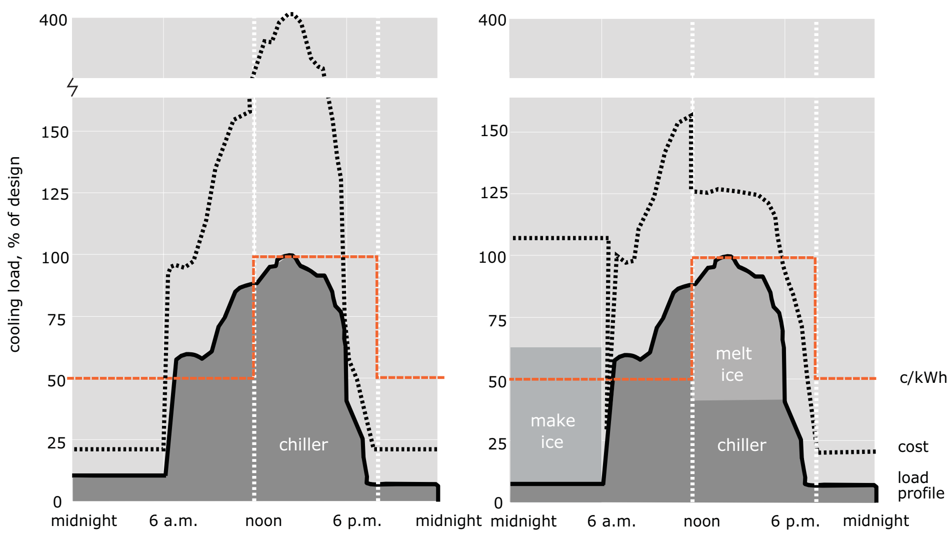


Figure 1 makes it easy to understand the cost benefit that ice storage can contribute. An electrical, consumption-only cost rate is superimposed over the building load profile, offering a visual approximation of the hourly building energy consumption costs contributed by the HVAC system. The *chiller-only* graph shows the energy cost burden when both the consumption charge and the electrical use peak at the same time. Ice storage makes it possible to control the peaking load by shifting the cooling capacity to a time of *off-peak* consumption rate, shown in the *ice storage* graph.

Some may claim that thermal energy storage (TES) isn't green because it uses about the same amount of power as non-storage systems. However, as shown in Figure 1, ice does a better job of load leveling the available power supply and infrastructure. This load shift can create source energy savings and reduce emissions.[1]

Table 1. Minimum energy-cost savings percentage threshold for each point

new buildings	existing building renovations	points
10.5%	3.5%	1
14%	7%	2
17.5%	10.5%	3
21%	14%	4
24.5%	17.5%	5
28%	21%	6
31.5%	24.5%	7
35%	28%	8
38.5%	31.5%	9
42%	35%	10

source: LEED for New Construction Reference Guide v2.2 Second Edition September 2006

[1] See ASHRAE Journal September 2003 "Thermal Energy Myths" by Mark M. MacCracken, PE.

LEED Design Considerations

Candidates for ice storage. Any building design is a candidate for chilled water and any chilled-water system is a candidate for ice storage. Even a relatively constant process load can be a candidate for ice storage based on redundancy and the potential for time-of-day, energy-cost savings.

For the following discussion, the focus is a standard office building and earning LEED points for energy cost savings. Initial design considerations are improvements in high-efficiency lighting, and improvements to the building envelope. These improvements will reduce the overall load on the building which in turn will reduce the needed capacity of the building HVAC equipment and the energy cost to operate it. Now the HVAC system design becomes paramount.

The important energy factors of the HVAC system are the pumps, the fans, the tower (if water-cooled), the heating, and of course, the chiller. As the energy of one is reduced, the energy of the others may increase. The optimized selection is the ultimate goal of the ice-storage system. Even without totally achieving this goal, ice storage can be of great value to the owner by reducing operating costs and earning LEED points.

LEED points and ice storage. The key element of a successful ice-storage system is a common understanding of the design goals. To gain LEED points, the goal is the balance between the first cost and the energy cost reduction based on the LEED EAc1 points desired. In order to qualify for LEED points, a proven hourly load and energy-modeling software program (such as TRACE™ 700, EnergyPlus, Carrier HAP E20-II, or DOE-2) must be used to verify energy savings. Once the first cost goal and desired LEED point goal are in place, the capacity shift from on peak to off peak is dictated. The energy cost savings may include both the peak electrical demand (kW), and the peak electrical consumption (kWh) depending on the local rate structures. Benefits of the energy modeling software include both an annual load duration curve shown in Figure 2 (discussed later) and a cooling, design-day, load profile shown in Figure 3. Further, the modeling software can aid in selecting ice-storage capacity to meet the desired tons shifted to off-peak energy hours. Figure 4 shows a typical building load profile with an overlay of a traditional chiller selection with ice. This ice-storage plan will shave both demand and peak energy consumption. Figure 5 shows a significant shift of the load to off-peak hours. A comparison of these figures shows the difference between the required chiller tonnage and the amount of ice created during off-peak hours and subsequently melted during on-peak hours.

Figure 2. Annual load-duration curve

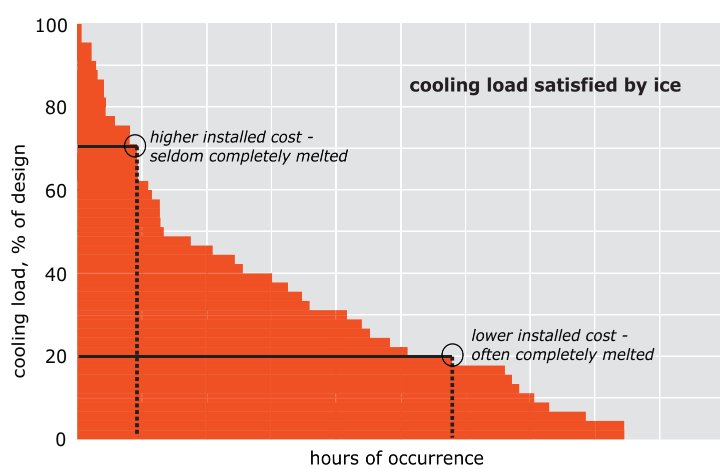


Figure 3. Traditional chiller, no ice

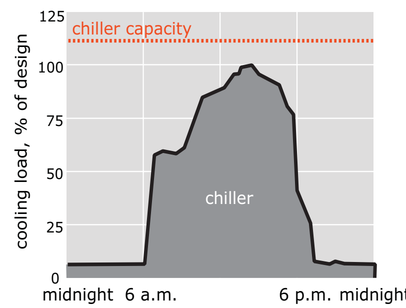


Figure 4. Demand and peak consumption reduction

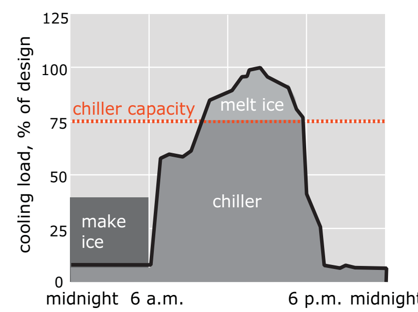
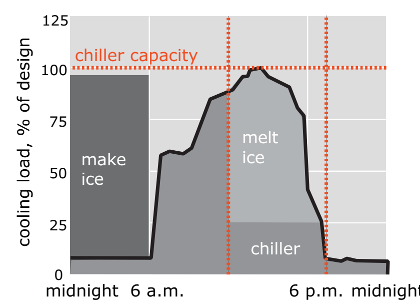


Figure 5. Increased system storage



Optimizing the System

Solution. Ice-storage systems must use a circulating fluid that will remain liquid while freezing the water inside the ice-storage tanks. The traditional circulating fluid has been ethylene glycol at a 25 percent by weight solution. When properly inhibited, this fluid is safe for coils, pumps, and chiller components. Propylene glycol at 30 percent concentration is frequently substituted for applications such as food processing in which toxicity is a concern.

The physical properties of ethylene glycol differ from water—the viscosity is greater and the sensible heat content is lower. At first glance, these fluid properties make selection of efficient components more difficult than standard water component selections. In order to regain some or all of the efficiency loss caused by the use of ethylene glycol, each component will need to be reevaluated using ethylene glycol and the parameter of the cooler supply temperature.

Coils, pumps and fans. Table 2 row 1 shows a coil selection using water as the circulating solution and a typical 45°F entering temperature. The capacity is 455 MBh, the air pressure drop is 0.64 in H_2O, the gpm is 75.5 and the water pressure drop is 2.98 psi. When the circulating solution for the same coil is 25 percent ethylene glycol (row 2) at the same gpm, the capacity is reduced 13 percent and the fluid pressure drop increases 18 percent. Both performance losses can be attributed to the glycol solution's greater viscosity and lower sensible heat content.

As the remainder of the data demonstrates, full coil capacity can be restored without penalizing pump horsepower by lowering the entering solution temperature to 38°F (row 6). The solution temperature reduction increases the log mean temperature differential across the coil, compensating for the heat transfer loss normally associated with the glycol solution. Significant pump horsepower reductions are also achieved. In this example, the 38°F glycol solution reduces both the required flow rate and solution pressure drop which reduces the required horsepower by approximately ten percent.

The colder 38°F fluid temperature creates the opportunity to lower the supply-fan energy use. Cold air systems can allow for lower airflow selection and/or smaller air handlers, smaller VAV terminals, and (potentially) smaller ducts.[2]

Table 2. Impact on cooling-coil performance

solution	entering fluid temp. °F (°C)	coil rows	total capacity MBh (kW)	pressure drop (air), in H_2O (Pa)	fluid flow rate, gpm (L/s)	pressure drop (fluid), psi (kPa)
water	45 (7.2)	6	455 (160)	0.64 (160)	75.5 (4.76)	2.98 (20.5)
ethylene glycol (25%)	45 (7.2)	6	395 (116)	0.62 (154)	75.5 (4.76)	3.51 (24.2)
ethylene glycol (25%)	45 (7.2)	8	455 (133)	0.83 (208)	75.5 (4.76)	4.39 (30.3)
ethylene glycol (25%)	45 (7.2)	6	455 (133)	0.65 (162)	105.3 (6.64)	6.42 (44.3)
ethylene glycol (25%)	40 (4.4)	6	455 (133)	0.64 (160)	73.3 (4.63)	3.37 (23.2)
ethylene glycol (25%)	38 (3.3)	6	455 (133)	0.64 (160)	66.9 (4.22)	2.87 (19.8)

Chiller and Ice. A first-cost and potential operating-cost advantage of an ice-storage system is to "right" size the chiller. When a load analysis is complete, a factor of safety is traditionally added to the calculated load and the chiller is sized accordingly. This is an inflated tonnage which may be necessary due to building inconsistencies, load analysis uncertainties, and anticipated future changes in the building load, and may result in oversized equipment running at less than peak efficiencies and an inflated purchase price. As an alternative, rather than adding the factor of safety as mechanical cooling, it can be added as ice-storage capacity. However, this only matches the chiller capacity to the building load, reducing the chiller by the tonnage value of the factor of safety. Instead, consider sizing the chiller 20 to 25 percent less than the load analysis and size the ice for the sum of this reduction plus the safety factor amount. This sizing philosophy can be balanced to appropriately match the agreed upon plan to reduce kW or kWh.

The more ice-storage capacity designed into the HVAC system, the more capacity can be taken out of the mechanical chiller. There are practical and financial limits. The chiller must be able to make the total required amount of ice in the off-peak electrical hours and the cost of storage capacity seldomly used is cost prohibitive. When considering a design day, the propensity is to design a system with a

Ice storage considerations.

- Downsize chiller capacity: load-20%.
- May reduce incoming power requirement and chiller operating cost.
- To minimize full load operating cost use a high-efficiency chiller for ice and for the base load.
- Use 25 percent ethylene glycol or 30 percent propylene glycol solution. Excess glycol degrades performance and requires more system power.
- Lower the solution temperature to improve coil/pump/fan efficiency.
- Select coil for minimal air and water pressure drop with larger solution delta T and lower entering solution temperature.
- If cost or space is constrained, don't overuse ice tanks.

[2] D. Eppelheimer, "Cold Air Makes Good Sense" Trane Engineers Newsletter, 2000, volume 29-2

lot of ice storage. However, some of the storage capacity will seldom be used during off-design days and may be difficult to economically justify (see Figure 2).

When making a chiller selection it is valuable to remember that the ice-making chiller(s) will be operating at 100% capacity for a disproportionate amount of its life. Ice chillers not only make ice at 100 percent load but they may be designated as the base-load chiller. To reduce energy cost, it would be prudent to consider the highest efficiency, full-load chiller for this design. During the "make ice" night operation, analysis has shown and history proven, that this chiller will need to make about 22ºF solution for a good balance between chiller capacity and ice-tank freeze rate.

Earning LEED points through energy cost reduction modeling.

Consider a five-story building where each story contains 150,000 square feet. The building is electrically cooled by an air-cooled chiller, sized at the peak load and heated by a gas-fired boiler.[3] The VAV delivery system has preheat and reheat hydronic coils. This building is hypothetically placed in three different locations; one *hot humid*, one *cold dry*, and the final, *cold*. Each building design is then modified to meet the minimum requirements of ASHRAE Standard 90.1-2004 for its location. Simulations are run to determine the building energy costs (Table 3, column 1). Changes made to the building and cooling system to earn LEED points will be rated against this baseline cost. For this analysis the on-peak consumption rate is 8 cents per kWh and the demand is $12 per kW. The off- peak consumption rate is 4 cents per kWh and the demand is $5 per kW. The energy costs in the chart include the cost of gas at $1.25 per therm.

Reduce the load. As stated earlier, the first step to reduce energy is to improve the building lighting and improve the building envelope. Comparing this model to the 90.1 model, the energy cost is reduced by double-digit percentages in each of the three zones qualifying for LEED points in all but the new construction in the cold climate (Table 3, column 2). The reduced load may also improve the first cost of the cooling system.

Add ice storage. Next, assume the improved building model is accepted and ice storage is added. The chiller size is reduced to 80 percent of load, reducing the chiller's first cost. This savings is then used to offset 2500 ton-hrs of ice-storage capacity. The modeling program indicates energy costs are significantly reduced which results in earning additional LEED points (Table 3, column 3).

Optimize storage capacity. An interesting limitation is revealed when the same chiller attempts to make 3000 ton-hrs ice: No energy cost benefit is produced (not shown). The reason being that the 2500 ton-hrs ice is the maximum the 80 percent chiller can produce in the allotted time. By chance the original design of 80 percent chiller and 2500 ton-hrs ice is very close to a balance of the minimum chiller capable of sustaining this ice-storage system on this building model.

In the next alternative, the chiller tonnage is increased to 100 percent of peak load and the ice storage is increased to 3000 ton-hrs. The modeling shows modest energy cost improvement in all three locations (Table 3, column 4). Although this improvement is not as dramatic as the previous simulation, all climates are able to increase their earned LEED points.

Table 3. TRACE™ report and LEED EAc1 points earned

Location	90.1		Improved envelope and lighting		80% chiller 2500 T-hr Ice		100% Chiller 3000 T-hr ice		100% chiller 6000 T-hr ice	
	energy (MMBtu/yr)	cost ($1000/yr)	energy (MMBtu/yr)	cost $1000/yr	energy (MMBtu/yr)	cost ($1000/yr)	energy (MMBtu/yr)	cost ($1000/yr)	energy (MMBtu/yr)	cost ($1000/yr)
Hot humid	9489	277	8291	243	8250	212	8214	209	8242	203
% reduction			12.6%	12.2%	13%	23.4%	13.4%	24.5%	13.1%	26.7%
LEED points (new)				1		4		5		5
LEED points (renovation)				3		6		7		7
Dry cold	7173	202	6116	173	6074	153	6052	152	6052	152
% reduction			14.7%	14.3%	15.3%	24.2%	15.6%	24.7%	15.6%	24.7%
LEED points (new)				2		4		5		5
LEED points (renovation)				4		6		7		7
Cold	7972	221	7221	198	7230	177	7218	174	7218	174
% reduction			9.4%	10.4%	9.3%	19.9%	9.4%	21.2%	9.4%	21.2%
LEED points (new)				0		3		4		4
LEED points (renovation)				2		5		6		6

[3] It is acceptable per ASHRAE Standard 90.1-2004 to oversize the chiller to 115% of load as a factor of safety. However risk is taken by increasing energy consumption.

Finally, the ice storage is increased to 6000 ton-hrs and the same 100 percent peak-load chiller is selected to simulate an ice-storage system capable of handling the entire cooling load during the on-peak electrical hours. It is interesting that the *cold*, and the *dry cold* climates don't gain enough energy cost benefit from this design to earn additional LEED points. The *hot humid* climate improves about two percent, not enough to earn an additional LEED point. Due to sizing, these systems will maintain ice that will never be used for the majority of the year (Table 3, column 5).

Shown in this modeling analysis are diminishing returns for increasing amounts of ice storage. This analysis is an example only. Each building and system design requires modeling analysis. Once the model is created, minor adjustments can be made to calculate the energy cost savings of varying amounts of ice and different chiller sizes. Partial storage is a strategy through which many chilled-water system designs can improve operating costs.

Summary

The value of system modeling cannot be overemphasized. Modeling is paramount to the success of an ice-storage system. Energy-cost results from modeling can be weighed against the system's first cost. Modeling is the only way design decisions can be logically made. The more aggressive the on-peak electrical charges, the more likely ice storage should be part of the building design (and potentially the more ice should be included in that design). Oversizing the ice can be a first-cost burden that can tip the scales away from using ice storage. Often times, the optimum selection is to have a small amount of ice rather than large amount.

Ice storage is an old design whose value becomes more apparent with time. Ice storage has green connotations from an environmental perspective, and from a cost-saving perspective and is a value-engineered system in the true sense of the term.

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