USACERL Technical Report E-89/13
September 1989
Energy Storage Cooling Systems

US Army Corps
of Engineers
Construction Engineering
Research Laboratory

Market Potential of Storage Cooling Systems in the Army

by
Chang W. Sohn
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This report presents a quantitative estimate of market potential of storage cooling systems in terms of annual electrical utility cost savings. A simple methodology was developed to estimate the market potential based on the current electrical utility rates, system first costs, and expected payback periods. Sensitivity analysis was performed to examine the effect of system first costs on the total market potential. The sample group for this study consisted of 40 installations of the U.S. Army Forces Command (FORSCOM). The market potential for the whole Army was extrapolated from the results of the sample group. The results were presented according to three first cost scenarios: new construction/replacement application, retrofit application with realistic first costs, and retrofit application with upper limit first costs. Storage cooling system applications for new construction/replacement of cooling plants with payback under 5 years have the potential to save the Army $5 million annually.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704 0188 Exp Date Jun 30 1986

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): USACERL TR E-89/13	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: U.S. Army Construction Engr Research Laboratory; 6b OFFICE SYMBOL (If applicable): CECER-ES	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State, and ZIP Code): P.O. Box 4005, Champaign, IL 61824	7b ADDRESS (City, State, and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION: USAEHSC; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code): Fort Belvoir, VA 22060- 5580	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Market Potential of Storage Cooling Systems in the Army (Unclassified)

12 PERSONAL AUTHOR(S)
Sohn, Chang W.; Cler, Gerald L.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM ______ TO ______	1989, September	42

16 SUPPLEMENTARY NOTATION
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	storage cooling systems
13	01		air conditioning equipment
			market research

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL: Diane P. Mann	22b TELEPHONE (Include Area Code): (217)352-6511 (X223); 22c OFFICE SYMBOL: CECER-IM

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

FOREWORD

This study was carried out for the U.S. Army Engineering and Housing Support Center (USAEHSC), under the Facilities Investigative Studies program "Energy Storage Cooling Systems." The Technical Monitor was Mr. B. Wasserman, CEHSC-FU-P.

Appreciation is expressed to Mr. Peter Lequerique of USAEHSC for his contribution to collection of electrical utility bill data from Army installations.

This work was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. Gilbert Williamson is Chief of USACERL-ES. Dr. Sohn and Mr. Cler are Principal Investigators at USACERL.

COL Carl Magnell is Commander and Director of USACERL, and Dr. R. L Shaffer is Technical Director.

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1 INTRODUCTION

Background

The U.S. Department of Energy (DOE) has projected a potential shortfall of electricity generating capacity nationwide within the next decade.[1] This prediction was partially substantiated by the well-publicized brownout that occurred in New England in the summer of 1988.[2] Cold storage cooling system (SCS) technology is being actively promoted by the utility industry to alleviate the problem of insufficient generating capacity. In the private sector, SCS is a rapidly growing field in heating, ventilating, and air-conditioning (HVAC) technologies.

The U.S. Army Construction Engineering Research Laboratory (USACERL) recently surveyed energy storage technologies applicable to the Army.[3] The report showed that electrical demand management through a diurnal-cycle SCS is the most cost-effective method for reducing electrical utility costs of air-conditioning Army facilities. In addition, USACERL has developed a series of ice storage cooling system demonstration programs to accelerate introduction of SCS technology to the Army.[4] Although SCS is new technology, especially for Army engineers, it can be implemented following standard engineering practices. The USACERL demonstration programs are producing sample designs and project documentation that could be used until a general design guide is developed. However, because SCS technology is in an early stage of development, no reliable market assessment of its potential has been made.[5]

The importance for the Army of an accurate market assessment of SCS technology is twofold. It will express the potential benefit in economic terms, which should provide a strong incentive for Army engineers to rapidly implement SCS technology. At the same time, the results will guide policy makers in allocating adequate resources for SCS development and technology transfer. In addition, a market assessment could be used as an input for cost-benefit analysis of SCS technology for the Army.

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[1] U.S. DOE, Office of Energy Storage and Distribution, "Ensuring National Electrical Adequacy for the 1990s: The Need for Advanced Technologies," in *Proceedings Diurnal/Industrial Thermal Energy Storage Research Activities Review, Mississippi State University, March 9-10, 1988* (U.S. DOE, 1988).

[2] R. J. Samuelson, "The Coming Blackouts?" *Newsweek* (December 26, 1988).

[3] R. J. Kedl and C. W. Sohn, *Assessment of Storage Technologies for Army Facilities*, Technical Report E-86/04/ADA171513 (USACERL, May 1988).

[4] C. W. Sohn, *Storage Cooling Systems for Army Facilities*, International Thermal Storage Advisory Council (ITSAC) Technical Bulletin (ITSAC, November 1987).

[5] R. O. Weijo and D. R. Brown, *Estimating the Market Penetration of Residential Cool Storage Technology Using Economic Cost Modeling*, Batelle, PNL-6571, UC-202 (Pacific Northwest Laboratory [PNL], September 1988).

Objective

The objectives of this report are to present a quantitative estimate of market potential of SCS in the Army and provide a methodology for calculating the potential benefit of SCS. The findings will be of interest not only to Army engineers and facility managers but also to private sector elements such as electrical utilities, HVAC engineers, and equipment manufacturers.

Approach

Army installations under FORSCOM command were selected as a test group, and a methodology of market analysis was developed. Input data for the analysis included installation electrical utility consumption, power demand profile characteristics, electrical utility rate schedules, system first costs, and associated economic parameters. Results from the test group were extrapolated for Army facilities as a whole, thereby projecting total market potential of SCS within the Army. As an extension of the market studies, the study discusses current general issues in SCS and lists unique Army characteristics that affect SCS implementation.

Scope

This report presents a global market potential of SCS in the Army. It is not intended to project the market potential for an individual installation, although the methodology can be used to evaluate the SCS market potential of an individual installation. Also, implementation of the SCS technology, such as design, construction, operation, maintenance, and performance of SCS, is not the subject of this report. That topic is addressed in USACERL's on-going diurnal ice storage cooling systems demonstration program and its reports.[6]

Mode of Technology Transfer

It is recommended that the information in this report be included in an Engineering Technical Note (ETN) on storage cooling systems that will also encompass SCS construction and operation.

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[6]C. W. Sohn and J. J. Tomlinson, *Design and Storage of an Ice-in-Tank Ice Storage Cooling System for the PX Building at Fort Stewart, GA*, Technical Report E-88/07/ADA197925 (USACERL, July 1988).

2 PARAMETERS OF MARKET POTENTIAL ANALYSIS

This report measures the market potential of SCS in terms of annual cost savings in air-conditioning for a number of predetermined payback periods (PBP). The critical factors in determining PBP are annual savings and system first costs. This report does not describe SCS technologies in detail; that information is readily available elsewhere.[7] However, brief descriptions of SCS will be given as needed for general discussion during the analysis.

Electrical Utility Cost Savings

Storage cooling systems reduce electrical utility costs of air-conditioning Army installations. The best way to illustrate how the savings can be realized is to examine a typical electrical utility bill. Each of the more than 3000 electrical utilities in the United States[8] has its own rate structure, with various residential, commercial, and industrial categories. Therefore, generalizing results from one Army installation to another would be difficult. However, most utility rate structures are based on two quantities: energy consumed (in kWh) and peak power demand (in kW). Fort Stewart, GA, was selected for illustration.

Table 1 summarizes Fort Stewart's 1986 monthly electrical utility bills. Note that billing demand is higher than actual demand from November to May. The trend is also shown in Figure 1. The demand charge constitutes approximately 37 percent of the total electrical cost. For installations Army-wide, the demand portion of the total electrical utility bill ranges from 30 to 50 percent. It can be as high as 62 percent of the total bill. SCS reduces the billing demand by shifting power consumption from onpeak to offpeak periods.

SCS has a potential to reduce the amount of energy (kWh) required in air-conditioning through cold air delivery systems.[9] But the immediate savings in air-conditioning costs are from reducing billing demand (kW). Demand charges are the utility's way of passing generating-capacity costs to the user. Demand charges are levied in two forms: the time-of-use (TOU) rate and/or straight demand ($/kW) based on the peak level of power drawn by the user. Most electric companies divide a day into onpeak and offpeak periods; for example, if 1000 to 2000 hours is onpeak, the rest of the day is offpeak. The exact time interval varies depending on the local environment. Under the TOU rate structure, the cost of energy ($/kWh) is cheaper during offpeak hours. Under straight demand, the charge is based on the highest level of power demand during a billing period (typically a month) or a fixed fraction of the highest level established during the preceding 11 month period, whichever is greater, or on the prearranged contract demand. If the billing demand is based on a fixed fraction of the highest demand during the preceding 11 months, it is called a ratchet schedule. For example,

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[7]C. W. Sohn and J. J. Tomlinson; G. A. Reeves, *Commercial Cool Storage Design Guide*, Electric Power Research Institute (EPRI), EM-3981, Project 2036-3, Final Report (EPRI, May 1985); J. R. Hull, R. L. Cole, and A. B. Hull, *Energy Storage Criteria Handbook*, CR 82.034 (Naval Civil Engineering Laboratory, October 1982).

[8]*Electrical World, Directory of Electrical Utilities 1987-1988* (McGraw Hill, 1986).

[9]C. E. Dorgan, "Low Temperature Air Distribution: Economics, Field Evaluation, Designs," in *Seminar Proceedings: Commercial Cool Storage State of the Art*, EPRI EM-5454-SR (EPRI, October 1987).

Table 1

1986 Monthly Electrical Utility Bills for Fort Stewart, GA

Date Read	Actual Demand (kW)	Billing Demand (kW)	Kilowatt Hours (kWh)	Fuel Charge ($)	Bill Amount ($)	Demand Charge ($)	Billing Hours
01 24	17510	24697	9676800	183937	435674	169455	391
02 24	19680	24697	9542400	181382	431973	169455	386
03 24	17856	24697	8505600	161674	403904	169455	344
04 23	17500	24697	8697600	165324	408767	169455	352
05 23	23155	24697	10809600	205469	467605	169455	437
06 24	26112	26112	14342400	272620	574377	178922	543
07 24	26918	26918	14630400	267049	576720	184314	543
08 25	27379	27379	15436800	281768	601324	187398	563
09 24	27360	27360	12614400	230521	5[illegible]5615	187271	461
10 23	26419	26010	11750400	214480	493381	178239	452
11 20	19085	26010	8659200	158056	410441	178239	333
12 22	17587	26010	9696800	176631	437489	178239	392
Total	266561	309284	134362400	2498910	5767271	2119900	

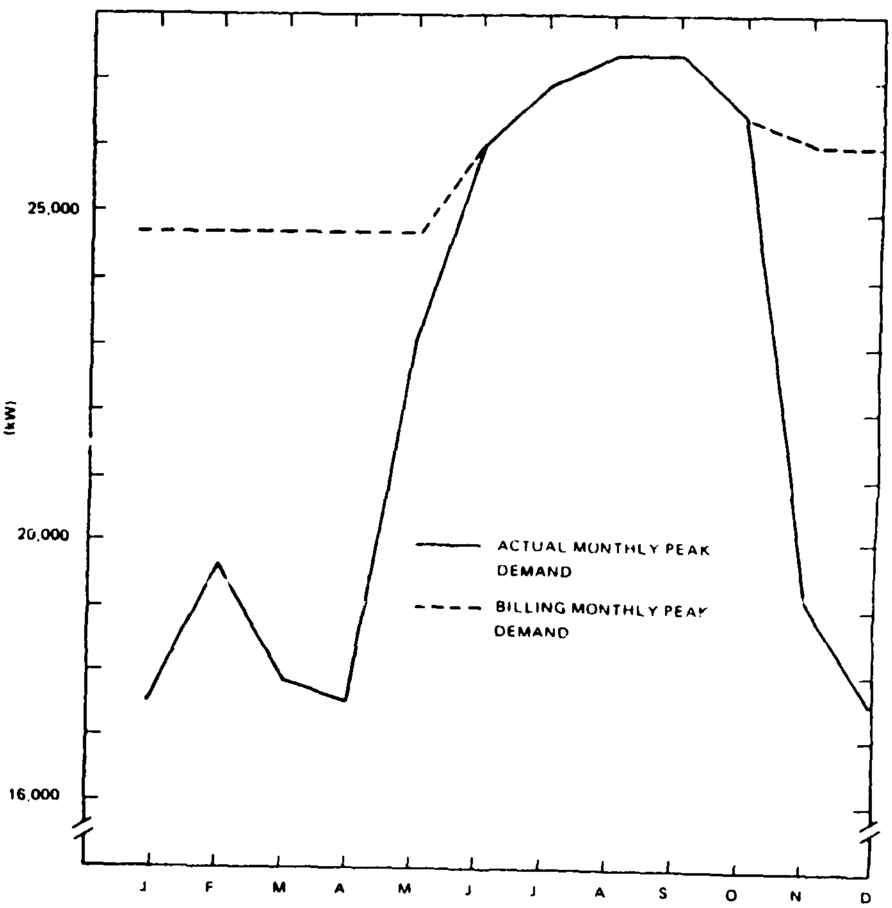

Figure 1. 1986 monthly actual and billing demand of Fort Stewart.

Fort Stewart is subjected to a 95 percent ratchet. Although Fort Stewart's actual demand in December 1986 is 17,587 kW, the billing demand for that month would be 26,010 kW, 95 percent of the peak (27,379 kW) established in August 1986.

Figure 2 illustrates Fort Stewart's power demand profile for the day it established the 1984 yearly peak. Demand that day fluctuated from 15,100 kW at 0430 hours to 25,200 kW at 1530 hours. The peak occurred when the air conditioners were working at full capacity. Chilled water or ice could have been produced and stored during the previous night, when the demand was low. Cooling the facility with stored refrigeration would have allowed the air conditioners to be shut off during that peak period. This would have reduced the peak demand, which in turn would have reduced the billing demand for the next 11 months. The actual monthly savings for Fort Stewart can be calculated for the cooling months by multiplying the demand shifted (kW) by the demand charge ($6.69) and taking 95 percent of this amount for the noncooling months.

System Costs

The cost of a storage cooling system, which is an important factor in determining its economic performance, is typically expressed in terms of a dollar amount per storage capacity expressed as Ton-hours ($/T-h). Due to SCS's relatively early stage of development, its cost is not firmly established yet; a significant gap between projected costs and actual expenditures is not uncommon.[10] SCS costs also depend on whether the system is for new construction, a replacement application, or retrofit application requiring a new condensing unit.

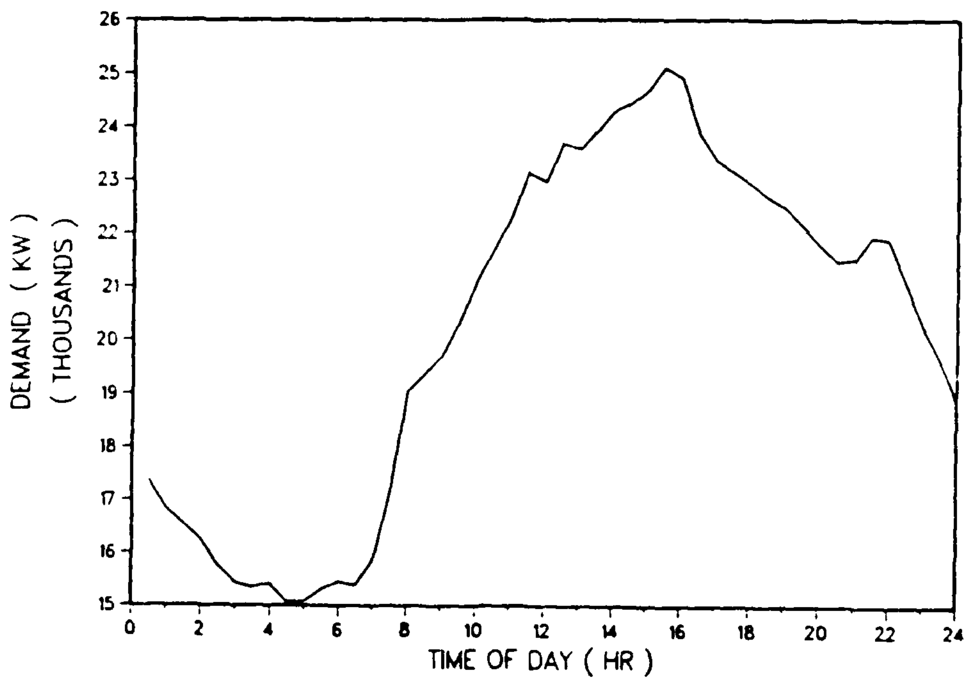

Figure 2. Hourly demand profile of Fort Stewart on 20 June 1984.

[10]C. W. Sohn and J. J. Tomlinson.

New Construction

SCS cost in this study is the differential cost between a conventional cooling system and an SCS serving the same building. For new construction, the total cost of an SCS employing a low-temperature air system could be the same as or less than that of a conventional cooling system.[11] (In this case, the payback period [PBP] of the SCS is zero; that is, the system pays back from the first year.) However, for new construction with a 40 to 42 °F (4.4 to 5.5 °C) chilled water supply, the differential cost of SCS is due to the storage tank and the associated labor. The cost situation is similar when a conventional cooling plant is replaced with an SCS. In both cases, the cost of equipment for ice making/chilled water production is offset by the cost of a conventional chiller. A rule of thumb for estimating the SCS cost is one-third each for the condensing unit, the storage tank, and installation. For example, an EPRI report divided the cost of an ice storage cooling system into 65 percent for major equipment and 35 percent for installation cost (24 percent material, 7 percent labor, and 4 percent miscellaneous).[12]

Figure 3 shows storage tank cost as a function of storage capacity for an ice-on-coil system (based on a manufacturer's cost quotation). The cost/storage capacity relationship can be approximated by

$$P = 40T + 5300 \qquad \text{[Eq 1]}$$

where P is the tank price in dollars and T is the storage capacity in Ton-hours.

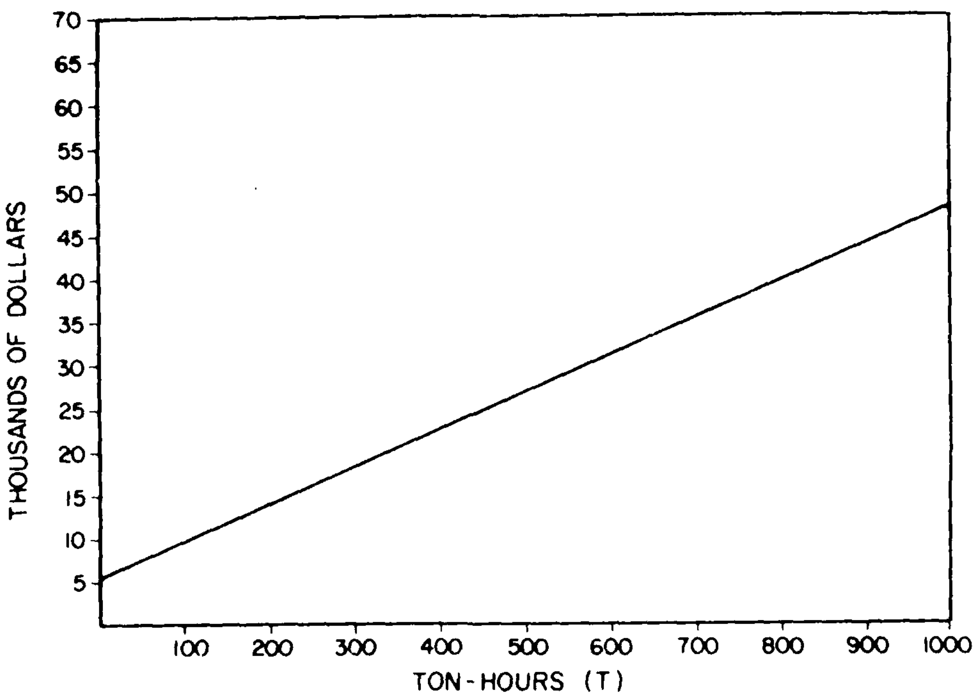

Figure 3. Cost of storage tank as function of storage capacity for ice-on-coil diurnal ice storage cooling system.

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[11] C. E. Dorgan.
[12] G. A. Reeves.

Most electrical utility companies are interested in SCS as a means of load management by end users. Figure 4 compares the costs of an ice storage SCS and a conventional cooling system. The comparison was used by San Diego Gas and Electric (SDG&E) to estimate the amount of rebate.[13] The curve represents the rebate program's maximum allowance per Ton-hour of storage. It reflects the installed costs of the storage tank, condensing units, and associated piping. According to SDG&E's estimate, the differential cost (excluding a smaller system affected by the economy of scale) is about $70/T-h.

Note that SDG&E's estimated differential cost, $70/T-h, is roughly twice the cost of the storage tank, $40/T-h, shown in Equation 1; the SDG&E cost includes installation charges. Note also that the rule of thumb in SCS cost estimate (one-third for tank, condensing unit, and installation) is roughly corroborated in this case ($40/T-h for tank and $30/T-h for installation). In this report, the differential cost for SCS in new construction will be set at $80/T-h, which should be a conservative estimate.

Cooling System Replacement

If an existing cooling system needs replacement, a new condensing unit must be purchased. Thus, the cost differential between an SCS and a conventional unit will be the same as for a new construction. The only extra cost for the SCS will be for the storage tank (cost of a storage tank can be estimated using Equation 1) and installation. The differential cost for SCS in replacement application is also assumed to be $80/T-h.

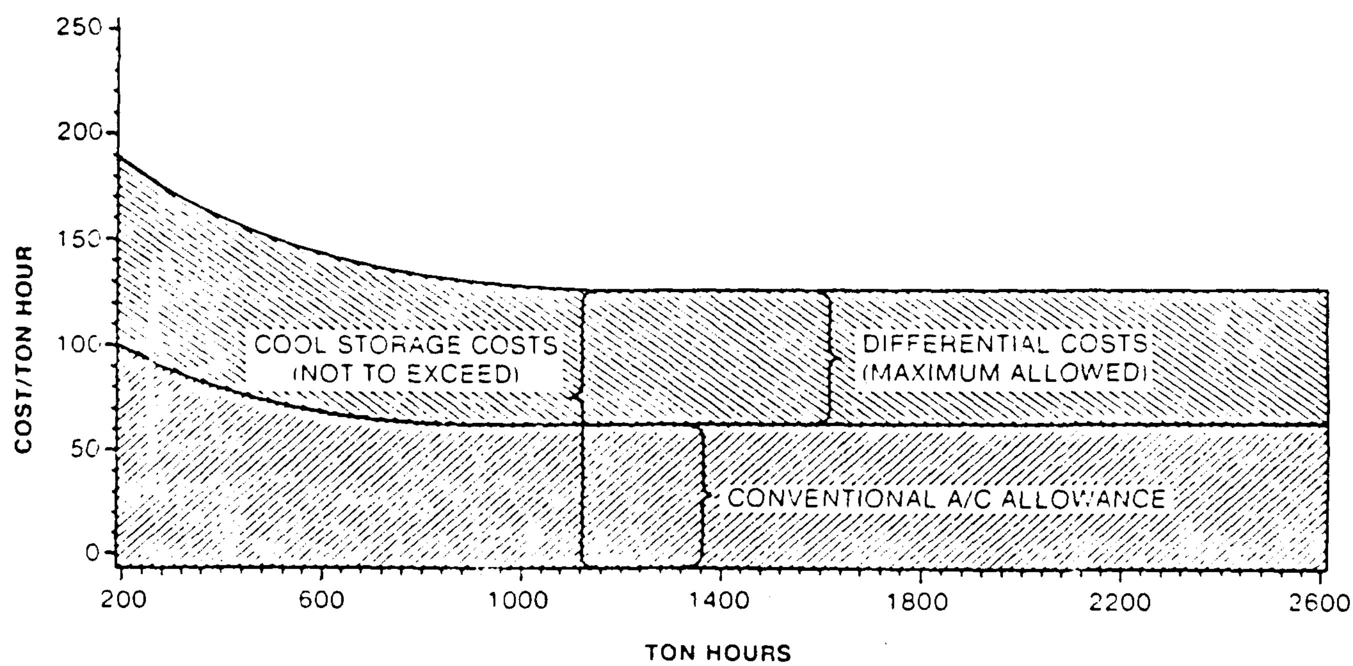

Figure 4. SCS system costs as a function of capacity.

[13] *Thermal Energy Storage, Inducement Program for Commercial Space Cooling* (San Diego Gas & Electric, November 1983).

Retrofit Application

Retrofit means adding an SCS to an existing cooling system which does not require replacement. A typical application would be adding an SCS to a central cooling plant. The SCS would provide cooling during the short period (approximately 2 to 4 hours) when the installation is experiencing peak demand. The cost of a retrofit application includes the purchase of a new condensing unit, storage tanks, and labor charges for system installation.

Methods for computing total system cost are not yet firmly established. Studies have identified paid-for system costs in the range of $100 to $300 per Ton-hour.[14] In this report, two system costs for retrofit application will be used: $150/T-h (realistic scenario) and $300/T-h (upper limit scenario).

Other Economic Parameters

Other economic parameters for an SCS cost analysis are system maintenance costs, the inflation rate of demand charges, and a discount rate to convert future savings into current dollars. SCS is expected to require the same maintenance service as a conventional cooling system, so the differential cost for SCS maintenance is zero.

This study is considering a relatively short-term payback period and presents payback scenarios of 3, 5, and 10 years. It is thus justifiable to assume that the inflation rate of demand charges will be equal to the discount rate; that is, for a short-term analysis the results from a simple payback analysis and those with a discounted payback should agree quite reasonably.

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[14] C. W. Sohn and J. J. Tomlinson; G. A. Reeves; *Case Studies, STEP Storage of Thermal Energy for the Peak* (Arizona Public Service Company, 1987); H. N. Hersh, *Current Trends in Commercial Cool Storage*, EPRI EM-4125, Project 2036-13, Final Report (EPRI, July 1985); M. A. Piette, E. Wyatt, and J. Harris, *Technology Assessment: Thermal Cool Storage in Commercial Buildings*, LBL-25521, UC-95d (Lawrence Berkeley Laboratory, January 1988).

3 ANALYSIS OF ARMY SCS MARKET POTENTIAL

Method of Analysis

The payback period of an SCS has been calculated based on the initial differential construction cost and expected annual savings. The operation and maintenance costs of an SCS are assumed to be the same as those of a conventional cooling system.

The payback period is calculated by

$$Y = C/S \qquad \text{[Eq 2]}$$

where Y = payback period (yrs)
C = initial differential system cost ($)
S = annual savings ($/yr).

Annual Savings

The specific annual savings (S/P) by SCS in a straight demand schedule can be calculated by:

$$S/P = D_1 \times F_1 \qquad \text{[Eq 3]}$$

where S = annual savings in demand charge by SCS ($/yr)
P = peak power reduced by SCS (kW)
D_1 = demand charge ($/kW)
F_1 = annual ratchet factor (1/year).

The annual ratchet factor (F_1) is a number which accounts for the ratchet clause in the electrical rate structure. For example: "A demand charge will be $10/kW. The billing demand shall be the greater between the maximum demand during the billing month and 80 percent of the highest demand occurring during the 11 preceding months." During the 4 summer months (June through September), typically, the billing month demand exceeds 80 percent of the highest demand among the preceding 11 months. Thus the annual ratchet factor is

$$\begin{aligned} F &= 1 \times 4 \text{ (summer months)} + 0.8 \times 8 \text{ (nonsummer months)} \\ &= 10.4. \qquad \text{[Eq 4]} \end{aligned}$$

For the example, then, the specific annual savings (for each shifted kW of peak power) is calculated to be

$$\begin{aligned} S/P &= D_1 \times F_1 \\ &= \$10/kW \times 10.4/yr \\ &= \$104/yr\text{-}kW. \end{aligned}$$

Note that the annual ratchet factor (F_1) in a straight demand schedule is a function of ratchet percentage and the number of months the ratchet is in effect.

For a rate schedule other than the straight demand, calculation of specific annual savings (S/P) is not so simple. It should be calculated case by case following the given rate structure. As an example, consider the following case, with a time-of-use (TOU) rate along with demand charges. Assume a demand charge of \$15/kW and no ratchet; onpeak energy charge is \$0.05/kWh, and offpeak is \$0.03/kWh.

An examination of total installation power demand profile (Figure 2) shows that a 4-hour window can capture the demand peak effectively. Reduction of the demand portion due to TOU rate per each kW for a period of N days is given by,

$$D_2 = d \times W \times N \qquad \text{[Eq 5]}$$

where D_2 = monthly savings by SCS due to TOU rate (\$/kW)
d = cost differential per kWh between onpeak and offpeak periods (\$/kWh)
W = size of window during which the demand is shifted (hr/day)
N = number of days in a month benefited by demand shift (day).

The quantity D_2 corresponds to the monthly demand charge in a straight demand rate schedule. The effective annual ratchet factor for this case is the number of months SCS is in service. According to Army regulations, it would typically be the 5 months from mid-May to mid-October.

$$F_1 = 5/\text{yr}$$
$$F_2 = 5/\text{yr} \qquad \text{[Eq 6]}$$

where F_1 = annual ratchet factor due to straight demand
F_2 = annual ratchet factor due to TOU rate.

Therefore, S/P will be given by

$$\begin{aligned} S/P &= D \times F \\ &= (D_1 \times F_1) + (D_2 \times F_2) \end{aligned} \qquad \text{[Eq 7]}$$

where D_1 = demand charge (\$/kW) due to straight demand
D_2 = implicit demand charge (\$/kW) due to TOU schedule.

For the above example

$$D_1 = 15 \text{ (\$/kW)},$$

and

$$\begin{aligned} D_2 &= d \times W \times N \\ &= \$0.02/\text{kWh} \times 4 \text{ hr/day} \times 22 \text{ days} \\ &= \$1.76/\text{kW}. \end{aligned}$$

Therefore

$$\begin{aligned} S/P &= (15 \times 5) + (1.76 \times 5) \\ &= \$83.80/\text{kW}. \end{aligned}$$

Annual Ratchet Factor

The critical factors determining the annual savings by SCS are the monthly demand charge and the ratchet schedule. The method of calculating the annual ratchet factor for the cases of straight demand and straight demand with time-of-use rate schedule was discussed in the previous section. For a more complicated rate structure, derivation of the factor may have to be customized. However, the basic idea of the annual ratchet factor is to normalize the explicit and/or implicit ratchet charge schedule in terms of the straight demand charge and the number of months when the demand charge clause stays in effect.

Differential System Cost

To calculate the payback period, the differential construction cost is taken from chapter 2. The initial differential system construction cost, C, is as follows: for a new construction or replacement work

$$C = 80(\$/\text{T-h});$$

for a retrofit application

$$C = 150(\$/\text{T-h}) \text{ (realistic scenario)},$$

and

$$C = 300(\$/\text{T-h}) \text{ (upper limit scenario)}.$$

Cost of Demand Shifting

The size of SCS (in T-h) to achieve a given percentage of reduction in peak demand is calculated as follows. Let Q be the annual peak power demand for an installation. The intent is to shift r percent of the peak demand to offpeak periods. The amount of shifted energy in kWh (K) for this application is always less than $(r_1/100) \times Q \times W_1$, where W_1 is the window of shift (in hours) (see Figure 5).

$$K <= (r_1/100) \times Q \times W_1 \qquad \text{[Eq 8]}$$

In an extreme case, when the demand profile over the window W_1 is a perfect rectangular shape, the shifted energy in kWh will be equal to $(r_1/100) \times Q \times W_1$.

To reduce the peak by another r_2 percent, the time window required would be W_2, which will probably be longer than W_1. As the reduction of peak demand increases, the time window also increases, which increases the size of the storage capacity, which in turn increases the cost of shifting power from the onpeak period. The storage size can be summarized as

$$K = Q \times \sum_i (r_i/100 \times W_i). \qquad \text{[Eq 9]}$$

For two equal reductions in demand, the above equation reduces to

$$K <= Q \times (r/100) \times (W_1 + W_2). \qquad \text{[Eq 10]}$$

The equal sign in Equation 10 applies to an extreme case wherein the demand profile over W_1 and W_2 is two perfect rectangles (Figure 5).

Examination of peak demand profiles from a number of installations shows that a 4-hour window will generally be sufficient to cover the first 5 percent of demand peak. In

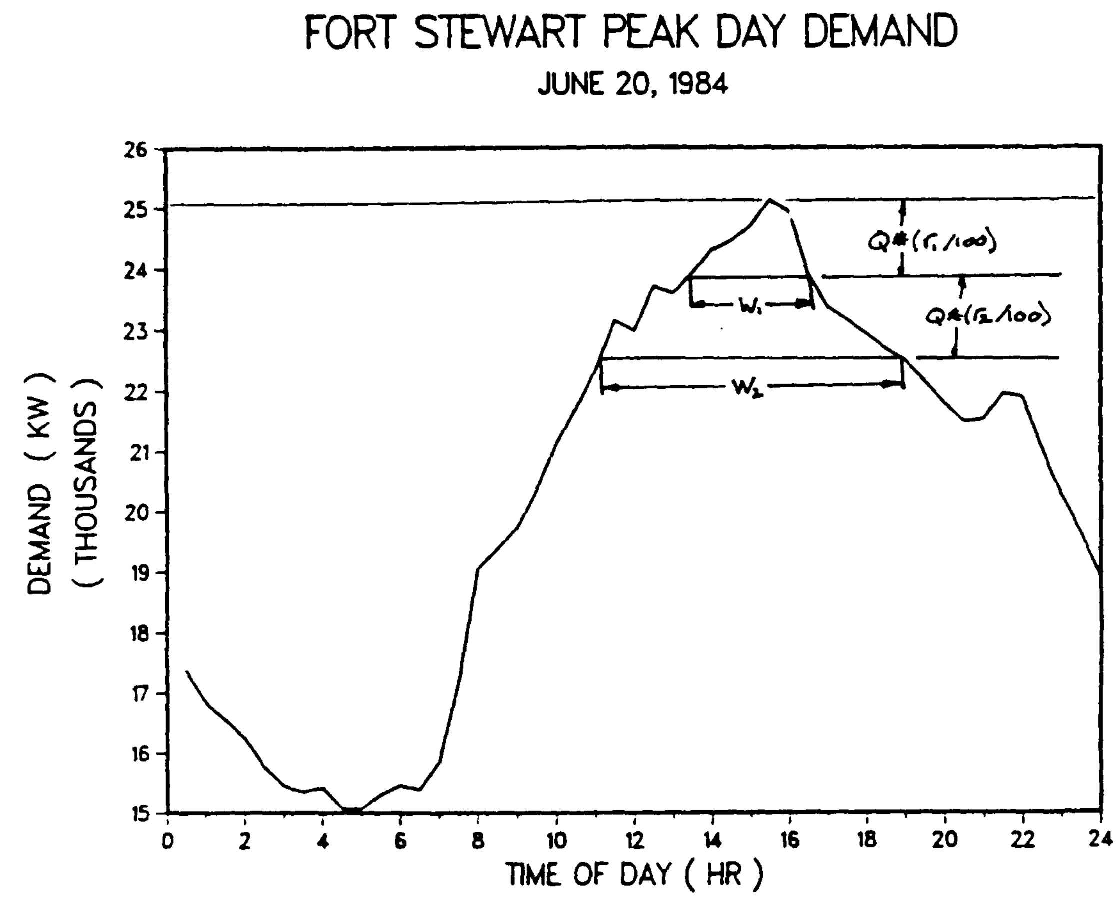

Figure 5. Daily peak demand profile.

Figure 5, 4 hours of W_1 covers 1,300 kW of peak demand, which is more than 5 percent of the total peak. Similarly, an 8-hour window is sufficient to cover the next 5 percent of demand (10 percent of the total demand). Therefore, a 4-hour window, W_1, and an 8-hour window, W_2, will be assumed for calculating the required SCS storage capacity to shift 5 percent and 10 percent, respectively, of the total peak demand.

Note that the unit of the amount of shifted energy (K) is in kWh, not in T-h, which is the accepted unit of storage capacity (T) of SCS. Both K and T represent units of energy. The conversion between K and T is given by the following analysis.

For a conventional cooling system, the power consumption factor of a typical centrifugal chiller is about 0.7 kW per Ton of cooling. If the SCS is a chilled water storage cooling system, the evaporator temperature of the chilled water generator (typically a centrifugal chiller) is the same as that for a conventional cooling system. However, if an ice storage cooling system is used as the SCS, the evaporator temperature must be about 20 °F (-6.6 °C), lower than that of a conventional chiller. The lower evaporator temperature implies the suction temperature of the ice maker to be about 20 °F (-6.6 °C). Due to the lower suction temperature, the volumetric efficiency of the compressor will be reduced, thereby resulting in a derating of the compressor. Also, due to the thermodynamic characteristics of the enthalpy-pressure relationship of the refrigerant, the lower suction temperature yields a lower coefficient of performance in the refrigeration cycle. The reported power consumption factor for ice SCS is a little over 1.0 kW/Ton.[15] For this study, the power consumption factor for an SCS is set at 1.0 kW/Ton. Therefore, a conversion factor (f) for the required storage capacity (T) of a SCS from the amount of shifted energy (K) is

$$f = 1.0(\text{Ton/kW}). \qquad \text{[Eq 8]}$$

Thus

$$T = f \times K(T\text{-}h). \qquad \text{[Eq 9]}$$

Incentives for Demand Shifting

A number of electrical utility companies are offering incentives to their customers to install storage cooling systems as a means of shifting the electrical demand from onpeak to offpeak periods. The motivation behind the incentive program is to improve the utility power factor, thereby achieving higher power generation efficiency and reducing the need for additional power plants to meet short-period peak power demand. As of August 1988, at least 27 utilities are offering incentives,[16] and this number is increasing. The incentive ranges from $60 to $500 per kW shifted from onpeak to offpeak periods. Typically, the utility requires that the user shift at least 8 hours of power from the onpeak period.

An incentive can reduce the user's initial construction cost and shorten the payback period significantly. However, the incentive may not be available for an SCS that shifts demand less than 8 hours. There may be a conflict in design of SCS storage capacity. For a given amount of power to be shifted, a shorter period of shift (say less than 8 hours) requires a smaller storage capacity. Although a smaller system has lower initial construction costs, it may not qualify for the incentive program requirement. Therefore, it may be advantageous to increase the window of shift at the expense of increased storage capacity to qualify for the incentive rebate. Whether this approach is cost-effective depends on the demands of the individual project and the specifications of the given incentive program. This report considers a 4-hour and an 8-hour demand shift windows, which shift 5 percent and 10 percent, respectively, of the total base demand. Only the analyses based on an 8-hour window included the contribution of a rebate program.

Data Collection/Reduction

The U.S. Army has 206 major installations and over 2000 subactivities.[17] An extensive effort would be required to examine every installation's power consumption data, utility rate schedule, and paid-for utility bills. Instead, one major Army command

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[15] "Chapter 46: Thermal Storage," in *ASHRAE Handbook HVAC Systems and Applications* (American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1987).

[16] *Utility Inducement Programs for Cool Storage*, ITSAC Technical Bulletin (ITSAC, August 1988).

[17] *Facilities Engineering and Housing Annual Summary of Operations: Volume 1: Executive Summary* (Department of the Army, Office of the Assistant Chief of Engineers, 1987).

(MACOM) was selected for a detailed study. The results from this sample group were extrapolated to yield the total market potential of SCS technology within the Army.

The U.S. Army Forces Command (FORSCOM) was selected as a representative sample group. Copies of electric service invoices for the summer of 1987 were collected from 40 sites of 22 Army installations under FORSCOM jurisdiction. The coordination and assistance were provided by the Utilities Contracts Office, U.S. Army Facilities Engineering Support Agency, and the Resources Division, FORSCOM. The rate structure and peak power demand for each installation were obtained from the electrical utility companies serving those installations. Table 2 summarizes the collected raw data.

The next step was to calculate the effective demand charge and the annual ratchet factor for each installation according to the applicable electrical utility rate schedule. The annual ratchet factor includes the straight demand charges as well as the implicit contribution from the applicable TOU rates. The results are presented in the Demand Charge and Ratchet Factor columns in Table 3.

Information on the amount of power shifted from onpeak to offpeak periods is needed for calculating the total annual electrical cost savings of each installation by the SCS. For a typical installation, it is estimated that about one-third of the peak demand is attributed to air-conditioning. Reduction of peak demand by 5 percent and 10 percent at an installation corresponds to 15 percent and 30 percent, respectively, of the air-conditioning loads met by the SCSs.

The cost savings will also vary depending on the desired payback period. An investment for a 3-year payback will be desirable not only for the military but also for private industry. A 5-year PBP will also be reasonably acceptable. But payback of more than 10 years is considered marginal. In this study, the cost savings are determined for each of these payback periods.

Spread Sheet Analysis

The potential utility cost savings from SCS for each installation listed in Table 2 were calculated according to the method described in *Method of Analyses*, with the data shown in *Data Collection/Reduction*. A computer spread sheet was used to perform the analysis based on the normalized demand charge schedule (Table 3) with various scenarios of shifted peak demands and system costs. A detailed calculation for Fort Stewart, GA, is discussed as an example.

Sample Illustration

Fort Stewart is served by the Georgia Power Company. The monthly demand charge is $6.69 for each kilowatt of demand. The billing demand is the higher of (1) the highest demand during the billing period or (2) 95 percent of the highest demand during the 11 preceding months. The peak demand for 1986 was 29,203 kW. Demand is over the ratchet for 5 months.

Table 2

Raw Data From 22 FORSCOM Installations

	Post	State	Power Company	Pk Dem kW	Onpeak Elec $/kWh	On-Off Pk difference $/kWh	Ratchet	Demand Charge $/kW
1	Ft Bragg MV	NC	CP&L	8222	0.030	0.000	NO	9.19
2	Ft Bragg #1	NC	CP&L	34214	0.025	0.005	NO	15.73
3	Ft Bragg #2	NC	CP&L	12545	0.030	0.000	NO	8.69
4	Ft Bragg #3	NC	CP&L	19596	0.030	0.000	NO	8.69
5	Ft Campbell	KY	Pennyrile	2500	0.031	0.000	YES	11.14
6	Ft Campbell	KY	TVA	42100	0.220	0.000	YES	12.08
7	Ft Carson	CO	C Springs	15973	0.025	0.000	YES	5.76
8	Ft Devens	MA	New Eng P	9603	0.029	0.000	YES	12.34
9	Ft Devens	MA	Boston Ed	2377	0.029	0.025	NO	15.02
10	Ft Drum	NY	Niag-M P	5800	0.050	0.014	YES	4.87
11	Ft Drum	NY	Niag-M P	1080	0.042	0.000	YES	5.50
12	Ft Gillem	GA	Georgia P	2011	0.039	0.000	YES	7.38
13	Ft Hood	TX	Texas P&L	52881	0.005	0.000	YES	4.05
14	Ft Indiantown Gap	PA	Met Ed	3672	0.039	0.009	YES	9.34
15	Ft Irwin	CA	S Cal Ed	9120	0.138	0.079	NO	3.00
16	Ft Lewis Cen Sup	WA	Tacoma	15149	0.010	0.000	NO	1.84
17	Ft Lewis Mad Sub	WA	Tacoma	5301	0.010	0.000	NO	1.84
18	Ft Lewis S Sub	WA	Tacoma	13128	0.010	0.000	NO	1.84
19	Ft McCoy	WI	NorthSP	2981	0.032	0.009	YES	4.41
20	Ft McPherson	GA	Georgia P	2532	0.039	0.000	YES	7.38
21	Ft Meade	MD	Balt G&E	68861	0.033	0.020	NO	9.81
22	Ft Ord Bay Park	CA	PG&E	453	0.071	0.033	NO	9.37
23	Ft Ord Main Gar	CA	PG&E	13104	0.071	0.033	NO	9.37
24	Ft Ord N Bay Pk	CA	PG&E	474	0.071	0.033	NO	9.37
25	Ft Ord Pres Mon	CA	PG&E	1724	0.071	0.033	NO	9.37
26	Ft Ord (Hunter)	CA	PG&E	2475	0.071	0.033	NO	9.37
27	Ft Pickett	VA	VA Power	2880	0.022	0.000	YES	10.78
28	Ft Polk	LA	LA P&L	34200	0.025	0.000	NO	2.90
29	Ft Polk N Post	LA	LA P&L	3360	0.025	0.000	NO	2.90
30	Ft Riley 1	KS	KPL	29301	0.022	0.000	YES	3.90
31	Ft Riley 2	KS	KPL	7785	0.022	0.000	YES	3.90
32	Ft Riley 3	KS	KPL	750	0.022	0.000	YES	3.90
33	Ft Sheridan	IL	Comm Ed	5224	0.058	0.031	NO	13.34
34	Ft Stewart	GA	Georgia P	29203	0.031	0.000	YES	6.69
35	Hunter Airfield	GA	SavanElec	8897	0.019	0.000	YES	3.25
36	Letterman Hospital	CA	PG&E	8366	0.071	0.033	NO	9.37
37	N Ft Hood	TX	TU Elec	1892	0.005	0.000	YES	5.19
38	U.S.Army Supp Det	PA	Duquesne	1056	0.032	0.000	YES	9.24
39	W Ft Hood	TX	Texas P&L	13987	0.028	0.000	YES	4.05
40	Yakima Firing Cen	WA	Pac Power	1248	0.037	0.000	NO	2.02

Table 3

Normalized Demand Charges and Ratchet Schedules

	Post	State	Power Company	Pk Dem kW	Demand Charge $/kW D_1	Demand Charge $/kW D_2	Annual Ratchet Factor F_1	Annual Ratchet Factor F_2	Annual Cost $/Pk kW
1	Ft Bragg MV	NC	CP&L	8222	9.19	0.00	5.00	0.00	45.95
2	Ft Bragg #1	NC	CP&L	34214	15.73	0.44	5.00	5.00	80.85
3	Ft Bragg #2	NC	CP&L	12545	8.69	0.00	5.00	0.00	43.45
4	Ft Bragg #3	NC	CP&L	19596	8.69	0.00	5.00	0.00	43.45
5	Ft Campbell	KY	TVA	42100	12.08	0.00	8.50	0.00	102.68
6	Ft Campbell	KY	Pennyrile	2500	11.14	0.00	10.95	0.00	121.98
7	Ft Carson	CO	C Springs	15973	5.76	0.00	9.55	0.00	55.01
8	Ft Devens	MA	New Eng P	9603	12.34	0.00	9.90	0.00	122.17
9	Ft Devens	MA	Boston Ed	2377	15.02	2.20	5.00	5.00	86.10
10	Ft Drum	NY	Niag-M P	5800	4.87	1.23	8.50	5.00	47.56
11	Ft Drum	NY	Niag-M P	1080	5.50	0.00	8.50	0.00	46.75
12	Ft Gillem	GA	Georgia P	2011	7.38	0.00	11.65	0.00	85.98
13	Ft Hood	TX	Texas P&L	52881	4.05	0.00	10.60	0.00	42.93
14	Ft Indiantown Gap	PA	Met Ed	3672	9.34	0.79	8.50	5.00	83.35
15	Ft Irwin	CA	S Cal Ed	9120	3.00	6.95	5.00	5.00	49.76
16	Ft Lewis Cen Sup	WA	Tacoma	15149	1.84	0.00	5.00	0.00	9.20
17	Ft Lewis Mad Sub	WA	Tacoma	5301	1.84	0.00	5.00	0.00	9.20
18	Ft Lewis S Sub	WA	Tacoma	13128	1.84	0.00	5.00	0.00	9.20
19	Ft McCoy	WI	NorthSP	2981	4.41	0.79	12.00	5.00	56.88
20	Ft McPherson	GA	Georgia P	2532	7.38	0.00	11.65	0.00	85.98
21	Ft Meade	MD	Balt G&E	68861	9.81	1.76	5.00	5.00	57.85
22	Ft Ord Bay Park	CA	PG&E	453	9.37	2.90	5.00	5.00	61.37
23	Ft Ord Main Gar	CA	PG&E	13104	9.37	2.90	5.00	5.00	61.37
24	Ft Ord N Bay Pk	CA	PG&E	474	9.37	2.90	5.00	5.00	61.37
25	Ft Ord Pres Mon	CA	PG&E	1724	9.37	2.90	5.00	5.00	61.37
26	Ft Ord (Hunter)	CA	PG&E	2475	9.37	2.90	5.00	5.00	61.37
27	Ft Pickett	VA	VA Power	2880	10.78	0.00	11.30	0.00	121.81
28	Ft Polk	LA	LA P&L	34200	2.90	0.00	5.00	0.00	14.50
29	Ft Polk N Post	LA	LA P&L	3360	2.90	0.00	5.00	0.00	14.50
30	Ft Riley 1	KS	KPL	29301	3.90	0.00	12.00	0.00	46.80
31	Ft Riley 2	KS	KPL	7785	3.90	0.00	12.00	0.00	46.80
32	Ft Riley 3	KS	KPL	750	3.90	0.00	12.00	0.00	46.80
33	Ft Sheridan	IL	Comm Ed	5224	13.34	2.73	5.00	5.00	80.34
34	Ft Stewart	GA	Georgia P	29203	6.69	0.00	11.65	0.00	77.94
35	Hunter Airfield	GA	SavanElec	8897	3.25	0.00	9.90	0.00	32.18
36	Letterman Hospital	CA	PG&E	8366	9.37	2.90	5.00	5.00	61.37
37	N Ft Hood	TX	TU Elec	1892	5.19	0.00	10.60	0.00	55.01
38	U.S.Army Supp Det	PA	Duquesne	1056	9.24	0.00	8.50	0.00	78.54
39	W Ft Hood	TX	Texas P&L	13987	4.05	0.00	10.60	0.00	42.93
40	Yakima Firing Cen	WA	Pac Power	1248	2.02	0.00	5.00	0.00	10.10

In calculating the annual savings with SCS, the annual ratchet factor for Fort Stewart is

$$F = 1/\text{month} \times 5 \text{ pk months/yr} + 0.95/\text{month} \times 7 \text{ non-pk months/yr}$$
$$= 11.65/\text{yr}.$$

Demand charge is

$$D = \$6.69/\text{kW}.$$

<u>A. 5 Percent Shift of Peak Demand (r = 5 Percent)</u>. The first step is calculating annual savings. For a 5 percent reduction in peak demand by SCS, the annual savings in demand charge by SCS is

$$S = P \times D \times F$$
$$= (29{,}203 \times 0.05) \times 6.69 \times 11.65$$
$$= \$113{,}800/\text{yr}.$$

The next step is calculating the system cost to shift 5 percent of the Fort Stewart peak electrical load. As discussed in *Cost of Demand Shifting*, a 4-hour window (W_1) is adopted for the shift of 5 percent peak load and an 8-hour window (W_2) is used for the 10 percent case. For a 5 percent reduction in peak demand by SCS (r = 5 percent), the amount of energy (kWh) to be shifted from onpeak to offpeak period is

$$K <= (r/100) \times Q \times W_1$$
$$= (5/100) \times 29{,}203 \times 4$$
$$= 5841 \text{ kWh}.$$

The required storage capacity is

$$T = f \times K$$
$$= 1 \text{ (ton/kW)} \times 5841$$
$$= 5841 \text{ T-h}.$$

The cost of SCS for a 5841 T-h capacity is as follows:

For a new construction/replacement application,

$$C = 80 \times 5841$$
$$= \$467{,}280.$$

For a retrofit application,

$$C = 150 \times 5841$$
$$= \$876{,}150 \text{ (realistic scenario)}$$

and

$$C = 300 \times 5841$$
$$= \$1{,}752{,}300 \text{ (upper limit scenario).}$$

The last step is calculating PBP. The payback period (Y) of each case is the following:

$$Y = C/S$$

= 467,280/113,800
= 4.1 years for new construction/replacement application.

Y = 876,150/113,800
= 7.7 years for retrofit with realistic scenario.

Y = 1,752,300/113,800
= 15.4 years for retrofit with upper limit scenario.

B. 10 Percent Reduction of Peak Demand (r = 10 Percent). Again, step one is to calculate annual savings by SCS. For a 10 percent reduction in demand (r = 10 percent),

$$S = P \times D \times F$$
$$= (29{,}203 \times 0.10) \times 6.69 \times 11.65$$
$$= \$227{,}600/\text{year}.$$

The second step is calculation of system costs. Recall that for an additional 5 percent reduction of the demand, we need a wider window of shift. The reason is, again, that the demand profile becomes flatter (see Figure 2). For the additional 5 percent reduction, the width of window (W_2) is increased to 8 hours. The amount of shifted energy during W_2 is

$$K <= (r/100) \times Q \times W2$$
$$= (5/100) \times 29{,}203 \times 8$$
$$= 11{,}681 \text{ kWH}.$$

The required storage capacity (for the second 5 percent of demand shift) is

$$T = f \times K$$
$$= 1 \text{ (ton/kWh)} \times 11{,}681$$
$$= 11{,}681 \text{ T-h}.$$

The cost of SCS for a capacity of 11,681 T-h is

C = 80 x 11,681
= $934,480 (new construction/replacement),

C = 150 x 11,681
= $1,752,150 (retrofit, realistic scenario),

and

C = 300 x 11,681
= $3,504,300 (retrofit, upper limit scenario).

The total cost of SCS for a 10 percent reduction in peak demand is

C = 467,280 + 934,480
= $1,401,760 (new construction/replacement),

C = 876,150 + 1,752,150
= $2,628,300 (retrofit, realistic scenario),

C = 1,752,300 + 3,504,300
= $5,256,600 (retrofit, upper limit scenario).

The payback period for each case is

$$Y = C/S = 1{,}401{,}760/227{,}600 = 6.2 \text{ years for new construction/replacement,}$$

$$Y = 2{,}628{,}300/227{,}600 = 11.5 \text{ years for retrofit with realistic scenario,}$$

and

$$Y = 5{,}256{,}600/227{,}600 = 23.1 \text{ years for retrofit with upper limit scenario.}$$

C. Summary of Sample Calculation. For the sample analysis shown for Fort Stewart, the results are summarized in Table 4.

New Construction/Replacement

Similar analyses have been performed for the installations listed in Table 2; most of the major installations under FORSCOM are included. The results of utility cost savings analyses for new construction/replacement applications are presented in Tables 5 and 6. Table 5 lists the projected annual savings in demand costs for each installation shifting 5 percent of the installation peak demand. Table 6 shows the results with a 10 percent reduction.

Retrofit Application

The potential utility cost savings from SCS for retrofit applications are presented in this section. Tables 7 and 8 show the results based on a realistic scenario for a reduction in peak electrical demand of 5 percent and 10 percent, respectively. Data collected by USACERL corroborates the accuracy of the results. As of 1988, USACERL installed two ice storage cooling systems as a demonstration for the Army. In one of the systems, retrofitted to a barracks/office/dining hall complex at Yuma Proving Ground, AZ, an Army Materiel Command (AMC) installation, the system is expected to pay back in 5 years. It matches the results shown in Table 7 rather nicely.

Tables 9 and 10 present the results of an upper limit scenario for a reduction in peak demand of 5 percent and 10 percent, respectively.

Summary of Intermediate Results

Tables 5 through 10 present the market potential of SCS for most FORSCOM installations under various applications and cost scenarios. The tables project annual savings and expected payback periods for each installation. These results are summarized in Table 11 as the expected annual savings in electrical utility costs for air-conditioning.

As Table 11 shows, market potential depends on the type of application because payback depends on the initial differential construction cost. This cost is lowest for a new construction or replacement application wherein the initial equipment and labor cost

Table 4

Market Potential of SCS for Fort Stewart ($/yr)

For 5 percent peak demand reduction

Payback	< 3 yrs	< 5 yrs	< 10 yrs
New/replacement	0	113,800	113,800
Retrofit, realistic	0	0	113,800
Retrofit, upper limit	0	0	0

For 10 percent peak demand reduction

Payback	< 3 yrs	< 5 yrs	< 10 yrs
New/replacement	0	0	227,600
Retrofit, realistic	0	0	0
Retrofit, upper limit	0	0	0

for the SCS is offset by the similar cost required for a conventional cooling system. The only extra cost for the SCS is the storage tank cost. For a retrofit application, the costs of hardware (pumps, piping, and possibly a new ice-making unit) and installation labor are all extra. Therefore, a retrofit application costs more initially than new construction for the same storage capacity and results in a longer payback period and less market potential.

Payback is quicker if the SCS shifts a smaller portion of the peak demand, i.e., 5 percent rather than 10 percent reduction of peak, if there is no rebate program. This can be understood by examining the peak demand profile (Figure 5). A narrow window (W_1) is sufficient to shift the first 5 percent of peak demand. For the next 5 percent, a wide window (W_2) is required. Thus, for a given size of SCS capacity, more reduction in peak demand is realized in the region with a sharp demand profile. However, this relationship may be changed by an incentive program providing no rebate for projects with short-duration demand reductions.

Please note that the SCS market potential presented in Table 11 is for FORSCOM installations only. The Army-wide potential is presented in Chapter 4. Expected annual savings and initial construction costs are the most critical factors in determining the PBP. The annual savings calculations were based on data from each installation, and are therefore actual figures rather than theoretical projections. The construction cost data are also real, but the construction cost data base is not large enough to permit projections as accurate as those for annual savings. Furthermore, as SCS technology matures, the construction cost will certainly decrease. As a result, the analysis in this report is based on a very conservative estimate of system construction costs.

An investment in SCS with a 3-year payback or less seems highly worthwhile, and one with a 5-year payback appears favorable. But if payback is from 5 to 10 years, the project should be studied carefully and local characteristics should be assessed. When payback is expected to take longer than 10 years, it seems prudent to watch further development of the market conditions rather than to implement SCS technologies.

Table 5

FORSCOM SCS Market Potential: 5 Percent Shift, New/Replacement

Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Simple Payback Years
1 Ft Devens	9603	480	122.17	58640	153600	2.6
2 Ft Pickett	2880	144	121.81	17541	46080	2.6
3 Ft Campbell	2500	125	121.98	15248	40000	2.6
4 Ft Campbell	42100	2105	102.68	216141	673600	3.1
5 Ft Devens	2377	118	86.10	10160	37760	3.7
6 Ft Gillem	2011	100	85.98	8598	32000	3.7
7 Ft McPherson	2532	126	85.98	10833	40320	3.7
8 Ft Indiantown Gap	3672	183	83.35	15253	58560	3.8
9 Ft Sheridan	5224	261	80.34	20969	83520	4.0
10 Ft Bragg #1	34214	1710	80.85	138254	547200	4.0
11 U.S.Army Supp Det	1056	52	78.54	4084	16640	4.1
12 Ft Stewart	29203	1460	77.94	113790	467200	4.1
13 Ft Ord Pres Mon	1724	86	61.37	5278	27520	5.2
14 Ft Ord (Hunter)	2475	123	61.37	7549	39360	5.2
15 Ft Ord Bay Park	453	22	61.37	1350	7040	5.2
16 Ft Ord Main Gar	13104	655	61.37	40197	209600	5.2
17 Ft Ord N Bay Park	474	23	61.37	1412	7360	5.2
18 Letterman Hospital	8366	418	61.37	25653	133760	5.2
19 Ft Meade	68861	3443	57.85	199178	1101760	5.5
20 Ft McCoy	2981	149	56.88	8475	47680	5.6
21 Ft Carson	15973	798	55.01	43896	255360	5.8
22 N Ft Hood	1892	94	55.01	5171	30080	5.8
23 Ft Irwin	9120	456	49.76	22691	145920	6.4
24 Ft Drum	5800	290	47.56	13791	92800	6.7
25 Ft Riley 1	29301	1465	46.80	68562	468800	6.8
26 Ft Riley 3	750	37	46.80	1732	11840	6.8
27 Ft Drum	1080	54	46.75	2525	17280	6.8
28 Ft Riley 2	7785	389	46.80	18205	124480	6.8
29 Ft Bragg MV	8222	411	45.95	18885	131520	7.0
30 Ft Bragg #3	19596	979	43.45	42538	313280	7.4
31 Ft Bragg #2	12545	627	43.45	27243	200640	7.4
32 W Ft Hood	13987	699	42.93	30008	223680	7.5
33 Ft Hood	52881	2644	42.93	113507	846080	7.5
34 Hunter Airfield	8897	444	32.18	14286	142080	9.9
35 Ft Polk	34200	1710	14.50	24795	547200	22.1
36 Ft Polk N Post	3360	168	14.50	2436	53760	22.1
37 Yakima Firing Cen	1248	62	10.10	626	19840	31.7
38 Ft Lewis Mad Sub	5301	265	9.20	2438	84800	34.8
39 Ft Lewis Cen Sup	15149	757	9.20	6964	242240	34.8
40 Ft Lewis S Sub	13128	656	9.20	6035	209920	34.8

Table 6

FORSCOM SCS Market Potential: 10 Percent Shift, New/Replacement

	Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Incentive for kWs Shifted	SCS Net Cost $	Simple Payback Years
1	N Ft Hood	1892	189	55.01	10398	90816	66150	24666	2.4
2	Ft Devens	9603	960	122.17	117279	460944	153600	307344	2.6
3	Ft Devens	2377	237	97.10	23013	114096	47400	66696	2.9
4	Ft Ord (Hunter)	2475	247	75.89	18745	118800	49400	69400	3.7
5	Ft Ord Pres Mon	1724	172	75.89	13053	82752	34400	48352	3.7
6	Ft Ord Bay Park	453	45	75.89	3415	21744	9000	12744	3.7
7	Ft Ord N Bay Park	474	47	75.89	3567	22752	9400	13352	3.7
8	Ft Campbell	2500	250	121.98	30496	120000		120000	3.9
9	Ft Pickett	2880	288	121.81	35082	138240		138240	3.9
10	Letterman Hospital	8366	836	75.89	63444	401568	150000	251568	4.0
11	Ft Irwin	9120	912	84.52	77082	437760	91200	346560	4.5
12	Ft Campbell	42100	4210	102.68	432283	2020800		2020800	4.7
13	Ft Ord Main Gar	13104	1310	75.89	99416	628992	150000	478992	4.8
14	Ft McCoy	2981	298	60.84	18130	143088	52150	90938	5.0
15	Ft Sheridan	5224	522	93.98	49058	250752		250752	5.1
16	Ft Indiantown Gap	3672	367	87.31	32043	176256		176256	5.5
17	Ft Gillem	2011	201	85.98	17281	96528		96528	5.6
18	Ft McPherson	2532	253	85.98	21752	121536		121536	5.6
19	Ft Bragg #1	34214	3421	83.05	284114	1642272		1642272	5.8
20	U.S.Army Supp Det	1056	105	78.54	8247	50688		50688	6.1
21	Ft Stewart	29203	2920	77.94	227580	1401744		1401744	6.2
22	W Ft Hood	13987	1398	42.93	60016	671376	294750	376626	6.3
23	Ft Meade	68861	6886	66.65	458952	3305328		3305328	7.2
24	Ft Hood	52881	5288	42.93	227014	2538288	781000	1757288	7.7
25	Ft Carson	15973	1597	55.01	87848	766704		766704	8.7
26	Ft Drum	5800	580	53.72	31155	278400		278400	8.9
27	Ft Riley 3	750	75	46.80	3510	36000		36000	10.3
28	Ft Riley 1	29301	2930	46.80	137124	1406448		1406448	10.3
29	Ft Riley 2	7785	778	46.80	36410	373680		373680	10.3
30	Ft Drum	1080	108	46.75	5049	51840		51840	10.3
31	Ft Bragg MV	8222	822	45.95	37771	394656		394656	10.4
32	Ft Bragg #3	19596	1959	43.45	85119	940608		940608	11.1
33	Ft Bragg #2	12545	1254	43.45	54486	602160		602160	11.1
34	Hunter Airfield	8897	889	32.18	28604	427056		427056	14.9
35	Ft Polk N Post	3360	336	14.50	4872	161280		161280	33.1
36	Ft Polk	34200	3420	14.50	49590	1641600		1641600	33.1
37	Yakima Firing Cen	1248	124	10.10	1252	59904		59904	47.8
38	Ft Lewis Mad Sub	5301	530	9.20	4876	254448		254448	52.2
39	Ft Lewis Cen Sup	15149	1514	9.20	13929	727152		727152	52.2
40	Ft Lewis S Sub	13128	1312	9.20	12070	630144		630144	52.2

Table 7

FORSCOM SCS Market Potential: 5 Percent Shift, Retrofit/Realistic

	Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Simple Payback Years
1	Ft Devens	9603	480	122.17	58640	288000	4.9
2	Ft Pickett	2880	144	121.81	17541	86400	4.9
3	Ft Campbell	2500	125	121.98	15248	75000	4.9
4	Ft Campbell	42100	2105	102.68	216141	1263000	5.8
5	Ft Devens	2377	118	86.10	10160	70800	7.0
6	Ft Gillem	2011	100	85.98	8598	60000	7.0
7	Ft McPherson	2532	126	85.98	10833	75600	7.0
8	Ft Indiantown Gap	3672	183	83.35	15253	109800	7.2
9	Ft Sheridan	5224	261	80.34	20969	156600	7.5
10	Ft Bragg #1	34214	1710	80.85	138254	1026000	7.4
11	U.S.Army Supp Det	1056	52	78.54	4084	31200	7.6
12	Ft Stewart	29203	1460	77.94	113790	876000	7.7
13	Ft Ord Pres Mon	1724	86	61.37	5278	51600	9.8
14	Ft Ord (Hunter)	2475	123	61.37	7549	73800	9.8
15	Ft Ord Bay Park	453	22	61.37	1350	13200	9.8
16	Ft Ord Main Gar	13104	655	61.37	40197	393000	9.8
17	Ft Ord N Bay Park	474	23	61.37	1412	13800	9.8
18	Letterman Hospital	8366	418	61.37	25653	250800	9.8
19	Ft Meade	68861	3443	57.85	199178	2065800	10.4
20	Ft McCoy	2981	149	56.88	8475	89400	10.5
21	Ft Carson	15973	798	55.01	43896	478800	10.9
22	N Ft Hood	1892	94	55.01	5171	56400	10.9
23	Ft Irwin	9120	456	49.76	22691	273600	12.1
24	Ft Drum	5800	290	47.56	13791	174000	12.6
25	Ft Riley 1	29301	1465	46.80	68562	879000	12.8
26	Ft Riley 3	750	37	46.80	1732	22200	12.8
27	Ft Drum	1080	54	46.75	2525	32400	12.8
28	Ft Riley 2	7785	389	46.80	18205	233400	12.8
29	Ft Bragg MV	8222	411	45.95	18885	246600	13.1
30	Ft Bragg #3	19596	979	43.45	42538	587400	13.8
31	Ft Bragg #2	12545	627	43.45	27243	376200	13.8
32	W Ft Hood	13987	699	42.93	30008	419400	14.0
33	Ft Hood	52881	2644	42.93	113507	1586400	14.0
34	Hunter Airfield	8897	444	32.18	14286	266400	18.6
35	Ft Polk	34200	1710	14.50	24795	1026000	41.4
36	Ft Polk N Post	3360	168	14.50	2436	100800	41.4
37	Yakima Firing Cen	1248	62	10.10	626	37200	59.4
38	Ft Lewis Mad Sub	5301	265	9.20	2438	159000	65.2
39	Ft Lewis Cen Sup	15149	757	9.20	6964	454200	65.2
40	Ft Lewis S Sub	13128	656	9.20	6035	393600	65.2

Table 8

FORSCOM SCS Market Potential: 10 Percent Shift, Retrofit/Realistic

Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Incentive for kWs Shifted	SCS Net Cost $	Simple Payback Years
1 Ft Devens	9603	960	122.17	117279	864270	153600	710670	6.1
2 Ft Devens	2377	237	97.10	23013	213930	47400	166530	7.2
3 Ft Campbell	2500	250	121.98	30496	225000		225000	7.4
4 Ft Pickett	2880	288	121.81	35082	259200		259200	7.4
5 Ft Campbell	42100	4210	102.68	432283	3789000		3789000	8.8
6 Ft Ord (Hunter)	2475	247	75.89	18745	222750	49400	173350	9.2
7 Ft Ord Pres Mon	1724	172	75.89	13053	155160	34400	120760	9.3
8 Ft Ord Bay Park	453	45	75.89	3415	40770	9000	31770	9.3
9 Ft Ord N Bay Park	474	47	75.89	3567	42660	9400	33260	9.3
10 Ft Irwin	9120	912	84.52	77082	820800	91200	729600	9.5
11 Letterman Hospital	8366	836	75.89	63444	752940	150000	602940	9.5
12 Ft Sheridan	5224	522	93.98	49058	470160		470160	9.6
13 N Ft Hood	1892	189	55.01	10398	170280	66150	104130	10.0
14 Ft Indiantown Gap	3672	367	87.31	32043	330480		330480	10.3
15 Ft Ord Main Gar	13104	1310	75.89	99416	1179360	150000	1029360	10.4
16 Ft Gillem	2011	201	85.98	17281	180990		180990	10.5
17 Ft McPherson	2532	253	85.98	21752	227880		227880	10.5
18 Ft Bragg #1	34214	3421	83.05	284114	3079260		3079260	10.8
19 U.S.Army Supp Det	1056	105	78.54	8247	95040		95040	11.5
20 Ft Stewart	29203	2920	77.94	227580	2628270		2628270	11.5
21 Ft McCoy	2981	298	60.84	18130	268290	52150	216140	11.9
22 Ft Meade	68861	6886	66.65	458952	6197490		6197490	13.5
23 W Ft Hood	13987	1398	42.93	60016	1258830	294750	964080	16.1
24 Ft Carson	15973	1597	55.01	87848	1437570		1437570	16.4
25 Ft Drum	5800	580	53.72	31155	522000		522000	16.8
26 Ft Hood	52881	5288	42.93	227014	4759290	781000	3978290	17.5
27 Ft Riley 3	750	75	46.80	3510	67500		67500	19.2
28 Ft Riley 1	29301	2930	46.80	137124	2637090		2637090	19.2
29 Ft Riley 2	7785	778	46.80	36410	700650		700650	19.2
30 Ft Drum	1080	108	46.75	5049	97200		97200	19.3
31 Ft Bragg MV	8222	822	45.95	37771	739980		739980	19.6
32 Ft Bragg #3	19596	1959	43.45	85119	1763640		1763640	20.7
33 Ft Bragg #2	12545	1254	43.45	54486	1129050		1129050	20.7
34 Hunter Airfield	8897	889	32.18	28604	800730		800730	28.0
35 Ft Polk N Post	3360	336	14.50	4872	302400		302400	62.1
36 Ft Polk	34200	3420	14.50	49590	3078000		3078000	62.1
37 Yakima Firing Cen	1248	124	10.10	1252	112320		112320	89.7
38 Ft Lewis Mad Sub	5301	530	9.20	4876	477090		477090	97.8
39 Ft Lewis Cen Sup	15149	1514	9.20	13929	1363410		1363410	97.9
40 Ft Lewis S Sub	13128	1312	9.20	12070	1181520		1181520	97.9

Table 9

FORSCOM SCS Market Potential: 5 Percent Shift, Retrofit/Upper Limit

	Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Simple Payback Years
1	Ft Devens	9603	480	122.17	58640	576000	9.8
2	Ft Pickett	2880	144	121.81	17541	172800	9.9
3	Ft Campbell	2500	125	121.98	15248	150000	9.8
4	Ft Campbell	42100	2105	102.68	216141	2526000	11.7
5	Ft Devens	2377	118	86.10	10160	141600	13.9
6	Ft Gillem	2011	100	85.98	8598	120000	14.0
7	Ft McPherson	2532	126	85.98	10833	151200	14.0
8	Ft Indiantown Gap	3672	183	83.35	15253	219600	14.4
9	Ft Sheridan	5224	261	80.34	20969	313200	14.9
10	Ft Bragg #1	34214	1710	80.85	138254	2052000	14.8
11	U.S.Army Supp Det	1056	52	78.54	4084	62400	15.3
12	Ft Stewart	29203	1460	77.94	113790	1752000	15.4
13	Ft Ord Pres Mon	1724	86	61.37	5278	103200	19.6
14	Ft Ord (Hunter)	2475	123	61.37	7549	147600	19.6
15	Ft Ord Bay Park	453	22	61.37	1350	26400	19.6
16	Ft Ord Main Gar	13104	655	61.37	40197	786000	19.6
17	Ft Ord N Bay Park	474	23	61.37	1412	27600	19.6
18	Letterman Hospital	8366	418	61.37	25653	501600	19.6
19	Ft Meade	68861	3443	57.85	199178	4131600	20.7
20	Ft McCoy	2981	149	56.88	8475	178800	21.1
21	Ft Carson	15973	798	55.01	43896	957600	21.8
22	N Ft Hood	1892	94	55.01	5171	112800	21.8
23	Ft Irwin	9120	456	49.76	22691	547200	24.1
24	Ft Drum	5800	290	47.56	13791	348000	25.2
25	Ft Riley 1	29301	1465	46.80	68562	1758000	25.6
26	Ft Riley 3	750	37	46.80	1732	44400	25.6
27	Ft Drum	1080	54	46.75	2525	64800	25.7
28	Ft Riley 2	7785	389	46.80	18205	466800	25.6
29	Ft Bragg MV	8222	411	45.95	18885	493200	26.1
30	Ft Bragg #3	19596	979	43.45	42538	1174800	27.6
31	Ft Bragg #2	12545	627	43.45	27243	752400	27.6
32	W Ft Hood	13987	699	42.93	30008	838800	28.0
33	Ft Hood	52881	2644	42.93	113507	3172800	28.0
34	Hunter Airfield	8897	444	32.18	14286	532800	37.3
35	Ft Polk	34200	1710	14.50	24795	2052000	82.8
36	Ft Polk N Post	3360	168	14.50	2436	201600	82.8
37	Yakima Firing Cen	1248	62	10.10	626	74400	118.8
38	Ft Lewis Mad Sub	5301	265	9.20	2438	318000	130.4
39	Ft Lewis Cen Sup	15149	757	9.20	6964	908400	130.4
40	Ft Lewis S Sub	13128	656	9.20	6035	787200	130.4

Table 10

FORSCOM SCS Market Potential: 10 Percent Shift, Retrofit/Upper Limit

Post	Pk Dem kW	Cooling kW	Annual Savings $/kW	Annual Savings $	SCS Cost $	Incentive for kWs Shifted	SCS Net Cost $	Simple Payback Years
1 Ft Devens	9603	960	122.17	117279	1728540	153600	1574940	13.4
2 Ft Campbell	2500	250	121.98	30496	450000		450000	14.8
3 Ft Pickett	2880	288	121.81	35082	518400		518400	14.8
4 Ft Devens	2377	237	97.10	23013	427860	47400	380460	16.5
5 Ft Campbell	42100	4210	102.68	432283	7578000		7578000	17.5
6 Ft Sheridan	5224	522	93.98	49058	940320		940320	19.2
7 Ft Irwin	9120	912	84.52	77082	1641600	91200	1550400	20.1
8 Ft Indiantown Gap	3672	367	87.31	32043	660960		660960	20.6
9 Ft Gillem	2011	201	85.98	17281	361980		361980	20.9
10 Ft McPherson	2532	253	85.98	21752	455760		455760	21.0
11 Ft Ord (Hunter)	2475	247	75.89	18745	445500	49400	396100	21.1
12 Ft Ord Pres Mon	1724	172	75.89	13053	310320	34400	275920	21.1
13 Ft Ord Bay Park	453	45	75.89	3415	81540	9000	72540	21.2
14 Ft Ord N Bay Park	474	47	75.89	3567	85320	9400	75920	21.3
15 Letterman Hospital	8366	836	75.89	63444	1505880	150000	1355880	21.4
16 Ft Bragg #1	34214	3421	83.05	284114	6158520		6158520	21.7
17 Ft Ord Main Gar	13104	1310	75.89	99416	2358720	150000	2208720	22.2
18 U.S.Army Supp Det	1056	105	78.54	8247	190080		190080	23.0
19 Ft Stewart	29203	2920	77.94	227580	5256540		5256540	23.1
20 N Ft Hood	1892	189	55.01	10398	340560	66150	274410	26.4
21 Ft McCoy	2981	298	60.84	18130	536580	52150	484430	26.7
22 Ft Meade	68861	6886	66.65	458952	12394980		12394980	27.0
23 Ft Carson	15973	1597	55.01	87848	2875140		2875140	32.7
24 Ft Drum	5800	580	53.72	31155	1044000		1044000	33.5
25 W Ft Hood	13987	1398	42.93	60016	2517660	294750	2222910	37.0
26 Ft Riley 3	750	75	46.80	3510	135000		135000	38.5
27 Ft Riley 1	29301	2930	46.80	137124	5274180		5274180	38.5
28 Ft Riley 2	7785	778	46.80	36410	1401300		1401300	38.5
29 Ft Hood	52881	5288	42.93	227014	9518580	781000	8737580	38.5
30 Ft Drum	1080	108	46.75	5049	194400		194400	38.5
31 Ft Bragg MV	8222	822	45.95	37771	1479960		1479960	39.2
32 Ft Bragg #3	19596	1959	43.45	85119	3527280		3527280	41.4
33 Ft Bragg #2	12545	1254	43.45	54486	2258100		2258100	41.4
34 Hunter Airfield	8897	889	32.18	28604	1601460		1601460	56.0
35 Ft Polk N Post	3360	336	14.50	4872	604800		604800	124.1
36 Ft Polk	34200	3420	14.50	49590	6156000		6156000	124.1
37 Yakima Firing Cen	1248	124	10.10	1252	224640		224640	179.4
38 Ft Lewis Mad Sub	5301	530	9.20	4876	954180		954180	195.7
39 Ft Lewis Cen Sup	15149	1514	9.20	13929	2726820		2726820	195.8
40 Ft Lewis S Sub	13128	1312	9.20	12070	2363040		2363040	195.8

Table 11

SCS Potential Savings in FORSCOM Installations ($thousands/year)

New Construction/Replacement Application

Shifted Demand	Payback Period < 3 Yr	< 5 Yr	< 10 Yr
5 %	91	630	1342
10 %	151	945	2451

Retrofit Application/Realistic

Shifted Demand	Payback Period < 3 Yr	< 5 Yr	< 10 Yr
5 %	0	91	711
10 %	0	0	877

Retrofit Application/Upper Limit

Shifted Demand	Payback Period < 3 Yr	< 5 Yr	< 10 Yr
5 %	0	0	91
10 %	0	0	0

In view of these criteria, SCS technology has a strong market potential within FORSCOM installations for new construction projects and replacement applications. The SCS has about $0.6 million per year savings potential with a payback of less than 5 years for both new construction and replacement application shifting the first 5 percent of the total electrical peak demand. If the first 10 percent of the peak is shifted, the potential savings would be as high as approximately $1 million per year. For a number of installations, SCS would pay back in less than 3 years.

For retrofit applications, however, the payback is not as encouraging. With a realistic cost scenario, the annual savings potential is estimated to be about $100,000 per year. If the upper limit scenario is employed, retrofit applications of SCS are not desirable except where local conditions are favorable for SCS technology implementation. However, even for the realistic cost scenario ($150/T-h), the cost estimate could be too conservative and the annual savings stated too low. Recall that the reports from EPRI[18] and LBL[19] quote the system costs at less than $100/T-h; that figure seems too optimistic. The upper limit scenario in retrofit application serves as an extreme upper limit and should not be considered typical. The most probable conditions for a retrofit application would be typified by the realistic cost scenario. A good example would be a retrofit ice storage cooling system installed at Yuma Proving ground, AZ. The system, at a cost of about $150/T-h, is expected to pay back in less than 5 years. The interim result for retrofit applications of SCS is that, for a small percentage of installations, an SCS shifting the first 5 percent of peak demand would pay back in 5 years. For the majority of the cases, however, the payback would be 5 to 10 years. In any case, a detailed feasibility study incorporating the local characteristics is recommended for retrofit applications of the SCS technologies.

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4 MARKET POTENTIAL OF STORAGE COOLING SYSTEMS IN THE ARMY

Projection of the Army-Wide Potential

The market potential of SCS technology in FORSCOM shown in Table 11 was calculated from data for 40 sites at 22 FORSCOM installations. The Army has more than 200 major installations.[20] Therefore, the total SCS market potential within the Army is expected to be at least 5 times that shown in Table 11. The factor of 5 is roughly corroborated by the ratio of the electrical utility costs paid by the Army to those by all the FORSCOM installations. The total electrical utility costs paid by the Army during FY87 was $539 million, versus $139 million for all FORSCOM installations including those analyzed in this report.[21]

The Army-wide SCS market potential is given in Table 12. It is extrapolated from Table 11 by multiplying by a factor of 5.

Interpretation of Results

Table 12 summarizes the findings of this report. The extrapolated savings projections are admittedly a rough estimate. It should be noted, however, that a marketing study cannot be an exact science. The purpose of Table 12 is to present the SCS market potential in quantitative terms. The data should be useful to those who make technology implementation decisions. At the MACOM Directorate of Engineering and Housing level, it will provide a rough payback estimate for an investment in SCS technology. At the installation level, it should provide an incentive to explore the cost savings possible from air-conditioning through SCS technology.

Table 12

SCS Market Potential Army-Wide (\$thousands/year)

Shifted Demand	Payback Period < 3 Yr	Payback Period < 5 Yr	Payback Period < 10 Yr
New Construction/Replacement Application			
5 %	457	3148	6708
10 %	753	4727	12252
Retrofit Application/Realistic			
5 %	0	457	3555
10 %	0	0	4385
Retrofit Application/Upper Limit			
5 %	0	0	457
10 %	0	0	0

[20] *Facilities Engineering and Housing Annual Summary of Operations.*
[21] *Facilities Engineering and Housing Annual Summary of Operations.*

Issues in SCS

Although SCS technology is still developmental, electrical utility companies are supporting its application. Storage cooling systems have the potential to improve the power factor of power-generating plants and accommodate short-term demand requirements. Utilities support SCS directly through incentive programs and indirectly by rate schedules that favor power consumption during offpeak periods. Current issues in SCS technology are discussed in the following sections.

General Issues

An SCS reduces the cost of air-conditioning by shifting the time energy is used for cooling, not by reducing the amount of energy needed for cooling. It is useful primarily when the power supplier (typically the electrical utility company) has difficulty meeting its customers' short-period peak demand because of insufficient generating capacity. But an SCS would not be useful if the power company has excessive generating capacity. Also, the charges associated with demand peaking may be avoided by the user if it has an economical means of generating electrical power, such as a cogeneration system. Therefore, understanding the generating capacity and rate structure of the power company serving an installation is mandatory before implementing SCS technology.

The system first cost is another critical factor in determining the payback period. An incentive rebate from the utility company can reduce the system first cost significantly. However, guidelines for estimating system first costs are not yet fully established. The cost of system hardware, such as condensing unit, storage tank, pump, heat exchanger, and associated plumbing supplies, is easily available and reliable. But the labor cost for assembling the system is difficult to determine. This situation should improve as contractors gain experience with SCS technology.

One promising trend in reducing system construction costs is the factory-packaged thermal storage cooling unit. As of February 1989, three manufacturers have made these systems available.[22] The prepackaged units could eliminate the complexities of custom-built storage cooling systems such as equipment optimization, plumbing, and warranty enforcement difficulties associated with multiple sources of responsibility (e.g., manufacturer of the ice maker and storage tank, and general contractor in charge of installation). In principle, the factory-packaged unit can simply replace a conventional chiller by tapping the supply and return chilled-water piping. It will virtually eliminate construction labor costs, which are a significant portion of custom-built systems. Recall that installation cost constitutes roughly a third of the total system cost.

The cost of the installed prepackaged system is between $125 and $150 per Ton-hour.[23] In this report, $150/T-h was used to analyze the realistic scenario for a retrofit system. The cost of the prepackaged system therefore reinforces the validity of the retrofit analysis basis. In a new construction or replacement application, the conventional cooling plant cost should be deducted from the cost of a storage cooling system. The differential construction cost for such an application could be even lower than $80/T-h assumed in the analysis. As a result, the cost basis employed in this study is conservative enough to support the claim that the SCS market potential reported here is the minimum that can be expected.

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[22]"Packaged Thermal Storage Gaining: Size, Simplicity Cited," *Energy User News* (February 1989).

[23]"Packaged Thermal Storage Gaining."

The Electric Power Research Institute (EPRI) and a few manufacturers and design companies have developed design guides for a number of SCS applications. However, an industry-wide general design guide is not yet available. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is currently working to develop and field test such a guide.

As of 1988, between 2000 and 3000 storage cooling systems have been installed and are operational. A number of programs for monitoring the performance of SCSs have been initiated, but their final results are not yet available. The operation and maintenance of an SCS should not be different from that of a conventional cooling system.[24] However, there are few reports on SCS operation and maintenance to corroborate this assumption.

Army Characteristics Affecting SCS

Several unique Army characteristics affect implementation of SCS technology. Favorable characteristics are listed below:

1. Each installation is metered by one or a few master power meters; thus peak electrical demand, which occurs during a relatively narrow and regular interval, is readily identifiable. A demand-limiting strategy can be employed to shift a large amount of demand for a short period of time.

2. The Army has many centralized cooling plants, which are ideal candidates for SCS technology.

3. Army building types are relatively standardized, and SCS technology could also be standardized. These factors would make it easy for Army engineers to share information concerning operation and maintenance of SCS.

The following are constraining characteristics:

1. The Army needs an official design guide to install these systems, even if SCS technology is judged to be immediately beneficial to the Army.

2. Large-scale SCS implementation will depend on the reliability of the system's operation and maintenance, which has yet to be proven.

3. The Army is often billed more for construction work than the private sector, which could potentially increase the system first cost.

[24] *1987 ASHRAE Handbook HVAC Systems and Applications.*

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Storage cooling systems have an immediate potential to reduce the Army's electrical utility costs for air-conditioning. When SCS technology is applied to new construction, the expected annual cost savings ranges from $3 million to $5 million with less than 5 years of payback. SCS will be less cost-effective in retrofit applications. A realistic assessment of its potential in retrofit applications with a payback period of less than 5 years is savings of $1/2 million per year in electrical utility costs for air-conditioning.

Recommendations

The applicability of SCS technology should be evaluated at all Army installations, especially those affected by utility company incentive awards. The methodology presented in this report will provide a guideline for verifying the economic feasibility of SCS technology.

It is also recommended that Army SCS specifications be developed as soon as possible to facilitate implementation of SCS.

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