Lecture 8: Thermal Energy Storage

This lecture will cover the basics of Thermal Energy Storage. Deep discussion and details is beyond the scope of this lecture.

8.1 Introduction

A majority of the technology developed for energy management has dealt with the more efficient *consumption* of electricity, rather than timing the demand for it. Variable frequency drives, energy efficient lights, electronic ballasts and energy efficient motors are a few of these consumption management devices. These techniques often only impact a small portion of the facilities demand (when compared to say the mechanical cooling equipment), which is normally a major portion of the facilities overall annual electric bill. The management of demand charges deals very little with conservation of energy but mainly with the ability of a generator to supply power *when* needed. It is this timing of consumption that is the basis of demand management and the focus of thermal energy storage (TES)

Utilities often charge more for energy and demand during certain periods in the form of on-peak rates and ratchet clauses. The process of managing the generation capacity that a particular utility has "on-line" involves the utilization of those generating units that produce power most efficiently first since these units would have the lowest avoided costs (ultimately the actual cost of energy). When the loads are approaching the connected generation capacity of the utility, additional generating units must be brought on line. Each additional unit has an incrementally higher avoided cost since these "peaking units" units are less efficient and used less often. This has prompted many organizations to implement some form of demand management.

Thermal energy storage (TES) is the concept of generating and storing energy in the form of heat or cold for use during peak periods.

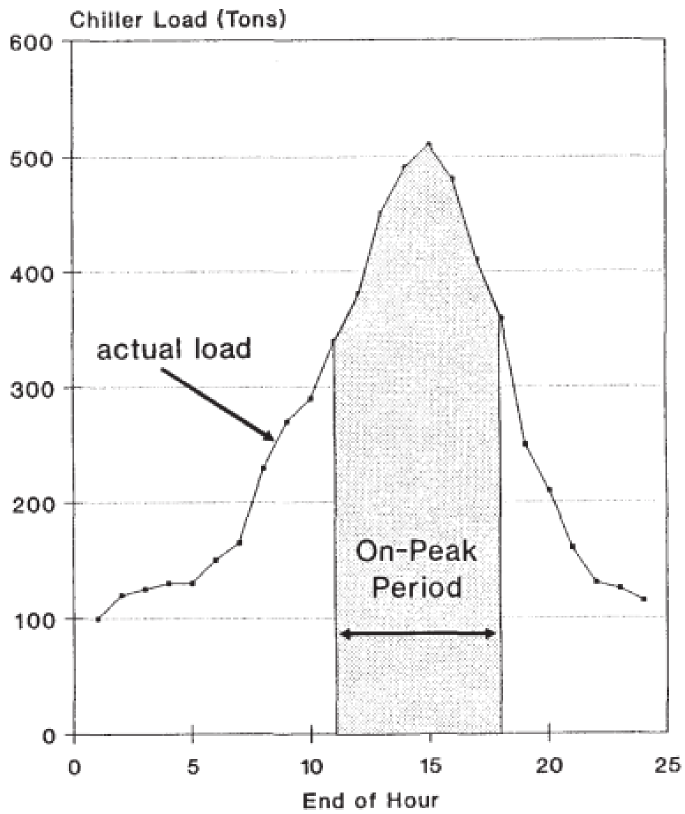

Figure 8.1. Typical office building chiller consumption profile.

For the profile in **Figure 8.1**, a cooling storage system could be implemented to reduce or eliminate the need to run the chillers during the on-peak rate period. *By running the chillers during off-peak hours and storing this capacity for use during the on-peak hours, a reduction in energy costs can be realized.* If this type of system is implemented during new construction or when equipment is being replaced, smaller capacity chillers can be installed since the chiller can spread the production of the total load over the entire day, rather than being sized for peak loads.

Thermal energy storage has been used for centuries, but only recently have large electrical users taken advantage of the technique for cost management. The process involves storing Btus (or lack of Btus) for use when either a heat source or a heat sink is required. Today, the ability to take advantage of a source of inexpensive energy (whether waste heat source or time based rate structure) for use during a later time of more expensive energy has extended the applications of TES.

For this lecture, the focus of discussion will concentrate on the storage of cooling capacity; the storage of heat will not be considered.

Often the chiller load and efficiency follow the chiller consumption profile, in that the chiller is running at high load, i.e. high efficiency, only a small portion of the day. This is due to the HVAC system having to produce cooling when it is needed as well as to be able to handle instantaneous peak loads. With smaller chiller systems designed to handle the base and peak loads during off-peak hours, the chillers can run at higher average loads and thus higher efficiencies.

Thermal energy storage also has the ability to balance the daily loads on a cooling system. Conventional air conditioning systems must employ a chiller large enough to handle the peak cooling demand as it occurs. This mandates that the cooling system be required to operate in a load following mode, varying the output of the system in response to changes in the cooling requirements. Systems that operate within a one or two shift operation or those that are much more climatically based, can benefit from the smoothing characteristics of TES.

A school, for example, that adds a new wing could utilize the existing refrigeration system during the evening to generate cooling capacity to be stored for use during the day. Although additional piping and pumping capacity would need to be added to the addition, new chiller capacity may not have to be added. A new construction project that would have similar single shift cooling demand profile could utilize a smaller chiller in combination with storage to better balance the chiller operation. Moving load from the on-peak rate period to the off-peak period can both balance the demand and reduce residual ratcheted peak charges. Thermal energy storage is one method available to accomplish just that.

8.2. Storage Systems

Full Storage Systems.

These ones that shut the chiller down during on-peak times and run completely off the storage system during that time. The full storage systems have a higher first cost since the chiller is off during peaking times and the cooling load must be satisfied by a larger chiller running fewer hours, with a larger storage system storing the excess. The full storage systems do realize greater savings than the partial system since the chillers are completely turned off during on-peak periods. Full storage systems are often implemented in retrofit projects since a large chiller system may already be in place.

Partial storage systems.

These are designed to have the chiller run during the on-peak period supplementing the storage system. A partial storage system provides attractive savings with less initial cost and size requirements. New construction projects will often implement a partial storage system so the size of both the chiller and the storage system can be reduced. An advantage of partial load systems is that they can provide a means of improving the performance of a system that can handle the cumulative cooling load but not the instantaneous peak demands of the building. In such a system, the chiller could be run nearer optimal load continuously throughout the day, with the excess cooling tonnage being stored for use during the peak periods. An optional method for utilizing partial storage is a system that already utilizes two chillers. The daily cooling load could be satisfied by running both chillers during the off-peak hours, storing any excess cooling capacity, and running only one chiller during the on peak period to supplement the discharge of the storage system. This also has the important advantage of offering a reserve chiller during peak load times. Early and late in the cooling season, the partial load system could approach the full load system characteristics. As the cooling loads and peaks begin to decline, the storage system will be able to handle more of the on-peak requirement, and eventually the on-peak chiller could also be turned off. A system such as this can be designed to run the chillers at optimum load, increasing efficiency of the system.

Storage systems also provide various operational advantages to mechanical systems. Even a partially charged storage system could provide a certain level of capacity if the primary system failed or if the utility became unavailable during an outage or a curtailment procedure. This “redundancy” could be provided with minimal power, say an emergency generator of small capacity since we could simply start the chilled water pumps rather than a back-up chiller to circulate water through a critical hospital system or data center. With the correct relationships in place, the utility could utilize a large storage system as a virtual generator during high power periods.

8.3 Storage Mediums

There are several methods currently in use to store cold in thermal energy storage systems. These are water, ice, and phase change materials. The water systems simply store chilled water for use during on-peak periods. Ice systems produce ice that can be used to cool the actual chilling water, utilizing the high latent heat of fusion. Phase change materials are those materials that exhibit properties (melting points for example) that lend themselves to thermal energy storage

8.3.1 Chilled Water Storage

Chilled water storage is simply a method of storing chilled water generated during off-peak periods in a large tank or series of tanks. These tanks are the most commonly used method of thermal storage. One factor to this popularity is the ease to which these water tanks can be interfaced with the existing HVAC system. The chillers are not required to produce chilled water any colder than presently used in the system, so the system efficiency is not sacrificed. The chiller system draws warmer water from one end of the system, and this is replaced with chilled water in the other. During the off-peak charge cycle, the temperature of the water in the storage will decline until the output temperature of the chiller system is approached or reached. This chilled water is then withdrawn during the on-peak discharge cycle, supplementing or replacing the chiller(s) output.

Facilities that have a system size constraint such as lack of space often install a series of small insulated tanks that are plumbed in series. Other facilities have installed a single, large volume tank either above or below ground. The material and shape of these tanks vary greatly from installation to installation. These large tanks are often designed very similar to municipal water storage tanks. The main performance factors in the design of these tank systems, either large or multiple, is location and insulation.

The advantages of using water as the thermal storage medium are:

1. Retrofitting the storage system with the existing HVAC system is very easy.
2. Water systems utilize normal evaporator temperatures.
3. With proper design, the water tanks have good thermal storage efficiencies.
4. Full thermal stratification maintains chilled water temperature differential, maintaining chiller loading and efficiencies.

5. Water systems have lower auxiliary energy consumption than both ice and phase change materials since the water has unrestricted flow through the storage system.

8.3.2 Ice Storage

Ice storage utilizes water's high latent heat of fusion to store cooling energy. One pound of ice stores 144 Btu's of cooling energy, while chilled water only contains 1 Btu per pound. This reduces the required storage volume approximately 75% if ice systems are used rather than water. Ice storage systems form ice with the chiller system during off-peak periods, and this ice is used to generate chilled water during on-peak periods.

The advantages of using ice as the thermal storage medium are:

1. Retrofitting the storage system with the existing HVAC chilled water system is feasible.
2. Ice systems require less space than that required by the water systems.
3. Ice systems have higher storage but lower refrigeration efficiencies than those of water.
4. Ice systems are available in packaged units, due to smaller size requirements.

8.3.3 Phase Change Materials

The benefit of capturing latent heat of fusion while maintaining evaporating temperatures of existing chiller systems can be realized with the use of phase change materials. There are materials that have melting points higher than that of water that have been successfully used in thermal energy storage systems. Several of these materials fall into the general category called "eutectic salts" and are salt hydrates that are mixtures of inorganic salts and water.

The advantages of using eutectic salts as the thermal storage medium are that they:

1. Can utilize the existing chiller system for generating storage due to evaporator temperature similarity,
2. Require less space than that required by the water systems,
3. Have higher storage and equivalent refrigeration efficiencies to those of water, and
4. Do not suffer the efficiency penalties of ice systems.

8.4 System Capacity

The performance of thermal storage systems depends upon proper design. If sized too small or too large, the entire system performance will suffer. Full discussion of this is beyond the scope of this lecture.

8.5 Conclusion

Thermal energy storage will play a large role in the future of demand side management programs of both private organizations and utilities. An organization that wishes to employ a system-wide energy management strategy will need to be able to track, predict, and control their load profile in order to minimize utility costs. This management strategy will only become more critical as electricity costs become more variable in a deregulated market. Real-time pricing and multi-facility contracts will further enhance the savings potential of demand management, which thermal energy storage should become a valuable tool.

The success of the thermal storage system and the HVAC system as a whole depend on many factors:

- The chiller load profile,
- The utility rate schedules and incentive programs,
- The condition of the current chiller system,
- The space available for the various systems,
- The selection of the proper storage medium, and
- The proper design of the system and integration of this system into the current system.

Thermal storage is a very attractive method for an organization to reduce electric costs and improve system management. New installation projects can utilize storage to reduce the initial costs of the chiller system as well as savings in operation. Storage systems will become easier to justify in the future, with increased mass production, and technical advances and more companies switching to storage.