ICE THERMAL STORAGE AND LEED GOLD

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1. BACKGROUND

Stored energy is a vital component in almost any natural or man-made system. Whether it is in the form of food in the cupboard, electricity in batteries or body fat, storage is essential for efficient system function and flexibility. Though market penetration is increasing, cool storage is not yet the norm in commercial air-conditioning systems. Conventional AC systems are not only designed to meet a load that will only occur a few hours per year, but are oversized for even those hours, due to uncertainty in the prediction methods or the need for redundancy. It is only fitting that "Green" designers look to nature for guidance in helping lower the impact that buildings have on our environment. This article will demonstrate why it is simply natural to design a building with stored cooling and how oversizing the chiller plant for "Safety Factor" or "Redundancy" is as unnatural as Hummers as taxis in New York City.

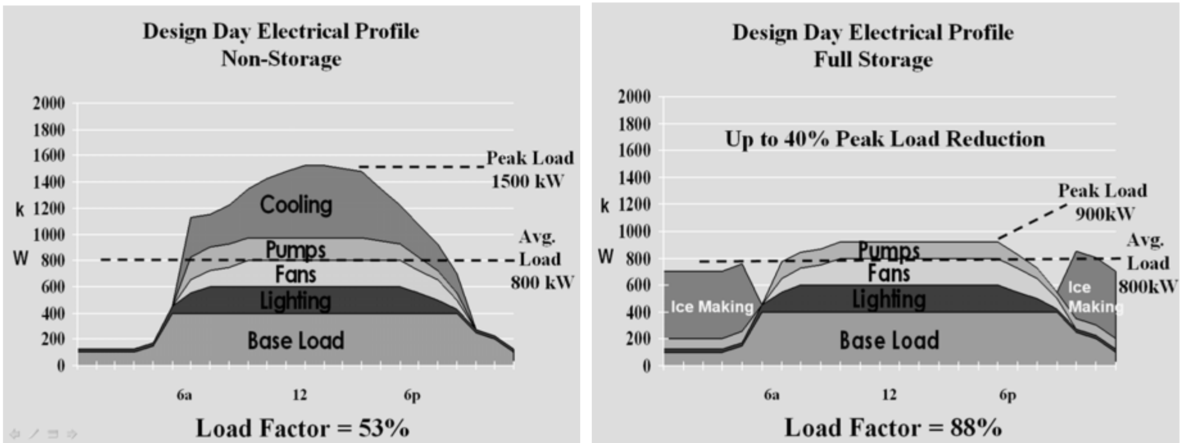
2. INTRODUCTION

The use of Thermal Energy Storage to meet mankind's needs is not new. Many ancient civilizations harvested ice from frozen rivers and stored it for all sorts of cooling requirements. Buildings were built with huge amounts of internal and external mass to dampen the diurnal ambient temperature swings. The domestic hot water storage tank is the most common use of TES which has achieved essentially 100% market penetration. With the ever increasing importance in demand reduction and stability of our electric grids, Thermal Energy Storage is once again becoming a valuable technology for air-conditioning buildings. However, what is also becoming apparent are the major "Green" benefits of shifting electric usage to off-peak hours, which include lowering source energy usage and emissions.

For decades Off-Peak Cooling (OPC) systems that use thermal energy in the form of ice or chilled water, have been used in the commercial cooling market place. The 80's and 90's were the developmental years of the technology with over 6,000 installations around the world. The industry has matured, refining design methods and producing systems that are reliable and cost effective which have the ability to:

- Reduce Peak Demand at most critical time 20-40%
- Reduce installed cost up to 10% [1]
- Reduce consumer's energy costs 10-20% [2]
- Reduce energy usage at the building up to 14%
- Reduce source energy usage at power plant 8-34%[3]
- Reduce emissions up to 50%
- Increase Load Factor of Generation up to 25%
- Provide operational flexibility

The value of storage is most clearly shown by what it does for the Load Factor (average load divided by the peak load) of the building. Figure 1a[4] represents a building that is designed with many energy efficiency features which we are all familiar with, integrated together into an effective holistic design. Figure 1b is the same building with a storage system added. Though the site energy use for each of the two designs will be essentially the same, the Load Factors are substantially different (53% vs. 88%).



a) b)

Figure 1. Load Factors change dramatically by adding storage, thereby lessening impact on Grid (Society)

With the simple addition of storage to all buildings needing air-conditioning, 40% fewer power plants and smaller transmission and distribution lines would be required. (Obviously this is only the case with utility grids that peak in the summer months which is increasingly the case around the world.) This highlights one major reason why cool storage has not made major penetration into the market place. In almost all "energy efficiency" building benchmarking systems around the world, Building Load Factor is not measured or reported; therefore little importance is placed on it. Utilities have tried to get the message across with rates which are normally much less expensive at night because of the simple laws of supply and demand. A simple example shows why the variation in day and night costs will continue, even though in a few areas of the world this is not the case now.

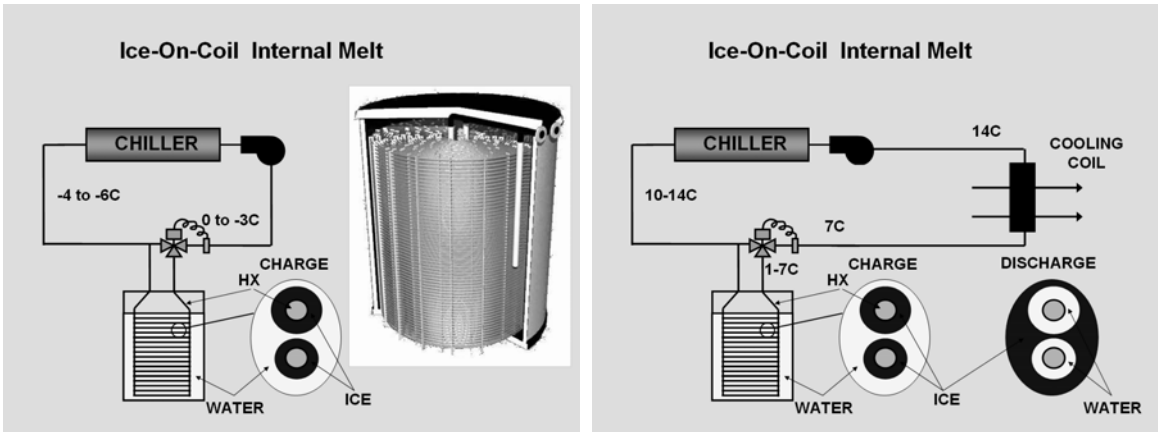
Assuming four buildings (non-storage buildings) that have a peak load of 1 megawatt, a utility would need a 4 megawatt (MW) generator and would sell 8,000MWh a year. If the peak demand of the 4 buildings where reduced by 20% to 0.8MW each (storage can actually take off 40% of a building's peak), utility could supply another similar building and now be selling 10,000MWh/year with the same generator. This equals 25% increase in generator Load Factor which is a huge savings to a utility. Although there are some small areas that have "flat rates" because they have overbuilt the electric supply, it is only a matter of time before large differences between day and night prices are ubiquitous[1]. Therefore, for the building owner, the simple reason to use Off-Peak Cooling is that it costs them less to cool their building, however the benefits extend much further than that, as will be explained later.

3. ACTIVE STORAGE VERSUS BUILDING MASS

Using the mass of a building to store cooling is being applied in some new construction (pipes embedded in concrete floor slabs) and even some retrofit applications (controls to pre-cooling the building). Successful applications need to take great care in assuring comfort conditions do not swing out of acceptable levels, since yearly salaries per square meter are over 100 times the cost of energy to condition that some space. Therefore a 10% savings in yearly energy use is lost with just 2 hours per year of non-productive time, keeping people comfortable and productive is the highest priority of most employers.

Active cool storage systems are undetectable by the occupants of the building and now are very similar to a standard central chilled water system (Figure 2). The systems are chiller based, closed and pressurized, with only three main differences: The chiller is controlled differently since it is not operated in direct response to building load; you need a secondary coolant (usually 25 % glycol/75% water solution) so you can run the chiller below freezing point of water, and of course the thermal storage device.

The most popular[5, 6] ice storage devices sold around the world are known as Internal Melt Ice-On Coil which have a heat exchanger coil submerged in an insulated tank (Figure 2a). The water in the tank never goes anywhere and depending on the mode of operation is frozen and thawed by the secondary coolant that circulates between the chiller, the storage device and the load. During off-peak hours, the chiller runs and creates a -4 C solution which gets circulated to the submerged ice coil, thereby slowly causing the water in the tank to freeze. The ice expansion simply increases the water level in the tank. This change in water level can be measured to give an accurate inventory of your storage.



a) b)

Figure 2. Storage is charged with a standard Chiller (a) and discharged with help from Modulating Valve

During the on-peak hours (Figure 2b) the chiller or the storage or a combination of both can be used to meet the load depending on the design, which is normally determined by the electric rates. The systems are designed with flexibility in mind so that if rates change, the systems can be controlled in a different way to optimize savings to the owner. The great advantage of storage is that you have disconnected the need for cooling (building load) from when you need to create it.

4. WHY IS "COOL" STORAGE GREEN?

There are a number of rating systems emerging around the world to determine the "Greenness" of buildings however in the US and many other parts of the world, the USGBC's LEED program is affecting market transformation. It is based on a point system of which there are 10 points for energy savings. The important fact to be aware of is that the LEED points are based on ANSI/ASHRAE/IESNA Energy Standard 90.1 and 90.1 is based on ***Energy Cost*** saving, not Energy saving. The reason for this is because cost is a good common denominator for all the different energy efficient features and fuels that could be used in a building as well as a powerful "language" that building owners understand well. Therefore, since it is clear that nighttime electric power is much cheaper than daytime power, and with the thousands of installations around the world that have demonstrated this fact, Thermal Storage Systems can reduce energy costs and help get valuable LEED points.

5. LEED GOLD BUILDINGS WITH STORAGE

There are numerous USGBC LEED Gold projects that have used Ice Storage to help in achieving this high rating. This was demonstrated in California's first LEED 2.0 Gold Building, The William and Flora Hewlett Foundation in Menlo Park. (Figure 9) This building had a total of 43 points of which 5 were because of the 35% energy cost reduction of the building. When you analyze all the different technologies that can have an impact on energy cost, you will find that there are only a few that can make a large percentage difference. This project took advantage of 4 of the major ones 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 what mechanical cooling is required to the inexpensive off-peak period. Figure 10 demonstrates the different operating modes of this project. The reduction of about 90kW dramatically reduced the cost of operating the system which helped get LEED credits.

FIGURE 9 William and Flora Hewlett Foundation

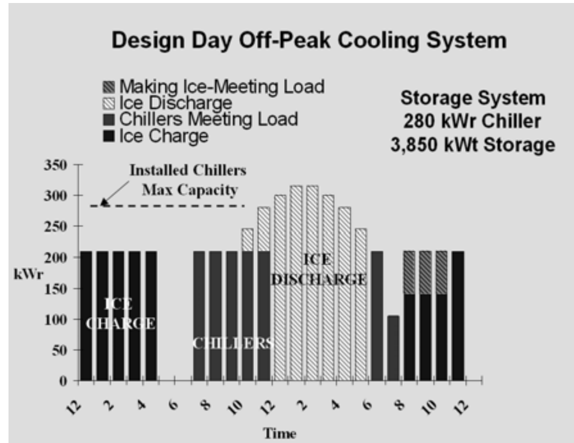


FIGURE 10 Operating modes for Hewlett HQ

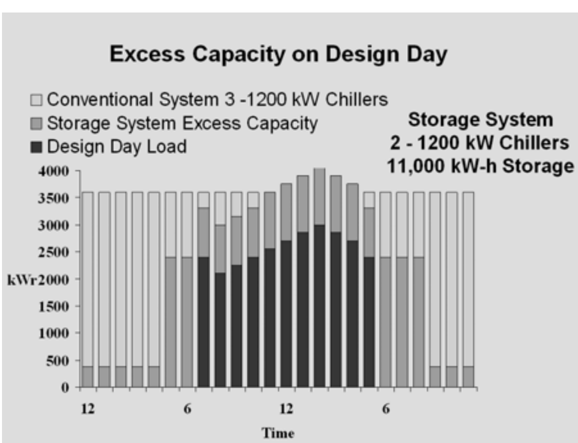
From small office buildings to two of the newest skyscrapers in New York City, each to be 220,000 m^2, and with one going for LEED Gold and the other LEED Platinum, ice storage is penetrating the mainstream of "Green" construction. So you could say storage is green because it gets LEED credits.

6. REAL REASON STORAGE IS GREEN

The real reason shifting power to nighttime use is "Green" is that it is much more efficient to produce and deliver power at night versus during the peak times of the day. Numerous studies[3, 7] have demonstrated that for many reasons you use less fuel to make an off-peak kWh. The reasons included off-peak base load plants are much more energy efficient than on-peak plants, line losses are also less and spinning reserve requirements are less. In addition to the reduction in emissions because of the need for less fuel, the peaking power plants that are the last to come online during a hot summer day are normally the dirtiest. In another report[8] done for the State of California, it is reported that the last power plants to come online are "almost twice" as dirty as the base load plants. These two reasons add up to a big environmental advantage to reducing peak load and shifting it to off-peak hours by utilizing storage.

7. STORAGE : THE BETTER "SAFETY FACTOR"

Designers are doing more and more to reduce the AC load in buildings. However unless you are in the cooler



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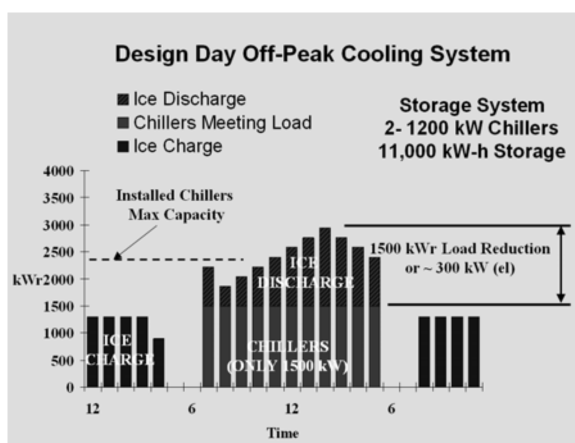

b)

Figure 3. Properly designed storage system, with no added cost, affords plenty of excess capacity and same redundancy while yielding a 300 kW_e reduction in demand.

regions of the world, active mechanical cooling systems will continue to be a vital part of any productive space. Storage can play a vital roll in reducing further the installed capacity for almost any system. For example, let's assume all the great energy conservation innovations have been designed into a building and still the building is estimated to have a load of approximately 3,000 kWr (See Figure 3). Most designers would install 3 chillers, each with a capacity of 1200 kW_r, for one or both of the following reasons: 1.) Added 20% extra capacity for things they might have missed as a "Safety Factor" or 2.) If a chiller fails they will want to meet 80% of the design day load for a certain level of "Redundancy". However the more strategic design would be to install 2-1200 kW_r chillers and, for no additional project cost, buy 11,000 kWh_r of storage. As shown in Figure 3a, with this design you will be able to meet a larger load if a miscalculation has occurred and it also can be shown that you will have the same amount of redundancy if a component fails. The added benefit is that now, instead of investing in a third chiller which would only be used a few hours per year, you have installed storage which can be utilized to take advantage of less expensive nighttime power. On a design day, only 1500 of the 2400 kW_r from the chillers will be needed on peak, with storage handling the rest (Figure 3b). Most of the year only one of the 1200 kW_r chillers will run during the day. The final advantage to downsizing the chiller plant is avoiding the inherent inefficiency of running an oversized system[9].

8. DISCONNECTING SUPPLY AND DEMAND

Two final benefits of storage are related to the flexibility in operation which it brings to the system. In a recent design meeting a prestigious customer insisted that because of past experience, a small, extra chiller should be added to the system (20,000kW_r peak load) to properly meet low occupancy conditions. However since the owner had already agreed that the building would have cool storage it was explained the storage system would be fully charged and could discharge at any low load for weeks without having to run any chiller. Moreover, what the owner also didn't realize is that most air-conditioning systems run very inefficiently at low loads (1-20%). So running the system in the chiller plant for one night to meet the next week's loads was also more efficient.

Similarly in a very large district cooling, heating and power plant (CHP), storage was used to balance the system. During "mild" months heating cooling and electricity is needed for the campus. However in the evening, electric use, and therefore waste heat that was needed for hospital and laundry loads, was so low that boilers had to be bought on to meet the heating requirements. The engineer's solution was simply to increase electric needs at night, by running chillers to make storage, thereby negating the use of the boilers while increasing the cooling capabilities during the day and creating excess electric power for campus growth.

9. CONCLUSION

Off-Peak Cooling using ice or water based thermal storage has come of age. Approximately 2 to 3 Gigawatts of power around the world have been shifted from on to off- peak. It is a tool that is being used to save building owners money as well as save energy and reduce emissions. It benefits the users, the grid and the environment. Offices, schools, places of worship, hospitals, and arenas have all proven to be good candidates for Off-Peak Cooling systems. Load Factor should be a metric included in the benchmarking systems of building performance to help highlight its importance. Creative engineers recognize many ways in which storage can efficiently address the challenges they face including buildings with limited electric capacity, back-up cooling, balancing thermal loads and even downsizing of back-up electric systems. Engineers must realize that sizing cooling systems to instantaneously meet building cooling loads is a major contributor to the electric generation and supply problems faced around the world. Storage is a simple, natural and proven technology that should be considered.

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