FINAL REPORT

FEASIBILITY STUDY OF A STORAGE COOLING SYSTEM FOR CENTRAL ENERGY PLANT (BLDG 7210) AT FORT RILEY, KS

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1. INTRODUCTION

1.1 Background

As a part of the Energy Engineering Analysis Program (EEAP), the feasibility of thermal energy storage at Fort Riley, KS has been studied in this report. The sponsor of the EEAP program is HQUSACE with Mr. Dan Gentile, CEMP-ET, as Point of Contact (POC), and Mr. Tony Battaglia of Mobile District, CESAM-EN-DM, is with the Technical Center of Expertise for the thermal energy storage portion of the EEAP program. The POC at Missouri River Division is Mr. David Werner, CEMRD-ED-MA, and the POC at Fort Riley is Mr. Larry Stillwagon, AFZN-PW-EE. This report was prepared by USACERL in Champaign, IL with Dr. Chang Sohn working as Principal Investigator and Mr. Douglas Anderson and Mr. Brian Boughton working as Research Assistants. Dr. Rich Liesen of the BLAST Support Office at the University of Illinois simulated the building cooling loads through the Building Load And System Thermodynamics (BLAST) program.

Ft. Riley has been interested in the application of thermal energy storage for improvement of its installation-wide electrical demand profile. Recently, Mr. Stillwagon of Fort Riley conducted a feasibility study of thermal energy storage for Building 7210 Central Energy Plant (CEP) [Reference 1] as part of his MS degree program. It is an excellent review of the feasibility of a chilled water storage system for Building 7210 as an alternative to replacement of the R-11 centrifugal chillers.

For a small scale demonstration of thermal energy storage, the application of an ice storage cooling system for a building with an independent cooling system has been suggested. One of the chapels at Fort Riley has been selected for discussion of the concept in this report.

1.2 Problem Statement

A prototype design of a chilled water storage (CWS) cooling system for Building 7210 CEP will be developed from an evaluation of on-peak electrical demand reduction capability as well as energy conservation potential. The problem is to determine if a CWS system is economically feasible, and if it is, what the optimal size of the system and system payback period are. Also, based upon the results from the selected chapel building, it will be determined whether an ice storage cooling system is economically feasible for Fort Riley.

These questions are answered through a review of previous studies conducted by Fort Riley, development of a prototype system based on the site survey, evaluation of savings by electrical demand reduction and energy conservation, and a life cycle cost analysis which results in payback periods.

1.3 Scope of Study

This report discusses the feasibility of a prototype storage cooling system for Building 7210 CEP, and an ice storage cooling system for a chapel, Building 5315. The prototype was selected through a feasibility analysis tool, STOFEAS, utilizing BLAST output and site chiller data for the load estimate and system storage capacity sizing. A detailed payback analysis of the selected prototype system is based on available data for Fort Riley's electricity consumption, electric utility rates, and industry-wide CWS cooling system cost data. The actual design of a system is beyond the scope of this report.

2. PRELIMINARY FEASIBILITY ANALYSIS

2.1 Fort Riley Electric Resources

2.1.1 Installation-wide Demand Characteristics

In considering a storage cooling system, the most critical piece of data is the peak day electric demand profile for the installation the system is to service. Figure 1 shows the peak day demand profile for Fort Riley on 2 Jul 1990. The profile shows a relatively sharp peak in the early afternoon topping at 34,110 kW at 1530. A "window" is defined as a period of time of a day during which an electrical device (such as a chiller) is turned off for the purpose of reducing the electrical demand during that period. An optimal size of window should be selected based on the installation electrical demand profile. The size of the selected window, in turn, determines the required capacity of a cool storage system. A 3.5-hour window (1300-1630) would cover the first 3 percent of the total demand, i.e., a shift of 1,023 kW from the on-peak period of 1300-1630 to an off-peak period would reduce total electric demand by 3 percent. A 6-hour (1130-1730) shift would reduce total demand by 6.4 percent, amounting to 2,196 kW. However, idling the Central Energy Plant would shave up to only 1,006 kW. Therefore, a 6-hour window would be too long for a storage cooling system for the Building 7210 CEP (see Section 3.1).

2.1.2 Electric Rate Structure

Western Resources, Inc (WRI) provides electricity to Fort Riley based on the rate of Large Power Contract Service [Reference 2, attached in APPENDIX A]. It has a straight 80 percent ratchet clause for determination of the monthly demand charge. The monthly demand charge is $4.05/kW, which is significantly lower than the national average of about $10/kW. A breakdown of monthly electric utility costs for calendar year 1993, from Reference [1], is shown in Table 1.

Table 1. Monthly Electric Utility Bill for CY 93

	Total Bill	Demand Cost	Energy Cost
Jan	513,156	107,236	405,919
Feb	503,704	107,236	396,468
Mar	509,719	107,236	402,483
Apr	469,216	107,236	361,980
May	427,582	107,236	320,346
Jun	543,973	117,437	426,536
Jul	663,803	126,185	537,618
Aug	654,292	134,005	520,287
Sep	466,440	107,236	359,204

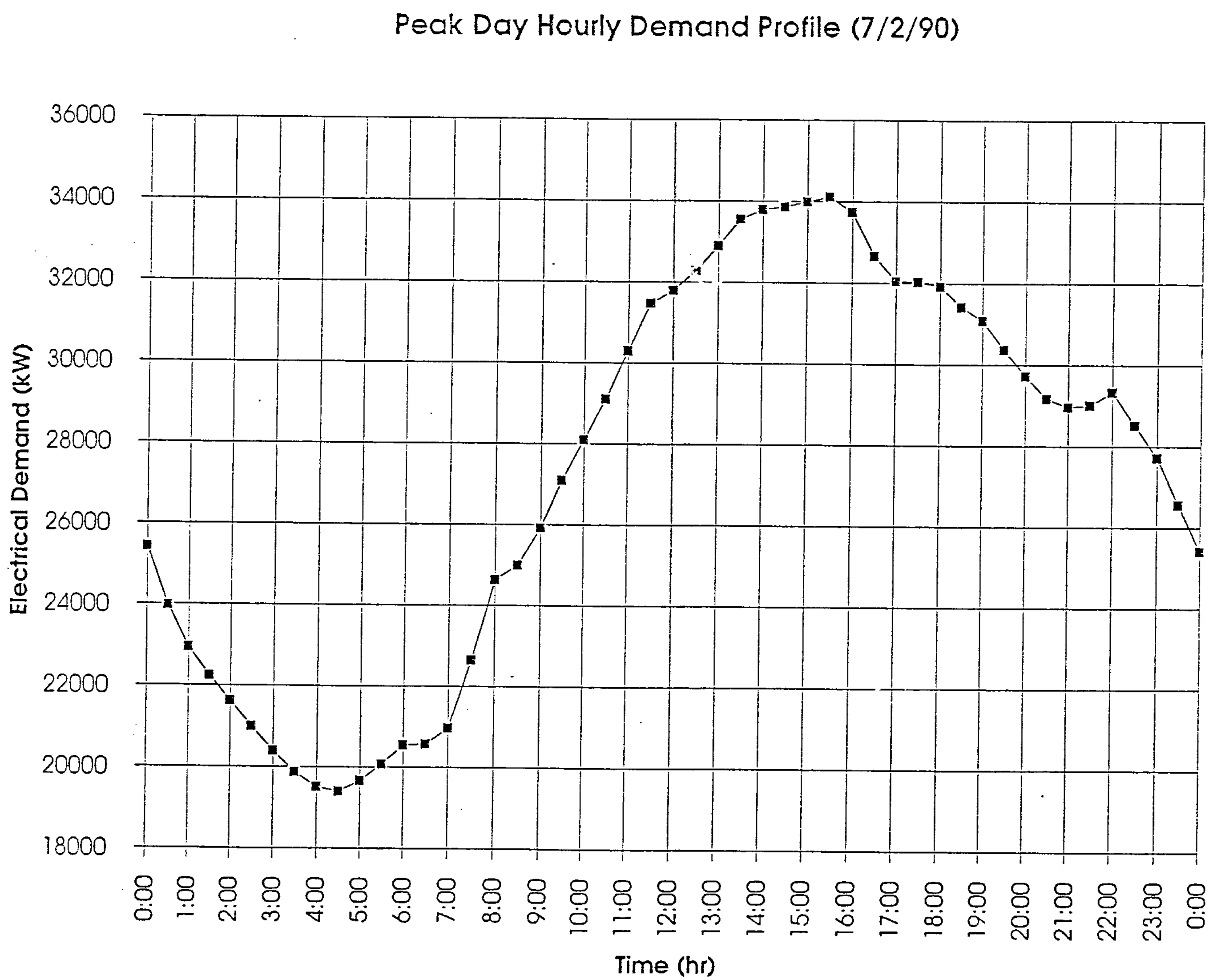

Figure 1. Peak Day Electrical Demand Profile at Fort Riley, KS

Oct	440,535	107,236	333,298
Nov	471,914	107,236	364,678
Dec	522,607	107,236	415,371
TOTAL	6,186,941	1,342,751	4,844,188

Note that the bills for CY 1993 are based on the annual peak electrical demand of 34,452 KW, which is slightly higher than the 34,110 KW shown in Figure 1 for CY 1990. Due to the negligible changes in the variation of the peak electrical demands, an analysis of a demand-shift window based on the CY 1990 data will be as accurate as the one with the current year consumption data.

2.2 STOFEAS Analysis

The first 3 percent of Fort Riley's total peak electrical demand (34,452 kW as shown in Figure 1) is 1,034 kW. Building 7210 CEP provides cooling to 22 buildings in the blocks of 7000, 7200, and 7400 of Fort Riley. The peak design day cooling load for these 22 buildings is estimated to be 1,258 tons based on the BLAST program analysis [Reference 1]. The value has been independently verified during this study. For a typical centrifugal chiller with an energy consumption factor of 0.8 kW/ton, the cooling load requires roughly 1,000 kW of electrical power to run the chiller. Therefore, a storage cooling system that can shift 1,000 kW of electrical demand of Building 7210 CEP from on-peak to off-peak periods would be the most promising candidate for further consideration.

Based on Fort Riley's peak day demand profile (Figure 1) and the electric rate structure (Section 2.1.2), a feasibility analysis of cool storage was performed with STOFEAS. STOFEAS is a simple, interactive PC program for economic feasibility analysis of storage cooling systems, based on an algorithm developed in a USACERL Technical Report [Reference 3]. The program calculates payback periods and saving-to-investment ratios based on user-provided data pertaining to electricity consumption, rate structure, and the built-in specific system construction cost model.

Results of the STOFEAS analysis under the WRI rate structure are provided in APPENDIX B. They are based on a default cost model that quotes \$80/ton-hour for a new/replacement application, \$150/ton-hour for a retrofit application, and \$300/ton-hour for an upper-limit test application. The output serves as a rough guide to the feasibility and optimal size of a cool storage system. A detailed feasibility study is discussed based on the prototype system size generated by the STOFEAS analysis. Note that the capacity of a storage cooling system is given in terms of ton-hr, which is a unit of energy. In comparison, the capacity of a chiller (which provides cooling on demand) is given in terms of ton (12,000 BTU/hr), which is a unit of power, i.e. the time rate of energy.

As expected due to the low electrical demand cost ($4.05/kW), the routine life cycle cost analysis output from STOFEAS shows that a storage cooling system would barely be economically feasible at an assumed construction cost of $80/ton-hour. At a more realistic estimate of $150/ton-hour, a storage cooling system is not economically feasible. The capacity of cool storage systems are measured in ton-hours in this report. This report will discuss the construction cost estimate in detail, taking into account unique conditions to which Building 7210 CEP is subjected. A final conclusion on the economic feasibility will be made based on the localized construction cost estimate. Results from the STOFEAS analysis show that the most cost-effective size of cool storage would be the one that would shift 1-3% of the total electrical demand of Fort Riley. It is reasonable that the first few percent of the load would require the minimal storage capacity (and cost) due to a smaller demand-shift window.

3. PROTOTYPE CHILLED WATER STORAGE COOLING SYSTEM

3.1 System Sizing

A prototype storage cooling system for this study would shift the peak cooling load (1,258 ton) of Building 7210 CEP from a selected window to an off-peak period. A typical centrifugal chiller would run at an energy consumption factor of 0.8 kW/ton of cooling. Therefore, turning off the chillers at Building 7210 CEP will reduce the peak electrical demand by 1,006 kW. An examination of the installation-wide demand profile in Figure 2 shows that a system with a 3.5-hour window will meet the requirement. However, allowing for minor variations in the future demand profile, a 4-hour period will be selected as the window of operation for the selected prototype storage cooling system.

To shift a cooling load of 1,258 tons of cooling for a 4-hour window, the required storage capacity of the system is

$$
\begin{aligned}
(1)\quad C &= Q * W \\
&= 1{,}258 \text{ tons} * 4 \text{ hours} \\
&= 5{,}032 \text{ ton-hours.}
\end{aligned}
$$

where C is the storage capacity in ton-hours, Q the cooling rate in tons and W the size of window in hours. Since the required storage capacity is greater than 2,000 ton-hours, a chilled water storage (CWS) cooling system is preferred to an ice storage cooling system [Reference 4].

For a CWS system, a typical design temperature difference between the supply and return water is 15-20 F [Reference 5]. For a conservative calculation of the storage volume, a 10 °F delta T will be assumed in this analysis. It is the typical delta T observed at central energy plants in most Army installations.. The tank storage efficiency reported in the literature from field performance monitoring ranges from 70 to 90 percent [Reference 6]. The required volume of water is given by

$$
\begin{aligned}
(2)\quad V &= (C * 12{,}000 \text{ BTU/t-h})/(8.33 \text{ lb/gal} * h * \text{delta } T * e) \\
&= (5{,}032*12{,}000)/(8.33*1*10*0.75) \\
&= 966{,}530 \text{ gallons.}
\end{aligned}
$$

where h is the specific heat of water (1 BTU/lb* F), delta T is the temperature differential, and e is the tank storage efficiency. Note that a conservative choice, delta T = 10 F and e = 75%, was used for calculation of required tank volume.

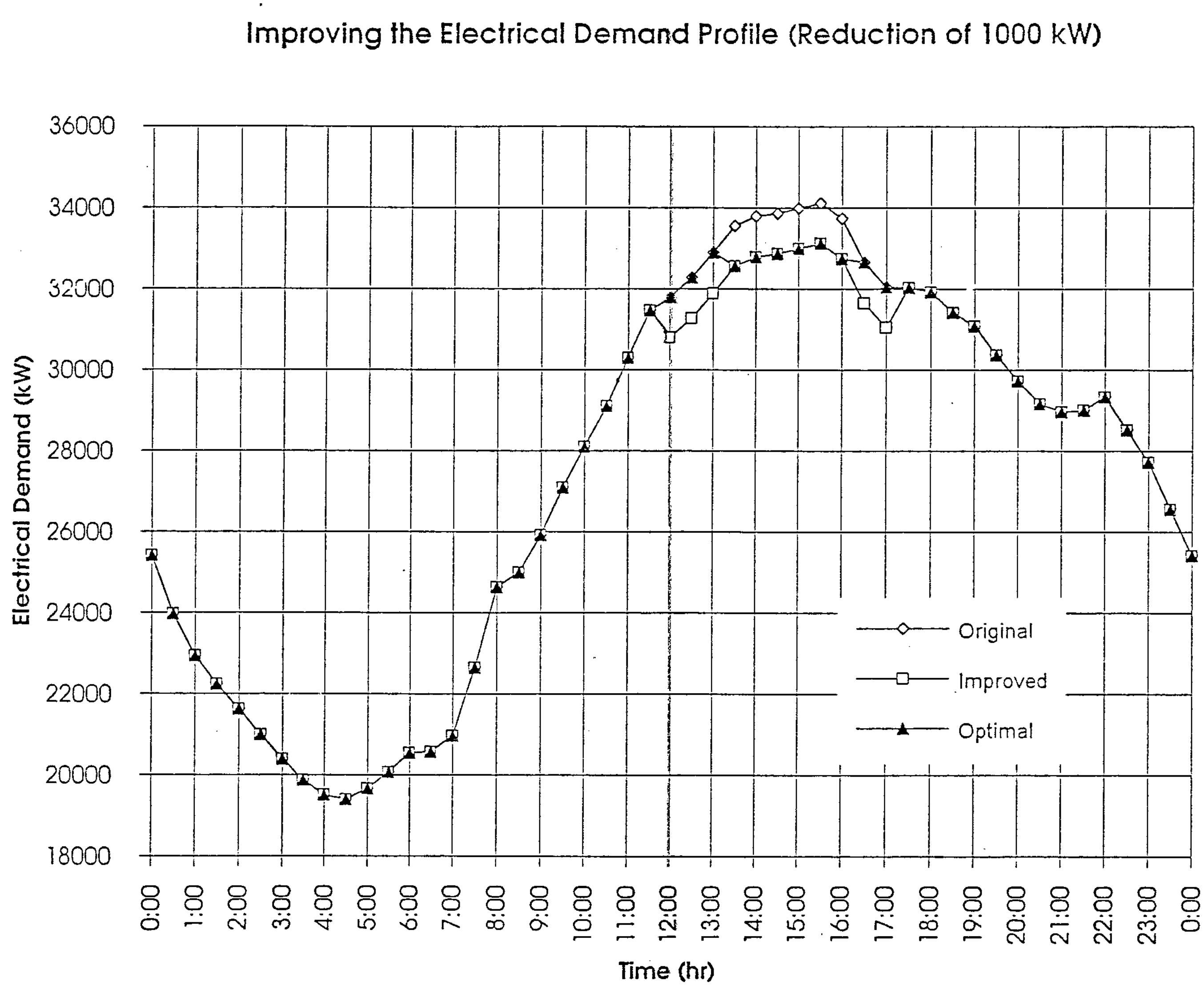

Figure 2. Design of Shift Window

3.2 Prototype System Construction Cost

The cost of storage varies depending on size of the capacity and the site-specific requirements. A firm cost estimate is possible only through a selected vendor or contractor who is awarded to build a system. The practice is not feasible under the federal acquisition regulations since the job must be subjected to an open bidding process. Therefore, a cost estimate is based on general budgetary cost data available in the industry.

3.2.1 Direct Quote

For a similarly sized CWS system, a manufacturer's budgetary quote for a turnkey base installation cost is roughly \$0.55/gal. The rate includes the cost of a chilled water storage tank and the piping necessary to connect the tank into the existing system. It is an above-ground, circular, insulated steel tank with approximately 1,000,000 gallons of water storage capacity. Based on a cost of \$0.55/gal, the total prototype system construction cost is

$$\text{(3)} \quad TC = \$0.55/\text{gal} * V = \$0.55/\text{gal} * 966{,}530 \text{ gallons} = \$531{,}592.$$

where TC is the total system-installed cost and V is the total storage volume required.

Precast concrete tanks are generally most economical in sizes of one-million gallons or more [Reference 5]. For the tank size of our interest, the cost of a concrete tank can be assumed same as that of a steel tank. Although a steel tank is seldom buried underground, a concrete tank has the option of above-ground or underground installation. The engineers from Fort Riley expressed their interests in burying the tank below an existing parking lot. Cost estimates were obtained from the <u>1995 Means Building Construction Cost Data</u>. Excavation, earth hauling, and pavement costs amount to \$53,600 for complete burial of the tank, resulting in a total tank construction cost of \$585,192. A second option would be to bury the tank half way. Excavation and earth hauling estimates for this option amount to \$23,400, resulting in a total tank construction cost of \$554,992.

3.2.2 Cost Data from Industry-wide Software Program

Table 2 shows the cost parameters associated with CWS cooling systems employed by COOLAID [Reference 6]. COOLAID is a commercially available computer program that analyzes the cost impacts of storage cooling systems for commercial buildings.

Table 2. Chilled Water Storage Parameters

Size Range (ton-hours)	Volume Required (cu ft/t-h	Tank Cost ($/cu ft)	Space Cost ($/cu ft)	Interface Cost ($/ton)	Tank Standby Efficiency (output/input)
500-2,000	15-20	6-9	0-4	50-150	0.80-0.98
2,000-10,000	13-20	5-7	0-4	50-150	0.90-0.98
Over 10,000	12-20	4-6	0-4	50-150	0.90-0.98

The volume required, in cu ft/ton-hour, for the prototype system with a storage capacity of 5,032 ton-hours is

(4) Vf = 5,032 ton-hours * 13 cu ft/ton-hour
= 65,416 cu ft.

where, Vf is the volume required in cubic feet. Based on Table 2, using the high number for a mid-size tank, the tank cost (C1) is

(5) C1 = Vf * $7/cu ft
= 65,416 cu ft * $7/cu ft
= $457,912.

There is no cost for space in our application. Note that the space cost in Table 2 applies to commercial buildings with rental space. The interface cost, C2, is given by

(6) C2 = $50/ton * 1,258 tons
= $62,900.

The total cost estimate for the prototype system, based on Table 2, is the sum of C1 and C2:

(7) TC = C1 + C2
= $457,912 + $62,900
= $520,812.

3.2.3 Selected System Construction Cost

Although the cost estimates for the prototype system based on a contractor's quote, Equation (3), and a calculation based on industry-wide data, Equation(7), are in close agreement, the storage capacity of the tanks used in calculating the costs varies by nearly a factor of two. The volume calculated by the first method is 966,530 gallons. The volume employed in COOLAID is 6,5416 cu ft * 7.48 gal/cu ft = 489,346 gal. The low tank volume employed in COOLAID is because it assumes a delta T of 20 °F. Note, however, that in most Army installations, the delta T is about 10 °F or less (See Section 3.1 System Sizing). In this study, the cost estimate is based on the storage capacity determined in Section 3.1 and the cost data for a budgetary estimate in Section 3.2.1. The cost of the storage tank is

(8) TC = $531,592.

According to the ASHRAE Design Guide for Cool Thermal Storage [Reference 5], it is not uncommon for a chilled water storage system to vary anywhere in cost between $30 and $100 per ton-hr.

In 1994, Fort Jackson built a chilled water storage tank with a storage capacity of 2.25 million gallons of water at a cost of $926,750. According to the 1995 Means Mechanical Cost Data, for site work the city cost index is 84.6 for Columbia, SC and 91.7 for Topeka, KS. The scale of economy for the tanks between one and two million gallons of storage is about 20 percent (see Table 2). Incorporating the scale of economy (20 percent) and the city cost index differential (8.4 percent), the tank cost for Fort Riley is projected to be $511,164.

In 1993, Fort Riley received a cost quote from the Natgun Co. for a thermal storage tank. Their quote for a tank with 960,000 gallons of storage capacity was $534,000.

In 1994, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) conducted a national survey of storage cooling systems in operation [Reference 7]. Cost equations for storage cooling systems were developed based on actual cost paid for the construction of the systems currently in operation. According to the cost equation for a retrofit CWS system under 1 million gallons of storage capacity, the cost of the prototype system is projected to be $526,497.

Comparing these numbers, a tank construction cost estimate given in Equation (8) would be quite realistic.

3.3 Annual Savings in Demand Charge through Prototype System

The amount of power shifted from on-peak to off-peak periods by the system is

(9) P = 1,006 kW.

According to the WRI rate schedule (attached in APPENDIX A) for Fort Riley and previous monthly billing records (in Table 1), the annual demand savings, S, realized through a reduction of 1,006 kW in peak demand, is given by

(10) S = (1,006 kW*$4.05/kW*3)+(1,006 kW*0.8*$4.05/kW*9)
= $41,558/yr.

where a demand charge of \$4.05/kW, an 80 percent ratchet, and three summer months when the actual demand exceeds the ratchet are incorporated into calculation.

3.4 Simple Payback Period

The payback period of the prototype CWS cooling system can be calculated from the system construction cost, Equation (8), and the expected annual savings, Equation (10). The simple payback period, Y, for an above-ground tank is

(11) $Y = \$531,592/\$41,558/\text{year}$
$= 12.8$ years.

For a fully buried tank the simple payback period is

(11a) $Y = \$585,192/\$41,558/\text{year}$
$= 14.1$ years.

For a half-way buried tank the simple payback period is

(11b) $Y=\$554,992/\$\$41,558/\text{year}$
$= 13.4$ years.

4. ICE STORAGE COOLING SYSTEM FOR CHAPEL BUILDING 5315

Building 5315 has been selected as a potential candidate for an ice storage cooling system at Fort Riley. It is a chapel and family life center with a total floor area of 19,748 square feet. An information sheet for the building 5315 and an activity schedule for a similar chapel is attached in APPENDIX C. An hourly simulation of the cooling load for a design week, incorporating the building usage schedule, has been performed through the BLAST program. The results are shown in Table 3.

Table 3. Hourly Cooling Load for Building 5315 for a Design Week (Units are tons of cooling)

D/H	MON	TUE	WED	THU	FRI	SAT	SUN
1	11.5	11.5	11.5	11.5	11.5	10.8	10
2	10.5	10.5	10.5	10.5	10.5	9.9	9.3
3	9.6	9.6	9.7	9.7	9.7	9.1	8.6
4	8.8	8.9	8.9	8.9	8.9	8.4	8
5	8.3	8.3	8.3	8.3	8.3	7.9	7.5
6	8	8	8.1	8.1	8.1	7.6	7.2
7	23	23.5	23.6	23.6	23.6	21.7	22.2
8	29.8	30	30.1	30.1	30.1	23.2	23.7
9	33	33.2	33.3	33.3	33.3	26.3	43.4
10	36.1	36.2	36.3	36.3	36.3	28.3	48.1
11	39.3	39.5	39.5	39.5	39.5	30.3	51.2
12	42.6	42.8	42.8	42.8	42.8	32.4	54.2
13	46.2	46.4	46.4	46.4	46.4	35.1	57.5
14	49.1	49.2	49.2	49.2	49.2	37.3	43.8
15	50.9	51	51.1	51.1	51.1	38.7	43.9
16	51.1	51.2	51.2	51.2	51.2	38.8	43.8
17	50.7	50.8	50.8	50.8	50.8	38.7	43.2
18	24.2	24.2	24.2	24.2	24.2	16.4	17.8
19	19.7	19.7	19.7	19.7	19.7	15.6	16.5
20	17.6	17.7	17.7	17.7	17.7	14.2	14.9
21	16.2	16.2	16.2	16.2	16.2	13.3	13.9
22	14.8	14.9	14.9	14.9	14.9	12.4	12.9
23	13.6	13.6	13.6	13.6	13.6	11.5	12
24	12.5	12.5	12.5	12.5	12.5	10.8	11.1
Daily Ton-Hr	627	629	630	630	630	499	625

The building has three distinctive areas which are fully occupied during the weekdays, as well as a sanctuary area occupied only on Sunday. It is interesting to note that the daily cooling requirements during the design week are rather constant except on Saturday. The hourly cooling load in Table 3 is plotted in Figure 3 for illustration of the trend. The weekly peak is predicted in the early afternoon of Sunday (57.5 tons at 1300), which is about 10 percent higher than the weekday peak of

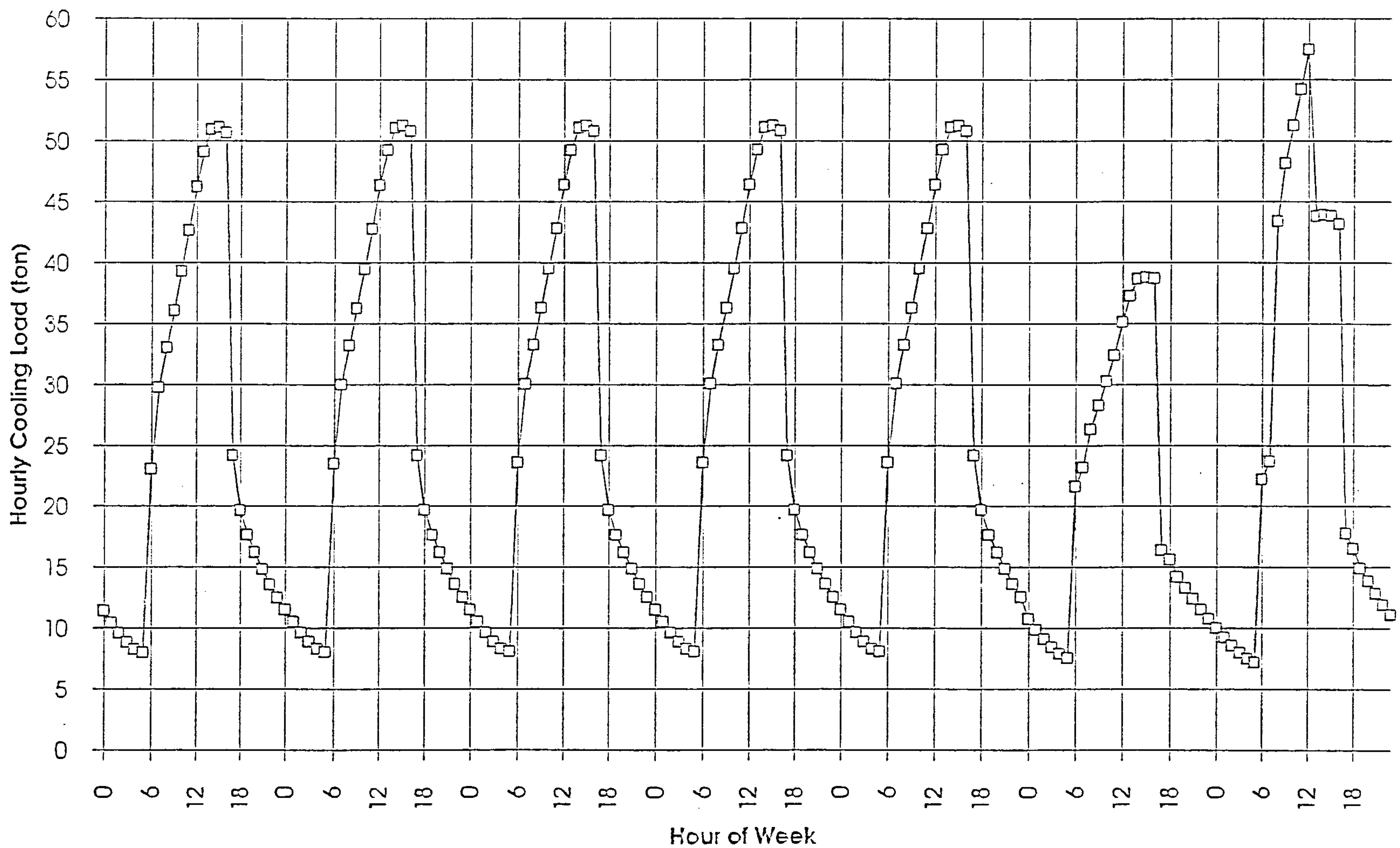

Figure 3. Hourly Cooling Load for Building 5315 for a Design Week

51.2 tons. This result is reasonable considering the building usage for Sunday service activities. However, the daily total ton-hour requirement for Sunday (625 ton-hours) is not higher than those of weekdays. The cooling requirement of Building 5315 is similar to that of a typical office building. Therefore, a storage cooling system for Building 5315 should be designed with a daily cycle operation rather than a weekly one.

4.1 System Sizing

From the installation-wide demand profile (Figure 2), a 4-hour period will be selected as the demand-shift window. Since all the hours on Saturday and Sunday fall under the utility off-peak period, the maximum cooling load to be shifted is the one during the early afternoon hours of weekdays. For a 4-hour window of 1400-1800 on Wednesday, the required storage capacity for the selected window is

$$(12)\quad C = 49.2 + 51.1 + 51.2 + 50.9 = 202.4 \text{ ton-hours.}$$

4.2 Expected Annual Savings in Demand Charges

Assuming an energy efficiency of 1.2 kW/ton of cooling for typical performance of a small capacity air cooled reciprocating chiller, the maximum amount of electrical demand to be shifted from on-peak to off-peak is

$$(13)\quad P = 51.2 \text{ tons} \times 1.2 \text{ kW/ton} = 61.4 \text{ kW.}$$

According to the WRI rate schedule (APPENDIX A), the annual demand charge savings, S, realized through a reduction of 61.4 kW from the peak demand is

$$(14)\quad S = (61.4 \text{ kW}*\$4.05/\text{kW}*3)+(61.4 \text{ kW}*0.8*\$4.05/\text{kW}*9) = \$2{,}536/\text{yr.}$$

where a demand charge of $4.05/kW, an 80 percent ratchet, and three summer months when the actual demand exceeds the ratchet are incorporated into the calculation.

4.3 Conceptual Design of a Prototype System

A 200 ton-hour storage capacity system is a rather small system. The existing 81 ton reciprocating chiller is to be converted to an ice maker, thereby eliminating the cost of a new ice maker for this application. A number of small packaged ice storage tanks could be used for this retrofit application, including an internal-melt ice-on-coil, an external-melt ice-on-coil, and an ice harvester tank. For a retrofit of this size of cooling system, a major portion of the total system cost is NOT the cost of the storage tank but is the installation cost of the tank, including the piping works [Reference 8]. Note that a few changes in the current cooling system are to be made: (1) the cooling loop will be charged with glycol solution (e.g., Dow Therm), (2) the existing 81.5 ton chiller will be converted for a dual use-- one as an ice maker with an added expansion device that will lower the supply glycol solution temperature down to 20 F for ice making and the other as a conventional chiller producing 42 F glycol solution through the existing expansion device, and (3) a 3-way valve and a control system for optimal charge and discharge of the ice storage are to be added.

In this report, an internal-melt ice-on-coil system is considered as the candidate prototype system for the following reasons. An ice harvester system requires a storage tank as well as an ice maker on top of the tank. Since an existing chiller is to be converted into an ice maker, the cost for a new ice maker would be extra. It would increase the system construction cost above that of the other types of systems. An external-melt ice-on-coil system would require an intermediate heat exchanger to keep the cooling system a closed system. An extra heat exchanger will be costly not only in the system first cost but also in the annual operating cost because of the unavoidable drop in energy efficiency due to the intermediate heat exchange process.

An internal-melt ice-on-coil system may be added to the current cooling system as shown in Figure 4. Figures 5 and 6, from Reference 5, illustrate the workings of the internal-melt ice-on-coil system. The storage tank is connected to the supply and return mains with a 3-way modulating valve controlling the flows in the main loop. From the point of view of the building load, the tank is parallel with the existing chiller, i.e., the chilled water comes either from the chiller or from the tank as dictated by the control of the 3-way valve based on the operational logic given in Table 4.

Table 4. System Operation Schedule

Hour of Day	Chiller Status	Tank Status
0600-1300	Run as a regular chiller, Cool Building with 42 F glycol solution	Idle No charge/ No discharge
1300-1700	Idle (Shut off)	Discharge, cool building
1700-2400	Run as regular chiller, Cool building with 42 F brine	Idle No charge/ No discharge
0000-0600	Run as an ice maker, Charge tank with 20 F glycol solution while meeting small night-time load	Charge

According to the ASHRAE Design Guide for Cool Thermal Storage (Reference 5), the existing chiller will be derated by roughly a third in the ice making conditions. At a capacity of 50 tons during the 6-hour ice making operation, the ice maker will deliver 300 ton-hours of cooling to the tank. The night time load during the period of 0000-0600 is 57 ton-hours (Table 3, Hourly Cooling Load for Building 5315). Therefore a 6-hour charge period is sufficient to charge the tank fully, up to 202.4 ton-hours, under the design week conditions.

The relatively short period (4 hours) of the discharge may become a design constraint for the selection of a storage tank. Each storage tank is rated for its maximum discharge rate. On the other hand, the charging period in this study would not be a concern. It can be lengthened, if required, for up to 12 hours of the off-peak period of the electrical utility.

4.4 Construction Cost Estimate

The cost breakdown of the prototype system is the cost for the storage tank, mechanical work for connecting the components (tank, circulation pump, 3-way valve, isolation valves and strainers), civil work for the tank pad construction and other related works such as fence and access arrangement, control systems, and electrical works for wiring and panel installation. Each category of cost estimate was made from either a direct quote from the manufacturer's representative or from the 1995 Means Mechanical Cost Guide [Reference 9].

The cost of the storage tank is quoted to be $8,500 for CALMAC Model 1190 and $6,500 for Model 1098. The Model 1190 has a net storage capacity of 160 ton-hours (nominal capacity of 190 ton-hours) and the Model 1098 one of 80 ton-hours [Reference 10]. One each of Model 1190 and Model 1098 tanks will provide 240 ton-hours net storage capacity to satisfy the design requirement. The cost of the tanks, therefore, is $15,000.

Based on 200 feet of piping works of 2 inch diameter, schedule 40, steel pipe with 20 elbows and tees, the cost for the piping work is estimated to be $6,100. Including the cost for conversion of the existing chiller for a dual expansion capability ($5,000), material and labor cost for a circulation pump ($1,350), a 3-way valve ($2,000), two isolation valves and a strainer ($3,000) and other miscellaneous parts and services ($3,000), the total cost estimate for the mechanical work is $20,450. The other cost estimates are $3,000 for the civil works including equipment rental, $5,000 for the control system, $3,000 for electrical works, and $4,700 for 15 percent overhead and profit. Summing them yields the total system construction cost as $36,150.

The estimated construction cost was compared with hard data from a number of previous constructions [Reference 4]. The actual construction cost (excluding the cost of tank and ice maker) for an ice harvester system with a slightly larger capacity at 300 ton-hours at Fort Bliss in 1989 was $129,000. The cost for an internal-melt ice-on-coil system (700 ton-hours) at Fort Stewart in 1986 was $83,900, and the cost for an external-melt ice-on-coil system (1,000 ton-hours) at Yuma Proving Ground in 1988 was $114,435. Note that the installation cost is not a strong function of system storage capacity, especially for small storage capacity systems of less than 1,000 ton-hours.

A general cost equation for internal-melt ice-on-coil systems for retrofit applications, developed by the ASHRAE study [Reference 7], is

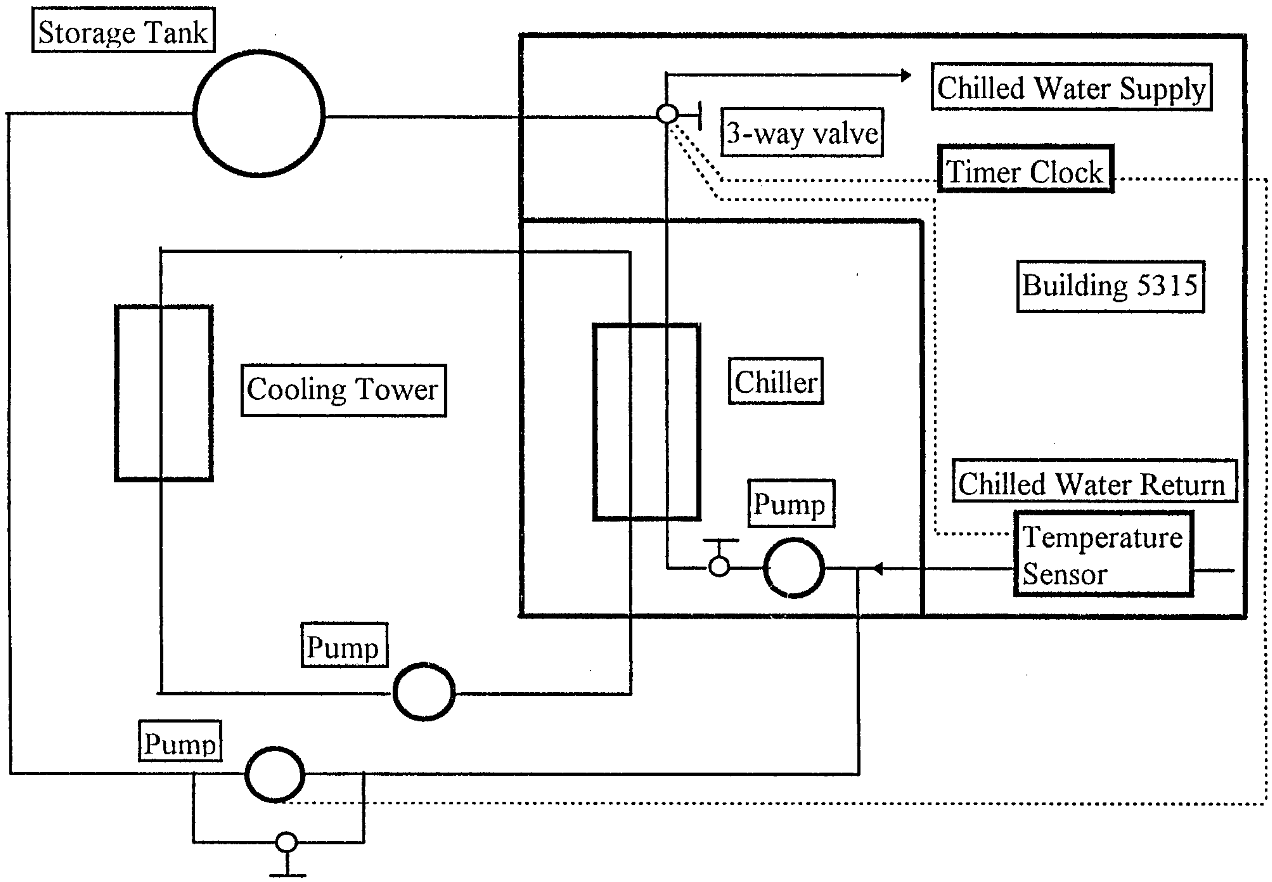

Figure 4. Addition of Ice Storage Tank to Building 5315

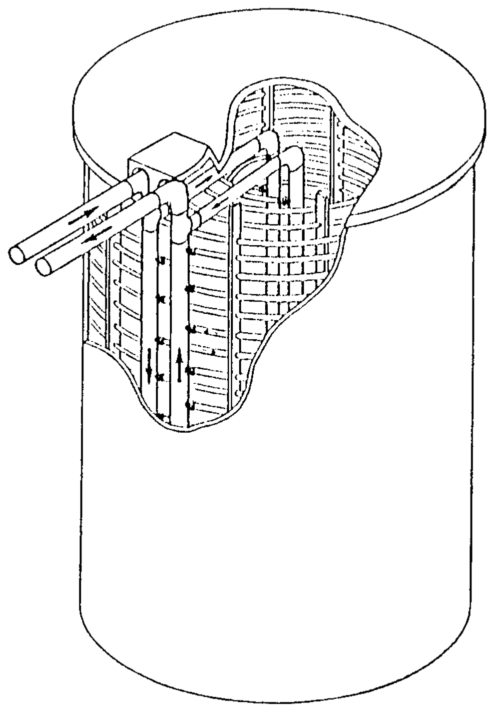

Figure 5. Modular Internal Melt Ice Storage Tank

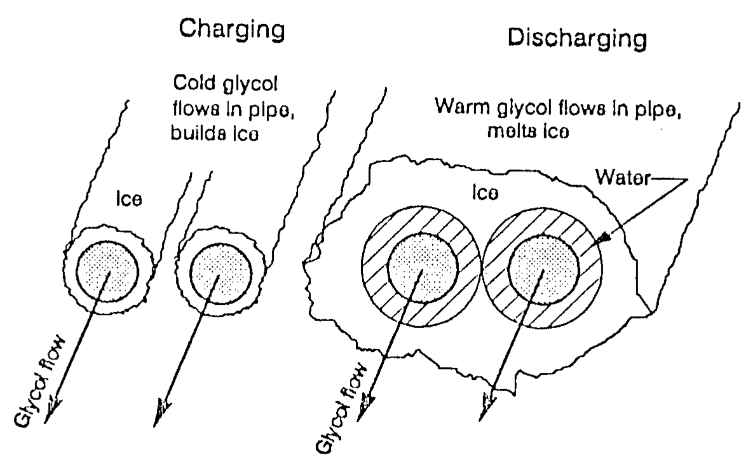

Figure 6. Charge and Discharge of Internal Melt Ice Storage

$$
\begin{aligned}
(15)\quad C &= 122.2 \times TH + 36{,}190 \\
&= 122.2 \times 202.5 + 36{,}190 \\
&= \$60{,}935.
\end{aligned}
$$

where, TH is the storage capacity in ton-hours. Note that the large value of the constant (y-intercept) may not be able to provide a good estimate for smaller capacity systems.

The above hard data shows that an accurate estimate of construction cost for small capacity systems is quite elusive. It is most likely that the estimated cost of the prototype system at $36,150 is an underestimate. However, this number is used for the calculation of a simple payback period.

4.5 Simple Payback Period

Based on the annual savings of $2,536 (in Section 4.2) and the system construction cost of $36,150 (in Section 4.4), the simple payback period is calculated to be 14.3 years.

5. DISCUSSION AND RECOMMENDATION

5.1 Discussion of Payback Results

The payback periods of both the chilled water storage cooling system for Building 7210 Central Energy Plant (12.8 years) and the ice storage cooling system for Building 5315 Chapel Building (14.3 years) are relatively short, considering the unusually low electrical demand charge rate ($4.05/kW) of the Western Resources, Inc. The reason is that the installation-wide demand profile (Figure 2) is favorable to applications of storage cooling systems. For the first 3 percent shift of the onpeak demand, a window of shift of only 3.5 hours is required.

It should be noted, however, that the cost of interface works between the storage tank and the distribution loop was not included in the calculation of the construction cost of the chilled water storage cooling system for Building 7210. It was assumed that the chillers in Building 7210 are approaching retirement ages, and the installation of the CWS cooling system would take place at the same time as the chiller replacement. Therefore, for a comparison between the direct replacement of chillers and the chiller replacement with the addition of a CWS tank, only the cost of a CWS tank was considered as extra for the latter option.

If an addition of a CWS tank is considered without replacement of the existing chillers (i.e., retrofit addition of a CWS cooling system to the existing cooling system), the interface cost of connecting the tank to the chilled water distribution system should be added to the cost of the tank ($531,592). The extra cost would be rather significant. As an illustration from an actual project cost at Fort Jackson, the interface cost was $910,000 while the cost of a CWS tank was $926,750. Therefore, the payback period of a retrofit CWS cooling system for Building 7210, including the interface cost, would be too long to merit any serious consideration.

The impact of the demand charge rate on the payback period is illustrated with the following example. If the demand charge rate for Fort Riley were at the national average of $10/kW with an 80 percent ratchet, the annual savings by the prototype system studied in this report would be $102,612/yr. It would yield a simple payback period of 5.2 years, which would make a good project for investment. Note, however, that the current demand charge of $4.05/kW is a significant factor for the relatively low electrical demand cost for Fort Riley at the present time.

5.2 Recommendations

It is again emphasized that the installation-wide electrical demand profile, rather than that of an individual building, is the basis of electrical demand management for the purpose of demand cost reduction. At the current rate of demand charge ($4.05/kW), storage cooling systems are not economically feasible at Fort Riley. Measures of reducing the energy consumption (kWH reduction) for a reduction in electrical demand (kW reduction) for the purpose of savings in electrical utility cost for Fort Riley would be economically more preferable.

The aging R-11 (CFC-11) centrifugal chillers in Building 7210 Central Energy Plant are recommended to be replaced by new centrifugal chillers operating with R-123 (HCFC-123) or R-134a (HFC-134a) refrigerants. Although the R-123 is an HCFC refrigerant scheduled for phaseout by the year 2030, the phaseout period is long enough to cover the service life of the chiller if the chillers are replaced before the year 2000. Addition of a chilled water storage tank in tandem with the chiller replacement is not recommended in the near future, unless Fort Riley experiences a catastrophic increase in electrical demand rates (more than double the current rate) from Western Resources, Inc.

REFERENCES

1. "Chilled-Water Storage Feasibility Study," Larry D. Stillwagon, MS Thesis to Kansas State University, 1994.

2. Western Resources, Inc. Schedule LP, filed to the State Corporation Commission of Kansas, August 2, 1991.

3. "STOFEAS: A Personal Computer Program for Estimating the Economic Feasibility of Storage Cooling Systems," USACERL Technical Report FE-93/12, C.W. Sohn and J.H. Kim, Dec 1992.

4. "Lessons from Field Demonstration and Testing of Storage Cooling Systems," EHSC Technical Note, TN 5-670-1, Apr 1992.

5. Design Guide for Cool Thermal Storage, ASHRAE, 1993.

6. Regional Economic Research, Inc., User's Guide for COOLAID 2.1: A Technology Assessment Tool for Cool Storage Systems, 1990.

7. Study of Operational Experience with Thermal Storage Systems - Results of a National Survey of Cool Thermal Energy Storage Systems, ASHRAE Research Project 766, May 1994.

8. "Analysis of System Installation Cost of Diurnal Ice Storage Cooling Systems for Army Facilities," USACERL Technical Report E-91/09, C.W. Sohn and R.W. Taylor, July 1991.

9. MEANS Mechanical Cost Data, 18th Annual Edition, 1995.

10. Paul Valenta, Telephone Communication, CALMAC representative in Ohio, May 1995.

APPENDIX A: Electrical Utility Rate for Fort Riley

THE STATE CORPORATION COMMISSION OF KANSAS

INDEX NO________

WESTERN RESOURCES, INC., dba KPL
(Name of Issuing Utility)

KANSAS - ALL RATE AREAS
(Territory to which schedule is applicable)

SCHEDULE LP

Replacing Schedule LP Sheet 1

which was filed August 3, 1992

No supplement or separate understanding shall modify the tariff as shown hereon.

Sheet 1 of 3 Sheets

LARGE POWER CONTRACT SERVICE

AVAILABILITY

Available throughout Company's service area to commercial and industrial customers with a Billing Capacity greater than or equal to 200 kilovolt-amperes (kVA) at one delivery point.

Service is subject to the DEFINITIONS AND CONDITIONS section below. Backup, breakdown, resale, shared, standby, supplemental, and temporary service are not available under this rate schedule. Availability also is subject to the customer signing an Electric Power Service Agreement with an initial term of at least one year.

NET MONTHLY BILL

CAPACITY CHARGE
$4.45 per kVA for the first 200 kVA of Billing Capacity
$4.25 per kVA for the next 400 kVA of Billing Capacity
$4.05 per kVA for all additional kVA of Billing Capacity

ENERGY CHARGE
3.924¢ per kWh for the first 50 kWh per kVA of Billing Capacity
3.404¢ per kWh for the next 100 kWh per kVA of Billing Capacity
3.084¢ per kWh for the next 250 kWh per kVA of Billing Capacity
2.864¢ per kWh for all additional kWh

MINIMUM BILL: The greater of $890.00 or the Capacity Charge multiplied by Billing Capacity plus applicable adjustments provided in the Tax Adjustment - Electric schedule.

DEFINITIONS AND CONDITIONS

1. Service is delivered at standard, three-phase voltage from available lines with adequate capacity. Company retains the right to change the voltage of its supply lines.

2. Service normally is measured at delivery voltage; however, Company reserves the right to locate its meters at a voltage other than delivery voltage and compensate for transformer losses.

95KPLE020TAR
Commission File Number

Issued JUL 7 1994
Month Day Year

Effective AUG 2 1994
Month Day Year

By James Haines
James Haines, Executive Vice President

NOTED & FILED AUG 2 1994
THE STATE CORPORATION COMMISSION OF KANSAS

By Judith McDonnell mfw
Secretary

THE STATE CORPORATION COMMISSION OF KANSAS

INDEX NO

WESTERN RESOURCES, INC., dba KPL
(Name of Issuing Utility)

SCHEDULE LP

KANSAS - ALL RATE AREAS
(Territory to which schedule is applicable)

Replacing Schedule LP Sheet 2

which was filed August 3, 1992

No supplement or separate understanding shall modify the tariff as shown hereon.

3. Highest Capacity, measured in kVA, shall be capacity in kW measured during the 30-minute period of maximum use during the billing month, including adjustments, divided by the Power Factor as defined in Section 5 below.

4. Billing Capacity shall be the Highest Capacity established during the current billing month, except that Billing Capacity shall not be less than:

   a) 80% of the Highest Capacity established in the most recent July, August, or September prior to the current billing month, or

   b) 50% of the contract capacity stated in the Application for Electric Service, or

   c) 200 kVA.

5. Power Factor shall be determined according to the following formulas.

   a) Customers with reactive meters, which measure kVArh:

$$PF = \frac{kWh}{\sqrt{(kWh^2) + (kVArh^2)}}$$

   b) Customers with "Q" meters, which measure kQh, must first convert the kQh reading into reactive kilovar hours (kVArh):

$$kVArh = \frac{(2 * kQh) - kWh}{\sqrt{3}}$$

   This product is to be inserted into the Power Factor equation in a) above.

Leading kVArh supplied during the period shall not be considered.

95KPLE020TAR
Commission File Number

Issued JUL 7 1994
Month Day Year

Effective AUG 2 1994
Month Day Year

By James Haines
James Haines, Executive Vice President

NOTED & FILED AUG 2 1994

THE STATE CORPORATION COMMISSION OF KANSAS

By Judith McConnell
Secretary

THE STATE CORPORATION COMMISSION OF KANSAS

INDEX NO__________

SCHEDULE LP

WESTERN RESOURCES, INC., dba KPL
(Name of Issuing Utility)

KANSAS - ALL RATE AREAS
(Territory to which schedule is applicable)

Replacing Schedule LP Sheet 3

which was filed August 3, 1992

No supplement or separate understanding shall modify the tariff as shown hereon.

6. Contract capacity shall be increased for customers who exceed the capacity specified in the Application for Electric Service two or more billing months during any 12 month period. The new contract capacity shall be equal to the greatest Highest Capacity established during the most recent 12 month period, unless customer and Company agree to a higher value.

7. Customers with a contract capacity of 1,000 kW or more, taking service at 34.5 kV or higher at the point of delivery, shall receive a discount of $0.20 per kVA of Billing Capacity for said delivery point.

8. Individual motor units, rated ten horsepower or greater, shall have starting equipment satisfactory to Company. Customer may contact a Company representative for assistance.

9. This rate schedule is subject to adjustments as provided in the Tax Adjustment - Electric schedule.

10. Service under this rate schedule is subject to Company's General Terms and Conditions, or successor documents, approved by the Kansas Corporation Commission.

11. All provisions of this rate schedule are subject to changes made by order of the regulatory authority having jurisdiction.

Commission File Number 95KPLE020TAR

Issued JUL 7 1994
Month Day Year

Effective AUG 2 1994
Month Day Year

By James Haines
James Haines, Executive Vice President

NOTED & FILED AUG 2 1994

THE STATE CORPORATION COMMISSION OF KANSAS

By mfd
Secretary

APPENDIX B: STOFEAS Output

FEASIBILITY REPORT ON STORAGE COOLING SYSTEMS

***** PROJECT DESCRIPTION *****

PROJECT TITLE: Bldg 7210 CEP
PROJECT LOCATION: Fort Riley, KS
PROJECT YEAR: FY 95
PROJECT NUMBER: N/A
CAT CODE: N/A
DESIGNER: C. Sohn
DATE: 05-09-1995

***** INPUT DATA *****

STUDY LIFE : 10yrs   DISCOUNT RATE : 4%

***** ELECTRIC UTILITY RATE STRUCTURE *****

--- STRAIGHT DEMAND ---

DEMAND CHARGE ($/kW): 4.05000
RATCHET PERCENTAGE (%): 80
NUMBER OF MONTHS (ACTUAL>RATCHET): 3
ENERGY COST ($/kWH): 0.02864

***** WINDOW SIZE FOR SHIFTED POWER PERCENTAGE ****

1- 3%	4- 6%	7- 9%	10- 12%	13- 15%	16- 18%	19- 21%	22- 24%
4 hr	6 hr	8 hr	8 hr	8 hr	8 hr	8 hr	8 hr

***** ELECTRIC UTILITY DATA *****

YEARLY PEAK DEMAND (kW): 34,110.00
UTILITY INCENTIVE ($/kW): 0.00

***** SYSTEM FIRST COST MODEL *****

NEW/REPLACEMENT ($/ton-hr)	RETROFIT ($/ton-hr)	UPPER LIMIT ($/ton-hr)
80	150	300

***** ECONOMY OF SCALE FOR FIRST COST *****

Small(<1000 t-h)	Medium	Large(>10kt-h)
1	.87	.77

***** SYSTEM O&M COST MODEL *****

PERCENT OF SYSTEM FIRST COST(%)
0

***** EXPECTED ANNUAL DEMAND CHARGE ESCALATION RATE *****

1-5th	6-10th	11-15th	16-20th	21-25th
0 %	0 %	0 %	0 %	0 %

***** New/Replacement *****

Shift (%)	Shifted (kW)	Storage Sz(ton-hr)	System 1st Cst(1000$)	1st yr Svns(1000$)	Payback Smpl	Payback Dsct	SIR	Net Svng (1000$)
1	341	1,364	95	14	6.7	9.0	1.1	10
2	682	2,729	190	28	6.7	9.0	1.1	20
3	1,023	4,093	285	42	6.7	9.0	1.1	29
4	1,364	8,186	570	56	10.1	**.*	0.7	-151
5	1,706	10,233	630	70	8.9	**.*	0.8	-107
6	2,047	12,280	756	85	8.9	**.*	0.8	-128
7	2,388	19,102	1,177	99	11.9	**.*	0.6	-443
8	2,729	21,830	1,345	113	11.9	**.*	0.6	-507
9	3,070	24,559	1,513	127	11.9	**.*	0.6	-570
10	3,411	27,288	1,681	141	11.9	**.*	0.6	-633
11	3,752	30,017	1,849	155	11.9	**.*	0.6	-697
12	4,093	32,746	2,017	169	11.9	**.*	0.6	-760
13	4,434	35,474	2,185	183	11.9	**.*	0.6	-823
14	4,775	38,203	2,353	197	11.9	**.*	0.6	-887
15	5,117	40,932	2,521	211	11.9	**.*	0.6	-950
16	5,458	43,661	2,690	225	11.9	**.*	0.6	-1,013
17	5,799	46,390	2,858	240	11.9	**.*	0.6	-1,077
18	6,140	49,118	3,026	254	11.9	**.*	0.6	-1,140
19	6,481	51,847	3,194	268	11.9	**.*	0.6	-1,203
20	6,822	54,576	3,362	282	11.9	**.*	0.6	-1,266
21	7,163	57,305	3,530	296	11.9	**.*	0.6	-1,330
22	7,504	60,034	3,698	310	11.9	**.*	0.6	-1,393
23	7,845	62,762	3,866	324	11.9	**.*	0.6	-1,456
24	8,186	65,491	4,034	338	11.9	**.*	0.6	-1,520
25	8,528	68,220	4,202	352	11.9	**.*	0.6	-1,583

* Annual O&M Cost is assumed to be 0% of system cost.

***** Retrofit Case *****

[illegible]ift (%)	Shifted (kW)	Storage Sz(ton-hr)	System 1st Cst(1000$)	1st yr Svns(1000$)	Payback Smpl	Payback Dsct	SIR	Net Svng (1000$)
1	341	1,364	178	14	12.6	**.*	0.6	-73
2	682	2,729	356	28	12.6	**.*	0.6	-147
3	1,023	4,093	534	42	12.6	**.*	0.6	-220
4	1,364	8,186	1,068	56	19.0	**.*	0.4	-649
5	1,706	10,233	1,182	70	16.8	**.*	0.4	-658
6	2,047	12,280	1,418	85	16.8	**.*	0.4	-790
7	2,388	19,102	2,206	99	22.4	**.*	0.3	-1,473
8	2,729	21,830	2,521	113	22.4	**.*	0.3	-1,683
9	3,070	24,559	2,837	127	22.4	**.*	0.3	-1,894
10	3,411	27,288	3,152	141	22.4	**.*	0.3	-2,104
11	3,752	30,017	3,467	155	22.4	**.*	0.3	-2,314
12	4,093	32,746	3,782	169	22.4	**.*	0.3	-2,525
13	4,434	35,474	4,097	183	22.4	**.*	0.3	-2,735
14	4,775	38,203	4,412	197	22.4	**.*	0.3	-2,946
15	5,117	40,932	4,728	211	22.4	**.*	0.3	-3,156
16	5,458	43,661	5,043	225	22.4	**.*	0.3	-3,367
17	5,799	46,390	5,358	240	22.4	**.*	0.3	-3,577
18	6,140	49,118	5,673	254	22.4	**.*	0.3	-3,787
19	6,481	51,847	5,988	268	22.4	**.*	0.3	-3,998
20	6,822	54,576	6,304	282	22.4	**.*	0.3	-4,208
21	7,163	57,305	6,619	296	22.4	**.*	0.3	-4,419
22	7,504	60,034	6,934	310	22.4	**.*	0.3	-4,629
[illegible]3	7,845	62,762	7,249	324	22.4	**.*	0.3	-4,839
[illegible]4	8,186	65,491	7,564	338	22.4	**.*	0.3	-5,050
25	8,528	68,220	7,879	352	22.4	**.*	0.3	-5,260

* Annual O&M Cost is assumed to be 0% of system cost.

***** Upper Limit Case *****

ft %)	Shifted (kW)	Storage Sz(ton-hr)	System 1st Cst(1000$)	1st yr Svns(1000$)	Payback Smpl	Payback Dsct	SIR	Net Svng (1000$)
1	341	1,364	356	14	25.3	**.*	0.3	-251
2	682	2,729	712	28	25.3	**.*	0.3	-503
3	1,023	4,093	1,068	42	25.3	**.*	0.3	-754
4	1,364	8,186	2,137	56	37.9	**.*	0.2	-1,718
5	1,706	10,233	2,364	70	33.6	**.*	0.2	-1,840
6	2,047	12,280	2,837	85	33.6	**.*	0.2	-2,208
7	2,388	19,102	4,412	99	44.7	**.*	0.2	-3,679
8	2,729	21,830	5,043	113	44.7	**.*	0.2	-4,205
9	3,070	24,559	5,673	127	44.7	**.*	0.2	-4,730
10	3,411	27,288	6,304	141	44.7	**.*	0.2	-5,256
11	3,752	30,017	6,934	155	44.7	**.*	0.2	-5,781
12	4,093	32,746	7,564	169	44.7	**.*	0.2	-6,307
13	4,434	35,474	8,195	183	44.7	**.*	0.2	-6,833
14	4,775	38,203	8,825	197	44.7	**.*	0.2	-7,358
15	5,117	40,932	9,455	211	44.7	**.*	0.2	-7,884
16	5,458	43,661	10,086	225	44.7	**.*	0.2	-8,409
17	5,799	46,390	10,716	240	44.7	**.*	0.2	-8,935
18	6,140	49,118	11,346	254	44.7	**.*	0.2	-9,460
19	6,481	51,847	11,977	268	44.7	**.*	0.2	-9,986
20	6,822	54,576	12,607	282	44.7	**.*	0.2	-10,512
21	7,163	57,305	13,237	296	44.7	**.*	0.2	-11,037
22	7,504	60,034	13,868	310	44.7	**.*	0.2	-11,563
3	7,845	62,762	14,498	324	44.7	**.*	0.2	-12,088
4	8,186	65,491	15,128	338	44.7	**.*	0.2	-12,614
25	8,528	68,220	15,759	352	44.7	**.*	0.2	-13,140

* Annual O&M Cost is assumed to be 0% of system cost.

APPENDIX C: Information Sheet for Building 5315

MORRIS HILL CHAPEL AND FAMILY LIFE CENTER
INFORMATION SHEET

Building Number: 5315

Total Square Feet: 19,748 SF

SANCTUARY AREA

Square Feet: 7,564 SF

Occupancy: Friday Service at 1200
Sunday Services at 0930 and 1115
Frequent Unit Training and Meetings

Air Conditioning & Ventilating Equipment:

81.5 Ton Chiller to Constant Volume Forced Air

Condition: ~~Fair to~~ Good

ADMINISTRATIVE AREA 1 - CHAPLAINS OFFICES

Square Feet: 2,638 SF

Occupancy: Mon thru Fri 0700-1800
Sunday Morning 0600-1400

Ventilating System: 7 Fan Coil Units

ADMINISTRATIVE AREA 2 - CLASSROOM AND LIBRARY

Square Feet: 3,040 SF

Occupancy: Occasional Training and Meetings
Sunday 0800-1600

Ventilating System: 14 Fan Coil Units

ADMINISTRATIVE AREA 3 - FAMILY LIFE CENTER

Square Feet: 3,852 SF

Occupancy: Mon thru Fri 0700-1800
Sunday Morning 0800-1200

Ventilating System: 12 Fan Coil Units

AIR CONDITIONING FOR ADMINISTRATIVE SECTIONS:

10 Ton Chiller to Fan Coil Units

Condition: Chiller - Poor to Fair
Fan Coil Units - Poor to Fair

NORMANDY CHAPEL RESERVATIONS

WEEKLY ACTIVITIES

SUNDAY

0845-1000 Charismatic Service
1100-1200 Protestant Service
1300-1500 Samoan Service
1700-1830 A.A. Together

SATURDAY

1630-1730 Charismatic Choir Rehearsal

WEDNESDAY

1130-1300 Bible Study

MONTHLY ACTIVITIES

1st Tuesday - 201st Family Support Group 1900
1st Wednesday - Charismatic Parish Council 1830
3rd Tuesday - HHC/MMC Family Support Group 1900
3rd Wednesday - Protestant Parish Council