THERMAL ENERGY STORAGE

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submitted to:
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<u>THERMAL ENERGY STORAGE</u>

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19.1 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. This side of electricity management effects only a portion of the actual electric cost, and often a small portion, compared to that dealing with the demand charge for electricity. Strangely enough the conservation of demand charges deals very little with the consumption of energy, but mainly with the ability of the utility to supply energy **when** needed. It is this timing of consumption that directly deals with demand management.

Experts agree that demand management is actually not a form of energy **conservation** but a form of energy <u>management</u>. Energy management has entered a new stage of maturation with the introduction of demand management. Utilities often charge more for energy used during periods when electricity is used most, ie. on-peak periods, and levy penalties for high demand during certain periods in the form of peak and ratchet clauses. This has prompted many organizations to implement some form of demand management. Companies often control the demand of electricity by utilizing some of the techniques listed above and other consumption management actions which also reduce demand. More recently the ability to shift the **time** when electricity is needed has provided a means of balancing or shifting the demand for electricity to "off-peak" hours. This technique is often called demand balancing or demand shedding. This demand balancing may best be seen with the use of an example 24-hour chiller consumption plot during the peak day, Figure 19.1 and Table 19.1. This facility exhibits a typical office building load profile. The utility rate schedule has a summer on-peak demand period from 10 am to 5:59 pm, an 8-hour peak. 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.

Thermal energy storage (TES) is the concept of generating and storing energy in the form of heat or cold for use during peak periods. For the profile in Figure 19.1, 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.

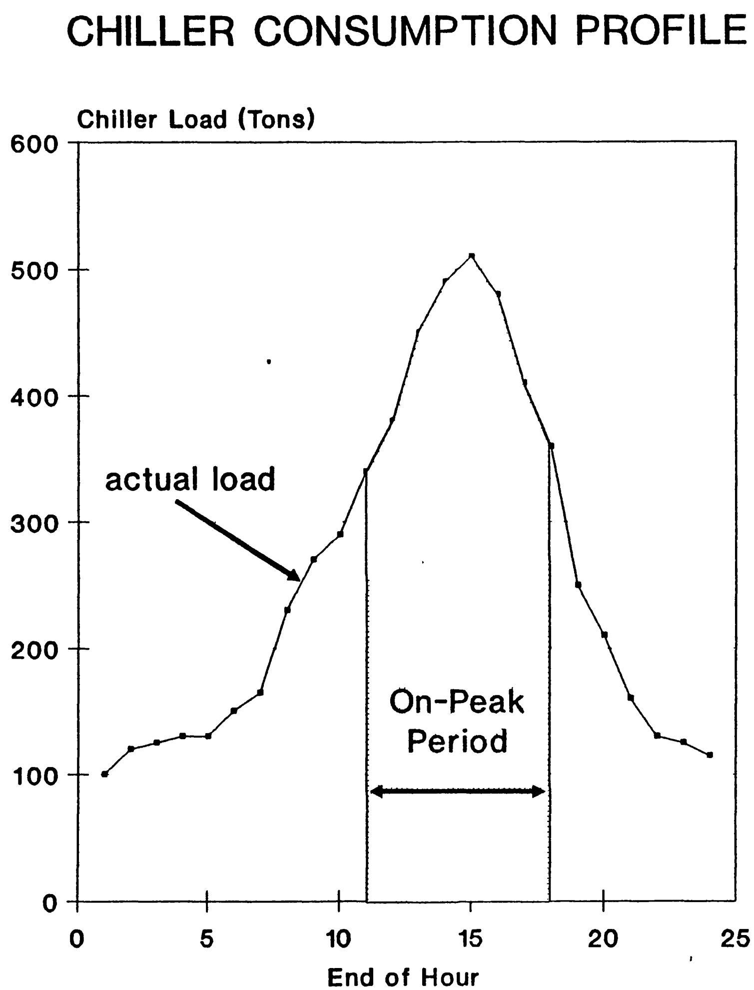

Figure 19.1 Typical Office Building Chiller Consumption Profile

Table 19.1 Example Chiller Consumption Profile

Chiller Consumption Profile		
End of Hour	Chiller Load (Tons)	Rate
1	100	Reg
2	120	Reg
3	125	Reg
4	130	Reg
5	130	Reg
6	153	Reg
7	165	Reg
8	230	Reg
9	270	Reg
10	290	Reg
11	340	On-Peak
12	380	On-Peak
13	450	On-Peak
14	490	On-Peak
15	510	On-Peak
16	480	On-Peak
17	410	On-Peak
18	360	On-Peak
19	250	Reg
20	210	Reg
21	160	Reg
22	130	Reg
23	125	Reg
24	115	Reg
Daily Total:	6123	Ton-Hrs
Daily Avg:	255.13	Tons
Peak Total:	3420	Ton-Hrs
Peak Demand:	510	Tons

Often the chiller load and efficiency follow the chiller consumption profile, in that the chiller is running at high load, ie. high efficiency, only a small portion of the day. This is due to the HVAC design 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. Appendix A following this chapter lists several manufacturers of thermal energy storage systems.

19.2 STORAGE SYSTEMS

There are two general types of storage systems, ones that shut the chiller down during on-peak times and run completely off the storage system during that time are known as "full storage systems". Those designed to have the chiller run during the on-peak period supplementing the storage system are known as "partial storage systems". 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 and a larger storage system storing the excess. The full storage systems does 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 the large chiller systems may already be in place.

A partial storage system provides an attractive amount of savings with less initial cost and size requirements. New construction projects will often implement a partial storage system so that the size of both the chiller and the storage system can be reduced. Figures 19.2 and 19.3 and Tables 19.2 and 19.3 demonstrates the chiller load required to satisfy the cooling needs of the office building presented in Figure 19.1 for the full and partial systems, respectively. Column 2 in these tables represents the building cooling load each hour, and column 3 represents the chiller output for each hour. Discussion of the actual calculations that are required for sizing these different systems is included in a subsequent section. For simplicity sake, these numbers do not provide for any system losses, which will also be discussed in a later section.

The full storage system has been designed so that the total daily chiller load is produced during the off-peak hours. This eliminates the need to run the chillers during the on-peak hours, saving the increased rates for consumption demand charges during this period and as well as any future peak penalties due to ratchet clauses. The partial storage system produces 255.13 tons per hour during the entire day, storing excess capacity for use when the building demand exceeds the chiller production. This provides the ability to control the chiller load, limits the peak chiller demand to 255.13 kW[1], and still take advantage of the off-peak rates

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1 assuming COP = 3.5 => $\dfrac{12{,}000 \text{ Btu/Hr}}{(\mathbf{X} \text{ kW}/3{,}412 \text{ Btu})}$ => **X** = 1 kW/Ton

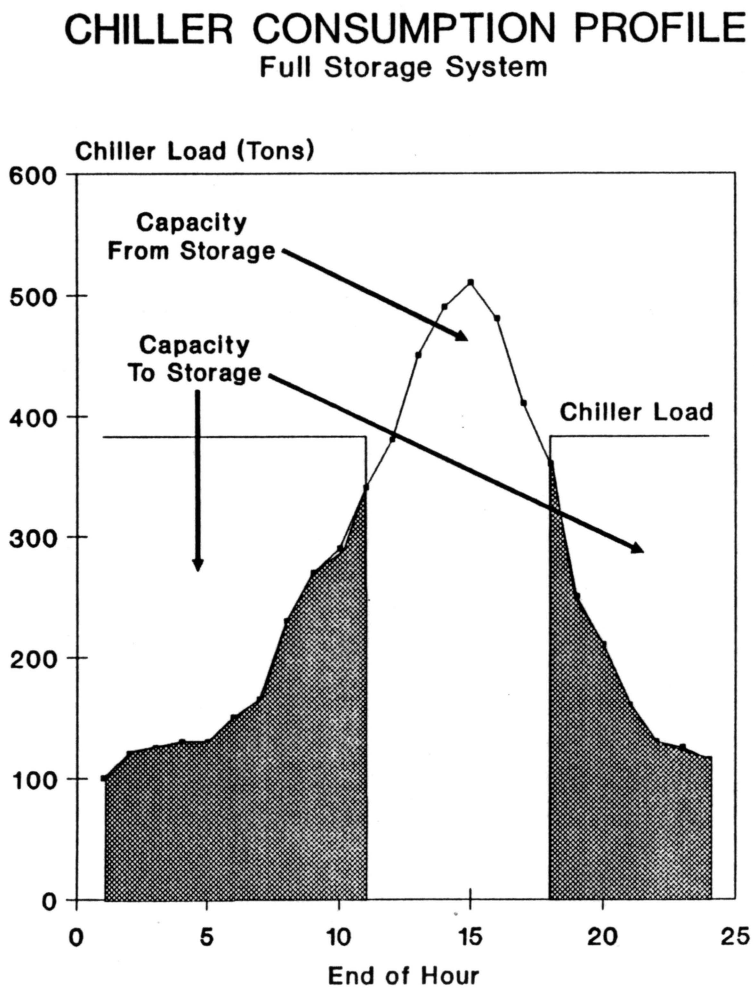

Figure 19.2 Full Storage Chiller Consumption Profile

Table 19.2 Full Storage Chiller Consumption Profile

Chiller Consumption Profile Full Storage System			
1 End of Hour	2 Cooling Load (Tons)	3 Chiller Load[2] (Tons)	4 Rate
1	100	382.69	Reg
2	120	382.69	Reg
3	125	382.69	Reg
4	130	382.69	Reg
5	130	382.69	Reg
6	153	382.69	Reg
7	165	382.69	Reg
8	230	382.69	Reg
9	270	382.69	Reg
10	290	382.69	Reg
11	340	0	On-Peak
12	380	0	On-Peak
13	450	0	On-Peak
14	490	0	On-Peak
15	510	0	On-Peak
16	480	0	On-Peak
17	410	0	On-Peak
18	360	0	On-Peak
19	250	382.69	Reg
20	210	382.69	Reg
21	160	382.69	Reg
22	130	382.69	Reg
23	125	382.69	Reg
24	115	382.69	Reg
Daily Total (Ton-Hrs)	6123	6123	
Daily Avg (Tons):	255.13 [1]	255.13	
Peak Total (Ton-Hrs)	3420 [3]	0 [4]	
Peak Demand (Tons)	510 [3]	0 [4]	

1 $\frac{\text{6123 Ton-Hr}}{\text{24 Hours}}$ = 255.13 Avg Tons

2 $\frac{\text{6123 Ton-Hr}}{\text{16 Hours}}$ = 382.69 Avg Tons

3 This load is supplied by the TES, not the chiller

4 This is the chiller load and peak during on-peak periods

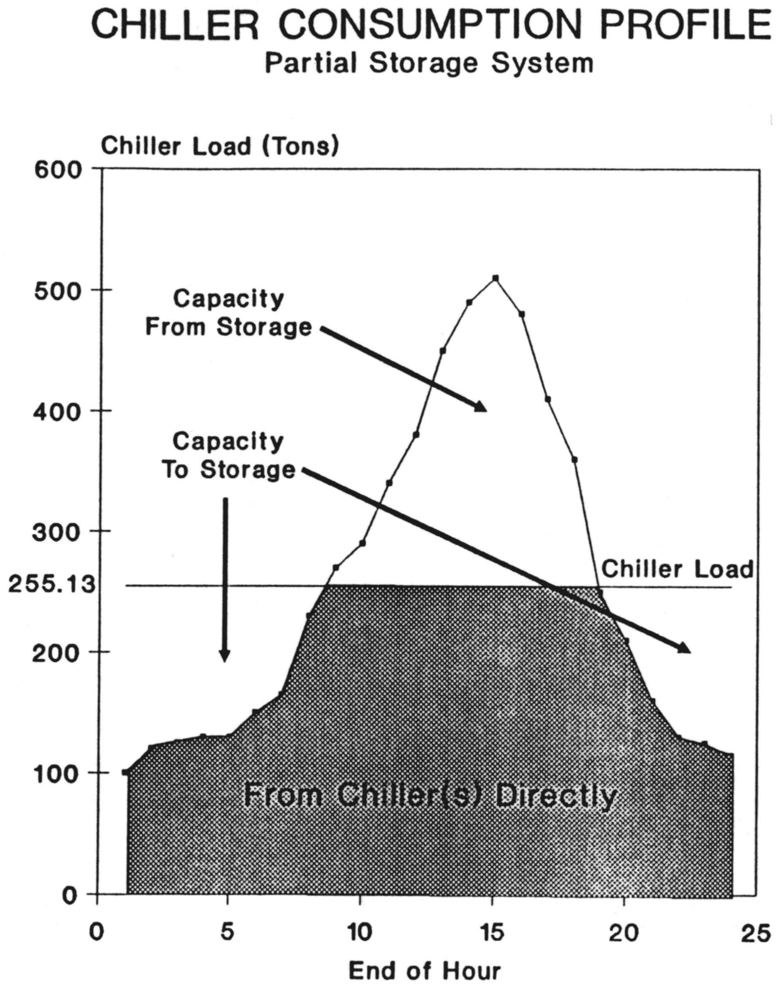

Figure 19.3 Partial Storage Chiller Consumption Profile

Table 19.3 Partial Storage Chiller Consumption Profile

Chiller Consumption Profile Partial Storage System			
1	2	3	4
Hour of Day	Cooling Load (Tons)	Chiller Load[1] (Tons)	Rate
1	100	255.13	Reg
2	120	255.13	Reg
3	125	255.13	Reg
4	130	255.13	Reg
5	130	255.13	Reg
6	153	255.13	Reg
7	165	255.13	Reg
8	230	255.13	Reg
9	270	255.13	Reg
10	290	255.13	Reg
11	340	255.13	On-Peak
12	380	255.13	On-Peak
13	450	255.13	On-Peak
14	490	255.13	On-Peak
15	510	255.13	On-Peak
16	480	255.13	On-Peak
17	410	255.13	On-Peak
18	360	255.13	On-Peak
19	250	255.13	Reg
20	210	255.13	Reg
21	160	255.13	Reg
22	130	255.13	Reg
23	125	255.13	Reg
24	115	255.13	Reg
Daily Total (Ton-Hrs):	6123	6123	
Daily Avg (Tons):	255.13	255.13	
Peak Total (Ton-Hrs):	3420[2]	2041[3]	
Peak Demand (Tons):	510[2]	255.13[3]	

1 $\frac{6123 \text{ Ton-Hr}}{24 \text{ Hours}} = 255.13$ Avg Tons

2 This load is supplied by the TES supplemented by the chiller

3 This is the chiller load and peak during the on-peak period.

for a portion of the on-peak load.

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 when the chiller cannot provide enough cooling. 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. Figure 19.4 shows the chiller consumption profile for this optional partial storage arrangement and Table 19.4 lists the consumption values. 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.

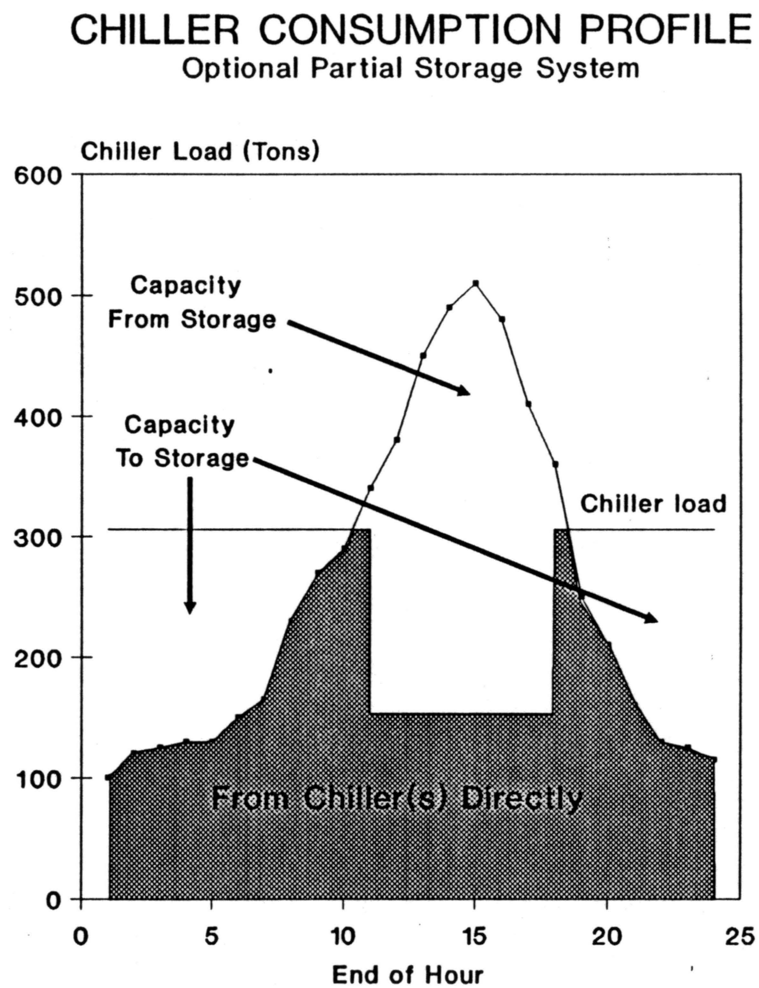

Figure 19.4 Optional Partial Storage Chiller Profile

Table 19.4 Partial Storage Chiller Consumption Profile

Chiller Consumption Profile Partial Storage System			
1	2	3	4
Hour of Day	Cooling Load (Tons)	Chiller Load[1,2] (Tons)	Rate
1	100	306	Reg
2	120	306	Reg
3	125	306	Reg
4	130	306	Reg
5	130	306	Reg
6	153	306	Reg
7	165	306	Reg
8	230	306	Reg
9	270	306	Reg
10	290	306	Reg
11	340	153	On-Peak
12	380	153	On-Peak
13	450	153	On-Peak
14	490	153	On-Peak
15	510	153	On-Peak
16	480	153	On-Peak
17	410	153	On-Peak
18	360	153	On-Peak
19	250	306	Reg
20	210	306	Reg
21	160	306	Reg
22	130	306	Reg
23	125	306	Reg
24	115	306	Reg
Daily Total (Ton-Hrs):	6123	6123	
Daily Avg (Tons):	255.13	255.12	
On-Peak (Ton-Hrs):	3420[3]	1225[4]	
Peak Demand (Tons):	510[3]	153[4]	

1 $\frac{\text{(6123 Ton-Hr)(2 Chillers Operating)}}{\text{(16 Hours)(2 Chillers) + (8 Hours)(1 Chiller)}} = 306 \text{ Tons}$

2 $\frac{\text{(6123 Ton-Hr)(1 Chiller Operating)}}{\text{(16 Hours)(2 Chillers) + (8 Hours)(1 Chiller)}} = 153 \text{ Tons}$

3 This load is supplied by the TES supplemented by the chiller.

4 This is the chiller load and peak during the on-peak period.

19.3 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. Figure 19.5a represents the configuration of the cooling system with either a water or phase change material thermal storage system and Figure 19.5b represents a general configuration of a TES utilizing ice as the storage medium. The next few sections will discuss these different mediums.

19.3.1 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

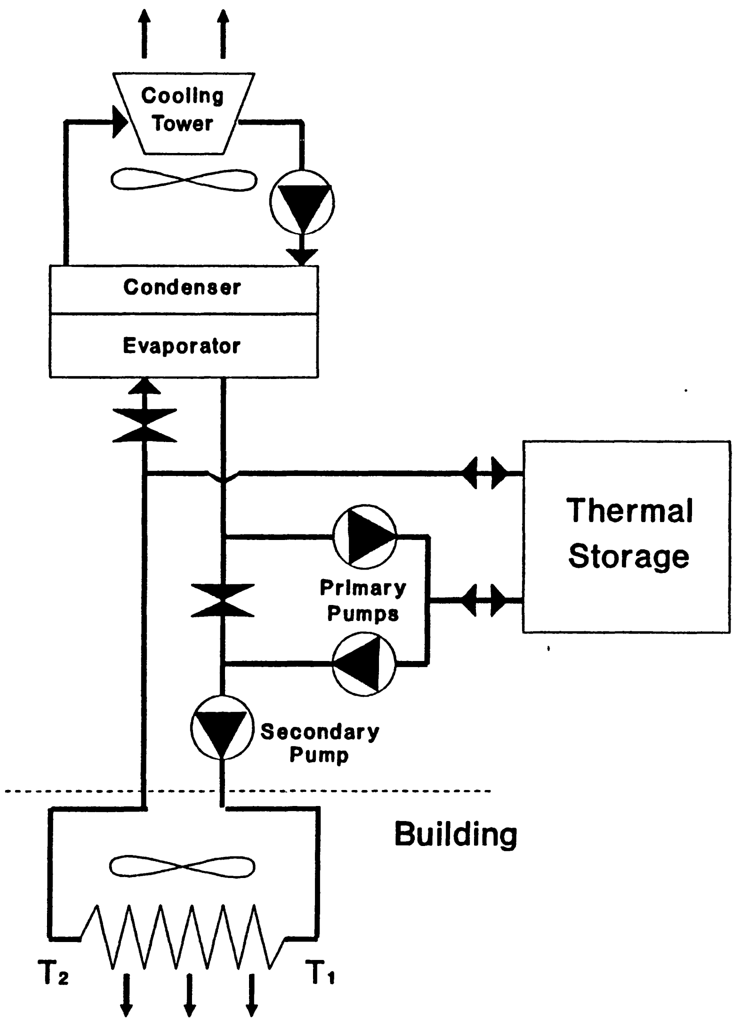

Figure 19.5a Water & Eutectic Storage System Configuration

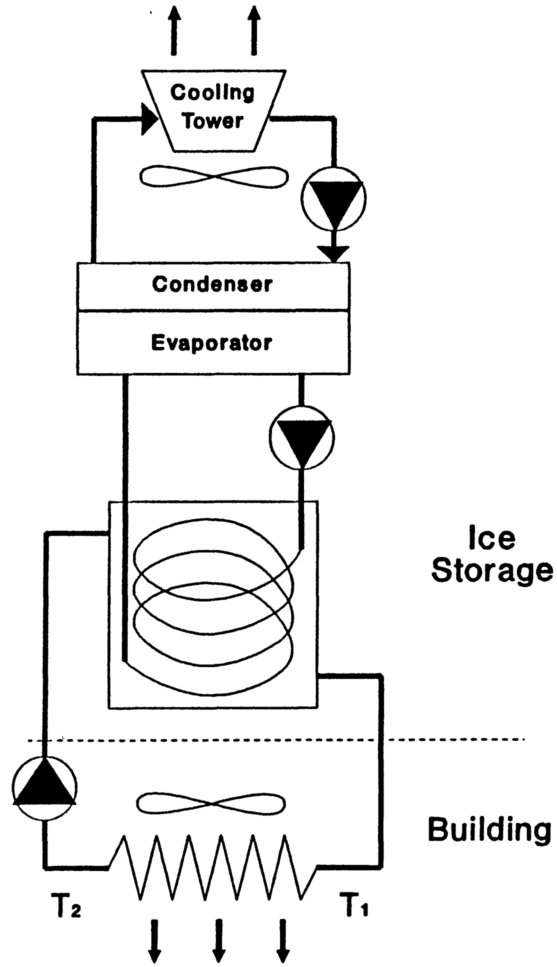

Figure 19.5b Ice Storage System Configuration

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. A Recent Electric Power Research Institute's (EPRI) Commercial Cool Storage Field Performance Monitoring Project (RP-2732-05) Report states that the storage efficiencies of tanks significantly decrease if tank walls were exposed to sunlight and outdoor ambient conditions and/or had long hold times prior to discharging [7]. To minimize heat gain, tanks should be out of the direct sun whenever possible. The storage efficiency of these tanks also decreased significantly if the water is stored for extended periods.

One advantage to using a single large tank rather than the series of smaller ones is that the temperature differential between the warm water intake and the chilled water outlet can be maintained. This is achieved utilizing the property of thermal stratification where the warmer water will migrate to the top of the tank and the colder to the bottom. Proper thermal stratification can only be maintained if the intake and outlet diffusers are located at the top and bottom of the tank and the flow rates of the water during charge and discharge cycles is kept low. This will reduce a majority of the mixing of the two temperature waters. Another method used to assure that the two temperature flows remain separated is the use of a movable bladder, creating a physical partition. One top/bottom diffuser tank studied in the EPRI study used a thermocouple array, installed to measure the chilled water temperature at one foot intervals from top to bottom of the tank. This tank had a capacity of 550,000 gallons and was 20 feet deep but had only a 2.5 foot blend zone where the temperature differential was almost 20 degrees [7].

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

1. Retrofiting 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, increasing chiller loading and efficiencies, and
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.

19.3.2 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 - °F [7,8]. This reduces the required storage capacity approximately 75% [7] 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.

There are two main methods in use to utilize ice for on-peak cooling. The first is considered a static system in which serpentine expansion coils are fitted within a insulated tank of cooling water. During the charging cycle, the cooling water forms ice around the direct expansion coil as the cold gases pass through it (see Figure 19.5b). The thickness of the ice varies with the ice building time (charge time) and heat transfer area. During the discharge cycle, the cooling water contained in the tank is used to cool the building and the warmer water returned from the building is circulated through the tank, melting the ice, and using its latent heat of fusion for cooling.

The second major category of thermal energy storage systems utilizing ice can be considered a dynamic system. This system has also been labeled a plate ice maker or ice harvester. During the charging cycle the cooling water is pumped over evaporator "plates" where ice is actually produced. These thin sheets of ice are fed into the cooling water tank, dropping the temperature. During on-peak periods, this chilled water is circulated through the building for cooling. This technology is considered dynamic due to the fact that the ice is removed from the evaporator rather than simply remaining on it.

Static ice storage systems are currently available in factory-assembled packaged units which provide ease of installation and can provide a lower initial capital cost. When compared to water storage systems, the size and weight reduction associated with ice systems makes them very attractive to facilities with space constraints. One main disadvantage to ice systems is the root to there advantage, the fact that the evaporator must be cold enough to produce ice. These evaporator temperatures usually range from 10° to 25° while most chiller evaporator temperatures range from 42° to 47° [9]. This required decrease in evaporator temperature results in a higher energy demand per ton causing some penalty in cooling efficiency. The EPRI Project reported that chillers operating in chilled water or eutectic salt (phase change material) used approximately 20% less energy than chillers operating in ice systems (0.9 vs. 1.1 kW/ton) [7].

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

1. Retrofiting 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, and
4. Ice systems are available in packaged units, due to smaller size requirements.

19.3.3 Phase Change Materials

The benefit of capturing latent heat of fusion while maintaining evaporating temperatures of current chiller systems can be realized with the use of other 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 which are mixtures of inorganic salts and water. Some eutectic salts have melting points of 47° [7], providing the opportunity for a direct retrofit using the current chiller system since this is at or above the existing evaporator temperatures. In a thermal storage system, these salts are placed in plastic containers, which are emersed within an insulated chilled water tank. During the charging cycle, the chilled water flows through the gaps between the containers, freezing the salts within them. During the on-peak discharge, the warmer building return water circulates through the tank, melting the salts and utilizing the latent heat of fusion to cool the building. These salt solutions have latent heat of fusion around 40 Btu/lb [9].

This additional latent heat reduces the storage volume by 66% of that required for an equivalent capacity water storage system [9]. Another obvious benefit of using eutectic salts is that the efficiency of the chillers is not sacrificed, as stated earlier, since the phase change occurs around normal evaporator suction temperatures. One problem with the eutectic salt systems is that the auxiliary energy consumption is higher since the chilled water must be pumped through the array of eutectic blocks. The auxiliary energy consumption of the ice systems is higher than both the water and eutectic salt systems since the chilled water must be pumped through the ice system coils, nozzles, and heat exchangers. The EPRI study found that the chilled water systems had an average auxiliary energy use of 0.43 kWh/Ton-Hr compared to the phase change systems (eutectic and ice) average auxiliary energy use of 0.56 kWh/Ton-Hr [5].

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, and
3. have higher storage and equivalent refrigeration efficiencies to those of water.

19.4 SYSTEM CAPACITY

The performance of thermal storage systems depends upon proper design. If it is sized too small or too large, the entire system performance will suffer. The following section will explain this sizing procedure for the example office building provided earlier. The facility has a maximum load of 510 tons, a total cooling requirement of 6,123 Ton-Hours, and a on-peak cooling requirement of 3,420 Ton-Hours. This information will be analyzed to size a conventional chiller system, a partial storage system, a full storage system, and the optional partial storage system. These results will then be used to determine the actual capacity needed to satisfy the cooling requirements utilizing either a chilled water, a eutectic salt, or an ice system. Obviously some greatly simplifying assumptions are made.

19.4.1 Chiller System Capacity

The conventional system would need to be able to handle the peak load independently, as seen in Figure 19.1. A chiller or pair of chillers would be needed to produce the peak cooling load of 510 tons. Unfortunately, packaged chiller units usually are available in increments that mandate excess capacity but for simplicity one 600 ton chiller will be used for this comparison. The conventional chiller system will provide cooling as it is needed and will follow the load presented in Figure 19.1 and Table 19.1.

To determine the chiller system requirement of a cooling system utilizing partial load storage, some further analysis is needed. Table 19.1 showed that the average cooling load of the office building was 255.13 tons per hour. The ideal partial load storage system will run at this load (see Figure 19.3 and Table 19.3). The chiller system would need to be sized to supply the 255.13 tons per hour, so one 300 ton chiller will be used for comparison purposes. Table 19.5

Table 19.5 Partial Storage Operation Profile

Thermal Storage Operation Profile Partial Storage System					
1 End of Hour	2 Cooling Load (Tons)	3 Chiller Load (Tons)	4 Capacity to Storage (Ton-Hrs)	5 Capacity in Storage (Ton-Hrs)	6 Storage Cycle
1	100	255.13	155	696	Charge
2	120	255.13	135	831	Charge
3	125	255.13	130	961	Charge
4	130	255.13	125	1086	Charge
5	130	255.13	125	1211	Charge
6	153	255.13	102	1314	Charge
7	165	255.13	90	1404	Charge
8	230	255.13	25	1429	Charge
9	270	255.13	-15	1414	Discharge
10	290	255.13	-35	1379	Discharge
11	340	255.13	-85	1294	Discharge
12	380	255.13	-125	1169	Discharge
13	450	255.13	-195	974	Discharge
14	490	255.13	-235	740	Discharge
15	510	255.13	-255	485	Discharge
16	480	255.13	-225	260	Discharge
17	410	255.13	-155	105	Discharge
18	360	255.13	-105	0	Discharge
19	250	255.13	5	5	Charge
20	210	255.13	45	50	Charge
21	160	255.13	95	145	Charge
22	130	255.13	125	271	Charge
23	125	255.13	130	401	Charge
24	115	255.13	140	541	Charge
Daily Total (Ton-Hrs):	6123	6123			
Daily Avg (Tons):	255.13	255.13			
Peak Total (Ton-Hrs):	3420	2041	Storage Total =		1429
Peak Demand (Tons):	510	255.13	Peak Storage Output =		255

Column 4 = Column 3 - Column 2

Column 5(n) = Column 5(n-1) + Column 4(n) shows how the chiller system would operate at 255.13 tons per hour, providing cooling required for the building directly and charging the storage system with the excess. Although the storage system is supplementing the cooling system for two hours before the peak period, the cooling load is always satisfied.

Comparing the peak demand from the bottoms of columns 2 and 3 of Table 19.5 shows that the partial storage system reduced this peak load almost 50% (510 - 255.13 = 254.87 Tons). Column 4 shows the tonnage that is supplied to the storage system and column 5 shows the amount of cooling contained in the storage system at the end of each hour of operation. This system was design so that there would be 0 capacity remaining in the thermal storage tanks after the on-peak period. The values contained at the bottom of Table 19.5 are the total storage required to assure that there is no capacity remaining and the maximum output required from storage. These values will be utilized in the next section to determine the storage capacity required for each of the different storage mediums.

The full storage system also requires some calculations to determine the chiller system size. Since the chillers will not be used during the on-peak period, the entire daily cooling requirement must be generated during the off-peak periods. Table 19.1 listed the total cooling load as 6,123 Ton-Hours for the peak day. Dividing this load over the 16 off-peak hours yields that the chillers must generate 383 tons of cooling per hour (6,123 Ton-Hours / 16 hours). A 450 ton chiller will be utilized in this situation for comparison purposes. Table 19.6 shows how the chiller system would operate at 383 tons per hour, providing cooling required for the building directly and charging the storage system with the excess.

Comparing the peak demand from the bottoms of columns 2 and 3 of Table 19.6 shows that the full storage system eliminated all load from the on peak period. Column 4 shows the tonnage that is supplied to the storage system and column 5 shows the amount of cooling contained in the storage system at the end of each hour of operation. This system was designed so that there would be 0 capacity remaining in the thermal storage tanks after the on-peak period. The values contained at the bottom of Table 19.6 are the total storage required to assure that there is no capacity remaining and the maximum output required from storage. These values will be utilized in the next section to determine the storage capacity required for each of the different storage mediums.

The optional partial storage system is a blend of the two systems presented earlier. The values given in Table 19.7 and Figure 19.4 are one combination of several possibilities that would drop the consumption and peak demand during the on-peak period. Once again this system has been designed to run both chillers during off-peak hours and run only one during on peak hours. Benefits of this arrangement are that the current chiller system could be used in

Table 19.6 Full Storage Operation Profile

Thermal Storage Operation Profile Full Storage System					
1 Hour of Day	2 Cooling Load (Tons)	3 Chiller Load (Tons)	4 Capacity to Storage (Ton-Hrs)	5 Capacity in Storage (Ton-Hrs)	6 Storage Cycle
1	100	383	283	1589	Charge
2	120	383	263	1852	Charge
3	125	383	258	2109	Charge
4	130	383	253	2362	Charge
5	130	383	253	2615	Charge
6	153	383	230	2844	Charge
7	165	383	218	3062	Charge
8	230	383	153	3215	Charge
9	270	383	113	3327	Charge
10	290	383	93	3420	Charge
11	340	0	-340	3080	Discharge
12	380	0	-380	2700	Discharge
13	450	0	-450	2250	Discharge
14	490	0	-490	1760	Discharge
15	510	0	-510	1250	Discharge
16	480	0	-480	770	Discharge
17	410	0	-410	360	Discharge
18	360	0	-360	0	Discharge
19	250	383	133	133	Charge
20	210	383	173	305	Charge
21	160	383	223	528	Charge
22	130	383	253	781	Charge
23	125	383	258	1038	Charge
24	115	383	268	1306	Charge
Daily Total (Ton-Hrs):	6123	6123			
Daily Avg (Tons):	255.13	255.13			
Peak Total (Ton-Hrs):	3420	0	Storage Total =		3420
Peak Demand (Tons):	510	0	Peak Storage Output =		510

Column 4 = Column 3 − Column 2

Column 5(n) = Column 5(n−1) + Column 4(n)

Table 19.7 Optional Partial Storage Operation Profile

Thermal Storage Operation Profile Optional Partial Storage System					
1 End of Hour	2 Cooling Load (Tons)	3 Chiller Load (Tons)	4 Capacity to Storage (Ton–Hrs)	5 Capacity in Storage (Ton–Hrs)	6 Storage Cycle
1	100	306	206	1053	Charge
2	120	306	186	1239	Charge
3	125	306	181	1420	Charge
4	130	306	176	1597	Charge
5	130	306	176	1773	Charge
6	153	306	153	1926	Charge
7	165	306	141	2067	Charge
8	230	306	76	2143	Charge
9	270	306	36	2179	Charge
10	290	306	16	2195	Charge
11	340	153	–187	2008	Discharge
12	380	153	–227	1782	Discharge
13	450	153	–297	1485	Discharge
14	490	153	–337	1148	Discharge
15	510	153	–357	791	Discharge
16	480	153	–327	464	Discharge
17	410	153	–257	207	Discharge
18	360	153	–207	0	Discharge
19	250	306	56	56	Charge
20	210	306	96	152	Charge
21	160	306	146	298	Charge
22	130	306	176	475	Charge
23	125	306	181	656	Charge
24	115	306	191	847	Charge
Daily Total (Ton-Hrs):	6123	6123			
Daily Avg (Tons):	255.13	255.12			
Peak Total (Ton-Hrs):	3420	1225	Storage Total =		2195
Peak Demand (Tons):	510	153	Peak Storage Output =		357

Column 4 = Column 3 – Column 2

Column 5(n) = Column 5(n–1) + Column 4(n) combination with the storage system and that the storage system does not require as much capacity as the full storage system. Also, a reserve chiller is available during peak load times.

Comparing the peak demand from the bottoms of columns 2 and 3 of Table 19.7 shows that the optional partial storage system reduces the peak load from 510 tons to 153 tons, or approximately 70% during the on-peak period. Column 4 shows the tonnage that is supplied to the storage system and column 5 shows the amount of cooling contained in the storage system at the end of each hour of operation. This system was designed so that there would be 0 capacity remaining in the thermal storage tanks after the on-peak period. The values contained at the bottom of Table 19.7 are the total storage capacity required and the maximum output required from storage. These values will be utilized in the next section to determine the storage capacity required for each of the different storage mediums. Table 19.8 summarizes the performance parameters for the three configurations discussed above. The next section summarizes the procedure used to determine the size of the storage systems required to handle the office building.

19.4.2 Storage System Capacity

Each of the storage mediums have different size requirements to satisfy the needs of the cooling load. This section will describe the procedure to find the actual volume or size of the storage system for the partial load system for

Table 19.8 System Performance Comparison

PERFORMANCE PERAMETERS	SYSTEM Conventional No Storage	Partial Storage	Full Storage	Optional Partial
Overall Peak Demand (Tons)	510	255.13	383	306
On-Peak, Peak Demand (Tons)	510	255.13	0	153
On-Peak Chiller Consumption (Ton-Hrs)	3,420	2,041	0	1,225
Required Storage Capacity (Ton-Hrs) [1]	-	1,379	3,420	2,195
MAXIMUM STORAGE OUTPUT (Tons) [1]	-	255	510	357

1 Values from Tables 19.5, 19.6, and 19.7. Represent the capacity required to be supplied by the TES.

all of the different storage mediums. The design of the chiller and thermal storage system must provide enough chilled water to the system to satisfy the peak load, so particular attention should be paid to the pumping and piping. Table 19.9 will then summarize the size requirement of each of the three different storage options.

To calculate the capacity of the partial load storage system the relationship between capacity (C), mass (M), specific heat of water (Cp), and the coil temperature differential (T_2-T_1) shown in figure 19.5a will be used, namely: $C = M\,Cp\,(T_2 - T_1)$

where $M = \text{lbm}$

$Cp = 1 \text{ Btu/lbm °R}$

$(T_2 - T_1) = \text{°R}$

The partial load system required that 1,429 Ton-Hrs be stored to supplement the output of the chiller during on-peak periods of the day. This value does not allow for any thermal loss which there normally is. For this discussion, a conservative value of 20% will be used, which is an average suggested in the EPRI report [7]. This will increase the storage requirements to 1,715 Ton-Hrs and chilled water storage systems in this size range cost approximately $200/Ton-Hr including piping and installation [5]. Assuming that there are 12,000 Btu's per Ton-Hr, this yields:
$C = (1{,}715 \text{ Ton-Hrs})*(12{,}000 \text{ Btu/Ton-Hr}) = 20.58 \times 10^6 \text{ Btu's}$.
Assuming $(T_2 - T_1) = 12°$ and $Cp = 1$ Btu/lbm °R the relation becomes:

$$M = \frac{C}{Cp(T_2 - T_1)} = \frac{20.58 \times 10^6 \text{ Btu's}}{(1 \text{ Btu/lbm °R})(12 \text{ °R})} = 1.72 \times 10^6 \text{ lbm } H_2O$$

$$\text{Volume of Water} = \text{Mass/Density} = \frac{1.72 \times 10^6 \text{ lbm}}{62.5 \text{ lbm/Ft}^3}$$

$$= 27{,}520 \text{ Ft}^3 \quad \text{or}$$

$$\frac{1.72 \times 10^6 \text{ lbm}}{8.34 \text{ lbm/gal}} = 206{,}235 \text{ gal.}$$

Sizing the storage system utilizing ice is completed in a very similar fashion. The EPRI study states that the ice storage tanks had average daily heat gains 3.5 times greater than the chilled water and eutectic systems due to the higher coil temperature differential (T_2-T_1). To allow for these heat gains a conservative value of 50% will be added to the actual storage capacity, which is an average suggested in the EPRI report [7]. This will increase the storage requirements to 2,144 Ton-Hrs. Assuming that there are 12,000 Btu's per Ton-Hr, this yields:

(2,144 Ton-Hrs)*(12,000 Btu's/Ton-Hr) = 25.73 x 10^6 Btu's.

The ice systems utilizes the latent heat of fusion so the Cp now becomes:

Cp = Latent Heat = 144 Btu/lbm.

Since ice systems can realize the benefits of the lower storage temperatures, the temperature differential (T_2-T_1) shown in Figure 19.5b can be increased to 20°, the mass of water required to be frozen becomes:

$$M = C/Cp(T_2-T_1) = \frac{25.73 \times 10^6 \text{ Btu's}}{(144 \text{ Btu/lbm °R})} = 1.79 \times 10^5 \text{ lbm } H_2O$$

$$\text{Volume of Ice} = \frac{\text{Mass}}{\text{Density}} = \frac{1.79 \times 10^5 \text{ lbm}}{62.5 \text{ lbm/Ft}^3} = 2{,}864 \text{ Ft}^3$$

The actual volume of ice needed will vary and the total amount of water contained in the tank around the ice coils will vary greatly. The ability to purchase pre-packaged ice storage systems makes their sizing quite easy. For this situation, two 1,080 Ton-Hr ice storage units will be purchased for approximately $150/Ton-Hr including piping and installation [4] (note that this provides 2,160 Ton-Hrs compared to the needed 2,144 Ton-Hrs).

Sizing the storage system utilizing the phase change materials or eutectic salts is completed just as the ice storage system. The EPRI study states that the eutectic salt storage tanks had average daily heat gains approximately the same as that of the chilled water systems. To allow for these heat gains a conservative value of 20% will be added to the actual storage capacity [5]. This will increase the storage requirements to 1,715 Ton-Hrs. Assuming that there are 12,000 Btu's per Ton-Hr, this yields:

$$(1{,}715 \text{ Ton-Hrs})*(12{,}000 \text{ Btu's/Ton-Hr}) = 20.58 \times 10^6 \text{ Btu's.}$$

The eutectic system also utilizes the latent heat of fusion like the ice system but since the storage temperature remains at 45°, the coil temperature differential shown in Figure 19.5a will remain at 12°. The Cp now becomes:

$$Cp = \text{Latent Heat} = 40 \text{ Btu/lbm}$$

Assuming $(T_2-T_1) = 12°$, the mass of water required to be frozen becomes:

$$M = C/Cp(T_2-T_1) = \frac{20.58 \times 10^6 \text{ Btu's}}{(40 \text{ Btu/lbm °R})} = 5.15 \times 10^5 \text{ lbm}$$

$$\underset{\text{(assuming = water)}}{\text{Volume of Eutectic Salts}} = \frac{\text{Mass}}{\text{Density}} = \frac{5.15 \times 10^5 \text{ lbm}}{62.5 \text{ lbm/Ft}^3}$$

$$= 8{,}232 \text{ Ft}^3$$

The actual volume of eutectic salts needed would need to be adjusted for density differences in the various combinations of the salts. Eutectic systems have not been studied in great detail and factory sized units are not yet readily available. The EPRI report [7] studied a system that required 1,600 Ton-Hrs of storage which utilized approximately 45,000 eutectic "bricks" contained in an 80,600 gallon tank of water. For this situation, a similar eutectic storage unit will be purchased for approximately $250/Ton-Hr including piping and installation. The ratio of Ton-Hrs required for partial storage and the required tank size will be utilized for sizing the other two systems.

Table 19.9 summarizes the sizes and costs of the different storage systems and the actual chiller systems for each of the three storage arrangements. The values presented in this example are for a specific case and each application should be analyzed thoroughly. The cost per ton hour of a water system dropped significantly as the size of the tanks rises as will the eutectic systems since the engineering and installation costs are spread over more capacity.

19.5 ECONOMIC SUMMARY

Table 19.9 covered the approximate costs of each of the three system configurations utilizing each of the three different storage mediums. Table 19.8 listed the various peak day performance parameters of each of the systems presented. To this point, the peak day chiller consumption has been used to size the system. To analyze the savings potential of the thermal storage systems, much more information is needed to determine daily cooling and chiller loads and the respective storage system performance. To

Table 19.9 Complete System Comparison

	SYSTEM			
PERFORMANCE PERAMETERS	Conventional No Storage	Partial Storage	Full Storage	Optional Partial
CHILLER				
SIZE (# and Tons)	1 @ 600	1 @ 300	1 @ 450	2 @ 175
COST ($)	180,000	90,000	135,000	105,000
WATER STORAGE				
Capacity (Ton-Hrs)	-	1,715	4,104	2,634
Volume (cubic feet)	-	26,520	65,664	42,144
Volume (gallons)	-	206,235	492,086	315,827
Cost per Ton-Hr ($)	-	200	135	165
Storage cost ($)	-	343,000	554,040	434,610
ICE STORAGE				
Capacity (Ton-Hrs)	-	2,144	5,130	3,293
# and size (Ton-Hrs)	-	2 @ 1,080	4 @ 1,440	3 @ 1,220
Ice volume (cubic feet)	-	2,864	6,840	4,391
Cost per Ton-Hr ($)	-	150	150	150
Storage cost ($) [1]	-	324,000	864,000	549,000
EUTECTIC STORAGE				
Capacity (Ton-Hrs)	-	1,715	4,104	2,634
Eutectic vol (cubic feet)	-	8,232	19,699	12,643
Cost per Ton-Hr ($)	-	250	200	230
Storage cost ($)	-	428,750	820,000	605,820

1 (2 units)(1,080 Ton-Hrs/unit)($150/Ton-Hr) = $324,000

calculate the savings accurately, a daily chiller consumption plot is needed for at least the summer peak period. These values can then be used to determine the chiller load required to satisfy the cooling demands. Only the summer months may be used since most of the cooling takes place and a majority of the utilities "time of use" charges (on-peak rates) are in effect during that time. There are several methods available to estimate or simulate building cooling load. Some of these methods are available in a computer simulation format or can also be calculated by hand.

For the office building presented earlier, an alternative method will be used to estimate cooling savings. An estimate of a monthly, average day cooling load will be used to compare the operating costs of the respective cooling configurations. For simplicity, it is assumed that the peak month is July and that the average cooling day is 90% of the cooling load of the peak day. The average cooling day for each of the months that make up the summer cooling period are estimated based upon July's average cooling load. These factors are presented in Table 19.10 for June through October [11]. These factors are applied to the hourly chiller load of the average July day to determine the season

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Table 19.10 Average Summer Day Cooling Load Factors

MONTH	kW FACTOR [1]	PEAK TONS [2]	kWh FACTOR [1]	Ton-Hrs/day [3]
JUNE	0.8	360	0.8	4,322
JULY	1	450	1	5,403
AUGUST	0.9	405	0.9	4,863
SEPT	0.7	315	0.7	3,782
OCT	0.5	225	0.5	2,702

1 kW and kWh factors were estimated to determine utility cost savings.

2 The average day peak load is estimated to be 90% of the peak day. The kW factor for each month is multiplied by the peak months average tonnage. For JUNE: PEAK TONS = (0.8)*(450) = 360

3 The average day consumption is estimated to be 90% of the peak day. The kWh factor for each month is multiplied by the peak months average consumption. For JUNE: CONSUMPTION = (0.8)*(5,403) = 4,322

chiller/TES operation loads. The monthly average day, hourly chiller loads for each of the three systems are presented in Table 19.11. The first column for each month in Table 19.11 lists the hourly cooling demand. The chiller consumption required to satisfy this load utilizing each of the storage systems is also listed. This table does not account for the thermal efficiencies used to size the systems but for simplicity, these values will be used to determine the rate and demand savings that will be achieved after implementing the system. The formulas presented for the peak day thermal storage systems operations have been used for simplicity. These chiller loads do not represent the optimum chiller load since some of partial systems approach full storage systems during the early and late cooling months. The bottom of the table contains the totals for the chiller systems. These totaled average day values will now be used to calculate the savings. The difference between the actual cooling load and the chiller load is the approximate daily savings for each day of that month.

A hypothetical southwest utility rate schedule will be used to apply economic terms to these savings. The electricity consumption rate is $0.04/kWh and the demand rate during the summer is $3.50/kW for the peak demand during the off-peak hours and $5.00/kW for the peak demand during the on-peak hours. These summer demand rates are in effect from June through October. This rate schedule only provides savings from balancing the demand, although utilities often

Table 19.11 Monthly Average Day Chiller Load Profiles

END OF	JUNE (in tons)				JULY (in tons)				AUGUST (in tons)				SEPTEMBER (in tons)				OCTOBER (in tons)			
HOUR	Actual	partial	full	optional	Actual	partial	full	optional	Actual	partial	full	optional	Actual	partial	full	optional	Actual	partial	full	optional
1	71	180	270	216	88	225	338	270	79	203	304	243	62	158	236	189	44	113	169	135
2	85	180	270	216	106	225	338	270	95	203	304	243	74	158	236	189	53	113	169	135
3	88	180	270	216	110	225	338	270	99	203	304	243	77	158	236	189	55	113	169	135
4	92	180	270	216	115	225	338	270	103	203	304	243	80	158	236	189	57	113	169	135
5	92	180	270	216	115	225	338	270	103	203	304	243	80	158	236	189	57	113	169	135
6	108	180	270	216	135	225	338	270	122	203	304	243	95	158	236	189	68	113	169	135
7	116	180	270	216	146	225	338	270	131	203	304	243	102	158	236	189	73	113	169	135
8	162	180	270	216	203	225	338	270	183	203	304	243	142	158	236	189	101	113	169	135
9	191	180	270	216	238	225	338	270	214	203	304	243	167	158	236	189	119	113	169	135
10	205	180	270	216	256	225	338	270	230	203	304	243	179	158	236	189	128	113	169	135
11	240	180	0	108	300	225	0	135	270	203	0	122	210	158	0	95	150	113	0	68
12	268	180	0	108	335	225	0	135	302	203	0	122	235	158	0	95	168	113	0	68
13	318	180	0	108	397	225	0	135	357	203	0	122	278	158	0	95	199	113	0	68
14	346	180	0	108	432	225	0	135	389	203	0	122	303	158	0	95	216	113	0	68
15	360	180	0	108	450	225	0	135	405	203	0	122	315	158	0	95	225	113	0	68
16	339	180	0	108	424	225	0	135	381	203	0	122	296	158	0	95	212	113	0	68
17	289	180	0	108	362	225	0	135	326	203	0	122	253	158	0	95	181	113	0	68
18	254	180	0	108	318	225	0	135	286	203	0	122	222	158	0	95	159	113	0	68
19	176	180	270	216	221	225	338	270	199	203	304	243	154	158	236	189	110	113	169	135
20	148	180	270	216	185	225	338	270	167	203	304	243	130	158	236	189	93	113	169	135
21	113	180	270	216	141	225	338	270	127	203	304	243	99	158	236	189	71	113	169	135
22	92	180	270	216	115	225	338	270	103	203	304	243	80	158	236	189	57	113	169	135
23	88	180	270	216	110	225	338	270	99	203	304	243	77	158	236	189	55	113	169	135
24	81	180	270	216	101	225	338	270	91	203	304	243	71	158	236	189	51	113	169	135
TOTALS:	JUNE	partial	full	optional	JULY	partial	full	optional	AUG	partial	full	optional	SEPT	partial	full	optional	OCT	partial	full	optional
TOTAL: (ton-hrs)	4,322	4,322	4,322	4,322	5,403	5,403	5,403	5,403	4,862	4,862	4,862	4,862	3,782	3,782	3,782	3,782	2,701	2,701	2,701	2,701
AVG: (tons)	180	180	180	180	225	225	225	225	203	203	203	203	158	158	158	158	113	113	113	113
OFF-PEAK MAX: (tons)	205	180	270	216	256	225	338	270	230	203	304	243	179	158	236	189	128	113	169	135
ON-PEAK MAX: (tons)	360	180	0	108	450	225	0	135	405	203	0	122	315	158	0	95	225	113	0	68
ON-PEAK CONSUMP: (ton-hrs)	2,414	1,441	0	864	3,018	1,801	0	1,081	2,716	1,621	0	972	2,112	1,261	0	756	1,509	900	0	540

For June Partial Storage: (4,322 Ton-Hrs)/(24 Hrs) = 180 Tons
For June Full Storage: (4,322 Ton-Hrs)/(16 Hrs) = 270 Tons

have cheaper off-peak consumption rates. It can be seen that the off-peak demand charge assures that the demand is leveled and not meerly shifted. This rate schedule will be applied to the total values in Table 19.11 and multiplied by the number of days in each month to determine the summer savings. These savings are contained in Table 19.12. The monthly average day loads in Table 19.11 are assumed to be 90% of the actual monthly peak billing demand, and are adjusted accordingly in Table 19.12. The total monthly savings for each of the chiller/TES systems is determined at the bottom of each monthly column.

These cost savings are not the only monitary justification for implementing TES systems. Utilities often extend rebates and incentives to companies installing thermal energy storage systems to shorten their respective payback period. This helps the utility reduce the need to build new generation plants. The southwest utility serving the office building studied here offers $200 per design day peak kW shifted to off-peak hours up to $200,000. Table 19.13 summarizes the incentives available for the various systems using this subsidy plan. Appendix B following this chapter contains a short list of the incentives provided by several utilities across the nation.

19.6 CONCLUSIONS

Thermal energy storage will play a large role in the future of demand side management programs of both private

Table 19.12 Summer Monthly System Costs and TES Savings

	JUNE (30 days)				JULY (31 days)				AUGUST (31 days)				SEPTEMBER (30 days)				OCTOBER (31 days)			
	Actual	Partial	Full	Optional	Actual	Partial	Full	Optional	Actual	Partial	Full	Optional	Actual	Partial	Full	Optional	Actual	Partial	Full	Optional
ON-PEAK, PEAK [1] (kW)	400	200	0	120	500	250	0	150	450	226	0	136	350	176	0	106	250	126	0	76
OFF-PEAK, PEAK [1] (kW)	228	200	300	240	284	250	376	300	256	226	338	270	199	176	262	210	142	126	188	150
CONSUMPTION [1] (kW-Hr)	4,322	4,322	4,322	4,322	5,403	5,403	5,403	5,403	4,862	4,862	4,862	4,862	3,782	3,782	3,782	3,782	2,701	2,701	2,701	2,701
DEMAND COST [2] ($)	2,797	1,700	1,050	1,440	3,496	2,125	1,314	1,800	3,144	1,917	1,182	1,623	2,446	1,492	918	1,263	1,748	1,067	657	903
CONSUMPTION COST [3] ($)	5,186	5,186	5,186	5,186	6,700	6,700	6,700	6,700	6,029	6,029	6,029	6,029	4,538	4,538	4,538	4,538	3,349	3,349	3,349	3,349
TOTAL COST [4] ($)	7,984	6,886	6,236	6,626	10,195	8,825	8,014	8,500	9,173	7,946	7,211	7,652	6,985	6,031	5,456	5,801	5,097	4,416	4,006	4,252
SAVINGS [5] ($)		1,097	1,747	1,357		1,371	2,181	1,696		1,227	1,962	1,522		954	1,528	1,183		681	1,091	845

1 Monthy average peak values from Table 19.11 are assumed to be 90% of the actual billed peak demands.

2 Consumption figures directly from Table 19.11.

3 Using \$3.50/kW for off-peak demand and \$5.00/kW for on-peak demand: (\$3.50/kW)(200 kW) + (\$5.00/kW)(200kW) = \$1,700

4 Using \$0.04/kWh for daily consumption for each day of month: (30 day/Jume)(4,322 kWh/day)(\$0.04/kWh) = \$5,186/June

5 Difference between the conventional chiller system and the operation of the respective TES system. For June: \$7,984 – \$6,886 = \$1,097

Table 19.13 Available Demand Management Incentives

PERFORMANCE PERAMETERS	SYSTEM: Conventional No Storage	Partial Storage	Full Storage	Optional Partial
Actual On-Peak Demand (kW) [1]	510	255	0	153
On-Peak Demand Shifted (kW) [2]		255	510	357
Utility Subsidy ($) [3]		51,000	102,000	71,400

1 Yearly design peak demand from Table 19.8.

2 Demand shifted from design day on-peak period. For partial: 510 kW - 255 kW = 255 kW.

3 Based upon $200/kW shifted from design day on-peak period. For partial: 255 kW * $200/kW = $51,000.

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organizations and utilities. The success of the 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, technical advances, and as more companies switch to storage.

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APPENDIX 19-A

Partial list of manufacturers of thermal storage systems.
Source: Energy User News, December 1991.

Company:	Address:
Baltimore Aircoil Co.	P.O. Box 7322 Baltimore, MD 21227 (301) 799-6146
Belyea Company, Inc.	45 Howell St. Jersey City, NJ 07306 (201) 653-3334
Carrier Corporation	One Carrier Place Farmington, CT 06034-4015 (203) 674-3139
Control Pak Corporation	23840 Industrial Park Drive Farmington Hills, MI 48335 (313) 471-0337
Control Systems Intl.	1625 West Crosby Rd. #400 Carrollton, TX 75006 (214) 323-1111
The Trane Company	3600 Pammel Creek Rd. La Crosse, WI 54601-7599 (608) 787-2000

APPENDIX 19-B

Partial list of Utility Cash Incentive Programs.
Source: Dan Mankivsky, Chicago Bridge & Iron, August 1991.

STATE **- Electric Utility**	**CASH INCENTIVE** **$/Kw Shifted**	 **Maximum**
ARIZONA		
- Arizona Public Sevice	75-125	no limit
- Salt River Project	60-250	no limit
CALIFORNIA		
- American Public Utilities Dept.	60	50,000
- L.A. Dept of Water & Power	250	40% cost
- Pacific Gas & Electric	300	50%-70%
- Pasedena Public Utility	300	no limit
- Riverside Public Utility	200	no limit
- Sacremento Municipal Util Dist.	200	no limit
- San Diego Gas & Electric	50-200	no limit
- Southern California Edison	100	300,000
DISTRICT OF COLUMBIA		
- Patomic Electric Power Co.	200-250	no limit
FLORIDA		
- Florida Power & Light Co.	250/ton	no limit
- Florida Power Corp.	160-180	25%
- Tampa Electric Co.	200	no limit
INDIANA		
- Indianapolis Power & Light	200	no limit
- Northern Indiana Public Service	200/ton	-
MARYLAND		
- Baltimore Gas & Electric	200	no limit
- Patomic Electric Power Co.	200-250	no limit
MINNESOTA		
- Northern States Power	400/ton	no limit
NEVADA		
- Nevada Power	100-150	no limit
NEW JERSEY		
- Atlantic Electric	150	200,000
- Jersey Central Power & Light	300	250,000
- Orange & Rockland Utilities	250	no limit
- Public Service Electric & Gas	125-250	no limit

APPENDIX 19-B cont.

Partial list of Utility Cash Incentive Programs.
Source: Dan Mankivsky, Chicago Bridge & Iron, August 1991.

STATE **- Electric Utility**	**CASH INCENTIVE** **$/Kw Shifted**	 **Maximum**
NEW YORK		
- Central Edison Gas & Electric	25/Ton-Hr	equip cost
- Consolidated Edison Co.	600	no limit
- Long Island Lighting Co.	300-500	no limit
- New York State Electric & Gas	113	no limit
- Orange & Rockland Utilities	250	no limit
- Rochester Gas & Electric	200-300	70,000
NORTH DAKOTA		
- Northern States Power	400/ton	no limit
OHIO		
- Cincinnati Gas & Electric	150	no limit
- Toledo Edison	200-250	-
OKLAHOMA		
- Oklahoma Gas & Electric	125-200	225,000
PENNSYLVANIA		
- Metropolitan Edison	100-250	40,000
- Orange & Rockland Utilities	250	no limit
- Pennsylvania Electric	250	no limit
- Pennsylvania Power & Light	100	no limit
- Philedelphia Electric	100-200	25,000
SOUTH DAKOTA		
- Northern States Power	400/ton	no limit
TEXAS		
- Austin Electric Department	300	150,000
- El Paso Electric Company	200	no limit
- Gulf States Utilities	250	-
- Houston Lighting & Power	350	-
- Texas Utilities (Dallas Power, Texas Electric Service, and Texas Power & Light)	125-250	no limit
WISCONSIN		
- Madison Gas & Electric	60 - 80	no limit
- Northern States Power	175	no limit
- Wisconsin Electric Power	350	no limit

* note: Some states have additional programs not listed here and some of the listed programs have additional limitations.