The Merits of Thermal Storage in An Unregulated Power Marketplace

Brian M. Silvetti, P.E.
Vice President, Engineering
Calmac Manufacturing Corporation

For many years, it was in the best interests of the electric power industry to financially support the installation of thermal storage systems for off-peak air-conditioning. By shifting electrical usage to night hours generating reserve was maintained at a far lower cost than the construction of new generating equipment would have required. This additional support from the utility industry influenced designers of commercial buildings to fully exploit the available rate structures by maximizing cool storage capacities.

However, deregulation is seen by some as a threat to the continuation of incentive programs. Additionally, questions regarding the future structure of time-of-use rates, as well as the introduction of other rate variants such as real-time pricing (RTP), has introduced considerable uncertainty into the economic forecasting necessary to justify large thermal storage systems with enough capacity to meet the entire cooling load of typical applications.

By minimizing or eliminating a first cost penalty, one can focus on the features of thermal storage that not only protect customers from uncertainties in utility rate structures, but also provide them with the flexibility to take advantage of the optimum available rate. By consuming a significant fraction of their power needs at night, customers become more attractive to generators anxious to fully utilize their power producing capacity in a competitive marketplace. With very few exceptions, it is unquestionably more economical to produce electrical power at night.

A properly selected, implemented and controlled thermal storage system creates a preferred customer who is prepared to respond to the inevitable market forces that will shape electrical power rate structures in an uncertain and unregulated power marketplace.

The blind and frenzied race to resolve questions that surround electric industry deregulation has temporarily obscured the ultimate direction of more mundane issues like rate structures, time-of-use differentials, and demand-side-management (DSM) programs. These, however, are the details that will determine how we select, design, and control thermal energy storage systems in the uncertain future of electric power.

The number and scope of factors that must be considered by regulators and utilities in restructuring an industry that equals 5% of the gross national product is staggering. The question of stranded investments alone, estimated by some at up to $135 billion[1], may have a profound impact on the survival, and certainly the profitability of some of our largest corporations. Perhaps no more than posturing, at least one utility, with an extensive inventory of nuclear generating equipment, has threatened bankruptcy.

Whether you believe that these investments were based on rational and prudent decisions made within the isolation of a regulator environment, or careless and reckless exploitation of a privileged position, the fact remains that an enormous percentage of generating equipment may be considered uneconomical to operate under the pressures of an open electric power market. This may have more impact on the future of power rates than the actual resolution of the investment burden.

Other issues relate to the precarious balance between the utilities' traditional responsibility to serve and their protection from competition, arbitrated by commissions responding to an assortment of legal, economic, political, and technical influences.

Demand-side-management programs, an assortment of both energy conserving and load leveling inducements, required or approved by regulatory commissions, have been used to enhance profitability and to serve the perceived interests of society. While the first goal is in little danger in a free market environment, the interests of society may not fare as well. As stated by the California Public Utilities Commission[1], "In a competitive (deregulated) electric market... utilities have no incentive to promote conservation and energy efficiency because doing so reduces their overall revenues." There aren't many service stations that give free oil changes if you will only stop buying so much gasoline.

Thermal energy storage is unusually well positioned in this respect. Although a well designed thermal storage system is energy conservative, its primary benefit is in shifting load from a period of high demand to a period of low demand, allowing significantly increased

total energy production from a limited generating capacity. Coincidentally, the added power production occurs during the period of highest generator efficiency, providing even greater benefits to both the power producer and society.

Utilities have been compelled by regulation to maintain enough generating reserve to guarantee a stable, high quality, power supply to their customers, and, with only a few spectacular lapses, our electric power system has been a world model of reliability. In a regulated environment, the cost of maintaining these reserves can be incorporated in the various service rate structures. As competitive pressures build, excess idle capacity will simply not be cost effective. The power producer that can generate electricity with less capital investment will do so at a lower price.

Customers that can provide a power supplier with a load that maximizes the useful output of their supplier's generating equipment will obviously enjoy a more attractive competitive position in negotiating a favorable power rate.

WHAT POWER PROVIDERS WILL NEED

The factors that will improve profit in the restructured power marketplace will be little changed from those of today's non-competitive electric industry. Instead of being enhancements to profit under the protective umbrella of a regulated monopoly, they will become weapons in a brutally competitive economic war of attrition. Incentive programs that simply reduce consumption will not survive unless they are regulated into existence or become a feature of broader marketing plans aimed at customer attraction or retention. Properly applied thermal storage, independent of, or in conjunction with support programs, can provide advantages to both power producers and customers that are mutually beneficial.

Demand Relief

The issues of "stranded investments," peak demand, reliability, and capacity margins are all related, and will be more so as deregulation (re-regulation?) progresses. Electric power consumption forecasts in the early 70's resulted in capacity margins of 33% by 1982. By 1993, those margins had fallen to a more realistic 21%, and are projected to drop to

17% by 2003[2,3]. The high cost of maintaining these reserves, has, of course, been passed on to the consumer.

Although few are predicting the collapse of our supply and distribution systems, there is no question that assigning responsibility for maintaining capacity reserves will become more difficult. Endless legions of marketers, packagers, energy service companies, generators, and other middlemen, will struggle to shoehorn themselves through regulatory loopholes that might otherwise force them to maintain idle capacity or power sources. For an industry that is five times more capital intensive[4] than other manufacturing enterprises, the economic albatross of idle capacity represents an enormous competitive disadvantage.

The commercial customer has been the primary target of thermal storage manufacturers and utility incentive programs for this very reason. Approximately 28% of the U.S. power generation is sold to the commercial sector[3]. Of this, about 30% is dedicated to cooling processes, primarily space conditioning. Unfortunately, while these cooling processes consume 30% of the energy, they contribute 44% to peak utility demand[5]. This represents an immense investment in usually idle generating capacity.

The effect on demand is even more striking when you consider that the poor energy to demand ratio for commercial cooling includes customers, like hotels, hospitals, shopping malls etc. whose load profiles are relatively benign. For other customer classifications, such as office buildings and schools, the impact on demand is considerably more serious.

In one energy analysis performed as an example for a respected design manual[6], the cooling equipment contributed approximately 1.9 W/ft^2 to the building's peak demand. This is compared to 4 W/ft^2 for all other lighting, tenant miscellaneous and distribution electrical demand. Projected energy use for the chiller was only 6% of the total annual facility kWh, but accounted for over 30% of the peak demand kW.

An actual installation at the Lunar and Planetary Institute in Houston, Texas[7], a mixed use facility, is even more interesting for several reasons. The rate structure in Houston is designed with an on-peak period that begins at noon. Therefore, as are most storage systems, this one is designed to operate directly from the chiller during the morning hours, switching to only stored cooling in the afternoon.

This provides the opportunity to monitor actual building demand, not projections or predictions, during a period normally considered as on-peak. The actual impact of the storage system can be measured as the transition to the metered, on-peak, period is made. For a typically warm day in June, total building demand rose to slightly over 400 kVA just before noon, when chiller operation ceased, and the demand dropped to approximately 200 kVA. Maximum demand savings, during the one year monitoring period, reached 260 kVA. At the same time, the total kWh sale from the utility remained essentially unchanged.

Even simple, "back-of-the-envelope," calculations give an indication of the disproportionate impact of chiller equipment. For a machine that consumes 1 kW/ton at peak design conditions, including condenser fans or pumps, installed in a building with a 500 ft^2/ton cooling load, the electrical demand will equal 2W/ft^2.

Demand considerations are not restricted to power generators. For instance, the Pennsylvania-New Jersey-Maryland transmission network imposes a monthly demand charge of almost $2/kW for power "wheeled" through their system[8].

Any power purchaser that can offer the ability to shift 40% to 100% of the chiller related demand, thereby releasing that generating capacity to serve another customer, is going to occupy an enviable position as energy providers vie for the most desirable customers.

Energy Efficiency

No one would disagree that the ability to deliver power to a customer, with less fuel at the generating source, is economically attractive. Some recent investigations indicate that the production of power during off-peak, nighttime periods, provides significant benefits in generating efficiency.

Using two different methods of analysis, a study performed for the California Energy Commission found improved heat rates for nighttime electricity generation of 10% to 43%[4]. The higher efficiencies incorporate "unit commitment" energy, the energy needed to maintain a plant in a state of readiness for the following day's on-peak operation.

Even the lower estimates, reflecting only the marginal energy penalties for the additional on peak capacity, virtually guarantee that the source energy used to power off-peak thermal storage equipment will be less than the energy required to operate the equipment on-peak. From this perspective, thermal storage provides energy cost savings for the customer, energy efficiency and load management benefits to the power producer, and reduced pollution and fuel use for the environment.

In fact, there is substantial evidence that properly designed and operated thermal storage systems will save energy, irrespective of the power plant efficiency. Depending on many factors, including the type of storage and refrigerating equipment, the arrangement of the components, operating strategy, climatic conditions, building characteristics etc., there will be no site energy penalty or, at most, only a minor one. The net result, however, will in almost every case, provide a fuel savings at the energy source.

Customer Retention

Utilities obviously want to preserve as much of their current customer base as possible. Many have recognized that strategic use of DSM programs can be a useful tool in establishing long term relationships.

Public and private schools in Ohio are being offered assistance in the installation of high-efficiency lighting, heating and cooling equipment as well as a 10% reduction in their energy rates. In return, they must agree to retain First Energy Corp. a result of the impending merger of Ohio Edison and Centerior Energy Corp., as their electric power supplier for a 7- or 8-year period[9].

In Houston, Texas, the local utility has been very successful in promoting thermal storage with a generous incentive program. Understandably, the utility is reluctant to subsidize investments that might benefit future competitors. Therefore, any customer who purchases power from another source within ten years would have to refund the incentive amount[10]. The utility gains a reliable customer with a favorable electrical load profile, and the customer continuously enjoys reduced rates with little or no additional initial investment.

Other comments regarding demand reduction programs are in order. Some predict a quick death for utility sponsored programs. As one analyst puts it, "...there may still be some DSM credits, but after the transition they will be relegated to regulatory purgatory.[11] Thermal storage is only a small component of these programs that address a wide variety of technologies. For the most part they promote the installation of high efficiency motors and lighting, variable speed drives etc. Thermal storage is quite different in that the major effect is the shifting of load rather than the elimination of load. The differences from a power provider viewpoint are striking and the future for storage programs may not be so dismal.

Table 1. Effect of Discharge Rate On Total Storage Capacity for a Common Cool Storage Module

Discharge Hours	Average Rate (tons)	Total Ton-hrs	% of Original
12	13.5	161	100
10	15.5	155	96
8	19.0	152	94
6	24.0	144	89
4	31.0	124	77

Many regulatory agencies have expressly prohibited incentive programs that require long term customer commitments. However, under a free market approach, customer attraction and retention will almost certainly be a primary focus of DSM programs. The unique appeal of thermal storage will be the ability to offer customers cost savings without totally eliminating the energy sale for the utility.

WHAT CUSTOMERS WILL NEED

Although any customer will be aggressively courted in the energy marketplace, thermal storage provides some unique features that will make customers even more attractive to power providers, improve the customer's negotiating position, minimize energy costs and reduce or eliminate any negative impact on daily operations for the customer.

Versatility

Other than the certainty that on-peak power consumption will continue to command a premium, there is little assurance as to the form those rates will take. In many cases the customer will have a choice as to the structure of his demand penalties. Traditionally, a simple demand charge (kW) and energy charge (kWh), often including a time-of-day differential, have been used to discourage on-peak electrical use.

Occasionally, demand charges have been imbedded in the energy charge by basing the energy charge on the ratio of energy usage to peak demand. Rate design will surely be more exotic in a deregulated environment as providers maneuver to offer the most competitive plans possible.

Utilities are already experimenting with real-time pricing (RTP), a method that ties the cost of energy to the immediate ability, or cost to the utility, of supplying that energy. Under these plans, the cost of energy can be many times greater during periods of high demand. They require advance notification to the customer that varies considerably by utility.

Often, real-time rates are superimposed on a traditional demand structure, either by applying the real-time rate to usage that exceeds a base demand or including a conventional, but reduced, demand charge. The available varieties of real-time pricing are sure to increase.

Interruptible rates, a fairly common tool in natural gas pricing, will also grow in availability. In exchange for lower demand and energy charges a customer agrees to occasionally curtail his electrical usage. The number and length of these curtailment periods are usually defined in the terms of the power contract.

The different "flavors" of rate structures, available to the power customer, will certainly multiply as creative marketing gradually enlivens the sober world of power generation. Obviously, attempting to optimize equipment selection for a particular application, when the form and substance of the energy rate structure is in such a state of flux, is difficult at best.

One of the most appealing benefits of cooling thermal storage is the wide range of performance typically available from the same equipment. Table 1, derived from published performance charts for a common ice storage device,[12] shows that equipment selected for one type of operating logic can be equally effective as the optimum discharge logic might change. This is due to both the innately high discharge rate capability of ice cooling storage and to the fact that increases in load are accompanied by increased storage inlet temperatures, improving the heat transfer characteristics of the device.

Row 1 of the table indicates 161 ton hours of total available cooling storage is obtainable over a 12-hour day at an average discharge rate of 13.5 tons. As discharge periods are compressed, and the cooling load on storage increased, there is only a modest decrease in the total storage availability. If rates eventually make it more economically attractive to discharge as much storage as possible in only a 4-hour period, the same equipment still possesses over 3/4 of its originally designed total capac-

Table 2. Comparison of Equipment For Conventional, Partial and Full Storage Options

	Conv.	Partial	Full
Peak Load (Tons)	500	500	500
Total Load (Ton-hrs)	4675	4675	4675
Chiller Cap. (Tons)	500	135	
Storage Cap. (Ton-hrs)	0	2032	4675
Tons Shifted	0	265	500

ity, providing discharge rates approximately 2.3 times those used in the extended discharge period. In a 6-hour discharge, almost 90% of the original total capacity is maintained at almost double the original rate. In each case, all the remaining stored capacity will still be available at the reduced discharge rates.

There are some obvious *caveats* to consider. Alterations to system control logic, that originally anticipated full loading of the chiller throughout the day, will result in reduced available cooling later in the day if the storage is prematurely depleted. At least, the customer has the option of maximizing economic savings while distributing the reduced cooling capacity over a longer period.

Alternatively, minor equipment capacity selections in the original design can virtually eliminate any penalty—if they are properly prepared for. Remember, periods of high electrical demand generally coincide with high cooling loads. In later hours, even a partially sized chiller will be capable of meeting most of the gradually decreasing cooling load of typical commercial buildings.

A properly designed cooling storage system is flexible enough to respond to virtually any variation in rate structure that might eventually emerge as the most economic.

Why Not?

DSM programs have undoubtedly helped to foster the growth and acceptance of thermal storage in the commercial and industrial sectors. The generous terms of these programs often made it economical to install storage capacities capable of avoiding all the on-peak chiller operation. This is referred to as "full storage."

What is often forgotten is that thermal storage can be installed with little or no cost penalty, as compared to conventional chiller systems, if the goals are more modest. DSM incentives are certainly welcome, but not necessary to make thermal storage a viable investment. There are no defined limits on the quantity of storage that can be theoretically applied to a building. The only certainty is that all of the cooling originates with the chiller or refrigerating equipment: Once this is understood, the economics of storage become more tractable.

In the simplest approach, a chiller, operating only at night, completely charges a storage component that has enough capacity to meet the entire on-peak load of the building. Running only in an ice-making mode, the chiller has about 65% to 70% of the capacity it would have running at conventional temperatures.

Remember, this is a capacity penalty and not an efficiency penalty. Due to reduced capacity and limited running hours, the chiller in the "full storage" approach ends up being approximately the same size it would have been in a conventional system.

The entire cost of storage, which also must have enough capacity for the entire cooling load of the building, is an additional investment. Although this approach will eventually provide the maximum energy cost savings, the time required to recover the original investment generally exceeds acceptable limits without utility provided incentives.

An alternative referred to as "partial storage," and still misunderstood by some, minimizes or eliminates any additional initial capital investment. By operating a chiller for the entire day, on-peak at standard conditions and off-peak at ice-making conditions, its size is usually reduced to 40% to 50% of the conventional design. Because the chiller operates fully loaded during the design day, on-peak period, a chiller, sized at perhaps 45% of the design day peak load, can typically meet almost 60% of the total daily cooling load directly. Storage is only needed for about 40% to 45% of the required ton-hours. Both chiller and storage are greatly reduced in size, compared to the "full storage" design.

Peak demand savings of 50% to 60% of the standard chiller demand are usually achieved. Table 2 summarizes the equipment and demand savings comparison of conventional, "full" and "partial" storage designs. The building is assumed to have a 500-ton peak load with an average load of 425 tons over its 11-hour cooling period.

There are many examples of effective thermal storage systems that were installed for little or no additional cost over their conventional alternatives. One storage system that eliminated *all* on-peak chiller demand was installed in a state government service center in southwest Florida for $56,000 less than the $2.1 million that was bid for conventional system. The additional $187,500 provided by the utility resulted in a net first-cost savings of almost a quarter of a million dollars. Annual demand and energy cost savings total $120,000 per year. The building operates with 10% less energy than the typical state owned facility and almost 42% less energy cost on a square foot basis.[13]

When it was decided to air-condition an 18,000 seat auditorium in western New York, the incorporation of almost 9,000 ton-hrs of thermal storage reduced the added electrical demand by over 70% from 1,650 kW to only 450 kW. The incremental cost of only $120,000 was returned in less than 2 1/2 years.[14]

A unique chilled water conversion of worn-out rooftop equipment has been performed at several facilities including an elementary school, community college and manufacturing plant. In each case, the installation of the storage based system was significantly below the cost of simple rooftop replacement.

In the case of the elementary school, storage was not even considered until after the bidding process on the rooftops was completed. This school was carefully monitored by the local utility, both before and after the conversion. Not only were demand reduction targets met, but significantly improved efficiency was also achieved.[15,16]

There will always be value to a power provider in the ability to supply energy during low demand periods and this value will be reflected in whatever rate structures emerge from today's uncertainty. Thermal storage offers commercial customers the ability to exploit that value without impacting the initial cost of the facility.

Low Facility Impact

There are many measures that can be taken when on-peak rates become excessively burdensome. Unfortunately, there is a false economy when these measures affect the comfort or productivity of a building's occupants, a common problem in responding to interruptible service provisos. Cooling storage avoids significant on-peak demand with no effect on the preferred condition of the facility. In fact, where the low temperatures available from ice storage are used to reduce humidity, comfort levels are generally considered to be superior to more conventional designs.

CONCLUSION

Assets of investor owned utilities in the U.S. total almost $600 billion.[17] Obviously the stakes in restructuring an industry of this magnitude are not high, they are astronomical. There seem to be as many opinions regarding the final form and substance of a restructured electric power industry as there are articles published on the topic. Perhaps, like one veteran consultant of the foreign deregulation wars, you are not particularly optimistic. As he foresees it, "There is a good chance that, within the next year, the U.S. reform process will be widely viewed as a policy disaster. And it is not clear what can be done to prevent this outcome, given the realities of the U.S. political and administrative situation."[18]

Others, of course, are more hopeful. As reported in a recent twenty-two page advertising supplement to the *New York Times*[9] whose only purpose seemed to be education and promotion of the deregulation process, "Nationally, savings may reach $60-billion to $80-billion a year." A remarkable estimate for an industry with approximately $210 billion in annual sales. And then, maybe most of us will end up like the residential participant in a northeast, pilot, free-access program, who said, "I don't know if I can go to Burger King and buy a burger (with money I've saved). It seems all we've seen is pennies.[19]

In any case, given that the industry is allowed to respond to free market forces, certain economic realities will prevail. Power generators and distributors will feel enormous pressure to maximize the output from a minimum capital investment. Although predictions abound on the eventual evolution of on-peak and off-peak rate differentials, everyone agrees that the difference, in whatever form it takes, will remain substantial.

In exploiting these differentials, thermal storage provides many benefits, to both the seller and the customer, not shared by most other load management techniques:

- The wide performance envelope of cooling thermal storage will allow it to respond to a broad variety of rate patterns.
- With or without utility incentives, thermal storage can be designed with little or no additional initial cost, while still protecting the customer from uncertainties in rate development.
- Thermal storage can shift a high percentage of on-peak demand to off-peak periods, freeing capacity to meet other customers.
- The demand shifted is typically the largest contributor to poor load factor in a commercial facility.
- Unlike load management techniques that only reduce the purchase of electricity, thermal storage efficiently shifts power use to off-peak periods, saving on energy costs while improving return for the provider.
- The comfort of the facility is unchanged, if not actually enhanced.
- The power provider gains a load that is served by equipment operating at its highest efficiency.
- Thermal storage improves a customer's negotiating position rather than diluting it.

Cooling storage addresses many of these same issues in today's regulated environment, however, in the free market future, these issues will represent competitive advantage, the rocket fuel of free enterprise.

References

1. Gotthried, David A., Heating/Piping/Air-Conditioning, May 1997, "Electricity Deregulation."
2. Energy Information Administration, U.S. Dept. of Energy, Washington, DC, Electric Power Annual 1994, Volume II, November 1995
3. Energy Information Administration Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Dept. of Energy, Washington, DC; "Performance Issues for a Changing Electric Power Industry," January, 1995.
4. Tabors Caramanis & Assoc., 'Prepared for the Thermal Energy Storage Systems Collaborative of the California Energy Commission, "Source Energy and Environmental Impacts of Thermal Energy Storage."
5. Electric Power Research Institute, (no date shown), "Commercial Cool Storage."
6. Lorsch Harold G. et al, ASHRAE Air-Conditioning Systems Design Manual, Appendix F, pp F-1 through F-11
7. Gansler, Robert A., McGuire, Mark R., P.E., Hunter, William L., Reindl, Douglas

T., Ph.D., P.E., EPRI International Conference on Sustainable Thermal Energy Storage/Conference Proceedings, August, 1996, "Case Study: The Lunar and Planetary Institute"
8. PJM Oasis Website, "Customer's Guide for the PJM Energy Market & Transmission Services," May 12, 1997
9. New York Times, June 9, 1997, Advertisement Section, "Energy: The Power to Choose"
10. Houston Lighting & Power Company, "Agreement for Commercial Cool Storage," March 15, 1996, Revision 3.0
11. Rouse, James B., *Energy User News*, March 1997, "Competitive Pressures Drive Businesses to Seek Electricity Choices."
12. Calmac Manufacturing Corp., "LEVLOAD ICE BANK® Performance Manual, System Charge, Discharge and Pressure Drop Curves."
13. O'Neal, Edward J., *ASHRAE Journal*, April, 1996, "Thermal Storage System Achieves Operating and First-Cost Savings."
14. Smith, Scott F., *ASHRAE Journal*, March 1993, "Thermal Storage HVAC System Retrofit Provides Economical Air Conditioning."
15. Calmac Manufacturing Corp., "Roofberg® System, Retrofit ice storage system for rooftop air conditioning units."
16. Galuska, Edward J., *ASHRAE Journal*, March 1994, "Thermal Storage System Reduces Costs of Manufacturing Facility "
17. Competition in the Electric Industry and Its Impacts on Texans, TU, February, 1997
18. Ruff, Larry E., Restructuring.htm, (Electricity on-line Home Page) "An Efficient, Competitive Electricity Industry: Can the Vision Become Reality?"
19. *Rockland Journal-News*, July 13, 1997, "Electrical choice to benefit public" by Barbara Woller.

ABOUT THE AUTHOR

Brian Silvetti, P.E., is vice president of engineering for Calmac Manufacturing Corporation. He holds a bachelor's degree from New York University as well as both a bachelor's and master's degree in mechanical engineering from the New Jersey Institute of Technology where he graduated *summa cum laude*. Mr. Silvetti has more than 20 years experience in the research, development, and application of phase change thermal storage systems and other HVAC-related products. He is a licensed professional engineer in the state of New Jersey.

Calmac Engineering Corporation, 101 West Sheffield Ave., P.O. Box 710, Englewood, NJ 07631; 201-569-0420; fax 7593; calmac@compuserve.com