Marriott Desert Springs Resort & Spa

Thermal Energy Storage System

1992 Performance Report

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Abstract

Southern California Edison has a pilot incentive program to evaluate a "Pay For Performance" concept. As part of this program, Transphase Systems has installed a 6,000 ton-hr storage system at Marriott Hotel's Desert Springs Resort & Spa in Palm Desert, California. Through monthly incentive payments, Edison will pay for 70% of the installation, assuming that the system meets the performance requirements established in the contract. The performance of the first complete year of operations is described in this report including an evaluation of the energy cost savings.

The storage system and heat exchanger were extremely effective in reducing the on-peak electrical usage at Marriott's Hotel. During the summer, the storage system provided an average of 6,000 ton-hrs of cooling during the on-peak period. A total of 381,500 kWh's were shifted from the summer on-peak period. During 1992, the storage system and heat exchanger reduced the facility's electrical cost by $108,300. Of these, $36,600 were from demand savings and $71,700 in energy savings. The initial results indicate that the approach of paying for performance is effective for ensuring proper storage system operation.

Introduction

Southern California Edison (SCE) has developed a new pilot incentive program for cool storage systems. The program is designed to test paying incentives based on the actual performance of a system, rather than on the unsubstantiated design of a system. In the past, it has not been uncommon for a customer to receive a rebate to install a cool storage system and then not operate or maintain the system properly. Thus the system does not reduce the on-peak electrical demand as it was intended, both SCE and the customer do not get what they paid for. This new approach pays the guarantor of performance, in this case the equipment supplier, if the on-peak demand is reduced, not just for installing the equipment.

SCE has promoted the installation of cool storage systems for the past 12 years. The incentive programs in the early 1980's were very successful and systems have been installed since then. During this period, the electrical rates were very favorable to TES systems, with a large cost difference between the on and off-peak periods. In the late 1980's, incentive levels were lowered and the electrical rates were changed. The number of new systems being install decreased. Also there were a number of customers who saw their savings drop due to this change in the rates. Some cool storage systems were either shutoff by the operators or fell into disrepair during this period.

SCE hopes to change the opinions of some of the building operators who believe that all cool storage systems perform poorly. They are trying to make their customers aware that when properly operated and maintained, a cool storage system can significantly reduce a facility's electric bills.

Transphase Systems Inc. is the first to participate in the program. Customers with large cooling requirements (>1,000 kW) were targeted as the economics are better for larger systems. Edison pays $600 per kW of demand reduction over a 7 year period. The remainder of the cost to build the system is paid by the customer. The $600 per kW is believed represents 70% of the total cost of the system. As part of the agreement, Transphase instruments the storage systems and collects the data to determine the performance of the system. The base incentive payment is made monthly. The performance results are used to determine if penalties should be assessed due to poor operation of the storage system or bonuses added when the TES system used less energy than the conventional system would have used. The penalties and bonuses are determined on a monthly basis and the payments adjusted three times per year to account for them. The procedures and agreements related to the payments are documented in the "Measurement And Evaluation Plan."

The Marriott Desert Springs Resort and Spa was the first customer to participate in the program. Transphase has installed an eutectic salt storage system at the Hotel. The system is designed to provide 6,000 ton-hrs of cooling during the summer on-peak rate period. This storage system was estimated to reduce the electrical demand by an average of 1,006 kw during the 6 hour period. Cooling is stored by freezing the eutectic salt at a temperature of 47°F during the night and melting it during the afternoons when the cooling is required.. Transphase and the Marriott have a separate agreement which defines their roles and responsibilities in the operation of the system.

Site Description

The Marriott Desert Springs Resort and Spa is located in Palm Desert, California. It is a luxury hotel with over 900 rooms. There is a large central atrium which has a lagoon and numerous fountains which create a large latent load. The hotel has several large ballrooms, and numerous shops and restaurants. There is approximately 2 million square feet of conditioned space. Figures 1 and 2 show the hotel and the atrium.

The hotel is cooled with chilled water that is supplied from a central plant. The design peak day load of the hotel is 1850 tons, based on a day with design conditions of 108 °F dry bulb and 78°F wet bulb temperatures. Prior to the installation of the cool storage system, the central plant consisted of two 1050 ton centrifugal chillers, three chilled water pumps, three condenser water pumps and a cooling tower. The conventional portion of the cooling system is controlled with a Energy Control System (ECS) energy management system. A schematic of the central plant and storage system is shown in Figure 3.

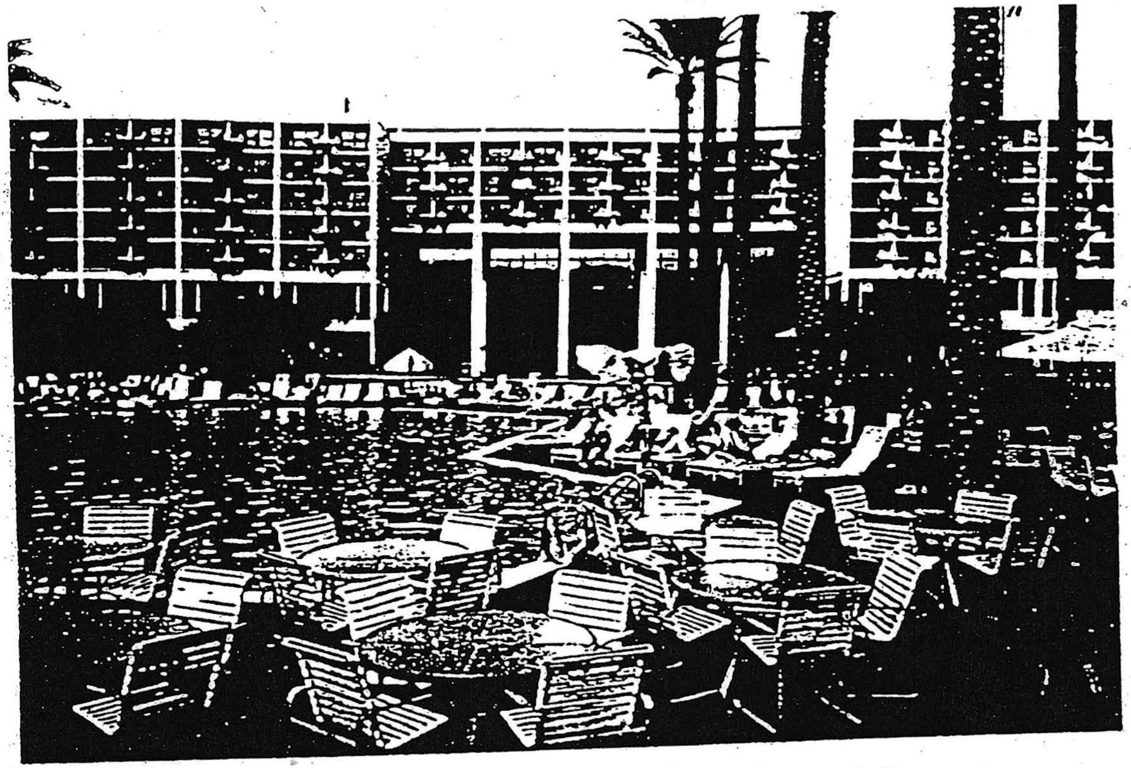


Figure 1. Marriott Desert Springs Resort & Spa

Figure 2. Lagoon Atrium At The Marriott Desert Springs Resort & Spa

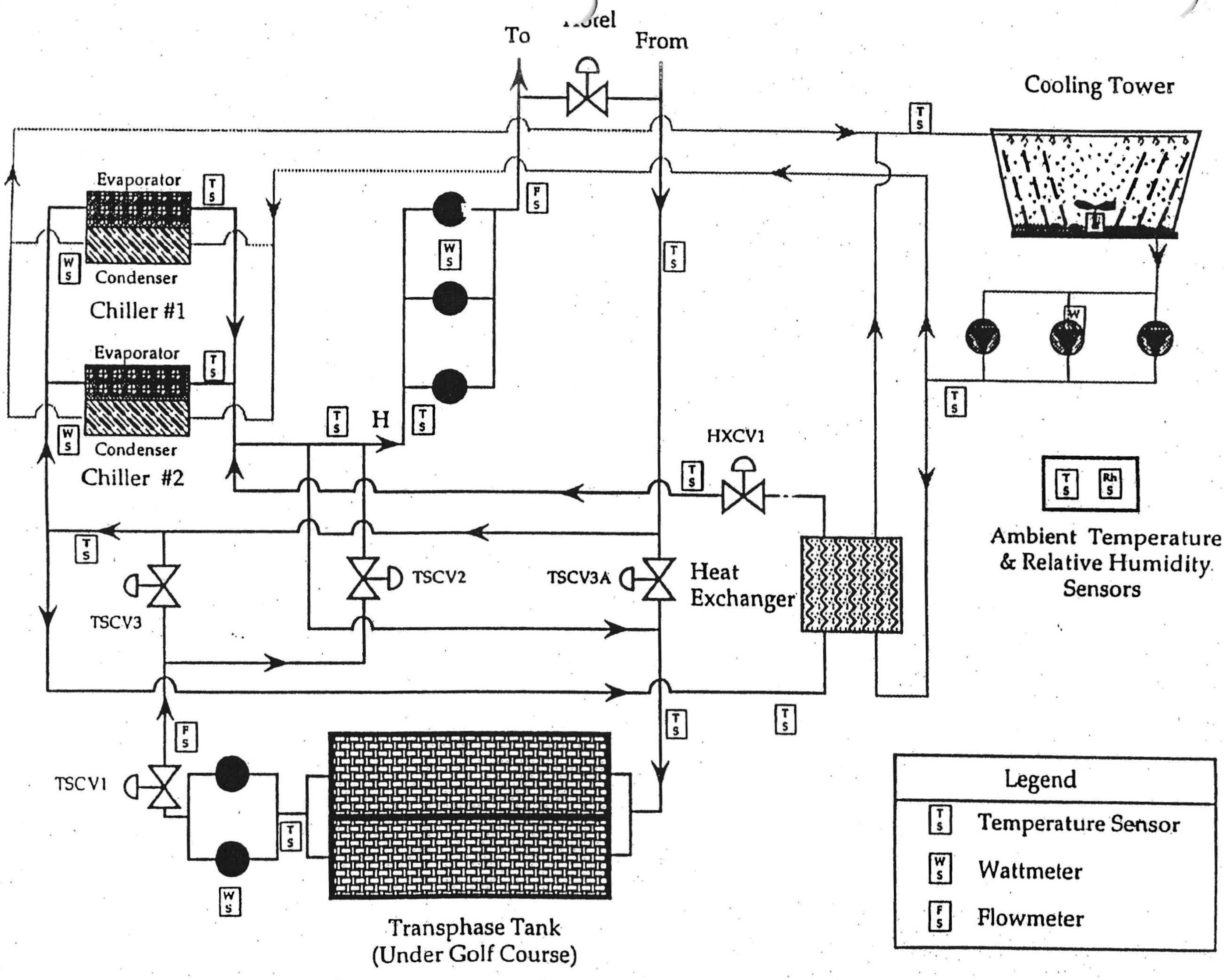


Figure 3. Schematic of Marriott's Chiller/TES system

In March of 1991, Transphase started construction on the storage system. The system was officially started on July 10, 1991. The design capacity of the system is 6,000 ton-hrs. The storage medium is an eutectic salt who's freezing point is 47°F. Interlocking plastic containers are used to hold the eutectic salt. The containers are stacked in an underground tank and are arranged in such a way as to enhance the heat transfer between the containers and water flowing through the tank. The tank at the Marriott is 90 ft. (l) x 40 ft. (w) x 12 ft.(h) and is divided lengthwise into two compartments. There are more than 168,000 containers in the storage system which provides over 6,300 ton-hrs of capacity. The additional 300 ton-hrs over the design capacity provides a 5% safety margin. The system was designed a partial storage system, intended to provide only a portion of the on-peak cooling load on the design day.

The tank is located under a section of rough of the golf course shown in Figure 4, approximately 500 ft from the central plant. There are a pair of storage booster pumps located in a sump at the tank. Normally one pump is used and the other serves as a backup. The pumps are used to provide the additional head needed to pump the water through the containers and back to the central plant.

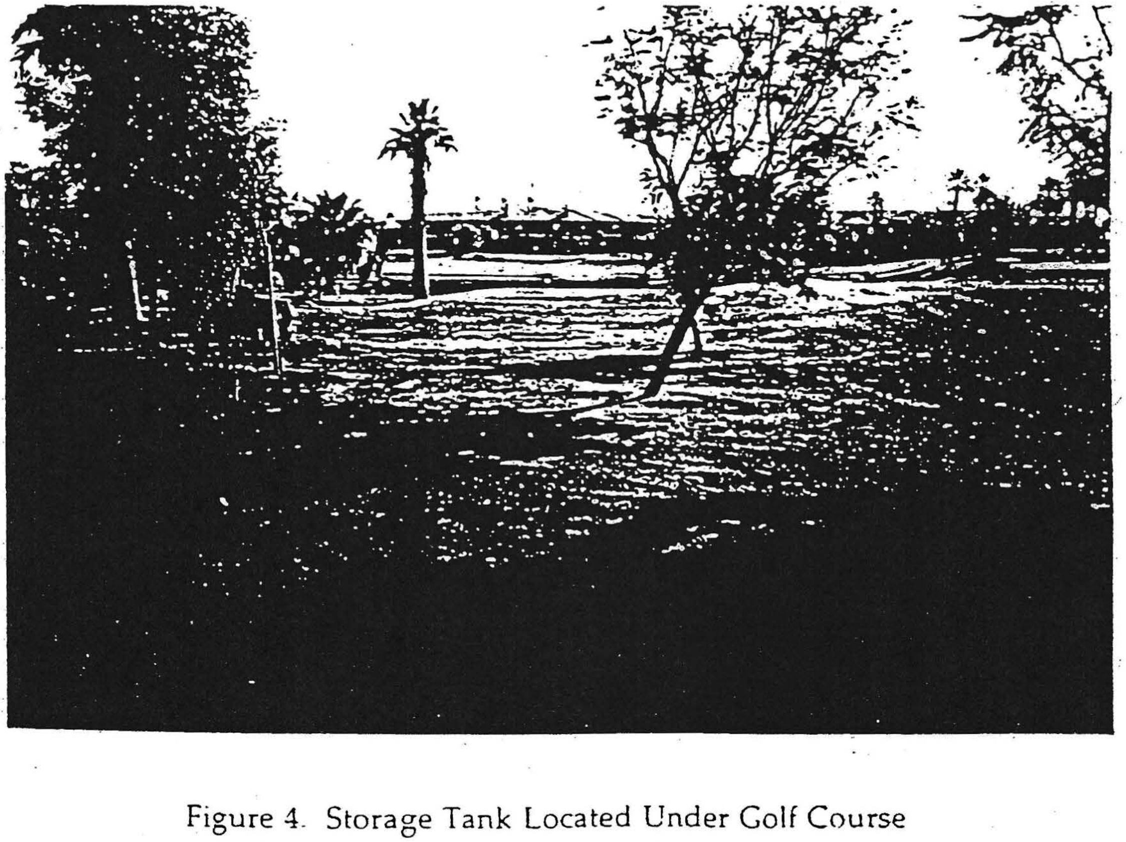


Figure 4. Storage Tank Located Under Golf Course

In addition to the cool storage system, Transphase has installed a 800 ton heat exchanger between the condenser water loop and the chilled water loop. This allows the hotel to take advantage of the low wet bulb temperatures that occur in the winter to 1) directly cool the building and 2) charge the storage system, using the cooling provided from the cooling tower.

The instrumentation used to monitor the system's performance is shown on the schematic. An Andover control system is used to control the storage system and monitor its performance. Measurements are made every 2 seconds and averaged over an hour. The data is collected from the control system every night automatically by Transphase's computer, over a telephone line using a modem. The results are processed on Transphase's computer using spreadsheet programs.

Cooling System Operating Modes

There are five basic operating modes of the cooling/storage system. These include: 1) direct cooling with chillers; 2) discharging storage; 3) discharging storage with chiller assist; 4) charging; and 5) cooling with heat exchanger. The following paragraphs describe these operating modes.

Direct Cooling

Direct cooling with chillers is the normal operation of a cooling system which does not have storage. At the Marriott, it is used to cool the building during periods when it is not economically advantageous to use storage or the heat exchanger. Warm water returning from the building is cooled in the chiller and circulated through the building. Figure 5 shows the flow configuration for this mode.

Storage Discharge

The storage discharge mode is when only storage is used to cool the building. Water returning from the building is pumped through the storage tank and is cooled by melting the eutectic salt. Figure 6 is a schematic of the cooling system in the discharge mode. The chilled water supply temperature is limited to approximately 49°F in this mode as the eutectic salt melts at 47°F.

Storage Discharge with Chiller Assist

Storage discharge with chiller assist is the normal storage discharging strategy for the Marriott. This system was designed as a partial storage system so the storage system provides only a portion of the cooling. Water returning from the building is first circulated through the storage tank where it is partially cooled. From the storage tank, the water is pumped to the chiller(s) where it is further cooled and delivered to the building. This allows the operator to determine the supply temperature for

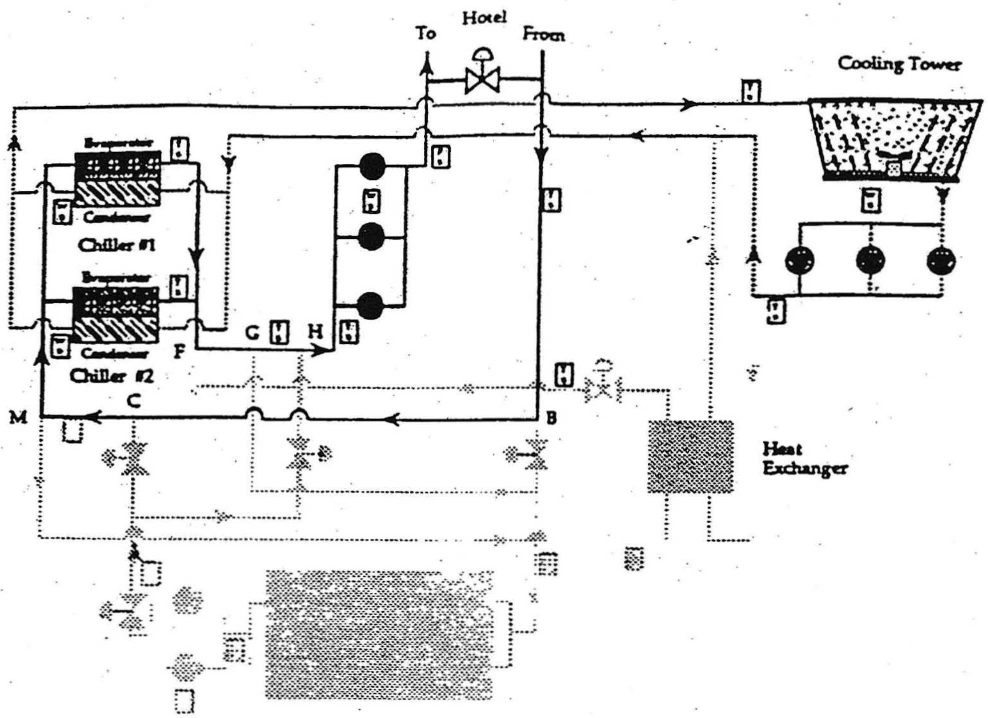


Figure 5 Direct Cooling With Chillers Schematic

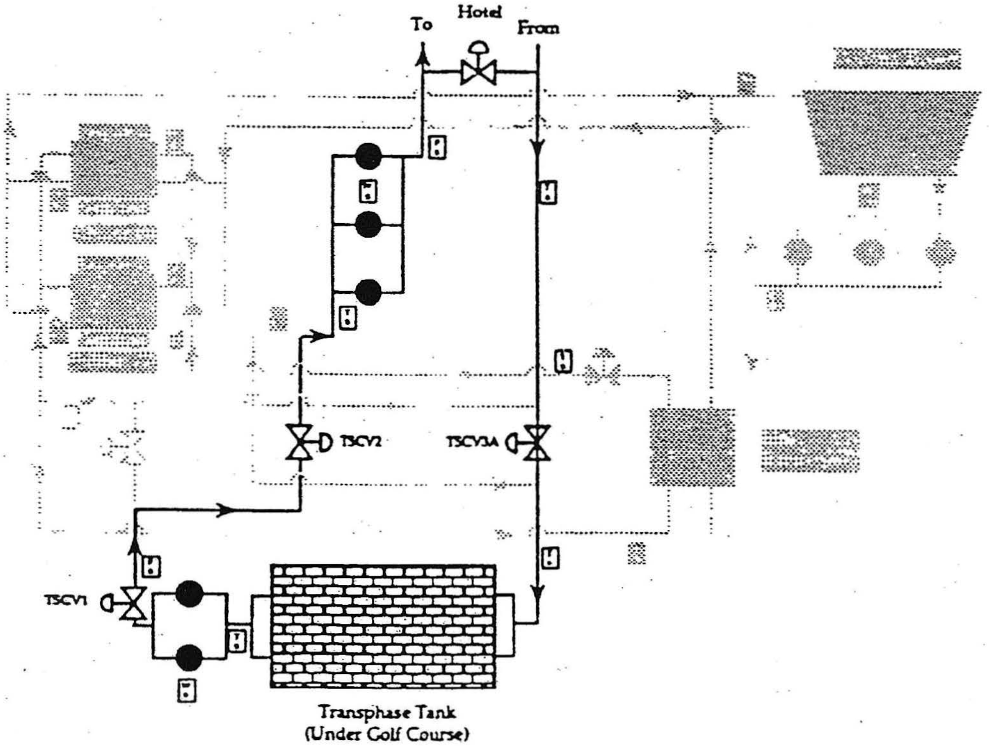


Figure 6. Storage Discharging Schematic

the chilled water. This modes takes advantage of the storage system's capabilities to provide cooling at 47° and still allows the operator some flexibility. If the supply chilled water temperature is too low, the water will return too cold to allow storage to be used. The operator or the control system must balance the supply temperature and the flow rates such that storage can provide its portion of the load and the supply temperature necessary for the desired comfort level. A system schematic for the storage discharging with chiller assist is shown in Figure 7.

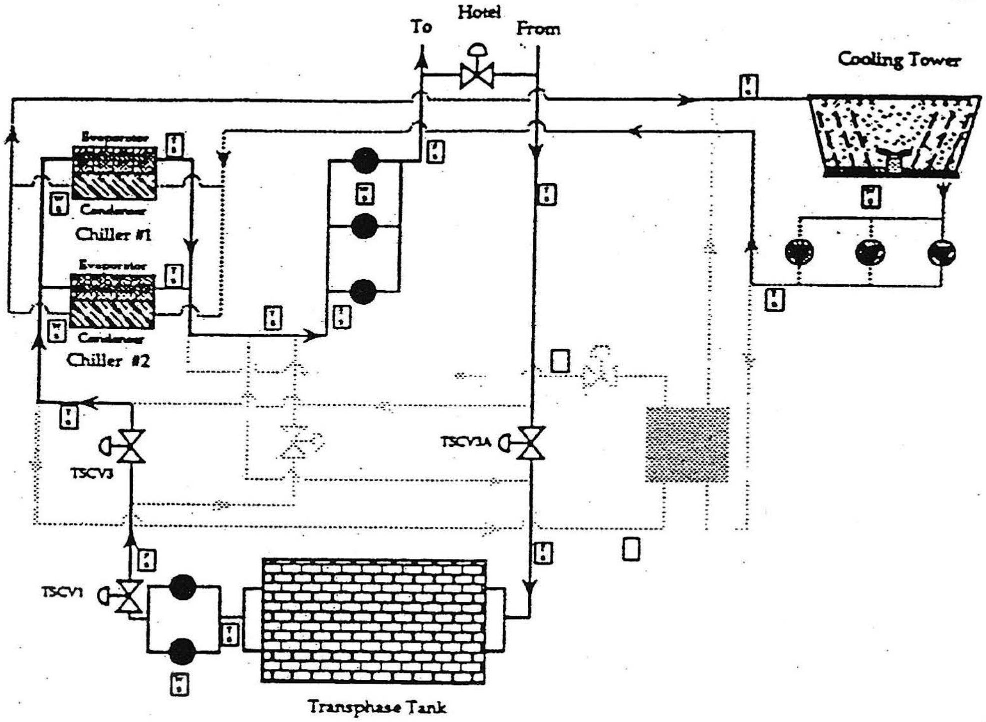


Figure 7. Storage Discharging With Chiller Assist

Storage Charging

The storage system is charged by circulating chilled water through the storage tank. This is usually done during the off-peak hours (11 pm to 8 am weekdays in the summer). Normally 40°F to 42°F chilled water is flowed through the storage system. The tank is considered fully charged when the water leaving the storage tank is between 41°F to 43°F. The building is cooled at the same time with the water leaving the storage system. If it is too warm, chilled water directly from the chiller is blended to get the desired supply temperature. This approach of combining the charging the storage system and provide cooling for the building helps to improve the efficiency of the chillers by reducing the low part load inefficiency. Figure 8 is the cooling system schematic for the charging mode.

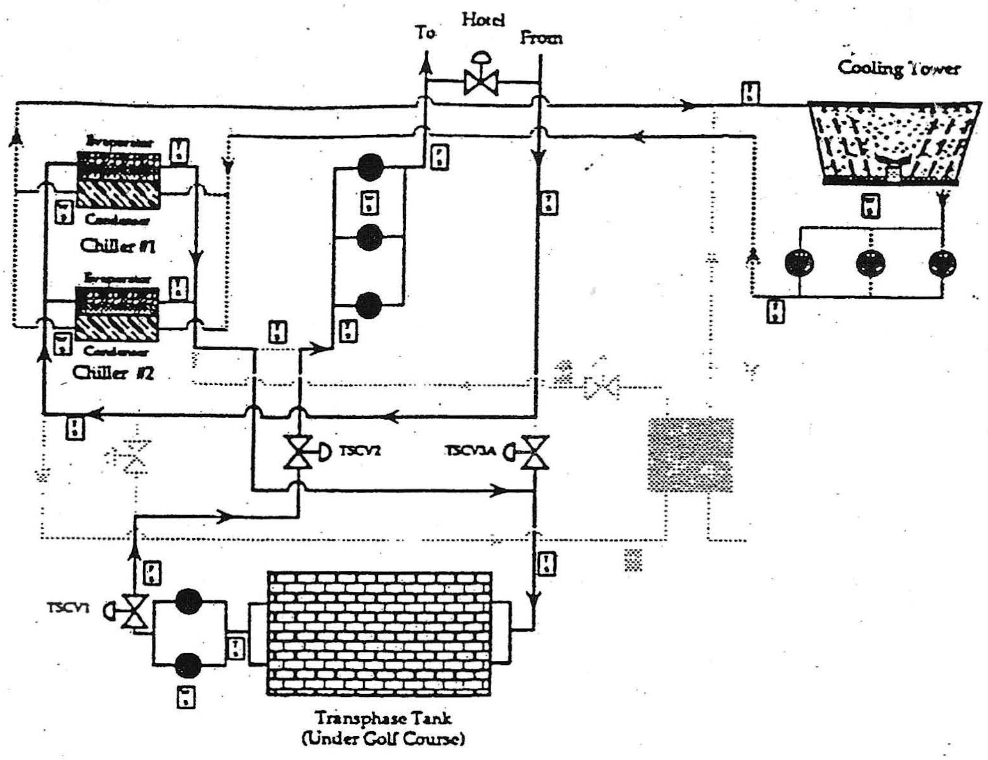


Figure 8. Charging Mode Cooling System Schematic

Heat Exchanger Cooling

The heat exchanger is used to cool the building when the ambient conditions are such that the wet bulb temperature is below 48°F. It is used to charge the storage system when the wet bulb temperature is less than 38 °F. The dry cool conditions of the desert during winter nights allows the cooling tower to produce cold enough water so that the building can be cooled directly. Figure 9 is the cooling system schematic for the heat exchanger cooling mode. This use of "free cooling" greatly reduces the electrical usage of the cooling system as the chillers are not operated.

System Operating Strategies

The cooling system at the Marriott is operated 24 hours a day, 7 days a week to provide a comfortable environment for their customers. Cooling loads are dependent on the weather, hotel's occupancy rate and scheduled events.

Prior to the installation of the storage system and heat exchanger, the chillers were operated to meet the loads of the building. The energy management system was

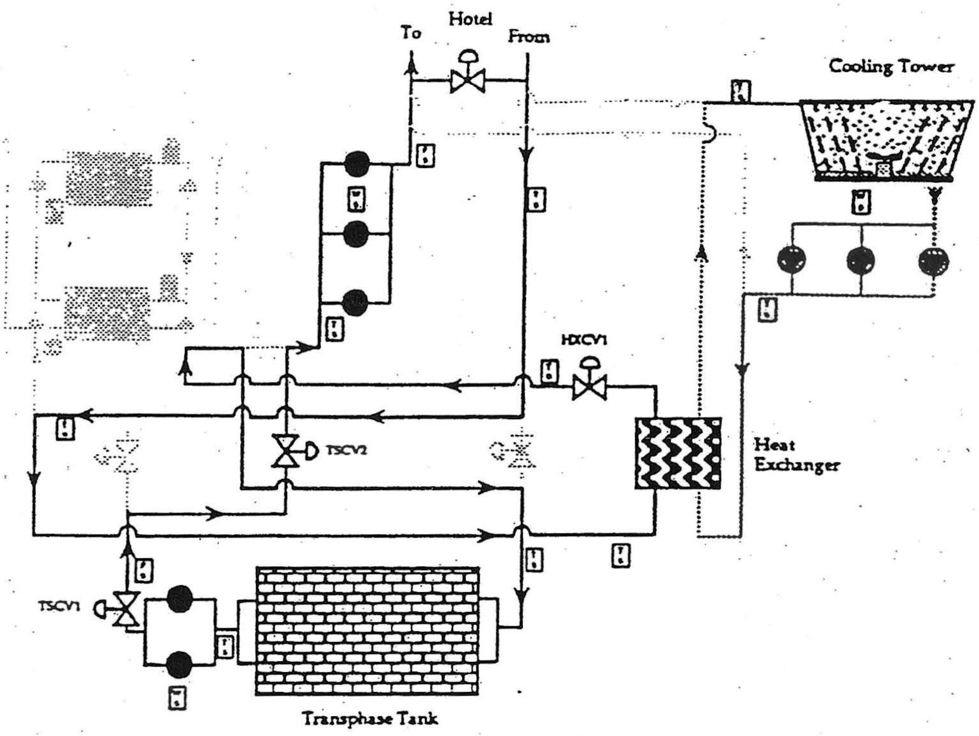


Figure 9. Heat Exchanger Cooling Operating Mode

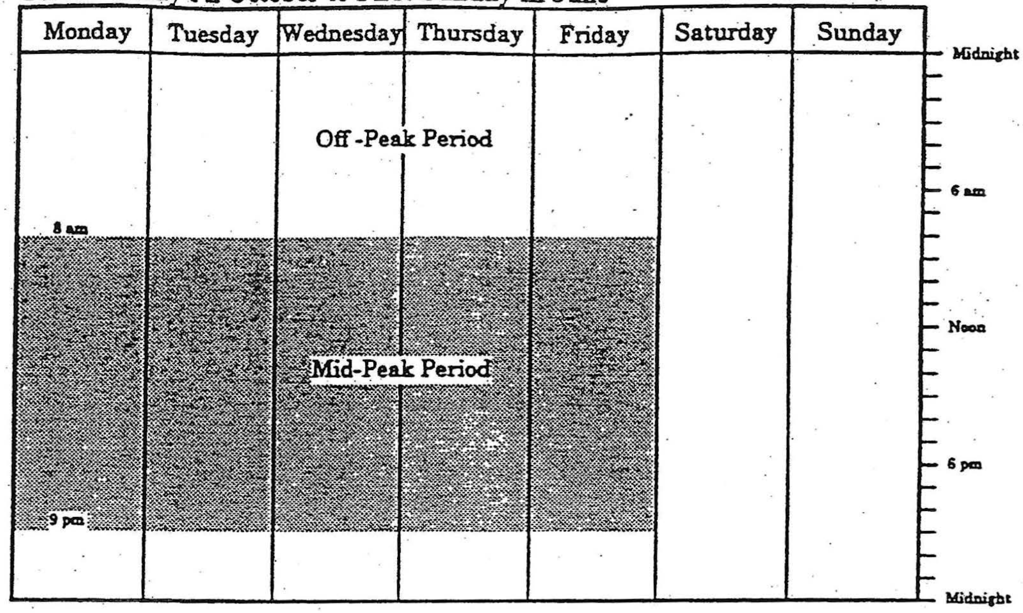
programmed to control the chillers based on the return temperature from the building. Depending on the cooling requirements, either 1 or 2 chillers were operated. Two of the three chilled water pumps were operated continuously. One operating change made by Transphase was to reduce the number of chilled water pumps operated to one under normal conditions. With the addition of the storage system and heat exchanger, the complexity of the operating strategies has significantly increased. It is now necessary to evaluate the cost of providing cooling with the different options and determining which is most economical. The electrical rate structures are critical to this decision making process. The Marriott is on SCE's TOU-8 rate schedule. This time-of-use (TOU) rate schedule has energy and demand components which are time of day dependent. There are two seasons, (summer and winter), and up to three rate periods. The current TOU-8 rates and rate periods are shown in Figure 10. Discussion of the current operating strategies will be broken down by summer and winter rate periods.

Summer Operating Strategy

During the summer, the primary objective is shift as much of the electrical usage associated with cooling the hotel in SCE's on-peak period to the off-peak period. The storage system is charged during the off-peak hours and discharged during on-peak hours.

Winter Rate Season

First Sunday in October to First Sunday in June



☐ Off-Peak Period ▨ Mid-Peak Period ■ On-Peak Period

Summer Rate Season

First Sunday in June to First Sunday in October

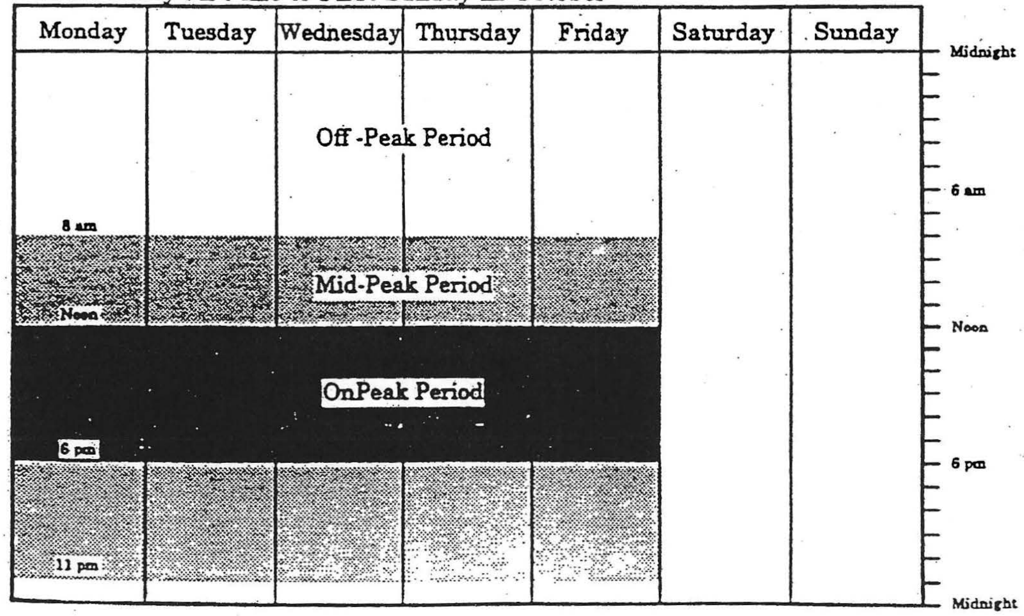


Figure 10. SCE's TOU -8 Rate Periods

The storage system is charged during the off-peak rate period (11 P.M. - 8 A.M. weekdays). The control system checks the building load and if the load is less that 300 tons, one chiller is used to both charge the tank and cool the building. If the building load is above 350 tons, a second chiller is started and both are used. The storage tank is considered fully charged when the chilled water return temperature is between 41°F to 43°F. After the storage tank is fully charged, the building is cooled with directly with the chillers. During the summer, the wet bulb temperatures are too high to make effect use of the heat exchanger. During the summer mid-peak periods, a single chiller is used to cool the building until the return temperature exceeds 60°F, when the second chiller is started. If the return temperature drops below 53°F and the load is below 1050 tons, one of the two chillers are turned off and one chiller is used to cool the building.

Approximately 15 minutes before noon on weekdays, the storage booster pump is started and storage discharging is started. During the first several hours of the on-peak period, the storage system is discharged at a rate which is above the rate needed to completely discharge the tank in six hours. The rate sometimes reached as high as 1500 tons. By discharging at a higher rate during the beginning of the period, this ensures that it will be possible to fully discharge the tank, even if there is a drop in the load at the end of the period. If one chiller is operating before the start of the o-peak period, it is shut off at 5 minutes to noon. If two chillers are operating, one chiller is shutoff after the flow to the storage system reaches steady state. The control system looks at the average cooling load for the past 24 hours and determines if it is below 1050 tons. If it is below that level, it shuts off the second chiller at 11:55 A.M. and the storage system is expected to provide the full load. If the average load is above 1050 tons, then the chiller is demand limited to 70%. The control system continually calculates the discharge rate needed to completely discharge the tank by the end of the on-peak period. When the chilled water temperature leaving the storage tank goes above 48°F, the first chiller is started if it is not already running. The control system regulates the chiller so that a building chilled water return temperature between 50°F to 55°F is maintained and the storage system is discharging at a rate above the rate needed to completely discharge the tank by the end of the on-peak period. In determining the rate needed to discharge, the amount of capacity remaining is divided by the time remaining. To ensure the tank is fully discharged by the end of the period, 300 ton-hrs is added to the storage system's capacity, making it appears there is a greater amount of storage available for discharging. The storage tank is considered fully discharged when the temperature of the water leaving the storage tank is above 53.5°F.

Winter Operating Strategy

During the winter there is no on-peak period, so the objective is to reduce the mid-peak usage. There are several options available as the heat exchanger can be used much of the time due to the cool dry conditions. During the mid-peak period, if possible the heat exchanger is used to cool the building, then the storage system and finally the chillers.

The control system allows the storage system to be charged between 9 P.M. and 8 A.M. on weekdays and all day on saturday and sunday. The control first checks the amount of storage left in the tank. If it is greater than 3,000 ton-hrs, the system is not normally charged. If it is on saturday or wednesday the tank is charged even if the amount stored is above 3,000 ton-hrs. The storage system is charged with the heat exchanger if the wet bulb temperature is 38°F or lower. A chiller is used if the wet bulb is above 38°F. The same logic for selecting the number of chillers used in charging applies as in the summer operating strategy. Once started, charging is continued until the tank is fully charged or the off-peak period ends.

During the winter mid-peak period, the heat exchanger is used to cool the building if the wet bulb temperature is in the range of 48°F to 54°F, depending on the indoor ambient conditions. If the return temperature to the building increases above 57.5°F to 58.5°F storage discharging is started. During storage discharge, if the storage outlet temperature exceeds 48°F, one of the chillers is started.

Performance Results

The performance monitoring results of the Marriott's storage and cooling system for 1992 are presented in this report. The cooling system at the Palm Desert Marriott Hotel is complex and there is significant interaction between the major subsystems. The way the storage system is operated in the winter is effected by the operation of the heat exchanger. The results presented are for the system as it exists, and is compared to a traditional conventional chiller system which does not have either storage or a condenser water heat exchanger. The last portion of this section attempts to evaluate the impact of the heat exchanger's operation on the storage system's performance in the winter.

During the year, data was collected and processed on 347 days, for a collection rate of 95%. The days that data were lost include 9 weekdays, 4 saturdays and 6 sundays. Four of the days occurred in the summer and eleven in the winter rate periods. There are an additional 5 days in November that the results are not included in the report. On these days, special tests were being conducted and the system was not operated in the normal manner. For the days that no data was collected, it was assumed that the performance and energy usage was similar to equivalent days during that month. If a weekday's data were missing, the averages for all of the weekdays during the month were inserted. The data sets were grouped by weekdays, saturdays and sundays as each has unique energy use patterns.

The performance results are summarized in Table 1 on a monthly basis. The measured results include the operation of both the storage system and the heat exchanger. It should be noted that at the start and end of the summer rate period,

Table 1. Cooling System Performance Results Summary

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December	Totals
Cooling Parameters		Winter Rate Period					Summer Rate Period				Winter Rate Period			
Building														
Cooling Load	ton-hrs	167,103	265,980	269,532	479,214	860,311	539,800	913,002	849,993	862,373	499,028	215,657	140,649	6,062,642
Average Day	ton-hrs	6,189	9,172	9,294	17,749	28,677	18,614	29,452	31,481	29,737	16,098	9,376	5,023	17,831
Peak Day	ton-hrs	10,224	13,073	12,035	23,991	27,349	30,770	33,834	40,046	31,941	27,263	15,660	6,803	40,046
Disch Period Load	ton-hrs	91,541	123,793	131,912	243,266	420,853	118,614	210,489	191,383	203,894	236,885	101,913	72,122	2,146,665
Weekdays in Month	days	22	19	22	22	25	17	23	21	23	20	20	23	
Storage System														
Discharge Load	ton-hrs	24,322	102,144	103,284	111,705	151,155	100,948	142,345	116,854	137,396	116,559	58,310	13,441	1,178,463
Average Daily	ton-hrs	2,702	4,643	5,164	5,319	6,046	5,938	6,189	5,843	5,974	5,828	5,301	2,240	5,507
Peak Day	ton-hrs	5,881	6,323	6,219	6,535	6,676	6,442	6,331	6,440	6,398	6,499	6,653	3,237	6,676
Charging Load	ton-hrs	25,085	104,650	115,391	118,293	158,763	102,349	143,902	124,375	148,507	123,472	76,315	13,848	1,254,950
Storage Efficiency	%	96.96%	97.61%	89.51%	94.43%	95.21%	98.63%	98.92%	93.95%	92.52%	94.40%	76.41%	97.06%	93.91%
Heat Exchanger														
Building Cooling	ton-hrs	121,761	18,841	9,871	675	0	0	0	0	0	0	48,876	112,102	312,126
Disch Period Load	ton-hrs	62,589	6,271	1,484	35	0	0	0	0	0	0	19,247	56,306	145,932
Electrical Usage And Demand														
Actual / Storage System														
Off-Peak	kWh	138,939	271,223	310,560	366,776	614,431	390,760	593,267	582,598	548,180	430,634	237,250	106,334	4,590,952
Mid-Peak	kWh	76,725	70,859	76,446	197,041	250,569	154,909	272,792	298,944	291,206	178,541	83,965	70,176	2,022,174
On-Peak	kWh	0	0	0	0	0	56,399	95,080	123,876	123,187	0	0	0	398,542
Total	kWh	215,664	342,082	387,006	563,817	865,000	602,069	961,139	1,005,418	962,573	609,175	321,215	176,510	7,011,668
Non-Time Related Dem.	kW	2,182	2,353	2,989	2,818	2,828	2,866	2,928	3,142	3,088	2,753	2,840	1,948	
Mid-Peak Demand	kW						2,864	2,894	3,142	3,088				
On-Peak Demand	kW						2,351	2,455	2,822	2,468				
Specific Energy Use	kW/ton	1.29	1.29	1.44	1.18	1.01	1.12	1.05	1.18	1.12	1.22	1.49	1.25	1.16
Simulated Conv. System														
Off-Peak	kWh	156,563	184,844	212,070	273,806	504,728	312,209	468,780	423,441	415,647	306,942	187,294	128,692	3,575,016
Mid-Peak	kWh	134,581	144,255	173,767	298,846	371,164	172,434	276,005	293,396	289,785	271,054	153,336	111,497	2,690,121
On-Peak	kWh	0	0	0	0	0	129,906	201,040	252,331	220,371	0	0	0	803,648
Total	kWh	291,144	329,099	385,837	572,653	875,892	614,549	945,824	969,169	925,802	577,996	340,630	240,189	7,068,784
Non-Time Related Dem.	kW	1,987	2,327	1,972	2,865	2,942	2,984	3,239	3,408	3,079	2,762	2,295	1,753	
Mid-Peak Demand	kW						2,553	2,866	3,211	2,718				
On-Peak Demand	kW						2,984	3,239	3,408	3,079				
Specific Energy Use	kW/ton	1.74	1.24	1.43	1.19	1.02	1.14	1.04	1.14	1.07	1.16	1.58	1.71	1.17

several days were added or subtracted to months so that the usage date would correspond to the correct rate period. The data for the first 6 days of June were added to May's results and the first 3 days of October were added to September's results. These changes result in slight changes in the totals for the months and should be considered when evaluating the results. It should also be noted that this evaluation was performed on calendar months, which do not necessarily match SCE's billing periods.

To determine the effectiveness of the storage system and heat exchanger, it is necessary to compare the results to that of a comparable conventional system. The approach used in this project is to collect performance data on the operation of the site's chiller system and use it to develop a performance map of the cooling system. The primary variables which effect a chiller's performance are the cooling load, chilled water supply temperature and entering condenser water temperature. The entering condenser water is determined using the ambient weather conditions (dry bulb temperature and relative humidity) and the cooling load using the following equation:.

$$CND = 50.4112 + 0.00453 * CL + 0.2273 * OAT + 12.9219 * OAR$$

Based on the performance data collected at the Marriott site, Transphase determined following equations:

For Cooling Loads between 200 and 800 tons

$$PKW = -292.8103 - 1.5225 * CST + 0.6261 * CL + 6.8495 * CND$$

For Cooling Loads greater that 800 tons

$$PKW = -721.9719 - 0.7076 * CST + 0.6261 * CL + 13.3722 * CND$$

Where CNC = Entering Condenser Water Temperature (°F)
CL = Cooling Load (tons)
OAT = Outdoor Ambient Temperature (°F)
OAR = Outdoor Ambient Relative Humidity (%)
CST = Chilled Water Supply Temperature (°F)
PKW = Chiller Plant Electrical Demand (kW)

These equations were then used to determine what the energy usage would have been for a conventional chiller system. The hourly data of cooling load, chilled water supply temperature and ambient conditions are inputted into a spread sheet with the equations and the simulated conventional system's energy usage is determined.

The energy usage of the storage system and the simulated conventional system are presented in Table 1, listed by the SCE rate periods. The simulated conventional system uses slightly more energy than the actual storage system. Although the storage system has thermal losses and the additional storage booster pump, the storage system uses less energy at night to charge the tanks due to the lower condenser water temperatures and the contributions of the cooling with the heat exchanger. The storage system was able to reduce the on-peak energy usage by 50%. During the winter, the storage system and heat exchanger were able to reduce the mid-peak usage by 39%.

Besides the usage, Table 1 contains estimated monthly peak electrical demands for the mid and on-peak periods and the non-time related demand. These demands were estimated using the 15 minute demand data taken at the SCE meter for billing purposes. The actual storage system demands in Table 2 are based on the highest measured hourly average demands. The conventional system demands are based on the simulated hourly demands which were tied to SCE's demand data. This involved calculating the hourly average demand from the meter data, subtracting the measured hourly demand of the storage system and adding in the simulated conventional system's demand. Since the demand data was provided on hard copy, these calculations were performed by hand. As a result, it was not possible to determine the conventional systems demands for every hour of the year. Extensive calculations were performed in an attempt to locate the peak values of the month. These demands are for whole hours rather than SCE's normal 15-minute periods and do not reflect the actual billings demands.

The monthly average specific energy uses of the two systems is shown on Table 1 and on Figure 11. This parameter is determined by dividing all of the electrical energy used by cooling system during the month by the amount of cooling delivered to the building, not the cooling produced by the chiller. The energy usage of the actual cooling/storage system includes the usage of the chillers, primary and secondary pumps, storage booster pump, condenser water pumps and cooling tower fans. The simulated conventional system's usage includes all of the same loads, except there is no storage booster pump required. During the winter months, the cooling systems uses more energy per ton of cooling delivered, especially the simulated conventional system. There are several factors which contribute to this increase. The cooling loads are so low that the chillers are inefficient due to the part load influence and use more energy to produce the cooling. Since less cooling is being used and the pumping energy is relatively constant, the energy used to distribute each ton of cooling is higher. The storage system usage is lower as it uses the heat exchanger to produce a portion of the cooling. Even if the storage system did not have a heat exchanger, it would use less energy as it allows the chillers to operate at higher loads during charging which is more efficient. During the

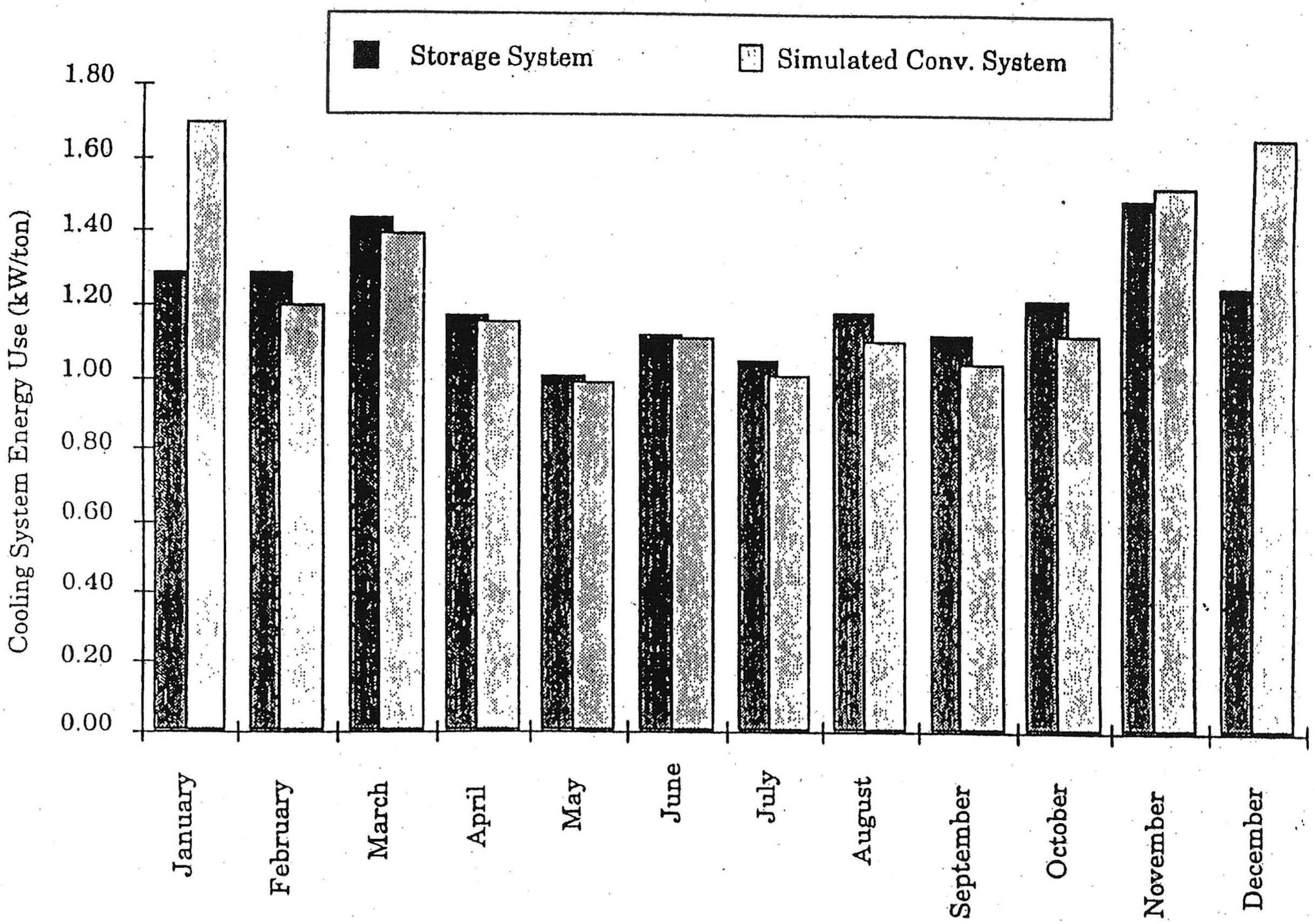


Figure 11. Comparison Of Monthly Average Cooling System Specific Energy Use

transition months, the cooling loads increase and the chillers operate more efficiently. The simulated conventional system has slightly lower energy use as the storage system has the additional pumping usage and the thermal losses. During the summer, the usage is nearly the same for both systems. The thermal losses are lower as the stored cooling is generally used the very next day and does not reside in the tank for long periods of time. The storage pump usage and the storage thermal is offset by the higher efficiencies of the chillers while charging the tanks, due to the lower condenser water temperatures at night.

The monthly cooling loads of the resort are shown on Figure 12. This stacked column chart shows the cooling loads of the hotel and how the cooling was supplied. As previously mentioned, the total cooling loads for June and October are lower as result of moving some of the days into adjacent months to maintain the rate periods. The storage system's contribution is fairly constant, except during the winter when it is displaced by the cooling provided from the heat exchanger. The daily average and peak day cooling loads are shown on Table 1, as are the discharge period cooling loads. The discharge cooling load is the load that the storage system is trying to displace. During the summer, the discharge period is the on-peak period and during the winter, it is the mid-peak period.

The operation of the storage system can be best understood by reviewing the load profiles of the peak cooling days. Figure 13 shows the cooling loads for the day with the highest total load for the year. It occurred on Thursday, August 20, 1992 and the cooling load for the day was 40,046 ton-hrs. This day was the fifth day in a heat storm. The storage system had been fully discharged on the previous days. Even though both chillers were being operated at full load during the off-peak period, they were unable to fully charge the storage tank. On this day the storage tank discharged 4061 ton-hrs and was able to reduce the hotel's on-peak demand by approximately 750 kW. As previously described, the storage tank is discharged at a high rate at the start of the on-peak period, which tapers off at the end of the on-peak period. This helps to ensure that the tank is fully discharged in the 6 hour period.

The summer peak discharge day load profile is shown on Figure 14. On this day, Monday August 17, the storage system discharged 6440 ton-hrs of cooling during the on-peak period. The building's load for the day was 35,198 tons, and was the second day of the heat storm previously mentioned. The storage system reduced this day's on-peak demand by approximately 1,150 kW, while providing 61% of the on-peak cooling load for the day.

The day with the maximum cooling load for winter rate period was June 4th, with a cooling load of 29,885 ton-hrs, as shown in Figure 15. The storage system discharged a total of 6,442 ton-hrs of cooling. On this day, soon after the storage system started to discharge, both chillers were turned off and the storage system provided all of the cooling for the building. During this time, the average discharge rate of 1,540 tons.

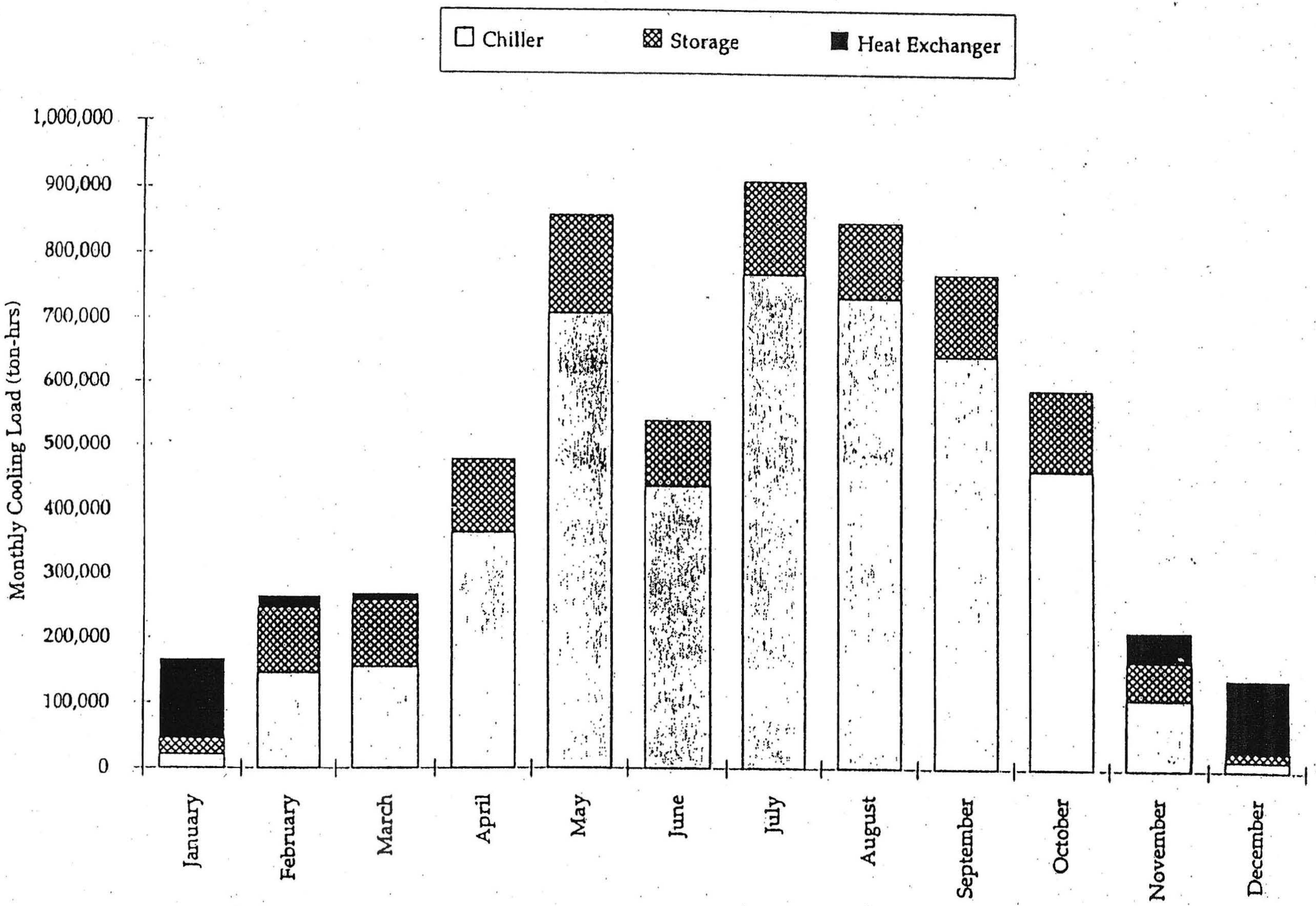


Figure 12. Monthly Cooling Loads

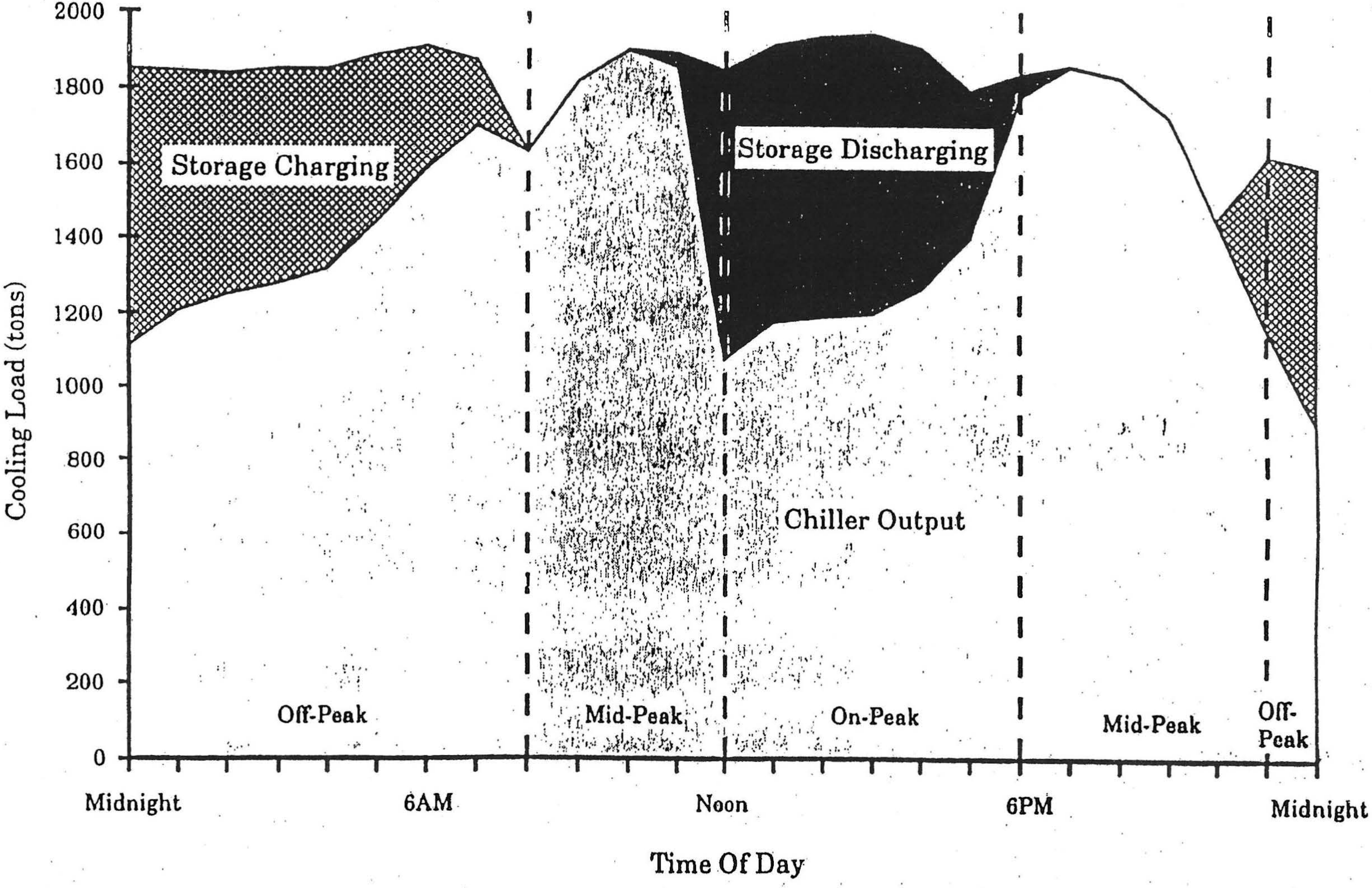


Figure 13. Load Profiles For Peak Cooling Day, August 20, 1992

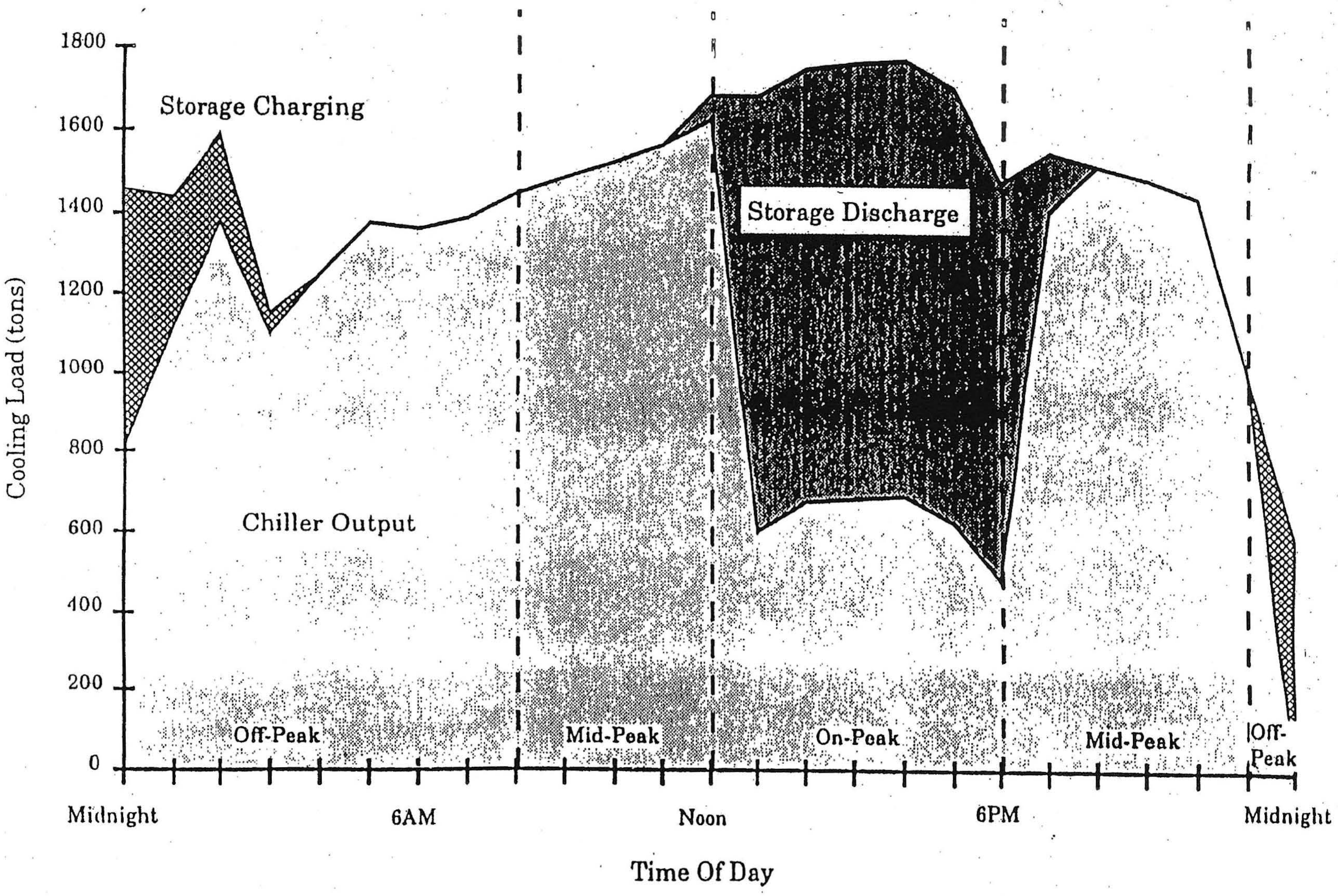


Figure 14. Load Profiles For Summer Peak Discharge Day, August 20, 1992

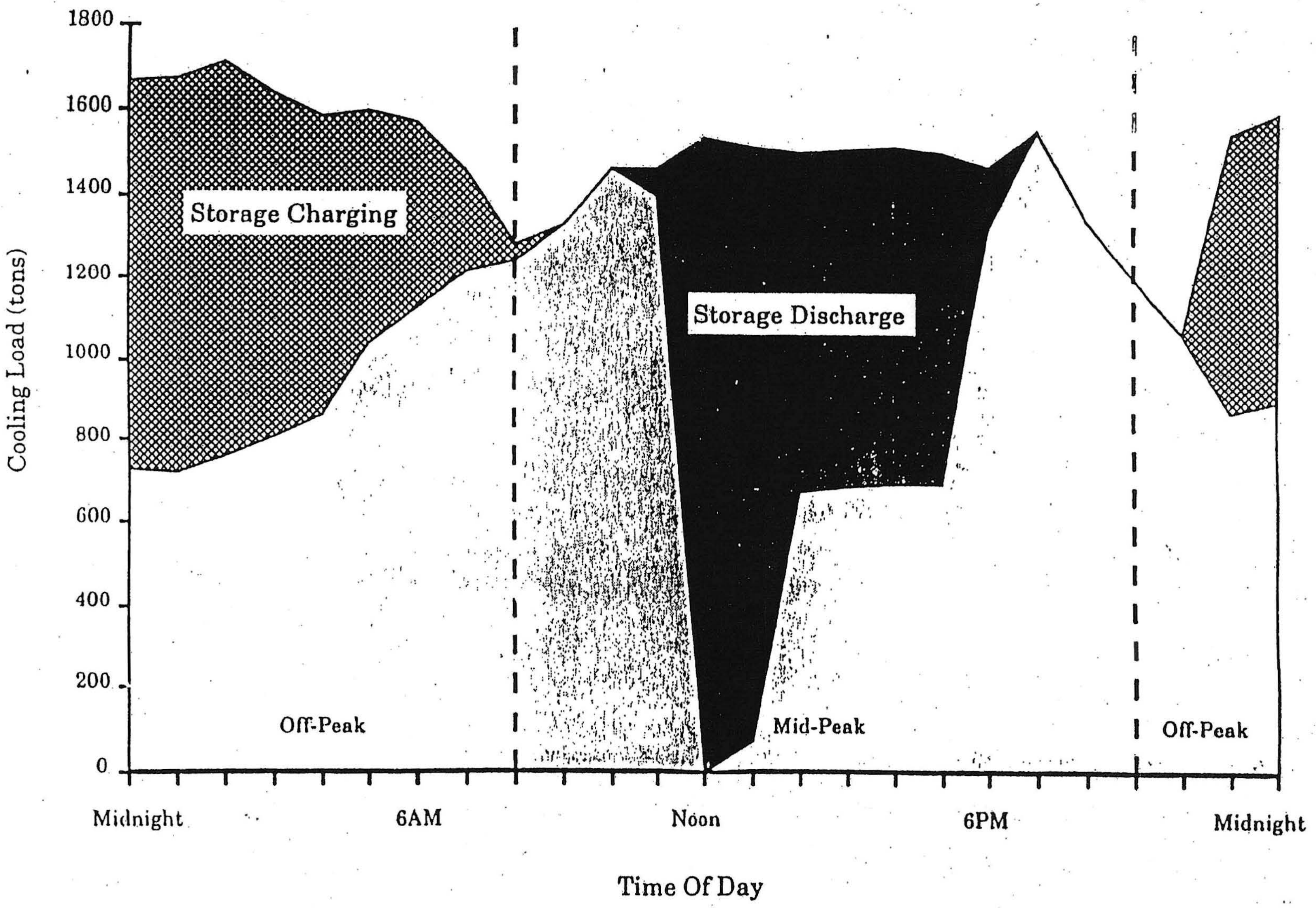


Figure 15. Load Profiles For Winter Peak Cooling Day, June 4, 1992

The control system started up one of the chillers and the storage discharge rate was cut back to ~800 tons and continued to discharge at this rate for 4 hours. The storage system had been charged with cooler than normal chilled water, giving the system extra sensible cooling capacity. At the end of charging cycle, the temperature of the water returning from the storage tank was 40.9°F.

The storage system and heat exchanger were effective in reducing the discharge period's cooling requirements. Figure 16 shows what percentage of the monthly discharge periods loads were provided by the storage and heat exchanger. During January, November and December the heat exchanger and storage provided nearly all of the hotels mid-peak cooling requirements. As the weather got warmer, the cooling requirements of the winter mid-peak period (13 hours) increased. The percentage of the load provided by storage system and the heat exchanger decreased with the increasing cooling loads. In May, the weather was relatively warm making the wet bulb temperature too high for effective use of the heat exchanger. Storage provided ~35% of the mid-peak loads for May. In June, the summer rate periods went into effect, with the discharge period being the 6 hour on-peak period. The June cooling loads were relatively low compared to the other summer months, the storage system provided 85% of the on-peak cooling requirements. During the remaining 3 summer months the storage system was able to provide over 60% of the on-peak cooling requirements.

The storage system consistently discharged its design capacity. The annual daily average discharge load of 5,505 includes a number of days when either the heat exchanger provided most of the discharge period's loads or the load was less than the storage tanks capacity. During the 4 summer months the storage system's daily average discharge was 5,994 ton-hrs, just 6 ton-hrs less than the design capacity.

Economic Evaluation

The electrical usage and demand results were used to evaluate the electrical operating costs of both systems to determine the economic effectiveness of the storage system. Table 2 is a summary of the 1992 electrical costs for both systems. In the top portion of Table 2, are the electric rates used to calculate the costs. It should be noted that a new set of rates went into effect at the end of June. The new rates have higher on-peak energy rates and lower mid- & off-peak energy rates. This helps improve the economics of storage systems and should encourage use. The monthly electrical costs for both systems are shown in Table 2. As mentioned earlier, data for several days in June and October were moved to May and September, respectively, so that they are in the correct rate seasons. The bottom portion of the table is used summarize the savings obtained from using the storage system and heat exchanger. The results indicate that the storage system was able to reduce the electrical costs by $108,300 in 1992. The demand savings were $36,600 while the energy savings were $71,700.

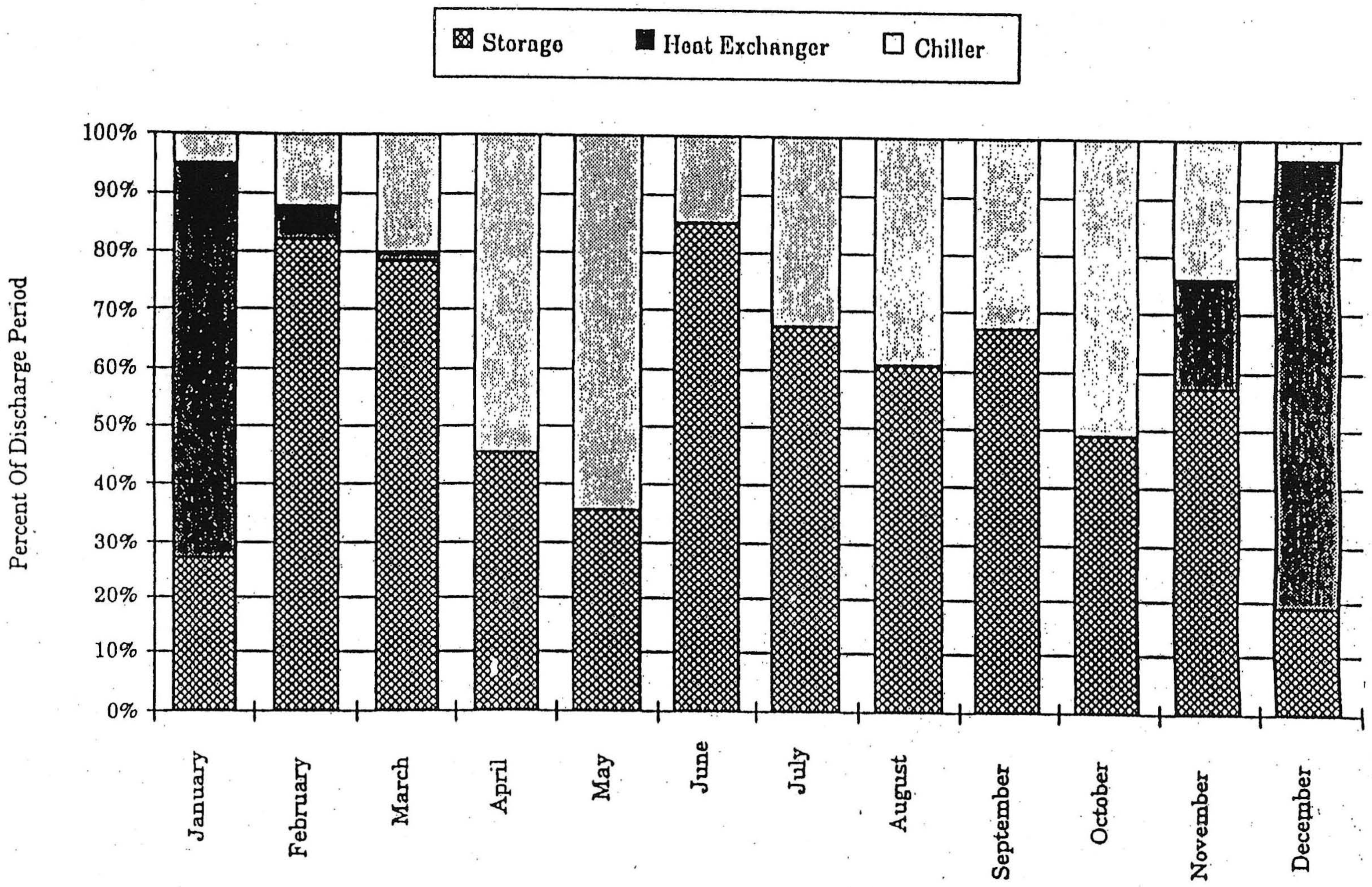


Figure 16. Percent Of Cooling Load For Discharge Period Provided By Storage

Table 2. Cooling System Economic Results Summary

Parameter	Units	January	February	March	April	May	June	July	August	September	October	November	December	Totals
Electric Rate Data		Winter Rate Period					Summer Rate Period				Winter Rate Period			
Energy Costs														
Off-Peak	$/kWh	0.05000	0.05000	0.05000	0.05000	0.05000	0.05000	0.04324	0.04324	0.04324	0.04659	0.04659	0.04659	
Mid-Peak	$/kWh	0.09905	0.09905	0.09905	0.09905	0.09905	0.08816	0.06916	0.06916	0.06916	0.08236	0.08236	0.08236	
On-Peak	$/kWh	N/A	N/A	N/A	N/A	N/A	0.10995	0.14601	0.14601	0.14601	N/A	N/A	N/A	
Demand Costs														
Non-Time Related Dem.	$/kW	2.25	2.25	2.25	2.25	2.25	2.25	3.15	3.15	3.15	3.15	3.15	3.15	
Mid-Peak Demand	$/kW	N/A	N/A	N/A	N/A	N/A	2.25	2.35	2.35	2.35	N/A	N/A	N/A	
On-Peak Demand	$/kW	N/A	N/A	N/A	N/A	N/A	15.05	15.75	15.75	15.75	N/A	N/A	N/A	
Basic Demand														
Electrical Cost														
Actual System														
Off-Peak	$	6,947	13,561	15,528	18,339	30,722	19,538	25,653	25,192	23,703	20,063	11,053	4,954	215,253
Mid-Peak	$	7,600	7,019	7,572	19,517	24,819	13,657	18,866	20,675	20,140	14,705	6,915	5,780	167,264
On-Peak	$						6,201	13,883	18,087	17,987				56,157
Total Energy Costs	$	14,547	20,580	23,100	37,856	55,540	39,396	58,402	63,954	61,830	34,768	17,969	10,734	438,674
Non-Time Related Dem.	$	4,910	5,293	6,725	6,341	6,364	6,449	9,223	9,899	9,726	8,671	8,945	6,135	88,681
Mid-Peak Demand	$						6,445	6,801	7,385	7,256				27,886
On-Peak Demand	$						35,383	38,663	44,447	38,869				157,362
Total Demand Costs	$	4,910	5,293	6,725	6,341	6,364	48,277	54,687	61,730	55,851	8,671	8,945	6,135	273,929
Total Costs	$	19,457	25,873	29,825	44,197	61,904	87,673	113,089	125,683	117,680	43,439	26,914	16,869	712,603
Simulated Conv. System														
Off-Peak	$	7,828	9,242	10,604	13,690	25,236	15,610	20,270	18,310	17,973	14,300	8,726	5,996	167,785
Mid-Peak	$	13,330	14,288	17,212	29,601	36,764	15,202	19,088	20,291	20,041	22,324	12,629	9,183	229,954
On-Peak	$						14,283	29,354	36,843	32,176	0	0	0	112,656
Total Energy Costs	$	21,158	23,531	27,815	43,291	62,000	45,095	68,712	75,444	70,190	36,624	21,355	15,179	510,395
Non-Time Related Dem.	$	4,471	5,236	4,438	6,446	6,618	6,715	10,203	10,735	9,699	8,699	7,230	5,521	86,012
Mid-Peak Demand	$						5,745	6,736	7,546	6,387				26,414
On-Peak Demand	$						44,915	51,017	53,676	48,494				198,103
Total Demand Costs	$	4,471	5,236	4,438	6,446	6,618	57,375	67,957	71,957	64,580	8,699	7,230	5,521	310,529
Total Costs	$	25,629	28,767	32,253	49,738	68,619	102,471	136,669	147,401	134,770	45,324	28,584	20,700	820,924
Energy Savings	$	$6,612	$2,951	$4,715	$5,435	$6,460	$5,700	$10,311	$11,490	$8,361	$1,857	$3,386	$4,445	$71,721
Demand Savings	$	($440)	($57)	($2,287)	$105	$254	$9,098	$13,270	$10,228	$8,729	$28	($1,715)	($614)	$36,600
Total Savings	$	$6,172	$2,894	$2,428	$5,540	$6,714	$14,798	$23,580	$21,718	$17,090	$1,885	$1,671	$3,831	$108,321

The electrical costs are compared in Figure 17. This is a stacked column chart with the monthly costs for both the actual system with storage and the simulated conventional system. The costs are broken down by usage and demand charges for the different rate periods. The plot shows that the majority of the savings were obtained in the summer months, with the savings tapering off in the winter. There were increased savings in January and December due to the impact of the heat exchanger's savings These results show the relative importance of the different season and rate periods..

The total cost of installing the storage system was $857,600, with Marriott Hotel providing $254,000. These costs were used to determine the simple payback periods of the storage system as shown in Table 3. Based on the contributions of the Hotel, the payback period is 2.3 years. The payback period for the total project is 7.9 years.

Table 3. Simple Payback Analysis

Source Of Funding	Cost Of Storage System	Simple Payback Period
Hotel's Contribution	$254,000	2.3 yrs
Hotel And Edison	$857,600	7.9 yrs

The energy cost savings are lower than projected in the original feasibility study by slightly more than 20%. The primary reason for the differences is that the Hotel's cooling system was more efficient than thought at the time of the feasibility study. The higher efficiency has resulted in lower demand and energy usage reductions.

The impact of the heat exchanger on the storage system savings was evaluated. Average energy usage values for the heat exchanger operation and the storage system were developed from the performance data. These values were then used to determine how the storage system would have performed if there had not been a heat exchanger. The results of this analysis are summarized in Table 4. The heat exchanger had a average energy use of 1.22 kW/ton during the 6 months it was operated. This energy use includes the includes the chilled water and condenser pumps and cooling tower pumps. Since the chilled water is pumped through the

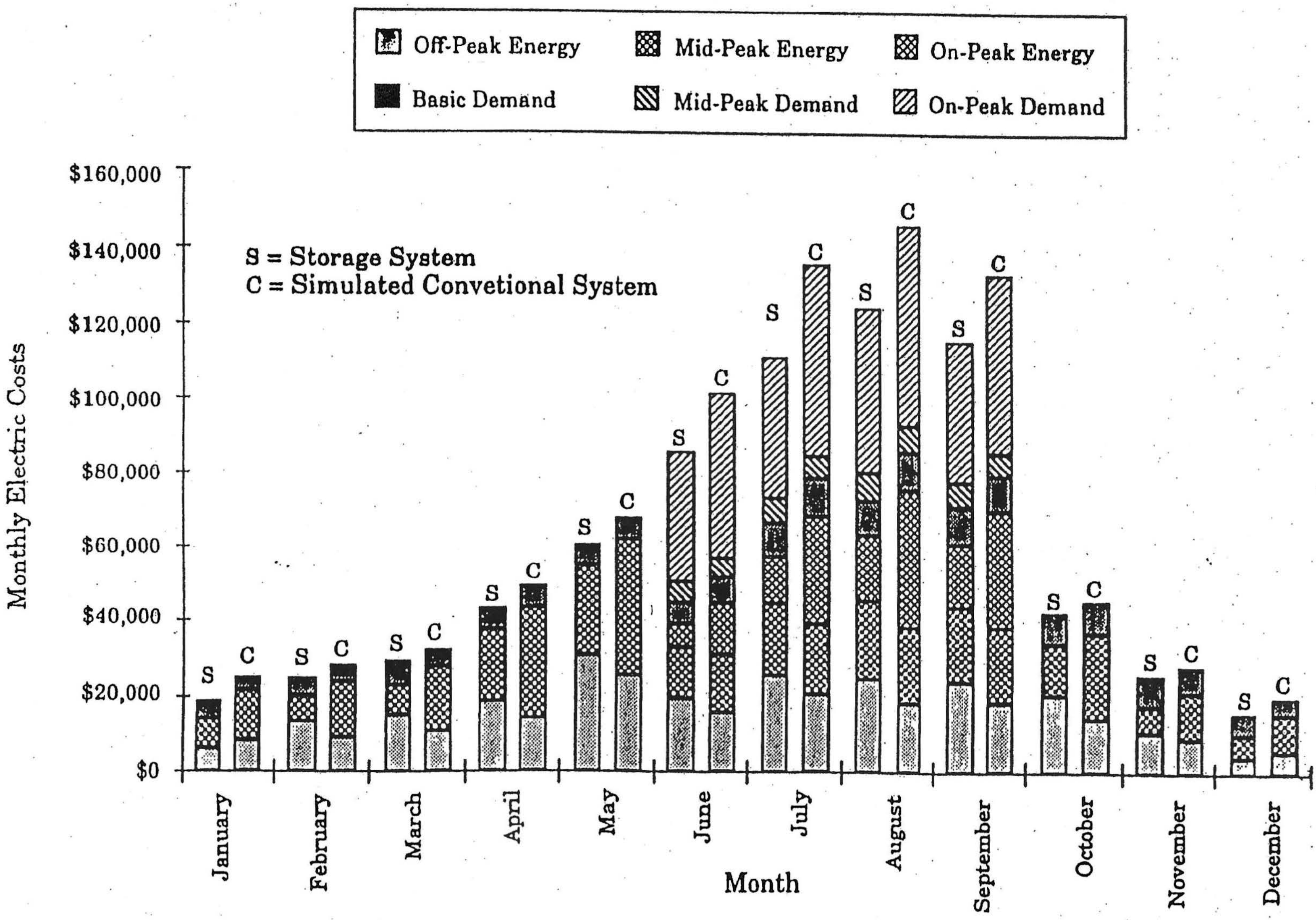


Figure 18. Comparison Of Monthly Electric Costs

exchanger. The energy required to pump the chilled water through out the resort remains relatively constant. With low loads, the specific energy use of the pumps become very high.

During the operation of the heat exchanger, it would have saved $11,000 in 1992 compared to the simulated conventional system. The heat exchanger saved an additional $3,000 more than a stand alone storage system would have saved. Since the non-time related demands were established by the storage system and not the heat exchanger, there was no impact on the basic demand charges of the facility. Energy usage savings resulted in the additional savings.

Conclusions

The storage system at the Marriott Desert Springs Resort and Spa was extremely effective in reducing the electrical usage and demand during the summer on-peak rate period. The storage system performed to the design specifications, providing an average of 6,000 ton-hrs per day during the summer on-peak rate period. The heat exchanger was effective during the winter, providing a majority of the hotel's cooling requirements.

Transphase has worked hard making sure that the system was operated properly and that it was effective in shifting the electrical loads of the cooling system from the on-peak period. Their direct involvement in the operation of the system has been extremely beneficial. These initial results indicate that the approach of paying for performance has merit.

Table 4. Heat Exchanger And Storage System Comparison

Parameter	Units	January	February	March	April	November	December	Totals
		Winter Rate Period						
Heat Exchanger Loads								
Mid-Peak Load	ton-hrs	59,172	12,570	8,387	640	29,629	55,796	166,194
Off-Peak Load	ton-hrs	62,589	6,271	1,484	35	19,247	56,306	145,932
Total Load	ton-hrs	121,761	18,841	9,871	675	48,876	112,102	312,126
Heat Exchanger Electrical Use								
Off-Peak	kWh	68,048	14,456	9,645	736	34,073	64,165	191,123
Mid-Peak	kWh	71,977	7,212	1,707	40	22,134	64,752	167,822
Total	kWh	140,025	21,667	11,352	776	56,207	128,917	358,945
Storage System Energy Use								
Off-Peak	kWh	76,332	16,090	11,742	756	41,481	69,745	216,145
Mid-Peak	kWh	80,740	8,027	2,078	41	26,946	70,383	188,214
Total	kWh	157,072	24,116	13,819	797	68,426	140,128	404,359
Conventional System								
Off-Peak	kWh	102,959	16,215	11,993	765	46,814	95,411	274,158
Mid-Peak	kWh	108,905	8,090	2,122	42	30,410	96,283	245,852
Total	kWh	211,864	24,305	14,116	807	77,224	191,694	520,010
Energy Savings Comparison								
Heat Exchanger Vs Conventional	$	$5,403	$175	$159	$2	$1,275	$4,053	$11,066
Heat Exchanger Vs TES	$	$1,282	$162	$142	$1	$741	$724	$3,052
TES Vs Conventional	$	$4,121	$12	$17	$0	$534	$3,329	$8,014