Thermal Energy Storage In Sustainable Buildings

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This article demonstrates why designing a building with stored cooling is a beneficial approach and how oversizing the chiller plant for safety factor does not make sense. This article discusses what makes thermal energy storage (TES) a green technology, TES and safety factor, and benefits from incorporating storage.

LEED™ Rating System

One system for rating the "greenness" of buildings is the U.S. Green Building Council's (USGBC) LEED rating system. Based on this unit of measure, TES is considered green. The ratings are based on a point system (10 points are for energy savings).

LEED points are based on ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* which is based on energy *cost* savings, not energy savings. Cost is the only common denominator for all the different energy-efficient possibilities, as well as the common metric that usually drives a building owner's decisions. To receive LEED points, the building must surpass Standard 90.1-1999 by more than a certain percentage for a certain amount of points (20% = 2 points, 30% = 4 points up to 60% = 10 points).

TES and LEED

The reason TES is a green technology in the LEED system is that, in most locations, electricity at night costs less than half as much as during the day.[1] As demonstrated in thousands of installations, major energy cost savings are realized by using inexpensive power at night to create and store cooling, and using storage to cool the building during the next day. These savings provide LEED points, which was demonstrated in California's first LEED 2.0 Gold building built by The William and Flora Hewlett Foundation in the City of Menlo Park.

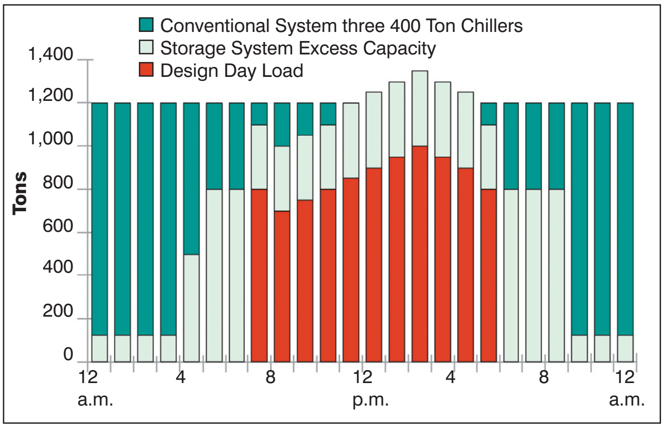
The building had a total of 43 points (out of 69), of which five were because of the 35% energy cost reduction. This project took advantage of four major cost/energy-saving techniques including external shading, natural lighting, natural ventilation and off-peak cooling (OPC) using ice-based thermal storage. Three of the four are reducing the amount of mechanical cooling, and the OPC system shifts most of what mechanical cooling is required to the inexpensive off-peak period.

Real Reason Thermal Storage Is Green

Many studies, most notably one by the California Energy Commission,[2] have demonstrated that, for many reasons, it takes less fuel to make an off-peak kWh. The main reasons are:

- Off-peak, base-load plants are much more energy efficient than on-peak plants, with 7,900 to 8,500 Btu/kW (8335 to 8970 kJ/kW) heat rates typical for base-load plants. The existing stock of "peaking" plants, which are comprised mainly of simple cycle combustion turbine units, are in the range of 9,000 to 12,000 Btu/kW (9495 to 12 660 kJ/kW).
- Line losses are less off-peak because that much less power is transmitted at night.
- Spinning reserve requirements are lower. (Spinning reserve essentially means power plants are forced to spin turbines at night, without generating power. So, the plants are ready to help meet the following day's peak load). Therefore, lower on-peak power requirements translate into less waste from spinning reserves.

The results of the Califonia Energy Commission's study showed that for the two major California utilities, it required



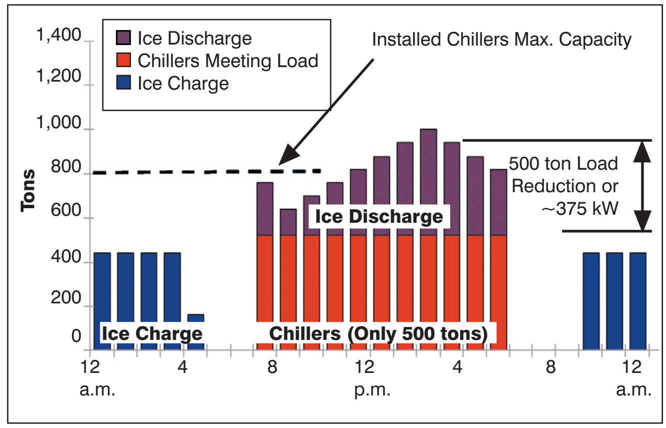


Figure 1 (left): Excess capacity on design day (storage system is two 400 ton chillers with 3,500 ton·hr storage. Figure 2 (right): Design day off-peak cooling system (storage system is two 400 ton chillers, 3,500 ton·hr storage).

10% to 30% less energy to create and deliver power off peak. In addition to the reduction in emissions because of using less fuel, the peaking power plants that are the last to come on-line during a hot summer day normally are the dirtiest.

Another report done for California, "The Costs and Financial Benefits of Building Green,"[3] states that the last power plants to come on-line are "almost twice" as dirty as the base-load plants. Obviously, the mix of power plants around the country affects the exact numbers. However, better efficiency and lower emissions combine for a big environmental advantage from reducing on-peak loads and shifting to off-peak hours by using storage.

Safety Factor Adds Value at No Extra Cost

At the 2003 USGBC's GreenBuild Conference, I often heard HVAC engineers being blamed for oversizing the mechanical systems and the negative impact that oversizing has on a building's performance.[4] The safety factor is necessary in this litigious world, especially when the engineer's license is at stake. However, the simple solution to this predicament is cool storage.

An article I wrote for *ASHRAE Journal*[5] essentially concluded with the statement that building owners would be better served if the HVAC designer's paradigm of adding 20% to 30% for safety be changed to decreasing the actual predicted chiller plant size by 20% and adding storage for the safety factor at no additional cost. In that article, the building had a predicted 1,000 ton (3517 kW) peak load and the designer had planned to install three 400 ton (1400 kW) chillers and related equipment. The TES system used two 400 ton (1400 kW) machines and 3,500 ton·hr (12 300 kW·hr) of storage, which provides excess capacity if the load predictions were incorrect (*Figure 1*).

Therefore, the storage system's chiller plant capacity was 33% less than planned (including safety factor). However, it was only 20% less than the actual design load (*Figure 2*).

What surprised one reader of the article is that those two systems could be constructed for the same cost. Using the costs from the article of $900/installed ton ($256/installed kW) of chiller plant and $100/installed ton·hr ($28/installed kW·hr) of storage the statement is true, as long as each ton of chiller capacity removed requires less than 9 ton·hrs (32 kW·hrs) of storage. In the previous example, 3,500 ton·hrs (12 300 kW·hrs) of storage is used to replace 400 tons (1400 kW) of chiller capacity or 8.75 ton·hrs/ton (kW·hrs/kW). (The normal range is between 5 and 9 ton·hrs/ton [kW·hrs/kW] based on load shape.)

For each ton a designer is comfortable reducing the installed chiller plant capacity, storage can be purchased at no additional cost. In doing so, it creates a system that has the flexibility to capitalize on the diurnal swings in electric rates—greater value with little or no extra cost.

Other System Benefits

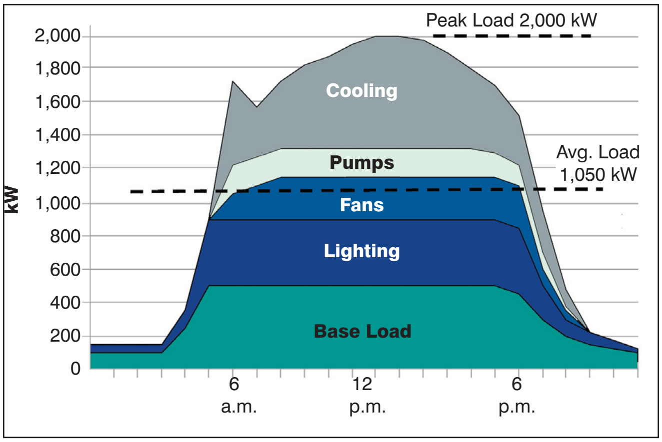
The additional system benefits are many. Here are a few:

First, it seems many designers believe that absorption chillers are green and inexpensive to operate because they avoid electric demand charges. Absorption chillers are a good technology if the energy used to run them is waste heat from some other process. However, if absorbers are direct fired with a source fuel, it is apparent from *Table 1* that the electric systems are the clear choice.

For instance, a centrifugal chiller with a kW/ton of 0.58 (0.165 kW/kW) is equal to a COP of 6.0. If we use a grid electric energy conversion efficiency of 33%, that equates into a source COP of 2.0. This compares to a COP of 1.0 for a single-effect absorber, which means the absorber would use twice as much fuel.

In addition, using the electric centrifugal chiller as a baseline, the cooling towers must be substantially larger and the amount of site water use is about 70% more. Having an electric centrifugal chiller make ice takes the performance to a COP of 1.66, which is still much better than any absorption chiller. Therefore, storage gives the same demand avoidance that absorption chilling does at much higher energy efficiencies.

The other major benefit is the overall demand of the building



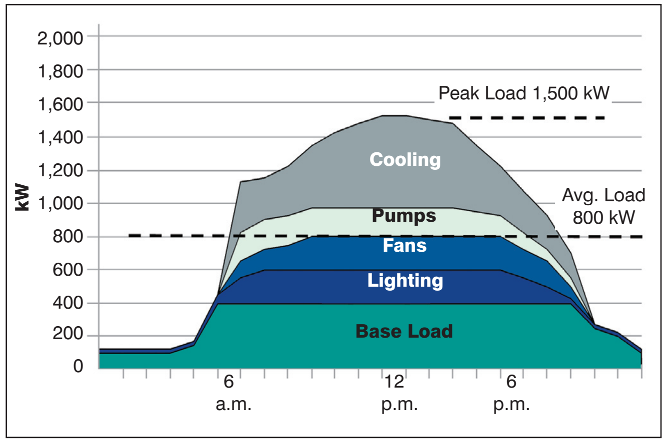


Figure 3 (left): Base building is the Standard 90.1 non-storage electrical profile (load factor 53%). Figure 4 (right): Base building is 20% less than the Standard 90.1 non-storage electrical profile (load factor 53%).

and its effect on generation supply (whether from the grid or on-site). This is most clearly shown by what it does for the load factor of the building. *Figures 3* and *4* show the load profiles of a building designed without storage. *Figure 3* shows a building design to meet Standard 90.1. *Figure 4* shows a building with many energy-saving features (better windows, external shading, variable speed pumps, etc.) and is predicted to use 20% less energy than Standard 90.1 requires. Even with all these energy-saving features, the load factor (the average load divided by the peak load) is about 53% for both designs.

When a full thermal storage system is added (*Figure 5*) the load factor moves up to 88%, because the peak load of the building has dropped from 1,500 kW to under 900 kW by shifting the production of cooling to off-peak hours.

To a generation company, this means that with the same investment in a 300 MW generation plant, it could supply 300 customers that use full storage and supply only 200 customers that do not. In the original example in *Figure 2*, which was partial storage, we removed 375 kW from the maximum building demand by having the ice storage handle 500 tons (1760 kW) instead of using chillers. Lower electric demand keeps energy costs down and minimizes the environmental impact of cooling for everyone.

If a customer plans to generate its own power or have a backup generation system, storage can translate into a major initial cost reduction for a system. *Table 2* shows approximate installed costs of chillers, storage and generation on a $/unit basis and for the hypothetical 1,000 tons (350 kW) building project. The most important point is, even if the cost savings from chiller plant reduction is disregarded, the capital cost of storage is about equal to the capital savings in site generation equipment it displaces.

Finally, since the example is limited to only purchasing a quantity of storage that we could pay for by chiller capacity reductions, the next question becomes should more storage be considered? The answer is, "yes." It is based on excess chiller capacity we still have in the storage design. Eight-hundred nominal tons (2815 kW) of chillers produce about 550 tons (1930 kW) at ice-making conditions, so in just over six hours we could charge the 3,500 ton·hr (12 300 kW·hr) of storage. If we assume 10 hours for charging, 5,500 ton·hr (19 300 kW·hr) could be stored and the peak reduction from storage would be close to 500 kW compared to 350 kW. Therefore, using some of this additional savings to purchase more storage might be prudent since we have already installed more chiller than needed.

Conclusion

Storage is a natural method to balance the instantaneous

Chiller Type	"Site" COP	EER	kW/ton	Source Energy COP†	Site Heat Rejection Factor	Water Use Increase
Electric Centrifugal	6.0	20.5	0.58	2.00	1.17 14,000 Btu/ton	—
Electric Screw or Centrifugal Making Ice	5.0	17.1	0.70	1.66	1.20 14,400 Btu/ton	3%
Electric Scroll	4.0	13.6	0.88	1.33	1.25 15,000 Btu/ton	7%
Absorption (Double Effect)	1.2			1.20	1.83 22,000 Btu/ton	57%
Absorption (Single Effect)	1.0			1.00	2.00 24,000 Btu/ton	71%

† Assumes 33% national electric grid efficiency.

Table 1: Chiller energy and water efficiency comparison.

needs of any system to the average needs. When applied to our industry, off-peak cooling is an efficient and affordable tool that saves building owners money, as well as saves energy and reduces emissions. *Thermal storage should be considered by designers as a more natural and cost-effective method of adding safety factor, and not just used in areas where electric rates may dictate.* Offices, schools, hospitals, places of worship, arenas and any other similar building with cyclic loads are possible candidates. With all these advantages it is clearly a technology that lowers the impact on the environment, which is what green is about.

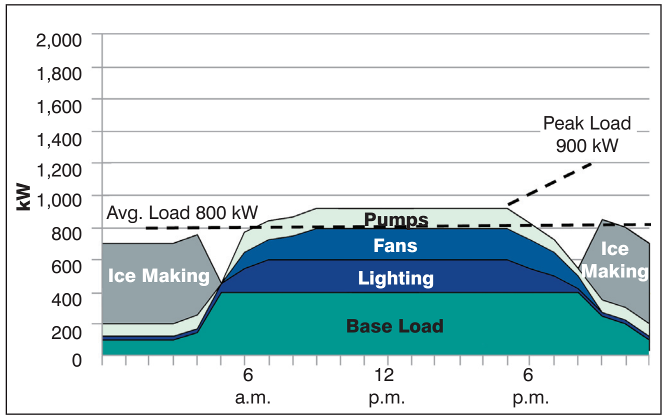


Figure 5: Base building is 20% less than the Standard 90.1 minimum full storage electrical profile. It has up to 40% peak-load reduction (load factor 88%).

References

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	$ per Ton	$ per Ton Hour	$ per Peak kW	Non-Storage System Cost	Storage System Cost
Chillers	$900			$1,080,000	$720,000
Storage (8.75 ton·hr/ton)	$875	$100	$875		$350,000
Subtotal Chiller Plant Cost				$1,080,000	$1,070,000
Less 375 kW† Backup Generation			$1,000	—	– $375,000
Non-storage sys					†
† Approximation includes chiller and all ancillary power.					

Table 2: Installed cost summary (1,000 ton peak with backup generator).