(2)

APPLICABILITY OF THERMAL STORAGE
SYSTEMS TO AIR FORCE FACILITIES

THESIS

David B. McCormick, Captain, USAF

AFIT/GEM/DEE/90S-11

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DTIC
ELECTE
DEC 21 1990
S E D

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

90 12 20 093

2

AFIT/GEM/DEE/90S-11

APPLICABILITY OF THERMAL STORAGE SYSTEMS TO AIR FORCE FACILITIES

THESIS

David B. McCormick, Captain, USAF

AFIT/GEM/DEE/90S-11

The opinions and conclusions in this paper are those of the author and are not intended to represent the official position of the DOD, USAF, or any other government agency.

AFIT/GEM/DEE/90S-11

APPLICABILITY OF THERMAL STORAGE SYSTEMS TO AIR FORCE FACILITIES

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering Management

David B. McCormick, B.S.M.E.
Captain, USAF

September 1990

Approved for public release; distribution unlimited

Acknowledgements

I wish to express my deepest thanks to my thesis advisor, Captain David Alley, and my thesis reader Captain Richard Boyce for their invaluable patience, insight and encouragement while I endeavored this study.

I am also greatly indebted to Dr Chang Sohn, Principal Investigator, U.S. Army Construction Engineering Research Laboratory (USA-CERL), for his personal interest in this study and his outstanding technical support. It was Dr Sohn's and Mr Gerald Cler's sound and proven research that provided the basic methodological structure for this thesis.

Finally, as always, I am especially thankful for my wife, Marie. Without her loving patience, understanding, and support this study would certainly be incomplete.

Table of Contents

Page

Table of Contents (Cont)

List of Figures

List of Tables

Abstract

Thermal storage is a technology that shifts the electrical demand for air conditioning from on-peak to off-peak periods. This is accomplished by chilling a storage medium during off-peak periods, storing this medium in an insulated container, and using it during on-peak periods to provide cooling. The result of this action is a lowered electric bill.

This study approaches this issue from both a qualitative and a quantitative stand point. The qualitative portion addresses the general validity and effectiveness of thermal storage. The quantitative portion determines the specific market potential of packaged ice thermal storage systems for the 51 CONUS bases studied based on three initial cost scenarios. These scenarios include new construction or replacement applications, realistic retrofit applications and upper limit retrofit applications. In addition, an economic analysis was performed on each base using simple payback and net present value techniques. The results of these analysis show the Air Force can save up to $850,000 per year by shifting base cooling demand loads by 15 percent for those bases showing a payback period less than five years. Based on these results, the climatic regional areas of the CONUS are prioritized according to their thermal storage market potential.

APPLICABILITY OF THERMAL STORAGE SYSTEMS TO AIR FORCE FACILITIES

I. Introduction

Overview

This chapter provides basic information of this study's general issue, the specific problem to be researched, the specific objective of the study, some investigative questions to be resolved, the scope of the study, and the primary focus of the study. In addition, some general background information on thermal storage systems, the organization of the thesis, and some key terms will be defined.

General Issue

In today's austere funding climate, it is necessary for the Air Force to identify and implement new technology that will reduce operational costs without jeopardizing operational efficiency. Electrical demand costs constitute a particularly auspicious area in which substantial cost savings can be realized by employing new technology without sacrificing efficiency.

Over recent years, utility companies have changed their electrical billing rate structure to reflect the cost of capital associated with high electrical demand loads during peak periods. These changes imposed a demand charge penalizing industrial and commercial consumers for using electrical power during peak periods and rewarding like users for using power in non-peak periods. The goal of the utility companies was to flatten out the 24 hour demand load profile produced by its customers. In most commercial facilities the major portion of electricity can be attributed to air conditioning. Typically, the demand for cooling in a facility coincides with the peak demand rate period set by the utility company, therefore the cost for facility air conditioning is usually calculated at the most expensive demand rate. Significant dollar savings can be realized if the electrical load for on-peak air conditioning can be deferred to off-peak periods. Thermal storage systems (TSS) provide one means for effectively accomplishing this task. In essence, these systems generate and store ice or chilled water during off-peak periods for use during on-peak hours. This allows the chilling portion of the air conditioning systems to be turned off or minimized during on-peak periods. In the civilian sector, thermal storage systems have been effectively used to lower energy costs; however, the Air Force is not taking full advantage of this technology.

Specific Problem

The Air Force may be wasting money by not employing thermal storage systems in its facilities. This thesis will illustrate if and where ice storage type thermal storage systems are cost effective for Air Force applications within the CONUS. In addition, the savings potential realized from these systems will be optimized by determining which type of facility is best suited for thermal storage.

Research Objective

The objective of this study will be to develop a data base consisting of the potential dollar savings affiliated with the application of packaged ice thermal storage systems to typical facilities at CONUS Air Force Bases. This data base will include the climatic regions and bases lending themselves to the benefits realized from packaged ice thermal storage systems.

Focus of Study

Determining the potential savings associated with packaged ice thermal storage systems for specific Air Force bases is the nucleus of this study. Actually designing a thermal storage system for Air Force application is not an objective. This action will be left up to the Base Civil Engineer if he or she decides thermal storage systems are worthwhile investments. However, the data base generated in support of the specific objective of this study can be used by the Base Facility Programmer as a tool in his or her decision making process as to whether to include thermal storage in the design of new or retrofitted facility projects.

Investigative Questions

Investigative questions relevant to determining the validation/application of ice storage systems to the Air Force are:

1. Are the Air Force electrical bills structured in such a way that savings realized from air conditioning demand load deferment are cost effective?
2. Which ice storage system is best suited for Air Force application?
3. What type of facility best lends itself to thermal storage systems?
4. What is the maintenance history of ice storage systems in civilian facilities employing these systems?
5. Are thermal storage construction incentives offered by some electrical utility companies applicable to the Air Force?

Scope

The limitations of this study consists of:

1. Use of package ice storage thermal storage systems
2. Air Force facilities within the CONUS

Packaged ice storage thermal storage systems was chosen for this study for two main reasons. First ice storage systems have overtaken the chilled water storage systems market because ice storage systems are more warrantable by their manufacturers than the chilled water type (9:19). Secondly, package systems relieves the engineer and contractor of the burden of designing and installing a field-customized thermal storage system and it also provides single-source support and responsibility for system performance. In addition, packaged systems significantly reduce on-site space requirements, an especially important consideration when retrofitting thermal storage into existing facilities (18:37).

The CONUS limitation on the Air Force Bases chosen for this study stems from the basic requisite supporting the being of thermal storage systems. This requisite is that thermal storage systems exploit the electrical billing incentives issued by utility companies residing within the CONUS. This author's literature research has not indicated that foreign utility companies are offering similar incentives, and without these incentives thermal storage systems offer no benefit.

Background of Thermal Storage Systems

The Electrical Power Research Institute is today's premier organization conducting research on thermal storage systems. In their 1989 report on commercial cool storage, they provide the following information on the background on thermal storage systems and the types of systems available.

Peak loads for most electric utilities occur during business hours, coincident with the peak demand for electricity by office buildings, stores, and other commercial-sector energy users. For summer-peaking utilities, as much as 30% of commercial peak demand can be attributed to space cooling. Consequently, deferring the use of electricity for commercial space cooling to off-peak periods can significantly reduce utility peak load growth while improving load factors.

Cool storage technologies shift the timing of maximum cooling energy purchase from on-peak periods, when a building is already consuming a significant amount of energy to meet occupant need, to off-peak periods, when energy use is ordinarily low. Typically, this is done by chilling a storage medium (chilled water or ice) during the night, storing it in a tank, and drawing from it during the day to provide cooling. This reduces building on-peak electricity demand without sacrificing occupant comfort.

The advantages to the customer can include first cost benefits, a lowered electric bill and increased operational flexibility. The capital savings from reduced equipment size can in some cases exceed the added cost of the storage system. In addition, many electric companies now offer cash incentives for cool storage installations, reflecting the utility's savings in generation plant investment. The use of cool storage decreases electric costs by reducing the building's peak demand. Most utility commercial and industrial rate schedules include a charge based on the user's highest demand during each monthly billing period.

Many rate structures also impose a demand ratchet, whereby some portion of the annual peak demand establishes a minimum throughout the year, even though the actual demand for subsequent billing periods may be far less. A further savings is available in those areas where time-of-day rates offer lowered electric price for nighttime use.

Storage cooling systems can be characterized both by the mode of operation, either full or partial storage, and by the storage medium employed, either water or ice. Ice storage systems offer the advantage of smaller space requirements and are available as packages from several manufacturers. Chilled water storage operates at higher temperatures and is therefore generally more energy

> efficient, and chilled water systems are more familiar to designers and operators, leading to easier use. (14:1-2)

Organization of the Thesis

This thesis will be organized in accordance with AFIT *Style Guide for Theses and Dissertations*. The first chapter is the introduction of the thesis and it basically answers the management questions and states the case for this thesis.

The second chapter will be dedicated to the literature search germane to the topic of this study. It will specifically deal with the validity and effectiveness of thermal storage technology.

The third chapter will include the methodology used to both gather and analyze data to accomplish the specific objective and address the specific problem of this study.

The fourth chapter will contain the actual analysis of the data obtained and in addition it will contain the data base as delineated in the specific objective.

The fifth chapter will summarize the results of this study and present the conclusions that are made evident through this work.

Key Terms

Thermal Storage - a technique for shifting all or part of the air conditioning requirements from peak to off-peak hours. It offers the potential to reduce peak electricity demands and generate significant savings in electric bills (14:i). Thermal storage can also be defined as systems that produce water or ice at night, store it, and draw from it during the day. These systems offer utilities an opportunity to fill off-peak valleys and reduce peak load growth while they provide comfortable cooling for commercial buildings (15:i). Some other terms interchangeable with thermal storage are, chilled storage, cool storage, ice storage, and chilled water storage.

Demand Load or Billing Demand - the maximum KW or electrical demand energy, used by an entity during a specific time period, usually 15, 30 or 60 minutes (20:64).

Ratchet rate - a type of billing demand that is based on a percentage of the peak demand for any one month. The billing demand remains at this ratchet rate for one year even though the actual demand for the succeeding months may be less (20:64).

Cold Air Distribution - the use of primary supply air in air conditioning systems at temperatures lower than 53 degrees Fahrenheit (5:20).

The following table provides a listing of the abbreviations used in this study.

TABLE 1.1

LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
A	Number of months typically greater than the ratchet percentage of the peak load.
B	Number of months typically less than the ratchet percentage of the peak load.
C	Initial differential system cost.
CDD	Cooling degree days
CONUS	Continental United States
D	Demand charge
F	Annual ratchet factor
HDD	Heating degree day
HVAC	Heating ventilation and air conditioning
K	Amount of shifted energy
kW	Kilowatts
kWH	Kilowatt-hours
LEH	Latent enthalpy hours
NPV	Net present value
OFF PEAKDEM	Off-peak demand load
ON PEAKDEM	On-peak demand load
ON/OFF ENG DIFF	Differential between on and off-peak demand loads.
P	Peak power reduced by TSS.
PAS	Potential annual savings
PCDL	Potential annual cooling demand load favorable for thermal storage
Q	Approximate annual adjusted cooling load.
r	Percent cooling load to be shifted.
RAD	Radiation and daylight index
RF	Ratchet factor
S	Annual savings
SC	System cost
SPB	Simple pay back
SPDL	Summer peak demand load
T	Required storage capacity
TSS	Thermal storage system
W	Numbers of hours of window shift
X	Percentage factor ratio

II. Literature Review

Overview

This chapter involves an investigative research of literature addressing the topic of thermal storage systems. It includes data on the validity of thermal storage systems, the effectiveness of thermal storage, what type of facility is suited for thermal storage, what types of thermal storage systems are available, and information on the sizes of these cooling systems.

Validity of Thermal Storage Systems

As with all new technologies, validity is one of the predominant questions that should be answered. The following paragraphs address this question through the viewpoints of several known experts in the field of thermal storage. These individuals are noted to be expert by the American Society of Heating, Refrigerating and Air Conditioning Engineers (12:31). Following the experts' exegesis, some conclusions are drawn about their opinions.

The first expert, Fredrick J. Pearson, P.E., is vice president and chief mechanical engineer of Henry Adams Inc., Baltimore, Maryland. He notes that the "design and construction options available through the combination of ice-storage/low temperature air (also called "cold air" and "chilled air") distribution systems could rapidly make off-peak generation with ice storage the dominant method of providing cooling energy in new office buildings (12:28)".

Pearson describes two typical conventional air conditioning systems and compares these systems to ones that employ thermal storage systems. The results of his comparison showed many benefits of air conditioning systems with thermal storage over the conventional type. These benefits are: (12:28,30)

1. improved indoor air quality
2. lower operating cost
3. reduced electrical power requirements
4. lower construction costs
5. improved occupant comfort
6. increased revenue potential

The second expert, Charles E. Dorgan, is a professor and director of the Energy Technology Center at the University of Wisconsin-Madison. He is also president of Dorgan Associates, a consulting firm primarily involved in thermal storage, industrial heating and cooling processes and innovative air conditioning. Dorgan describes the attributes of cold air distribution and shows why this product of thermal storage systems is auspicious. He first describes the relationship between cold air distribution and thermal storage systems. He notes that, cold air distribution is a technology that makes cool storage competitive with the first cost of conventional air conditioning, and it reduces the electrical demand related to air conditioning. Because cold air distribution has both first and operating cost benefits, Dorgan feels applicability of thermal storage should be analyzed for all new facilities and wherever existing facilities are upgraded or cooling capacity is increased (7:20). Even in its short widespread existence, Dorgan claims that cold air distribution in its current form has become the preferred system in multi-story and large facilities in London and in some locations in the U.S. He also says that he cannot foresee any reason why cool storage and cold air distribution will not be the state-of-the-art system in five years. He maintains it is a win-win situation for the following reasons (7:24):

1. lower first cost
2. lower operating cost
3. better comfort
4. lower electric demand
5. increased air-conditioning demand factor
6. good retrofit option

The third expert, Dr. MacCracken, president of Calmac Manufacturing Corporation, Englewood, New Jersey, and an active participant on many ASHRAE Society committees, also supports the validity of thermal storage systems. He lists the major changes that have evolved in thermal storage systems over the last four to five years. These changes demonstrate the emergence of thermal storage from a good idea to a healthy and growing technology. They are (10:18,20):

- Commercial cool storage becoming predominant as summer load peaks proliferate.

- Chilled water storage evolving into ice systems caused by the marketing by manufacturers of warrantable package products.

- Single point responsibility of entire systems provided by manufacturer's representatives and distributors.

- People asking, "Does it fit my building?" instead of "Does it Work?"

_ Cool storage becoming international as American-designed ice banks are made and sold around the world.

- Cost of a partial storage system, in which a downsized compressor runs all hours, becoming competitive with a non-storage conventional central system.

- Computer models providing key engineering design and reliable data assisting the problems in mastering a new technology.

- Utilities offering a variety of incentives to promote use, including cash subsidies and high demand charges as their summer peak loads grow.

- The lowering of distributed air temperature in so-called cold air systems providing lower cost, lower energy use, more usable space, greater comfort and a technology perfectly adapted to the temperature of ice.

- Recovering both condenser heat for winter warmups and consequent ice for afternoon cooling yielding substantial energy savings.

- The strong and very effective support of the Electric Power Research Institute (EPRI).

The fourth expert, Ronald D. Wendland, also praised the results noted from the employment of thermal storage systems across the United States. Wendland is the senior project manager for thermal storage technology-customer systems division, Electric Power Research Institute, Palo Alto, California. He cites several studies conducted by the Electric Power Research Institute. The result of these studies unanimously endorse thermal storage systems. The first study he mentions discounts the claim that cold air distribution causes poor indoor air quality. Although the final results of this study were not available at the publishing of his article, the preliminary findings indicate that cold air systems do not promote the growth of unusual types or concentrations of microorganisms that may be detrimental to human health. In another study, EPRI indicates that cold air distribution actually increases human comfort because of reduced humidity associated with cold air systems (21:30,32).

Wendland finishes his article by predicting the future of thermal storage systems. In essence, he claims that the past breakthroughs in this new technology is only the beginning to the advances yet to be made.

These authors maintain the technology supporting thermal storage systems is sound. In addition, their unanimous opinion suggest that thermal storage systems offer competitive investment costs plus many operational benefits over conventional air conditioning systems. From these professional opinions it is evident that thermal storage systems are a valid, if not preferred, technology over many conventional air conditioning systems.

Effectiveness of Thermal Storage Systems

Now that the question of the validity of thermal storage systems has been answered, the question of effectiveness should be addressed. A reliable method of approaching this question is to examine facilities currently employing thermal storage systems and evaluating the effect of these system over time. Three case studies are presented to accomplish this task.

Case Study One. The Worthington Hotel in Fort Worth is the subject of this case study. This hotel consists of 525,000 square feet of air conditioned space. The demand period set by the local electrical company is Monday through Friday from noon to 8:00 pm, and the demand is recorded in fifteen minute intervals. In 1986, a thermal storage system was installed to help reduce the electrical demand cost which typically ran around 2,484kW during the summer. This system became operational in August 1987, and reduced the electrical demand by $78,336 in its first year (8:42).

The storage system installed was an ice-harvesting type. This system makes ice during off-peak hours and stores the ice in an insulated storage tank. During peak demand hours, the chillers are turned off and the ice is used to cool the facility. The total price tag for this conversion was $350,000 (8:42).

One incentive made this retrofit particularly attractive. The hotel management informed the local electric company of their plan to install a full load thermal storage system to defer the electrical demand for the hotel from on-peak to off peak periods. The electric company was so enthused with this idea that they decided to participate in the project with a $200,800 inducement payment. This reduced the total project cost for the hotel to $149,200 (8:36,42).

With the inducement payment, the simple payback period for this project was only 1.9 years (8:42). This case study demonstrates the potential cost benefits affiliated with thermal storage retrofits.

Case Study Two. This case study involves a utility company that installed a thermal storage system on a new computer facility. This new facility has 100,000 square feet of conditioned space where 20,000 square feet is devoted to computer and telecommunication equipment (9:36). The focus of this article evolves around the decisions associated with installing a new cooling system for a new facility addition. The selection process of choosing the most effective energy saving system involved not only the first cost considerations, but also operational savings considerations.

> A myriad of possible mechanical systems were evaluated. Water source heat pumps with stand-alone computer room units were considered as the basis of comparison due to lowest initial cost. Against this option were evaluated such diverse systems as ice storage, gas-fired absorption chillers, and cogeneration-fired absorption chillers. Ice storage emerged as the clear-cut choice when considering the utility cost advantages, the relatively small increase in capital cost, and the much lower maintenance costs. (9:36)

This study also demonstrated how low temperature air and water distribution associated with thermal storage systems reduced capital costs for the new computer facility.

> Utilizing low temperature water and air presents several near- and long-term benefits. Because 40 percent less air is circulated, all air handling equipment and ductwork are dramatically reduced in size. Fan and pump horsepower requirements are also reduced. In general, capital cost reductions associated with the low temperature air and water are sufficient to offset the cost of the ice tanks. (9:38)

New facilities are particularly good candidates for thermal storage systems as demonstrated in this case study. Not only do these systems offer excellent cost savings in demand reduction, but the service of cold air and water distribution actually reduces the initial investment costs of the total air conditioning system.

Case Study Three. By employing two thermal storage systems, the Christian Broadcasting Network (CBN) located in Virginia Beach, Virginia, was able to save $165,000 in first year operating costs through the advent of reducing demand load costs. This savings constituted a reduction of electrical demand charges of approximately 31 percent. The systems installed were a R22 storage system and a glycol ice storage system. The first system was designed into a new 290,000 square foot multi-purpose building, where its purpose was intended solely for electrical peak load shedding. The second system was retrofitted into an existing chilled water system supplying chilled water to three separate facilities. This system gives CBN backup cooling to its engineering equipment used for television production. It also gives the ability to shed unpredictable KW loads generated by the studio's lighting and cooling demands (6:45-52).

From these three case studies, it is evident that thermal storage is an effective technology. Not only are the demand savings realized from these systems significant, but the actual capital investment costs are competitive with conventional air conditioning systems which do not promise any electrical demand cost benefits. These studies also show cool storage systems can be beneficial if used on either new systems or on existing systems. The following table summarizes some of the notable aspects of these cases.

TABLE 2.1

CASE STUDIES SUMMARY

CASE STUDY	SYSTEM TYPE	CHARACTERISTICS
One	Ice-harvester Retrofit	Initial cost of system was $350,000, however a $200,000 inducement payment from the utility company

TABLE 2.1 (CONT)

CASE STUDIES SUMMARY

CASE STUDY	SYSTEM TYPE	CHARACTERISTICS
		reduced the total initial cost to $149,000. This allowed a simple payback for the project to be only 1.9 years.
Two	Ice-on-coil New construction	This case demonstrated that ice storage was chosen over other alternatives such as cogeneration-fired absorption c lers and gas-fired rption chillers. It also d the beneficial initial and rational costs of thermal storage, particularly when cold air distribution systems are utilized.
Three	Ice-on-coil New construction Ice-harvester Retrofit	This case demonstrated the potential savings that can result from thermal Ice storage. The first year operations of these systems produced a savings of $165,000.

The only negative connotation surrounding thermal storage systems is the newness of the technology. Nevertheless, the abundant benefits associated with today's technology of thermal storage at least merits the interest to investigate the feasibility of these systems in lieu of conventional systems.

Types of Thermal Storage Systems Available

Thermal storage systems can be categorized into three major groups, water or sensible storage, eutectic salt, and ice or latent storage.

Water Storage. In the beginning years of thermal storage, sensible storage was the principal system of choice. Its simple design and suitable operational temperatures permitted lower initial costs than its ice storage counterpart. Since then, technology advances in ice storage have amplified the disbenefits of water storage systems, such as large storage tanks. Thus the early year cost advantages of water systems are now overshadow in many cases by the small storage volume and the cold air distribution benefits associated with latent storage. There are a myriad of water storage designs available, however, these designs will not be addressed in this report since the emphasis of this study is ice storage.

Eutectic Salt System. In a eutectic salt system, the typical evaporator temperature for the icemaker is about 20 F. These systems freeze and thaw at temperatures of 47 F. The latent heat of diffusion is about 3.5 times less than that of ice (17:14). The efficiency of these systems is better than either the chilled water or ice systems. The hesitation of using these systems comes from the newness of this technology. In a few years, these systems are anticipated to be very competitive with the traditional chilled water and ice systems.

Ice Storage. According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), there are three basic types of latent storage systems available for commercial use. They are static-direct contact, static-indirect contact and dynamic-direct contact.

> Probably the most numerous applications are of the "ice on coil" which can be described as static direct contact storage. Either refrigerant or a secondary coolant is circulated through a pipe coil that is immersed in a tank of water so as to build ice on the pipe coil. The chilled water circulated through the tank and to the load is in direct contact with the ice (see Fig 2.1).
>
> The static-indirect contact type which freezes water in containers, uses a secondary coolant to freeze as well as to melt the storage. The secondary coolant circulates through the storage and to the load (see Fig 2.2).
>
> The dynamic-direct contact systems are commercially available in two types. The "ice harvester" uses an ice generator located over a storage tank. Water is circulated over the ice generator from the storage by one pump. Another chilled water pump delivers from the storage to the load coils and back over the refrigerated evaporator plates (see Fig 2.3).
>
> The "slurry generator" uses a binary solution of a small percent glycol in water. A slurry of ice crystals in glycol is generated in the refrigerated evaporator and then pumped into the storage tank. Then the cold "brine" is circulated to the load (see Fig 2.4). An interesting and important characteristic of the slurry systems is that the temperature of the storage indicates the amount of ice in storage. As more ice is formed the freezing point of the remaining glycol is depressed as it becomes more concentrated. Thus the temperature of the storage becomes a control input for operating the system. (11:3-2)

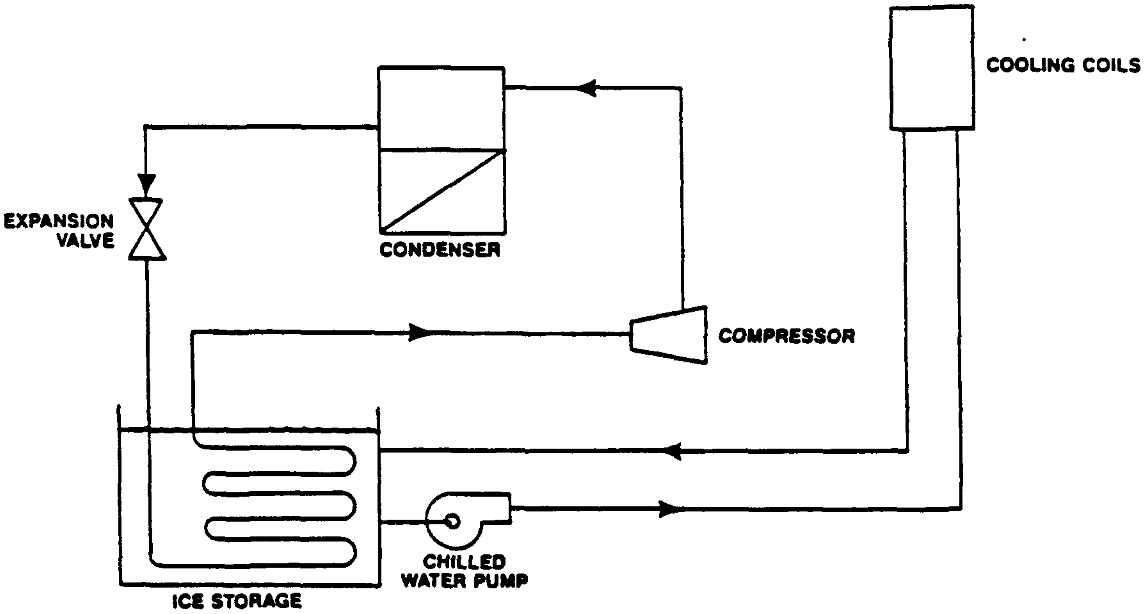

Figure 2.1 Static Direct Contact Storage System (11:3.6)

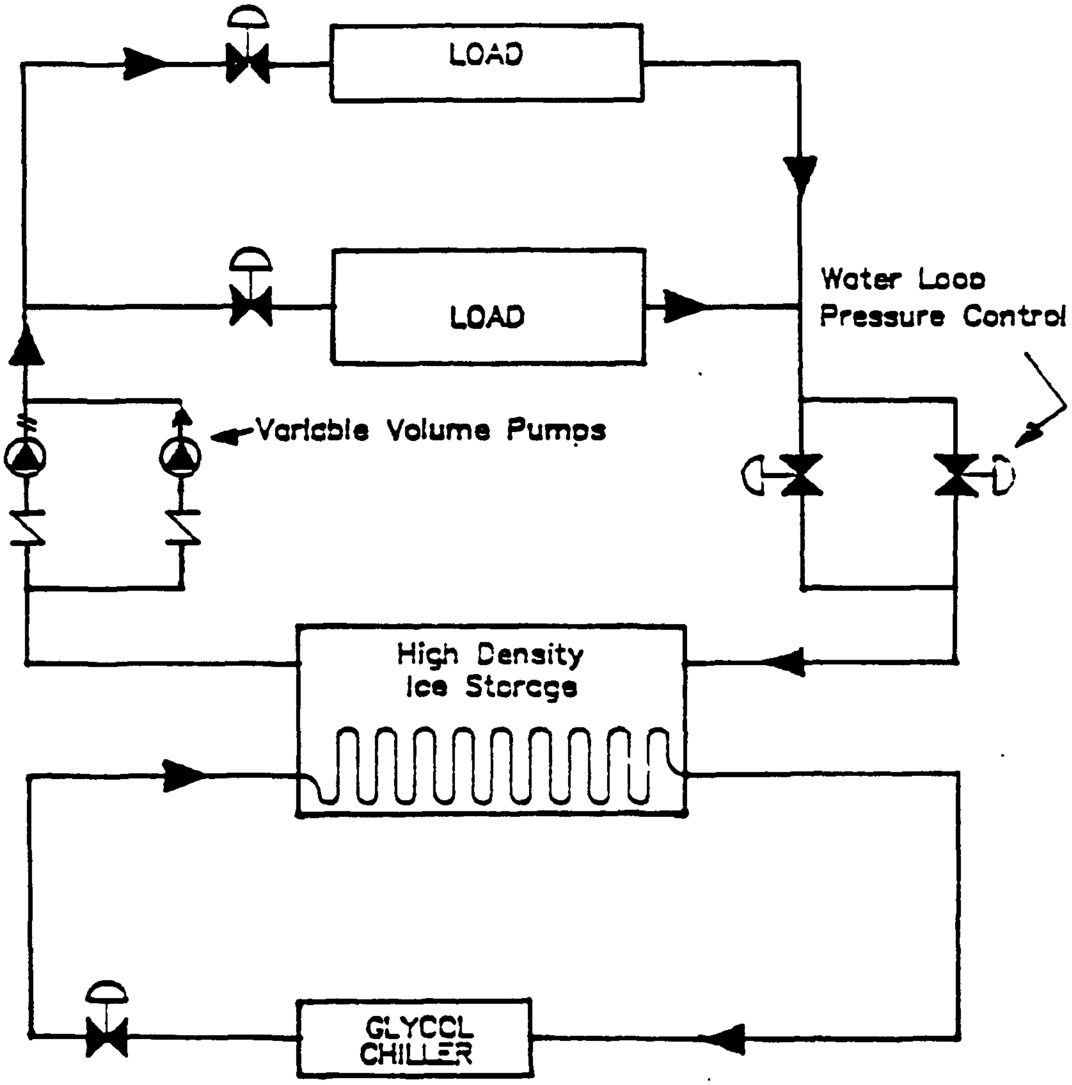

Figure 2.2 Static Indirect Contact Storage System (11:3.7)

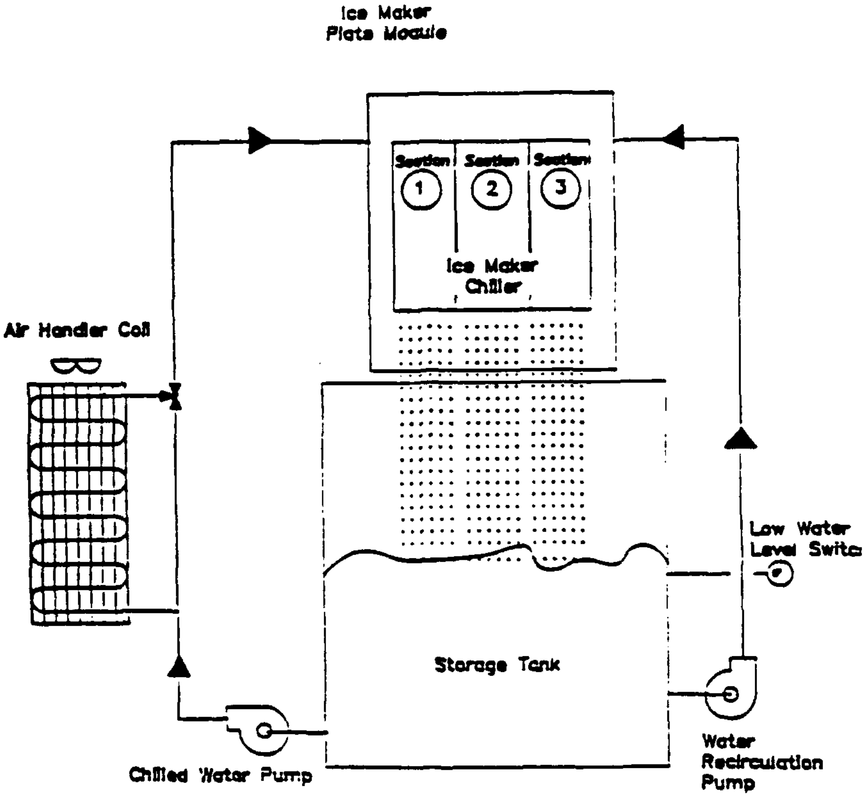

Figure 2.3 Dynamic Direct Contact Storage System (11:3.8)

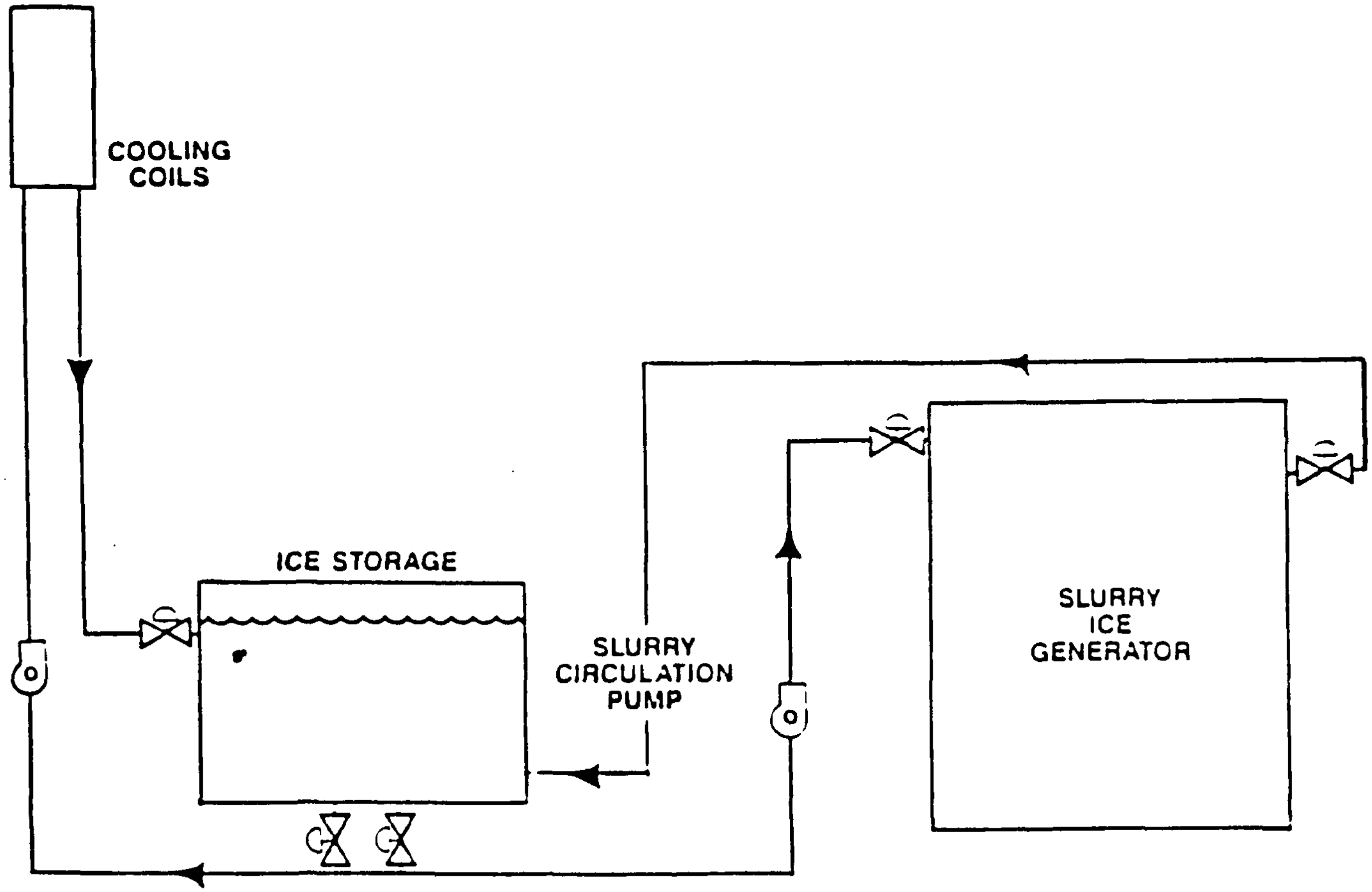

Figure 2.4 Slurry Generator Storage System
(11:3.9)

Another discriminator among ice systems is package systems verses custom systems. Laura Thomas delineates in her article "A Case for Packaged Thermal Storage Systems" that custom systems require much expertise in design. She says that the integration of the wide range of components from various manufactures necessitates careful planning and execution for the system to be efficient and reliable. One item of particular concern is matching the compressor package or brine chiller with the correct ice tank. If the compressor is too large, high operating costs will be incurred. Likewise, a high initial cost will be incurred if the storage tank is oversized. Large scale applications, over 400 tons, can probably afford the care and expense associated with custom systems, however smaller systems are usually more suitable for packaged systems.

A package system can be either a static-direct contact, static-indirect contact or a dynamic-direct contact type. They usually include all the controls, chilling and storage equipment in one self-contained, skid mounted, factory packaged unit. Since the components are self-contained, the matching problem mentioned above is not a concern. Additionally, accountability and warranty is much clearer with a package unit since one manufacturer is responsible for the unit (17:39). Obviously the ultimate choice of system type is left up to the actual designers since they have the data to make the best decision. However, because of the mentioned advantages, this study recommends package ice storage systems over the other available systems in most Air Force applications.

Facility Types Suited for Thermal Storage

The best type of facility conducive to packaged ice thermal storage systems is a new facility under design that has an expected cooling load range of 100 to 400 tons. In addition, this facility must have a period during off-peak hours when its air conditioning system is not required to cool the conditioned envelope. A new facility is best because the thermal storage equipment is a part of the original plan and infrastructure of the facility. From this vantage point all the initial cost incentives and benefits of a thermal storage system can be fully realized.

There does not appear to be a best category of facilities according to function that best lends itself to thermal storage. The driving factor as alluded to above is the cooling load of the facility and the cooling load characteristic of the facility. The larger the window of non-operation, the smaller the mechanical equipment can be. For example, consider a full storage thermal storage system that must defer 100 tons of cooling for a four hour peak period. The size of the chillers to make the ice for this system is proportional to the time the chillers can dedicate its efforts to building ice to handle the peak load. Ergo, an ice-building window of 16 hours requires about one half the chiller size of an ice-building window of 8 hours. In some extreme cases, such as churches, a very small chiller may be adequate to handle a very large peak load since the window of ice-building is large.

When considering existing facilities to install thermal storage, it is best to consider first those facilities in which the existing air conditioning systems need replacement and also meet the load and non-working periods requirements mentioned above. As mentioned earlier, the initial cost of thermal storage systems is competitive with the first costs of conventional air conditioning systems. Therefore if a facility's air conditioning system is scheduled for replacement, the additional cost of installing a storage system is minimal.

The Army has identified the following characteristics that should be considered when determining a facility for thermal storage. These characteristics are:

1. The facility has a sharp peak load coinciding with the installation's peak electrical demand.
2. The installation's electrical demand charge is high.
3. The facility has a well defined occupancy schedule.
4. The facility is separately metered, or at least has its own chiller to cool it (for monitoring performance).
5. The installation will strongly support the project.
6. The facility has space available for installing the cooling system.
7. Experienced contractors are available locally. (17:17)

Choosing facilities for thermal storage retrofit is the final option that should be considered. Retrofitting a facility with thermal storage can incur excessively high initial costs because the initial air conditioning system must be altered to accommodate the thermal storage equipment. This alteration may also require extensive design costs depending on the location and condition the existing air conditioning system is in. One important factor to consider when appraising a facility for retrofit is the type of chiller connected with that facility. Many ice storage systems are designed to take advantage of the benefits associated with cold air distribution systems. When this is true, the temperature of the cooling medium is much colder than that of conventional distributed air temperatures. For some equipment, this temperature difference creates problems. According to Laura Thomas, product manager of thermal storage, York International Corporation, centrifugal chillers do not work well under these retrofit conditions. Positive displacement chillers on the other hand have no problem handling the cold medium, however minor modifications may be required on the thermal expansion valves and reset controls of these chillers (18). The main point of this explanation is not to discourage retrofitting as an option for thermal storage, but rather to urge careful consideration when discriminating facilities for this application.

Sizes of Cooling Systems

Packaged ice thermal storage systems come in various sizes. The common unit used in sizing these systems is the Ton-hour. A Ton-hour refers to the total amount of stored cooling available. To compare thermal storage and water chiller ratings, the length of time a thermal storage system is required to provide cooling must be specified. For example, a 1000 Ton-hour thermal storage system can provide 200 tons for five hours or 100 tons for ten hours (2:38). As stated earlier in this report, when considering what size of cooling system is more appropriate for thermal storage, the period of "ice-burning" and "ice-building" must be considered. Consider a hypothetical case where two facilities requiring 100 tons of cooling with identical "ice-burning" times are being considered for thermal storage. If facility "A" has a non-cooling off peak period of ten hours and facility "B" has a non-cooling off peak period of 8 hours, which facility should be chosen to implement thermal storage? The obvious answer is facility "A" since the chiller system has more time to build ice than in facility "B". Thus smaller equipment sizes can be installed in facility "A" to meet the cooling load. Since this study considers the potential savings associated with Air Force bases, as opposed to specific facilities, certain considerations must be made to properly aggregate base facilities conducive to thermal storage. Because of the various cooling equipment located on an Air Force base, a decision on which equipment size to consider for thermal storage implementation is necessary. For this study existing cooling systems of 50 tons or greater are considered as potential recipients for thermal storage. Even though a 100 ton minimum seems to be the most economical choice according to this author's literature search, the large number of 50 to 100 ton units located on Air Force bases warrants the attention granted to these systems.

The procedure used to aggregate the base cooling systems is described in detail in the methodology section of this study.

Maintenance History of Ice Storage Systems

Since the implementation of ice thermal storage systems is relatively new, the maintenance history over the entire economic life of a storage system was not available. However, several users and manufacturers of thermal storage systems were contacted and queried about the maintenance requirements of their systems. The consensus among all parties was packaged ice thermal storage systems, as well as custom built systems, required no more maintenance and expertise than do conventional air conditioning systems. Some of the comments made by the parties contacted are described in the following paragraphs.

Mr Redding, chief of hotel maintenance at the Worthington Hotel in Fort Worth TX, said that they have not had any serious maintenance problems with their thermal storage systems since installation (see case study one for details of system). He mentioned there was one minor problem at first with the viewing plates freezing up, but the problem was solved by installing a solenoid valve ahead of the defrost cycle (13).

Mr Finn Andreasen, maintenance supervisor at Bolar Pharmaceutical Company, maintained that their 80 ton ice-harvester system, installed in summer of 1989, has not had any maintenance requirements other than reoccurring maintenance similar to a conventional system. His staff maintains the system as recommended by the manufacturer and they did not have any prior experience with thermal storage systems (1).

Mr Bob Seidler, supervisor of building services at the Christian Broadcasting Network (CBN), agrees that the maintenance requirement on his thermal storage systems is similar to the maintenance required for conventional systems (see case three, chapter two of this study for further details of these systems). He claims the key to a successful system lies in proper commissioning. Therefore close quality assurance, as in any mechanical system, should be exercised when installing a new thermal storage system.

He also mentioned that some training may be necessary for maintenance personnel since most new systems are solid state, however, this requirement also applies to new conventional systems since they too use electronic components and controls (16).

Ms Laura Thomas, product manager of thermal storage, York International Corporation, also confirmed that packaged ice thermal storage systems required no more maintenance than do conventional air conditioning systems. She did mention that she had experienced some problems with the refrigerant pump failing in some ice-harvester systems (19).

Mr Tom Bosiger, representative of Turbo Refrigerating Company, stated he did not know of any specific maintenance requirement associated with their ice-harvester systems that are unique from conventional maintenance requirements. He also said that well-trained conventional air conditioning personnel should be able to perform the maintenance on their ice storage systems (2).

Dr Chang W. Sohn, co-author of the USACERL Technical Report E-89/13, "Market Potential of Storage Cooling Systems in the Army", claims in his report that the maintenance requirement for thermal storage systems is expected to be the same as the maintenance service required by a conventional cooling system (3:14).

Incentives

One aspect that makes thermal storage systems particularly attractive is monetary incentives sometimes offered by electrical utility companies. The private sector has experienced these benefits as delineated in the previous case studies, however, the Air Force has yet to benefit from such incentives. According to Dr Sohn, the utility companies' motivation behind these incentives 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 (3:19). The types of incentives offered vary depending on the utility company and the circumstance. Some only provide the investigative design funds to determine if thermal storage is warranted for a particular application. In the appendix of this report a copy of such a contract as written by a utility company is provided. Other types of incentives include the utility company providing construction funds to offset the initial implementation cost of installing thermal storage systems. This type of incentive is particularly attractive because this action can drastically reduce the payback period of the system.

Because of their large electrical demand, most Air Force bases should be good targets for incentives. However, in order to receive these benefits, the Air Force must enter into a contract with the utility company that is offering the incentive. Since this contract must be subject to the Federal Acquisition Regulations (FAR), it must be a mutually binding, legal relationship obligating the seller to furnish supplies or services and the buyer to pay for them (7). In addition, this contract must include the following elements:

1. Offer and acceptance with terms and conditions (mutual consent by both parties).
2. Consideration (something of value each party gives).
3. Competent parties (has legal ability to contract).
4. Lawful purpose.
5. Certainty of terms.
6. Form required by law (contract is written) (7).

Since the government is usually purchasing a service or a good from a contractor, the normal format of the aforementioned definition and elements of a contract is catered to this flow. However, when considering thermal storage incentives, the government is receiving the monetary benefit. Eventhough this may require the contract to be a sort of hybrid, it is legal to effect. A similar example of this type of contracting is the build to lease contract that was authorized under section 801 and 802 of the Military Construction Act of 1984. This type of contract allows a contractor to build housing units at his own expense to be occupied by military members where the government pays the rent. The parallel in this contract with an incentives contract is like the utility company, the housing contractor is investing his capital to receive a future benefit from the government. In the build to lease contract the benefit is the future rent to be paid by the government, whereas in the incentives contract the future benefit is the reduced costs associated with a lower electrical peak demand the utility company must provide.

Although the requirement of entering into a government contract may deter some utility companies from offering the Air Force incentives, the opportunity still exists for the Air Force to exploit these benefits to offset the implementation cost of thermal storage systems. The motivation to streamline the contracting process should be high in this case since the Air Force is in a situation to receive a no-cost benefit.

Back in August 1988, at least 27 utility companies throughout the CONUS were offering some type of incentive to promote the use of TSS by its private sector customers (3.19). Since then, on-peak demand loads have become an even greater concern to utility companies due to the increased construction of more air conditioned commercial facilities. This phenomenom suggests that even more utility companies may be interested in offering incentives to those customers that can shift a significant portion of their demand load to off-peak periods. If the Air Force can pinpoint these utility companies and take advantage of their incentives, the economic analysis of the TSS's resulting from these inducement payments should be extemely promising. Unfortunately, this research does not include locating these utility companies; therefore, future study of this area is highly recommended.

III. Methodology

Overview

In this chapter the method to be used to determine where the Air Force can save money by employing packaged ice thermal storage systems will be discussed. First the methods used to obtain the data for this study will be presented. Next, the methodology for analyzing this data will be discussed. Finally, the steps used to answer the investigative questions presented in chapter one will be addressed. It should be noted that most of the quantitative methodology used in this chapter is based on the methodology derived in the USACERL Technical Report E-89/13, "Market Potential of Storage Cooling Systems in the Army", authored by Chang W. Sohn and Gerald L. Cler. A copy of this report is provided in Appendix B of this thesis.

Data Collection Procedures

Before the procedure for collecting the data for this study is discussed, the type of data needed should be addressed. This study uses both qualitative and quantitative data. Qualitative data is required to validate and determine the effectiveness of thermal storage systems in general. This is important because if the technology cannot be validated, the case to be made for this study is worthless. The quantitative data provides the data base used to calculate the potential effectiveness of packaged ice thermal storage systems at each Air Force location studied. The term potential effectiveness means the amount of dollars that can be saved using packaged thermal storage systems compared to conventional air conditioning systems that do not exploit demand load deferment. One final type of data necessary for this study is that data which identifies the feasibility of employing packaged ice thermal storage systems in Air Force facilities. If packaged ice thermal storage systems cannot be maintained or easily operated by the existing base work force, these systems should not be used by the Air Force unless the benefits prove greater than the cost of training and/or obtaining more personnel to service the systems, which is unlikely.

The qualitative data used to validate and determine the effectiveness of thermal storage systems was obtained through a literature search. The data, mostly historical in nature, primarily focused on either opinions of respected experts in the field of heating, ventilation, and air conditioning (HVAC), or on case studies documenting the advantages/disadvantages of thermal storage systems experienced by existing users of such systems. Most of the sources for this data came from established professional journals such as The Journal of American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), Heating/Piping/Air Conditioning Journal (HPAC), Engineered Systems, and Energy User News. Other sources included research reports from EPRI and other technical reports relative to this study.

The quantitative data necessary for this study was obtained from several different sources. The data required to determine the gross potential savings for each base rely upon the electric demand rates and the air conditioning load sizes per facility for each base. This data was acquired from individual bases by sending out a data form to each base requesting specific information about base electrical rate structures. Base real property records were also requested from these bases to obtain the air conditioning load sizes for each CONUS Air Force base.

Another source of quantitative information needed is the typical cost of packaged ice thermal storage systems for a given size system. This data was collected by contacting different manufacturers of such systems and requesting budget quotes detailing equipment and installation costs.

The last type of data needed was that which defines any special operation or maintenance necessary for the employment of packaged ice thermal storage systems. This data was gathered by querying existing owners and manufacturers of packaged ice thermal storage systems.

Data Analysis

The questions concerning the validity and effectiveness of thermal storage systems is addressed in the literature review in chapter II. To address this issue the review includes sections subtitled as, validity of thermal storage, and effectiveness of thermal storage.

The validity section contains the opinions of several known experts in the field of HVAC. Each opinion was evaluated to determine if it supports or rejects the notion of validity concerning thermal storage technology.

The effectiveness section presents several different case studies as documented in several different professional journals. From these studies, an inference was drawn as to whether thermal storage systems can produce significant cost savings and to what magnitude of savings can be expected for a given size and type of facility employing thermal storage systems.

A conclusion following the effectiveness section consolidates the information in the validity and effectiveness sections and makes an inference of whether or not the technology of thermal storage is appropriate for Air Force use.

The quantitative data was used to accomplish the specific objective of this study-that is, to develop a data base depicting potential cost savings available to bases that choose to employ packaged ice thermal storage systems. The data obtained from the electrical rate structure for each CONUS base contains the current cost of energy in KWH and demand load in KW for both on-peak and off-peak periods. To determine the level of savings available to a base, an assessment of the average cooling load for that base was estimated. This estimate was calculated by comparing the summer peak demand load to the winter peak demand load. This action required the following assumptions:

1. No new or additional electrical loads are placed on the base system between the measured summer and measured winter demand. However, if more loads are in fact added, this will only make the calculated potential savings more conservative.

2. The demand loads do not include military family housing since the saving potential is calculated only for industrial and/or commercial facilities. This is not a blind assumption since the segregation of data was requested in the letter requesting the data from each base.

3. The difference between the summer and winter demand peaks depict a conservative savings potential since year-around air conditioned facilities are not considered in the calculated difference and these facilities may be good candidates for thermal storage.

4. Most chillers for air conditioning run during the peak summer demand period but do not run during the winter demand period (except for the facilities that require year-around cooling - see assumption number 3 above).

5. Air handling units should run equally in summer and winter periods since ventilation is required for both seasons.

6. Other electrical loads such as interior and exterior lights, cold storage equipment, office and other operational equipment, etc. are considered consistent for both summer

utility companies usually fall within normal office hours such as 0800-1700, and deviation of these mentioned electrical loads do not usually change seasonally.

Not all air conditioning systems on base are appropriate for thermal storage. For instance, most of the smaller systems, such as window units and small roof top units, do not merit the effort associated with installing thermal storage since the potential demand load savings are minimal on these systems. Therefore these unlikely candidates for thermal storage must be segregated from the more propitious systems in order to obtain a good estimate of potential savings possible. This task was effected by analyzing the real property records and interpreting a percentage factor from the data that portrays a estimated proportion of choice systems. Specifically, this percentage was obtained by dividing the total base tonnage by the tonnage associated with the favorable cooling systems, units of 50 tons or more. Because of lack of data, one base per region was analyzed. The results from this analysis was then applied to the other bases in the appropriate region. The formulation of the applicable cooling demand load in equation form is:

$$PCDL = X\% \times (SPDL - WPDL) \qquad (1)$$

where

PCDL = potential annual cooling demand load favorable for thermal storage (kW)

X = the percentage factor ratio (%)

SPDL = the maximum monthly Summer Peak Demand Load (kW)

WPDL = the minimum monthly Winter Peak Demand Load (kW)

Once the peak cooling demand loads are approximated for a particular base, then the potential dollar savings resulting from thermal storage can be determined for that base. Since these savings are resultant of the particular electrical rate structure affiliated with a particular base, each base required individual assessment to determine these savings. The individual calculations are shown in Appendix A of this report. The following procedure, however, describes in general the methodology used to determine the potential annual savings for a base. This procedure parallels the methodology used in the USACERL Technical Report E-89/13 (3:15-17).

Annual Savings. The straight demand schedule (no ratchet) annual savings can be calculated by:

$$S/P = D_1 \times F_1 \qquad (2)$$

where

S = annual savings resulting from TSS ($/yr)

P = peak power reduced by TSS (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. This ratchet factor is usually a percentage of the peak monthly demand load realized by a base for the previous 11 months. The billing demand is then calculated from the greater of the actual demand peak for a particular month or the ratchet percentage of the peak load. It is delineated as follows in equation form:

$$F_t = A + (RF \times B) \qquad (3)$$

where

A = number of months typically greater than the ratchet percentage of the peak load (months)

RF = ratchet percentage (%)

B = number of months typically less than the ratchet percentage of the peak load (months)

For bases with schedules other than straight demand calculations, an individual analysis is required (see Appendix A).

Once these savings are determined, an economic analysis of the systems can be performed using the investment costs obtained by the manufacturers. Two types of economic analysis are performed for each Air Force installation studied, the simple payback method and present value analysis. These types of economic analysis were chosen because they are the most common tools used by Civil Engineering when determining if a project is cost effective.

System Cost. One important differentiation between types of applications of packaged ice thermal storage system implementation is the consideration of whether the system is installed as new construction, a replacement of an existing air conditioning system or if it is retrofitted on an existing system. If the installation is on new construction or is a replacement, the initial investment cost of the thermal storage system will not be as critical as compared to a retrofit action. The reason behind this assumption is that according to many professional publications, see chapter II, the initial investment cost of thermal storage systems is competitive, if not less expensive, than conventional air conditioning systems not employing thermal storage. However, existing air conditioning systems requiring thermal storage system to be retrofitted incur all costs associated with the installation and operation of the storage system since it is an addition to an existing system. Therefore it makes more sense to install these systems on new facilities whenever possible.

When considering the initial cost of a thermal storage system, the size of the system must be considered. The typical method of accounting for the size of the system cost is to express the costs in terms of a dollar amount per storage capacity expressed as Ton-hours ($/T-h). In this study, as in the USACERL report, the cost of the TSS is the differential cost between a conventional cooling system and an TSS serving the same building. As mentioned earlier in this report, for new construction and replacement scenarios, the initial cost for TSS employing cold air distribution is practically the same initial cost of conventional systems. Since cold air distribution cannot be assured in every application, this study will assume a cold air system will not accompany the TSS. This means the differential cost for new construction and replacement systems will approximately equal the cost of the ice storage tank. Dr Sohn approximates this initial differential cost to be about $80/T-h (3:13). This figure was confirmed by this author by contacting other manufacturers and requesting budget figures for each application of thermal storage.

For the retrofit option, initial costs are not as clearly defined. In fact, each case could vary significantly depending on the situation. For purposes of this study, two system costs are attributed to the retrofit option, $150/T-h for a realistic scenario and $300/T-h for an upper limit scenario. These are the same amounts Dr Sohn used in his analysis where he claims that "studies have identified paid-for system costs in the range of $100 to $300 per Ton-hour" (3:14).

As delineated in chapter II, the maintenance of TSS is similar to the maintenance of conventional air conditioning systems. Therefore the differential cost for maintenance is considered to be insignificant in this analysis.

Cost of Demand Shifting. Since the size of a thermal storage system determines the cost of the system, a method is needed to determine the different implementation cost for the various sizes and applications of thermal storage systems. Dr Sohn points out in his report that for a typical Army installation a five percent reduction in the peak demand requires a four hour window of peak load deferment. Likewise a ten percent reduction requires an eight hour peak load deferment (3:18). Unlike the USACERL report, this study determined the approximate cooling load conducive for TSS for each studied Air Force installation. Therefore instead of a five and ten percent reduction that includes all the electrical load associated with a base, a 15 and 30 percent reduction of the calculated cooling load is used for the four and eight hour load deferment for each base.

Using these factors the cost of demand shifting can be expressed as follows:

$$K <= (r_i/100) \times Q \times W_i \qquad (4)$$

where

K = amount of shifted energy (kWh)

r_i = percent of cooling load to be shifted

Q = approximate annual adjusted cooling load (kW)

W_i = numbers of hours of window shift (hrs)

The inequality in this equation is due to the geometry of the peak shaving. In the most extreme case the demand profile over the window is a perfect rectangle. In this case K would be equal to $(r_i/100) \times Q \times W_i$ (3:17). For more detailed information on this see page B.11 in Appendix B.

To determine the cost of the shifted energy, it must be expressed in terms of Ton-hours. The following explanation describes this conversion process.

> 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 TSS 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 TSS, the evaporator temperature must be about 20 degrees F lower than that of a conventional chiller. The lower evaporator temperature implies the suction temperature of the ice maker to be about 20 degrees F. 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 TSS is a little over 1.0 kW/Ton. Therefore, a conversion factor (f) for the required storage capacity (T) of a TSS from the amount of shifted energy (K) is: (3:18-19)

$$f = 1.0 \text{(Ton/kW)} \qquad (5)$$

Thus

$$T = f \times K \qquad (6)$$

where

T = required storage capacity (Ton-hr)

K = amount of shifted energy (kWh)

From this the system cost for each application can be calculated as follows:

$$SC = T \times C \qquad (7)$$

where

SC = system cost ($)

C = initial differential system cost ($/T-h)

Economic Analysis. This analysis uses the simple payback method and the present value method to analyze the economic strength of implementing thermal storage at various

CONUS Air Force bases. The simple payback method is represented by the following equation:

$$SPB = SC/PAS \tag{8}$$

where

SPB = payback period (yrs)

SC = system cost ($)

PAS = potential annual savings ($/yr)

The present value analysis is expressed as follows:

$$NPV = -SC + S(P/A,10,20) \tag{9}$$

where

NPV = net present value of the investment ($)

SC = system cost ($)

S(P/A,10,20) = discounted annual savings at 10 percent interest rate over 20 years of expected economic life of TSS ($)

The information derived from these analysis will determine which Air Force base considered in this study is suitable for thermal storage application. In addition, some generalizations concerning thermal storage applications at different CONUS regions may be evident through examining these analysis.

Steps for Investigative Question 1

Are the Air Force electrical bills structured in such a way that savings realized from air conditioning demand load deferment are cost effective? To answer this investigative question, data obtained from each installation was studied to observe if the electrical rate structure and the climatic characteristics were conducive to warrant potential savings associated with thermal storage systems. When so, the economic analysis procedure explained above was used to determine the amount of potential savings that can be exploited from thermal storage.

Steps for Investigative Question 2

Which ice storage system is best suited for Air Force application? To answer this question, a qualitative review of historical literature was accomplished. In addition, telephone interviews with existing users and experts was conducted to determine which type system they preferred.

Steps for Investigative Question 3

What type of facility best lends itself to thermal storage systems? Like investigative question 2, this question is answered by examining historical cases and expert opinion. The literature review revealed many sources that addressed this issue. In essence the knowledge from previous cases show that the peak electrical demand load of certain facilities naturally coincide with the peak demand period set by the utility company. These facilities present significant savings since the deferment of the demand to an off-peak period is accomplished without a functional modification of the facility.

Steps for Investigative Question 4

What is the maintenance history of ice storage systems in civilian facilities employing these systems? To answer this question, an inquiry to several different existing civilian users of packaged thermal storage systems was done. These users were found by reviewing current journals delineating case studies of users employing these systems. Once contact was made with these users, specific questions requesting information on special or extraordinary maintenance or operating procedures was asked. In addition, three manufacturers of packaged ice thermal storage systems was contacted to determine if their systems require special maintenance or operating requirements. This information is vital because any savings attributed to thermal storage can be negated if the proper operation and maintenance of the systems are not properly performed. This study only briefly addressed this issue since the main concern of this thesis deals the with potential savings that can result if thermal storage systems are successfully employed at specific Air Force Installations.

Steps for Investigative Question 5

Are thermal storage construction incentives offered by some electrical utility companies applicable to the Air Force? This question was answered by examining the basic requirements of a government contract and determining if the criteria associated with a potential incentives contract met these requirements. In addition, a comparison is made between an incentives contract and another similar type of contract that has been successfully contracted.

IV. Findings and Analysis

Overview

This chapter presents raw quantitative data gathered from the solicited sources originating from this research. In addition, this data will be processed and analyzed as outlined in the methodology chapter.

Data Collection

To collect the quantifiable data for this research, letters requesting base electrical rate structures were sent to Base Civil Engineers throughout the CONUS. A total of 75 different bases were solicitated for information and a total of 60 bases responded. Of these 60 responses, 56 provided enough data to analyze. The cross-section represented by the useable responses represents each delineated region of the CONUS. These regions are explained in the following section.

Climate Regions

One of the secondary purposes of this study was to be able to generalize the results of this research over specific CONUS regions. This purpose requires a method of demarcation to divide the CONUS into different climate regions. The method used was taken from the *United States Air Force Passive Solar Handbook*. This handbook groups different geographic locations according to specific sets of climate variables: heating degree days (HDD), cooling degree days (CDD), latent enthalpy hours (LEH), and cloudiness index (RAD). Each of these variables are explained in detail below:

Heating Degree Days.

The number of Heating Degree Days (HDD) in a single day is determined by subtracting the average (maximum - minimum) temperature for that day from a reference temperature: 65 F in the United States. The average temperature must be less that 65 F for heating degree days to occur. Heating is assumed to be required under these conditions. (4:34)

Cooling Degree Days

Cooling Degree Days (CDDs) are quite similar to HDDs except they represent a cooling condition rather than a heating condition. Therefore, the number of Cooling Degree Days in a single day is determined by subtracting the reference temperature from the average temperature for the day. Since this is a cooling condition, it is assumed that the average temperature is greater than the reference temperature (65 F).

Since an air conditioning system is used to cool a building, then CDDs provide some information about the climate related cooling load. Since the CDD is an indicator of cooling needs, values are low in cold climates, which have little cooling, and high in climates which are warm. (4:35)

Latent Enthalpy Hours

Latent Enthalpy Hours (LEH) are a measure similar in format to a degree-day. An LEH is defined as the number of hours in which the energy requirement for removing moisture from the air is greater than the energy requirements to maintain the moisture content of the air equal to the upper extremes of the ASHRAE thermal comfort zone. Arid, high altitude climates (such as Denver, Colorado) may have LEH values less than 100 and tropical climates (such as Honolulu, Hawaii) may have LEH values in excess of 25,000. Because this is a new climate measure, little worldwide data exists to establish the upper boundary. (4:36)

Radiation and Daylight Index

> Daylighting and passive solar heating potential are considered through a cloudiness index, also known as a Radiation and Daylight (RAD) index. The RAD index varies form 0.0 to 1.0 and is defined as the ratio of monthly mean values of daily global horizontal radiation divided by the available radiation at the edge of the atmosphere (called the extraterrestrial radiation constant). The RAD value is a term commonly used to express solar radiation in combination with cloud cover. (4:36)

From these variables, 12 different regions have been created to represent both overseas and CONUS bases. The following tables identify which climate region each CONUS Air Force base is in.

TABLE 4.1

CLIMATE REGION 2

Climate Characteristics	U.S. Air Force Bases	
HDD (Range) 4,750 to 11,000	Chanute Ellsworth	Malmstrom Mcguire
CDD (Range) 500 to 1,200	Fairchild Grand Forks	Minot Offutt
LEH (Range) 2,500 to 10,000	Griffiss Grissom	Pease Plattsburgh
RAD (Range) 0.40 to 0.60	Hanscom K.I. Sawyer Loring	Wright-Patt Wurtsmith

TABLE 4.2

CLIMATE REGION 3

Climate Characteristics	U.S. Air Force Bases	
HDD (Range) 1,250 to 6,000	Beale	Norton
	Castle	Travis
CDD (Range) 0 to 2,250	George	Vandenberg
	March	
LEH (Range) 0 to 3,000	Mather	
	McClellan	
RAD (Range) 0.40 to 0.70	McChord	

TABLE 4.3

CLIMATE REGION 4

Climate Characteristics	U.S. Air Force Bases	
HDD (Range) 4,500 to 10,000	Cannon	Williams
	Davis-Monthan	
CDD (Range) 0 to 1,500	Edwards	
	Holloman	
LEH (Range) 0 to 1,000	Kirtland	
	Luke	
RAD (Range) 0.50 to 0.70	Reese	

TABLE 4.4

CLIMATE REGION 5

Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	1.000 to 6,000	Falcon	Petersen
		F.E. Warren	USAF Academy
CDD (Range)	250 to 2,250	Hill	
		Indian Springs	
LEH (Range)	5,000 to 15,000	Lowry	
		Mountain Home	
RAD (Range)	0.60 to 0.75	Nellis	

TABLE 4.5

CLIMATE REGION 6

Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	1,750 to 5,000	Altus	Little Rock
		Andrews	
		Pope	
CDD (Range)	650 to 2,500	Arnold	Robins
		Bolling	Scott
LEH (Range)	10,000 to 20,000	Charleston	Sey John
		Dobbins	Shaw
RAD (Range)	0.45 to 0.60	Dover	Tinker
		Eaker	Whiteman
		Langley	
		McConnell	

TABLE 4.6

CLIMATE REGION 7

Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	1,500 to 4,000	Bergstrom	Kelly
		Brooks	Lackland
CDD (Range)	1,750 to 3,500	Carswell	Laughlin
		Columbus	Maxwell
LEH (Range)	15,000 to 27,500	Dyess	Randolph
		Goodfellow	Sheppard
RAD (Range)	0.45 to 0.60	Gunter	Vance

TABLE 4.7

CLIMATE REGION 12

Climate Characteristics		U.S. Air Force Bases	
HDD (Range)	0 to 1,750	Barksdale	Macdill
		Eglin	Moody
CDD (Range)	2,250 to 4,500	England	Patrick
		Homestead	Tyndall
LEH (Range)	15,000 to 27,500	Hurlburt	
		Keesler	
RAD (Range)	0.45 to 0.55		

Data Collection Instrument

The letters sent to the Base Civil Engineers contained an attached data form that queried the base utility engineers about their electrical rate structure. This data form contained the following questions and comments:

1. Base Name
2. Major Command
3. Point of Contact (Name of Utility Engineer or EMCS operator and office symbol)

4. Autovan # of Point of Contact

5. What is the name of the utility company from whom you purchase electrical power? (If none, please indicate)

6. Are you charged two different rates for electrical demand? YES/NO (ie. do you pay a different rate for demand during on-peak demand periods as opposed to off-peak demand periods)

7. Please provide a copy of your base electrical bills for the last 12 months. (If you don't have bills for all 12 months, please send at least one month's bill)

IF YOU ANSWERED "NONE" TO QUESTION 5 OR "NO" TO QUESTION 6, PLEASE STOP HERE AND SEND IN THIS DATA FORM AND THE COPY OF YOUR ELECTRICAL BILLS USING THE SELF ADDRESSED ENVELOPE PROVIDED.

****THE FOLLOWING QUESTIONS PERTAIN ONLY TO BASE FACILITIES EXCLUDING MILITARY FAMILY HOUSING****************************

8. What is your off-peak electrical demand rate?

9. What is your on-peak electrical demand rate?

10. Please list any peculiarities associated with your rate structure. (ie. ratchet rate)

11. When is your designated on-peak demand period/periods? (ie. 0800 - 1600 hrs July, August, September. Your demand deriod may vary drastically from this example)

12. What was your monthly demand peak load readings for the past 12 months? (KW)

Dec89__________
Nov89__________
Oct89__________
Sep89__________
Aug89__________
Jul89__________

Jun89__________
May89__________
Apr89__________
Mar89__________
Feb89__________
Jan89__________

13. Please provide a copy of your real property records that indicate the tons of cooling associated for each of your on-base non-military family housing facilities.

Other Comments:

Some personnel filling out these forms misinterpreted question 13. The intent of this question was to obtain real property records for all base facilities excluding military family housing facilities from the contacted bases. The misinterpretation arose from the phrase on-base non-military family housing facilities. Some took this to mean on-base civilian family housing facilities, and since they did not have such a category of facilities, they did not send any real property records.

Raw Data

The following tables consolidates the pertinent data necessary for this study's analysis. Table 4.8 contains the demand charge rates and energy charge rates for each base depicted. The "off/on engpeak diff" column is the difference between the on peak and off peak energy charges. If these charges are the same, they did not have an effect on the data analysis and are delineated with zeros.

TABLE 4.8

RAW ENERGY DATA

BASENAME	ON PEAKDEM (kW)	OFF PEAKDEM (kW)	ON PEAKENG (kWh)	ON/OFF ENG DIFF (kWh)
ALTUS	7.00	7.00	0.026910	0.000000
BARKSDALE	5.00	5.00	0.029885	0.000000
BEALE	8.29	8.29	0.014430	0.000000
BLYTHEVILLE	12.11	10.61	0.035640	0.000000
CANNON	7.76	7.76	0.063000	0.000000
CARSWELL	4.05	4.05	0.025000	0.000000
CASTLE	11.07	11.07	0.015760	0.000000
CHARLESTON	17.30	11.30	0.020000	0.000000
COLUMBUS	10.36	10.36	0.004900	0.000000
DAVIS-MONTHA	8.25	8.25	0.038609	0.000000
DOVER	6.75	5.20	0.032200	0.000000
DYESS	13.04	7.41	0.488000	0.000000
EGLIN	6.32	6.32	0.041130	0.016600
EGLIN	7.73	7.73	0.029700	0.000000
ELLSWORTH	1.65	1.65	0.012200	0.000000
ENGLAND	7.30	7.30	0.075500	0.000000
F E WARREN	1.65	1.65	0.000000	0.000000
FAIRCHILD	3.46	3.46	0.014400	0.000000
GOODFELLOW	13.04	7.41	0.048800	0.000000
GRAND FORKS	11.40	11.40	0.018550	0.000000
GRISSOM	9.99	9.99	0.016777	0.000000
HANSCOM	6.43	6.43	0.027770	0.021070
HILL	6.10	6.10	0.026968	0.000000
HOLLOMAN	19.00	19.00	0.022035	0.000000
HOMESTEAD	6.25	6.25	0.039520	0.006800
K I SAWYER	8.48	8.48	0.040820	0.000000
KEESLER	3.25	3.25	0.042870	0.000000
KELLY	8.00	6.65	0.000000	0.000000
KIRTLAND	8.43	8.28	0.029571	0.014540
LANGLEY	8.33	8.33	0.025384	0.000000
LAUGHLIN	8.16	8.16	0.481000	0.000000
LITTLE ROCK	17.20	15.02	0.025340	0.001290
LORING	3.76	2.01	0.057569	0.012156

TABLE 4.8 (CONT)

RAW ENERGY DATA

BASENAME	ON PEAKDEM (kW)	OFF PEAKDEM (kW)	ON PEAKENG (kWh)	ON/OFF ENG DIFF (kWh)
LOWRY	6.15	3.75	0.024800	0.000000
LUKE	11.14	11.14	0.035000	0.000000
MACDILL	6.75	6.75	0.061310	0.021670
MARCH	10.98	2.10	0.030820	0.000000
MCCHORD	4.19	4.19	0.016200	0.000000
MCCLELLAN	8.10	6.70	0.000000	0.000000
MCCONNELL	13.04	13.04	0.053900	0.000000
MCGUIRE	8.91	8.91	0.063710	0.014530
MINOT	1.85	1.85	0.005060	0.000000
MOODY	7.50	7.50	0.033000	0.000000
MT HOME	3.22	3.22	0.020467	0.000000
MYRTLE BEACH	11.30	11.30	0.020000	0.000000
NORTON	11.68	2.10	0.030740	0.000000
PATRICK	6.25	6.25	0.039060	0.003950
PLATTSBURGH	5.76	5.76	0.064800	0.030878
REESE	9.10	9.10	0.009600	0.000000
SCOTT	16.32	4.51	0.042400	0.056200
SEYMOUR JOHN	10.50	10.50	0.029620	0.000000
SHEPPARD	5.19	5.19	0.026834	0.000000
TRAVIS	8.92	8.92	0.015700	0.000000
TYNDALL	6.32	2.97	0.041130	0.016600
WURTSMITH	8.02	8.02	0.041270	0.023510

The following table contains data from one representative base from each climatic region. This data is the ratio of the air conditioning tonnage for each representative base that is greater than or equal to 50 tons to total base tonnage (X). This information is applied to each base within its particular region to approximate the existing percentage of a base's cooling load that may be a potential candidate for thermal storage.

TABLE 4.9

POTENTIAL TSS APPLICATION

BASE NAME	REGION	TONS OVER 50 (TONS)	TOTAL TONS (TONS)	X (%)
MCGUIRE	2	2747	4446	66
BEALE	3	4181	6655	62
LOWRY	4	6942	8948	78
KIRTLAND	5	6100	7792	78
SCOTT	6	9278	17407	53
COLUMBUS	7	2132	5858	40
EGLIN	12	27067	40793	66

The next table contains cooling load data for each base. It includes the maximum summer electrical peak demand load (SPDL), the minimum winter electrical peak demand load (WPDL) and the region each base is located in. In addition the potential TSS ratio (X) is used from the Table 9 to calculate the potential TSS cooling load (PCDL) for each base indicated. The algorithm used to determine the potential TSS cooling loads for most bases is SPDL minus WPDL times X. Exceptions to this algorithm are delineated by asterisks or number signs and are described in the bottom portion of the table.

TABLE 4.10

COOLING LOAD DATA

BASENAME	SPDL (kW)	WPDL (kW)	REGION	X	PCDL (kW)
ALTUS*	9673	9673	6	0.53	0
BARKSDALE	15588	9348	12	0.66	4118
BEALE	21432	16313	3	0.63	3225
BLYTHEVILLE	10287	5401	6	0.53	2590
CANNON	9840	5832	4	0.78	3126
CARSWELL	14052	8575	7	0.4	2191
CASTLE	9716	6739	3	0.63	1876
CHARLESTON	16762	8761	6	0.53	4241
COLUMBUS	9947	8294	7	0.4	661
DAVIS-MONTHAN	17162	9800	4	0.78	5742
DOVER	14850	9000	6	0.53	3101
DYESS	16675	12030	7	0.4	1858
EGLIN	68500	37200	12	0.66	20658
EGLIN	3882	3438	12	0.66	293
ELLSWORTH	7500	5210	2	0.62	1420
ENGLAND	9200	4800	12	0.66	2904
F E WARREN	3300	2938	5	0.78	282
FAIRCHILD	8439	6450	2	0.62	1233
GOODFELLOW	6993	4308	7	0.4	1074
GRAND FORKS **	9171	9171	2	0.62	0
GRISSOM	9765	7076	2	0.62	1667
HANSCOM	16136	12480	2	0.62	2267
HILL	38235	31998	5	0.78	4865
HOLLOMAN	14520	9032	4	0.78	4281
HOMESTEAD	19495	13416	12	0.66	4012
K I SAWYER	8953	8277	2	0.62	419
KEESLER	31580	17340	12	0.66	9398
KELLY	60200	30800	7	0.4	11760
KIRTLAND	59520	49440	4	0.78	7862
LANGLEY **	19900	13950	6	0.53	3154
LAUGHLIN***	8903	6232	7	0.4	1068
LITTLE ROCK	16166	12818	6	0.53	1774
LORING *	7704	7776	2	0.62	1433
LOWRY	13660	10838	5	0.78	2201
LUKE	17638	13370	4	0.78	3329

TABLE 4.10 (CONT)

COOLING LOAD DATA

BASENAME	SPDL (kW)	WPDL (kW)	REGION	X	PCDL (kW)
MACDILL	18816	14112	12	0.66	3105
MARCH	12840	8381	3	0.63	2809
MCCHORD**	15598	15598	3	0.63	0
MCCLELLAN	36335	25560	3	0.63	6788
MCCONNELL	10326	7943	6	0.53	1263
MCGUIRE	15800	10160	2	0.62	3497
MINOT **	10246	14638	2	0.62	1905
MOODY	7540	5277	12	0.66	1493
MT HOME	12970	10660	5	0.78	1802
MYRTLE BEACH	10796	8009	6	0.53	1477
NORTON	15960	10760	3	0.63	3276
PATRICK	24804	14730	12	0.66	6649
PLATTSBURGH**	7620	7620	2	0.62	1402
REESE	7272	4608	5	0.78	2078
SCOTT	26064	15600	6	0.53	5546
SEYMOUR JOHNSON	17340	13375	6	0.53	2101
SHEPPARD	22063	11661	7	0.4	4161
TRAVIS	13984	10757	3	0.63	2033
TYNDALL	18310	11306	12	0.66	4623
WURTSMITH	8604	6224	2	0.62	1476

* The explicit demand for this base is set by contract, therefore demand deferment does not effect the utility cost.

** The winter demand data was not available for use, therefore the overall peak cooling load was assumed to be 30% of the maximum peak summer demand.

*** Comfort air conditioning is operates year round for this base, therefore the overall peak cooling load was assumed to be 30% of the maximum peak summer demand.

* The annual demand peak is set in the winter period, therefore the overall peak cooling load was assumed to be 30% of the maximum peak summer demand.

** The annual demand peak is set in the winter period. The summer peak demand loads are less than the ratcheted demand loads from winter peaks, therefore the existing summer loads are inconsequential to the utility cost.

Although the information provided in Table 4.11 is not required for the data analysis portion of this study, it was included to provide a consolidated source of utility companies of the analyzed bases. This data may be needed if research on utility companies' incentives is performed on this topic in the future.

TABLE 4.11

UTILITY COMPANIES

BASE NAME	UTILITY COMPANY NAME
ALTUS	WESTERN FARMER'S
BARKSDALE	SOUTHWESTERN ELECTRICAL POWER CO.
BEALE	WAPA
BLYTHEVILLE	ARKANSAS P&L MISSISSIPPI COOP
CANNON	SOUTHWESTERN PUBLIC SERVICE CO
CARSWELL	TU ELECTRIC
CASTLE	WAPA & PG&E
CHARLESTON	SANTEE COOPER, SOUTH CAROLINA PUBLIC SERVICE AUTHORITY
COLUMBUS	TENNESSE VALLEY AUTHORITY
DAVIS-MONTHAN	TUCSON ELECTRIC POWER
DOVER	CITY OF DOVER
DYESS	WEST TEXAS UTILTIES CO

TABLE 4.11 (CONT)

UTILITY COMPANIES

BASE NAME	UTILITY COMPANY NAME
EGLIN	GULF POWER COMPANY
EGLIN	CHOCTAWHATCHEE ELECTRIC CO
ELLSWORTH	WAPA, HEARTLAND CONSUMER POWER DIST
ENGLAND	CENTRAL LOUISIANA ELECTRIC COMPANY
F E WARREN	WESTERN AREA POWER ADMIN & ROCKY MOUNTAIN GENERATION CO
FAIRCHILD	BONNEVILLE POWER ADMINISTRATION
GOODFELLOW	WEST TEXAS UTILITIES
GRAND FORKS	NODAK RURAL ELECTRIC
GRISSOM	PUBLIC SERVICE OF INDIANA
HANSCOM	BOSTON EDISON
HILL	UTAH POWER AND LIGHT 90% WAPA 10%
HOLLOMAN	EL PASO ELECTRIC CO
HOMESTEAD	FLORIDA POWER AND LIGHT
HURLBURT FLD	SAME AS EGLIN
K I SAWYER	UPPER PENINSULA POWER COMPANY
KEESLER	MISSISSIPPI POWER COMPANY
KELLY	CITY PUBLIC SERVICE CITY OF SAN ANTONIO, TX
KIRTLAND	PUBLIC SERVICE CO OF NEW MEXICO AND WESTERN AREA POWER
LANGLEY	VIRGINIA POWER
LAUGHLIN	CENTRAL POWER AND LIGHT
LITTLE ROCK	ARKANSAS POWER AND LIGHT COMPANY
LORING	MAINE PUBLIC SERVICE CO
LOWRY	PUBLIC SERVICE OF COLORADO
LUKE	ARIZONA PUBLIC SERVICE
MACDILL	TAMPA ELECTRIC CO
MARCH	SOUTHERN CALIFORNIA EDISON
MCCHORD	TACOMA CITY LIGHT
MCCLELLAN	SACRAMENTO MUNICIPAL UTILITY DISTRICT
MCCONNELL	KANSAS GAS & ELECTRIC CO
MCGUIRE	JERSEY CENTRAL POWER AND LIGHT
MINOT	VERENDRYE ELECTRIC

TABLE 4.11 (CONT)

UTILITY COMPANIES

BASE NAME	UTILITY COMPANY NAME
MOODY	COLQUITT EMC
MT HOME	IDAHO POWER
MYRTLE BEACH	SANTEE COOPER
NORTON	SOUTHERN CALIFORNIA EDISON CO
PATRICK	FLORIDA POWER AND LIGHT
PLATTSBURGH	NEW YORK STATE ELECTRIC AND GAS COMPANY
REESE	SOUTHERN PUBLIC SERVICE
SCOTT	ILLINOIS POWER COMPANY
SEYMOUR JOHNSON	CAROLINA POWER AND LIGHT COMPANY SHEPPARD
SHEPPARD	TU ELECTRIC
TINKER	OKLAHOMA, GAS AND ELECTRIC
TRAVIS	WESTERN AREA POWER ADMIN (WAPA)
TYNDALL	GULF POWER COMPANY
WURTSMITH	CONSUMERS POWER CO

Data Analysis

This section manipulates the raw data described in the previous section as delineated in the methodology chapter of this report. To illustrate this methodology, one base, Holloman AFB, is singled out for detailed analysis. The remaining calculations are performed by Quattro Pro, a spreadsheet program developed by Borlad.

Sample Calculation. The electrical rate structure at Holloman AFB, does not have a ratchet nor does it have time of use rates associated with either its demand or energy rates. Therefore the dollar savings resulting from thermel storage would come solely from shaving the daily demand peak by deferring air conditioning loads to off-peak periods. Table 4.3 shows Holloman AFB to be in region four, therefore the percentage ratio factor X is 78% (see Table 4.9). Table 4.10 gives the SPDL and WPDL to be 14520 kW and 9032 kW respectively. From this data the potential cooling demand load favorable for thermal storage (PCDL) for Holloman AFB can be calculated as follows:

$$\begin{aligned} \text{PCDL} &= (\text{SPDL} - \text{WPDL}) \times X \\ &= (14520 - 9032) \times .78 \\ &= 4281 \text{ kW} \end{aligned}$$

Now the potential annual savings per kW will be determined. From Table 4.8 the demand charge (D_1) can be found. Since Holloman AFB does not have a ratchet factor, the number of months that would be affected by thermal storage is the number of months the thermal storage systems are actually in effect. Based on the number of monthly cooling degree days for Holloman, the number of months the TSS was estimated to be operational is five. Thus:

$$\begin{aligned} S/P &= D_1 \times F_1 \\ &= 19.00 \times 5 \\ &= 95 \text{ (\$/kW-yr)} \end{aligned}$$

The system cost was based on three different scenarios. In addition, since the size of the system is directly proportional to the cost of the system, a 15 percent and a 30 percent in reduction of the PCDL was considered for each scenario. For the new construction/replacement scenario, the cost was estimated to be $80/T-h. Considering a 15 percent reduction in the PCDL, Holloman AFB's initial systems cost can be estimated as follows:

$$\begin{aligned} K &= r_1 \times \text{PCDL} \times W_1 \\ &= 15\% \times 4281 \text{ kW} \times 4 \text{ hr} \\ &= 2568.6 \text{ kWh} \end{aligned}$$

$$\begin{aligned} T &= K \times f \\ &= 2568.6 \text{ kWh} \times 1.0 \text{ T/kW} \end{aligned}$$

$$\begin{aligned} SC &= T \times C \\ &= 2568.6 \text{ T-h} \times 80 \text{ \$/T-h} \\ &= \$205488 \end{aligned}$$

For a realistic retrofit scenario where the estimated cost is 150 ($/T-h):

$$\begin{aligned} SC &= 2568.6 \times 150 \\ &= \$385320 \end{aligned}$$

And for a upper limit retrofit scenario where the estimated cost is 300 ($/T-h):

$$\begin{aligned} SC &= 2568.6 \times 300 \\ &= \$770580 \end{aligned}$$

Considering a 30 percent reduction in the PCDL for each scenario we find for the new construction/replacement scenario:

$$\begin{aligned} K &= 15\% \times 4281 \text{ kW} \times 8 \text{ hr} \\ &= 5137.2 \text{ kWh} \end{aligned}$$

$$T = 5137.2 \text{ kWh} \times 1.0 \text{ T/kW}$$

$$\begin{aligned} SC &= 5137.2 \text{ T-h} \times 80 \text{ \$/T-h} \\ &= \$410976 \quad \text{(second 15\% reduction)} \end{aligned}$$

$$\begin{aligned} SC &= 205488 + 410976 \\ &= \$616464 \quad \text{(total 30\% reduction)} \end{aligned}$$

For a realistic retrofit scenario:

$$\begin{aligned} SC &= 5137.2 \times 150 \\ &= \$770580 \quad \text{(second 15\% reduction)} \end{aligned}$$

$$\begin{aligned} SC &= 385320 + 770580 \\ &= \$1155900 \quad \text{(total 30\% reduction)} \end{aligned}$$

For an upper limit retrofit scenario:

$$SC = 5137.2 \times 300$$

= \$1541160 (second 15% reduction)
SC = 770580 + 1541160
= \$2311740 (total 30% reduction)

Now the potential annual savings will be calculated.

For a 15% reduction in the PCDL:

PAS = 15% x PCDL x S/P
= .15 x 4281 x 95
= \$61004

For a 30% reduction in the PCDL:

PAS = 30% x PCDL x S/P
= .30 x 4281 x 95
= \$122008

Since the potential annual savings and system costs are known, the economic analysis can be performed. For the simple payback analysis the following calculations are offered:

New construction/replacement scenario reduced 15%:

SPB = SC/PAS
= 203488/61004
= 3.3 years

Realistic retrofit scenario reduced 15%:

SPB = SC/PAS
= 385320/61004
= 6.3 years

Upper limit retrofit scenario reduced 15%:

SPB = SC/PAS
= 770580/61004
= 12.6 years

New construction/replacement scenario reduced 30%:

SPB = SC/PAS
= 616464/122008
= 5.1 years

Realistic retrofit scenario reduced 30%:

$$
\begin{aligned}
SPB &= SC/PAS \\
&= 1155900/122008 \\
&= 9.5 \text{ years}
\end{aligned}
$$

Upper limit retrofit scenario reduced 30%:

$$
\begin{aligned}
SPB &= SC/PAS \\
&= 2311740/122008 \\
&= 18.9 \text{ years}
\end{aligned}
$$

The net present value analysis are as follows:

New construction/replacement scenario reduced 15%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -203488 + 61004 \times 8.5136 \\
&= \$315873
\end{aligned}
$$

Realistic retrofit scenario reduced 15%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -385320 + 61004 \times 8.5136 \\
&= \$134041
\end{aligned}
$$

Upper limit retrofit scenario reduced 15%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -770580 + 61004 \times 8.5136 \\
&= -\$251218
\end{aligned}
$$

New construction/replacement scenario reduced 30%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -616464 + 122008 \times 8.5136 \\
&= \$422258
\end{aligned}
$$

Realistic retrofit scenario reduced 30%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -1155900 + 122008 \times 8.5136 \\
&= -\$117177
\end{aligned}
$$

Upper limit retrofit scenario reduced 30%:

$$
\begin{aligned}
NPV &= -SC + S(P/A,10,20) \\
&= -2311740 + 122008 \times 8.5136 \\
&= -\$1273017
\end{aligned}
$$

Data Base. The next six tables delineate the data base that was described as the specific objective of this study. Tables 4.12 through 4.14 show the potential simple payback in years and the potential present value savings in dollars that can be realized if a 15 percent reduction of the peak cooling load is accomplished for the three scenarios offered. Tables 4.15 through 4.17 show the potential simple payback in years and the potential present value savings in dollars that can be realized if a 30 percent reduction of the peak cooling load is accomplished for the three scenarios offered.

TABLE 4.12

15 PERCENT REDUCTION FOR NEW CONSTRUCTION

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	18533	197683	10.7	-39903
BEALE	3225	41	20059	154799	7.7	15971
BLYTHEVILLE	2590	61	23520	124300	5.3	75938
CANNON	3126	138	64690	150060	2.3	400681
CARSWELL	2191	24	7985	105155	13.2	-37172
CASTLE	1876	55	15570	90024	5.8	42532
CHARLESTON	4241	104	66025	203545	3.1	358563
COLUMBUS	1194	52	9275	57295	6.2	21665
DAVIS-MONTHA	5742	85	73442	275633	3.8	349622
DOVER	3114	34	15763	149460	9.5	-15258
DYESS	1858	65	18171	89184	4.9	65518
EGLIN	20658	62	192883	991584	5.1	650537
EGLIN	293	62	2718	14066	5.2	9076
ELLSWORTH	1420	7	1406	68150	48.5	-56184

TABLE 4.12 (CONT)

15 PERCENT REDUCTION FOR NEW CONSTRUCTION

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ENGLAND	2904	88	38159	139392	3.7	185473
F E WARREN	282	7	280	13553	48.5	-11173
FAIRCHILD	1233	17	3200	59193	18.5	-31948
GOODFELLOW	1074	37	10504	51552	4.9	37872
GRAND FORKS	NA	NA	NA	NA	NA	NA
GRISSOM	1667	100	24983	80025	3.2	132667
HANSCOM	2267	33	11267	108803	9.7	-12883
HILL	4865	31	22257	233513	10.5	-44029
HOLLOMAN	4281	95	60999	205471	3.4	313849
HOMESTEAD	4012	48	28851	192583	6.7	53039
K I SAWYER	419	43	2723	20118	7.4	3061
KEESLER	9398	16	22909	451123	19.7	-256089
KELLY	1760	60	105752	564480	5.3	335845
KIRTLAND	7862	94	110509	377395	3.4	563427
LANGLEY	3164	93	44263	151877	3.4	224956
LAUGHLIN	1068	90	14384	51281	3.6	71181
LITTLE ROCK	1774	84	22424	85173	3.8	105737
LORING	1433	18	3114	68781	22.1	-42267
LOWRY	2201	17	5745	105656	18.4	-56745
LUKE	3329	56	27814	159794	5.7	77003
MACDILL	3105	78	36284	149023	4.1	159880
MARCH	2809	65	27550	134840	4.9	99705
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	49486	325836	6.6	95469
MCCONNELL	1263	65	12352	60621	4.9	44535
MCGUIRE	3497	51	26721	167846	6.3	59642
MINOT	1417	56	1715	91482	53.3	-76878
MOODY	1493	90	20154	71660	3.6	99926
MT HOME	1802	13	3481	86486	24.8	-56850
MYRTLE BEACH	1477	57	12519	70901	5.7	35676
NORTON	3276	66	32343	157248	4.9	118104
PATRICK	6649	59	59220	319144	5.4	185026
PLATTSBURGH	2286	42	14527	109728	7.6	13950
REESE	2078	70	21852	99740	4.6	86301

TABLE 4.12 (CONT)

15 PERCENT REDUCTION FOR NEW CONSTRUCTION

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
SCOTT	5546	126	104858	266204	2.5	626510
SEYMOUR JHN	2101	53	16549	100870	6.1	40021
SHEPPARD	4161	54	33688	199718	5.9	87082
TRAVIS	2033	62	19048	97588	5.1	64580
TYNDALL	4623	68	47032	221887	4.7	178527
WURTSMITH	1476	30	6640	70829	10.7	-14297

TABLE 4.13

15 PERCENT REDUCTION FOR RETROFIT REAL SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	18533	370656	20.0	-212876
BEALE	3225	41	20059	290247	14.5	-119478
BLYTHEVILLE	2590	61	23520	233062	9.9	-32824
CANNON	3126	138	64690	281362	4.3	269378
CARSWELL	2191	24	7985	197165	24.7	-129183
CASTLE	1876	55	15570	168796	10.8	-36240
CHARLESTON	4241	104	66025	381648	5.8	180461
COLUMBUS	1194	52	9275	107428	11.6	-28468
DAVIS-MON	5742	85	73442	516812	7.0	108443
DOVER	3114	34	15763	280238	17.8	-146035
DYESS	1858	65	18171	167220	9.2	-12518
EGLIN	20658	62	192883	1859220	9.6	-217099
EGLIN	293	62	2718	26374	9.7	-3232
ELLSWORTH	1420	7	1406	127782	90.9	-115815

TABLE 4.13 (CONT)

15 PERCENT REDUCTION FOR RETROFIT REAL SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ENGLAND	2904	88	38159	261360	6.8	63505
F E WARREN	282	7	280	25412	90.9	-23033
FAIRCHILD	1233	17	3200	110986	34.7	-83742
GOODFELLOW	1074	65	10504	96660	9.2	-7236
GRAND FORKS	NA	NA	NA	NA	NA	NA
GRISSOM	1667	100	24983	150046	6.0	62646
HANSCOM	2267	33	11267	204005	18.1	-108085
HILL	4865	31	22257	437837	19.7	-248353
HOLLOMAN	4281	95	60999	385258	6.3	134062
HOMESTEAD	4012	48	28851	361093	12.5	-115471
K I SAWYER	419	43	2723	37721	13.9	-14542
KEESLER	9398	16	22909	845856	36.9	-650822
KELLY	11760	60	105752	1058400	10.0	-158075
KIRTLAND	7862	94	110509	707616	6.4	233206
LANGLEY	3164	93	44263	284769	6.4	92064
LAUGHLIN	1068	90	14384	96152	6.7	26310
LITTLE ROCK	1774	84	22424	159700	7.1	31211
LORING	1433	18	3114	128965	41.4	-102451
LOWRY	2201	17	5745	198104	34.5	-149194
LUKE	3329	56	27814	299614	10.8	-62816
MACDILL	3105	78	36284	279418	7.7	29485
MARCH	2809	65	27550	252825	9.2	-18281
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	49486	610943	12.3	-189637
MCCONNELL	1263	65	12352	113664	9.2	-8509
MCGUIRE	3497	51	26721	314712	11.8	-87223
MINOT	1906	6	1715	171528	100.0	-156925
MOODY	1493	90	20154	134363	6.7	37223
MT HOME	1802	13	3481	162162	46.6	-132526
MYRTLE BCH	1477	57	12519	132940	10.6	-26363
NORTON	3276	66	32343	294840	9.1	-19488
PATRICK	6649	59	59220	598396	10.1	-94226
PLATTSB	2286	42	14527	205740	14.2	-82062
REESE	2078	70	21852	187013	8.6	-972

TABLE 4.13 (CONT)

15 PERCENT REDUCTION FOR RETROFIT REAL SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
SCOTT	5546	126	104858	499133	4.8	393581
SEYMOUR JHN	2101	53	16549	189131	11.4	-48240
SHEPPARD	4161	54	33688	374472	11.1	-87671
TRAVIS	2033	62	19048	182977	9.6	-20809
TYNDALL	4623	68	47032	416038	8.8	-15624
WURTSMITH	1476	30	6640	132804	20.0	-76272

TABLE 4.14

15 PERCENT REDUCTION FOR RETROFIT UPPER LIMIT SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	18533	741312	40.0	-583532
BEALE	3225	41	20059	580495	28.9	-409725
BLYTHEVILLE	2590	61	23520	466124	19.8	-265887
CANNON	3126	138	64690	562723	8.7	-11983
CARSWELL	2191	24	7985	394330	49.4	-326347
CASTLE	1876	55	15570	337592	21.7	-205035
CHARLESTON	4241	104	66025	763295	11.6	-201187
COLUMBUS	1194	52	9275	214855	23.2	-135895
DAVIS-MONTHAN	5742	85	73442	1033625	14.1	-408369
DOVER	3114	34	15763	560475	35.6	-426273
DYESS	1858	65	18171	334440	18.4	-179738
EGLIN	20658	62	192883	3718440	19.3	-2076319
EGLIN	293	62	2718	52747	19.4	-29605
ELLSWORTH	1420	7	1406	255564	181.8	-243597
ENGLAND	2904	88	38159	522720	13.7	-197855

TABLE 4.14 (CONT)

15 PERCENT REDUCTION FOR RETROFIT UPPER LIMIT SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
F E WARREN	282	7	280	50825	181.8	-48445
FAIRCHILD	1233	17	3200	221972	69.4	-194728
GOODFELLOW	1074	65	10504	193320	18.4	-103896
GRAND FORKS	NA	NA	NA	NA	NA	NA
GRISSOM	1667	100	24983	300092	12.0	-87401
HANSCOM	2267	33	11267	408010	36.2	-312090
HILL	4865	31	22257	875675	39.3	-686191
HOLLOMAN	4281	95	60999	770515	12.6	-251195
HOMESTEAD	4012	48	28851	722185	25.0	-476564
K I SAWYER	419	43	2723	75442	27.7	-52263
KEESLER	9398	16	22909	1691712	73.8	-1496678
KELLY	11760	60	105752	2116800	20.0	-1216475
KIRTLAND	7862	94	110509	1415232	12.8	-474410
LANGLEY	3164	93	44263	569538	12.9	-192705
LAUGHLIN	1068	90	14384	192305	13.4	-69842
LITTLE ROCK	1774	84	22424	319399	14.2	-128489
LORING	1433	18	3114	257930	82.8	-231416
LOWRY	2201	17	5745	396209	69.0	-347298
LUKE	3329	56	27814	599227	21.5	-362430
MACDILL	3105	78	36284	558835	15.4	-249932
MARCH	2809	65	27550	505651	18.4	-271106
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	49486	1221885	24.7	-800580
MCCONNELL	1263	65	12352	227329	18.4	-122173
MCGUIRE	3497	51	26721	629424	23.6	-401935
MINOT	1417	56	1715	343056	200.0	-328453
MOODY	1493	90	20154	268726	13.3	-97140
MT HOME	1802	13	3481	324324	93.2	-294688
MYRTLE BEACH	1477	57	12519	265880	21.2	-159303
NORTON	3276	66	32343	589680	18.2	-314328
PATRICK	6649	59	59220	1196791	20.2	-692621
PLATTSBURGH	2286	42	14527	411480	28.3	-287802
REESE	2078	70	21852	374026	17.1	-187984
SCOTT	5546	126	104858	998266	9.5	-105552

TABLE 4.14 (CONT)

15 PERCENT REDUCTION FOR RETROFIT UPPER LIMIT SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
SEYMOUR JOHNSON	2101	53	16549	378261	22.9	-237371
SHEPPARD	4161	54	33688	748944	22.2	-462143
TRAVIS	2033	62	19048	365953	19.2	-203785
TYNDALL	4623	68	47032	832075	17.7	-431662
WURTSMITH	1476	30	6640	265608	40.0	-209076

TABLE 4.15

30 PERCENT REDUCTION FOR NEW CONSTRUCTION SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	37066	593050	16.0	-277489
BEALE	3225	41	40117	464396	11.6	-122857
BLYTHEVILLE	2590	61	47040	372900	7.9	27576
CANNON	3126	138	129379	450179	3.5	651302
CARSWELL	2191	24	15970	315464	19.8	-179499
CASTLE	1876	55	31140	270073	8.7	-4961
CHARLESTON	4241	104	132050	610636	4.6	513581
COLUMBUS	1194	52	18549	171884	9.3	-13965
DAVIS-MONTHAN	5742	85	146885	826900	5.6	423611
DOVER	3114	34	31527	448380	14.2	-179975
DYESS	1858	65	36342	267552	7.4	41852
EGLIN	20658	74	458191	2974752	6.5	926087
EGLIN	293	62	5436	42198	7.8	4086
ELLSWORTH	1420	7	2811	204451	72.7	-180518
ENGLAND	2904	88	76317	418176	5.5	231555
F E WARREN	282	7	559	40660	72.7	-35900

TABLE 4.15 (CONT)

30 PERCENT REDUCTION FOR NEW CONSTRUCTION SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
FAIRCHILD	1233	17	6400	177578	27.7	-123089
GOODFELLOW	1074	65	21007	154656	7.4	24192
GRAND FORKS	NA	NA	NA	NA	NA	NA
GRISSOM	1667	100	49965	240074	4.8	185310
HANSCOM	2267	41	27577	326408	11.8	-91630
HILL	4865	31	44513	700540	15.7	-321572
HOLLOMAN	4281	95	121998	616412	5.1	422228
HOMESTEAD	4012	52	62743	577748	9.2	-43582
K I SAWYER	419	53	6625	60353	9.1	-3947
KEESLER	9398	16	45817	1353370	29.5	-963302
KELLY	11760	60	211504	1693440	8.0	107209
KIRTLAND	7862	104	245671	1132186	4.6	959351
LANGLEY	3164	93	88525	455630	5.1	293036
LAUGHLIN	1068	90	28769	153844	5.3	91081
LITTLE ROCK	1774	85	45090	255519	5.7	128359
LORING	1433	18	7608	206344	27.1	-141571
LOWRY	2201	17	11490	316967	27.6	-219146
LUKE	3329	56	55628	479382	8.6	-5787
MACDILL	3105	95	88552	447068	5.0	306828
MARCH	2809	65	55099	404520	7.3	64569
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	98973	977508	9.9	-134898
MCCONNELL	1263	65	24703	181863	7.4	28448
MCGUIRE	3497	57	60148	503539	8.4	8536
MINOT	1906	6	3173	274445	86.5	-247429
MOODY	1493	90	40309	214980	5.3	128191
MT HOME	1802	13	6962	259459	37.3	-200186
MYRTLE BEACH	1477	57	25037	212704	8.5	450
NORTON	3276	66	64685	471744	7.3	78960
PATRICK	6649	63	124679	957433	7.7	104032
PLATTSBURGH	1417	56	23791	204094	8.6	-1552
REESE	2078	70	43705	299220	6.8	72862
SCOTT	5546	151	250857	798612	3.2	1337079
SEYMOUR JOHNSON	2101	53	33098	302609	9.1	-20828

TABLE 4.15 (CONT)

30 PERCENT REDUCTION FOR NEW CONSTRUCTION SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
SHEPPARD	4161	54	67375	599155	8.9	-25554
TRAVIS	2033	62	38096	292763	7.7	31573
TYNDALL	4623	85	118014	665660	5.6	339056
WURTSMITH	1476	36	16146	212486	13.2	-75026

TABLE 4.16

30 PERCENT REDUCTION FOR RETROFIT REAL SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	37066	1111968	30.0	-796408
BEALE	3225	41	40117	870742	21.7	-529203
BLYTHEVILLE	2590	61	47040	699187	14.9	-298711
CANNON	3126	138	129379	844085	6.5	257395
CARSWELL	2191	24	15970	591494	37.0	-455530
CASTLE	1876	55	31140	506388	16.3	-241275
CHARLESTON	4241	104	132050	1144943	8.7	-20726
COLUMBUS	1194	52	18549	322283	17.4	-164363
DAVIS-MONTHAN	5742	85	146885	1550437	10.6	-299926
DOVER	3114	34	31527	840713	26.7	-572308
DYESS	1858	65	36342	501660	13.8	-192256
EGLIN	20658	74	458191	5577660	12.2	-1676821
EGLIN	293	62	5436	79121	14.6	-32837
ELLSWORTH	1420	7	2811	383346	136.4	-359413
ENGLAND	2904	88	76317	784080	10.3	-134349
F E WARREN	282	7	559	76237	136.4	-71477
FAIRCHILD	1233	17	6400	332959	52.0	-278470
GOODFELLOW	1074	65	21007	289980	13.8	-111132
GRAND FORKS	NA	NA	NA	NA	NA	NA

TABLE 4.16 (CONT)

30 PERCENT REDUCTION FOR RETROFIT REAL SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
GRISSOM	1667	100	49965	450139	9.0	-24755
HANSCOM	2267	41	27577	612014	22.2	-377237
HILL	4865	31	44513	1313512	29.5	-934544
HOLLOMAN	4281	95	121998	1155773	9.5	-117133
HOMESTEAD	4012	52	62743	1083278	17.3	-549112
K I SAWYER	419	53	6625	113162	17.1	-56756
KEESLER	9398	16	45817	2537568	55.4	-2147500
KELLY	11760	60	211504	3175200	15.0	-1374551
KIRTLAND	7862	104	245671	2122848	8.6	-31312
LANGLEY	3164	93	88525	854307	9.7	-100641
LAUGHLIN	1068	90	28769	288457	10.0	-43532
LITTLE ROCK	1774	85	45090	479099	10.6	-95220
LORING	1433	18	7608	386895	50.9	-322122
LOWRY	2201	17	11490	594313	51.7	-496492
LUKE	3329	56	55628	898841	16.2	-425246
MACDILL	3105	95	88552	838253	9.5	-84357
MARCH	2809	65	55099	758476	13.8	-289387
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	98973	1832828	18.5	-990217
MCCONNELL	1263	65	24703	340993	13.8	-130682
MCGUIRE	3497	57	60148	944136	15.7	-432061
MINOT	1906	6	3137	514584	162.2	-487568
MOODY	1493	90	40309	403088	10.0	-59917
MT HOME	1802	13	6962	486486	69.9	-427213
MYRTLE BEACH	1477	57	25037	398820	15.9	-185665
NORTON	3276	66	64685	884520	13.7	-333816
PATRICK	6649	63	124679	1795187	14.4	-733722
PLATTSBURGH	1417	56	23791	382676	16.1	-180134
REESE	2078	70	43705	561038	12.8	-188956
SCOTT	5546	151	250857	1497398	6.0	638293
SEYMOUR JOHN	2101	53	33098	567392	17.1	-285611
SHEPPARD	4161	54	67375	1123416	16.7	-549815
TRAVIS	2033	62	38096	548930	14.4	-224594
TYNDALL	4623	85	118014	1248113	10.6	-243397
WURTSMITH	1476	36	16146	398412	24.7	-260952

TABLE 4.17

30 PERCENT REDUCTION FOR RETROFIT UPPER LIMIT SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR)	COST ($)	SPB (YR)	NPV ($)
ALTUS	NA	NA	NA	NA	NA	NA
BARKSDALE	4118	30	37066	2223936	60.0	-1908376
BEALE	3225	41	40117	1741484	43.4	-1399945
BLYTHEVILLE	2590	61	47040	1398373	29.7	-997898
CANNON	3126	138	129379	1688170	13.0	-586689
CARSWELL	2191	24	15970	1182989	74.1	-1047024
CASTLE	1876	55	31140	1012775	32.5	-747663
CHARLESTON	4241	104	132050	2289886	17.3	-1165669
COLUMBUS	1194	52	18549	644566	34.7	-486646
DAVIS-MONTHA	5742	85	146885	3100874	21.1	-1850363
DOVER	3114	34	31527	1681425	53.3	-1413020
DYESS	1858	65	36342	1003320	27.6	-693916
EGLIN	20658	74	458191	11155320	24.3	-7254481
EGLIN	293	62	5436	158242	29.1	-111958
ELLSWORTH	1420	7	2811	766692	272.7	-742759
ENGLAND	2904	88	76317	1568160	20.5	-918429
F E WARREN	282	7	559	152474	272.7	-147715
FAIRCHILD	1233	17	6400	665917	104.0	-611429
GOODFELLOW	1074	65	21007	579960	27.6	-401112
GRAND FORKS	NA	NA	NA	NA	NA	NA
GRISSOM	1667	100	49965	900277	18.0	-474894
HANSCOM	2267	41	27577	1224029	44.4	-989251
HILL	4865	31	44513	2627024	59.0	-2248056
HOLLOMAN	4281	95	121998	2311546	18.9	-1272906
HOMESTEAD	4012	52	62743	2166556	34.5	-1632389
K I SAWYER	419	53	6625	226325	34.2	-169919
KEESLER	9398	16	45817	5075136	110.8	-4685068
KELLY	11760	60	211504	6350400	30.0	-4549751
KIRTLAND	7862	104	245671	4245696	17.3	-2154160
LANGLEY	3164	93	88525	1708614	19.3	-954948
LAUGHLIN	1068	90	28769	576914	20.1	-331989
LITTLE ROCK	1774	85	45090	958198	21.3	-574319
LORING	1433	18	7608	773790	101.7	-709017
LOWRY	2201	17	11490	1188626	103.4	-1090805

TABLE 4.17 (CONT)

30 PERCENT REDUCTION FOR RETROFIT UPPER LIMIT SCENARIO

BASE NAME	P (kW)	S/P ($/kW-YR)	PAS ($/YR	COST ($)	SPB (YR)	NPV ($)
LUKE	3329	56	55628	1797682	32.3	-1324087
MACDILL	3105	95	88552	1676506	18.9	-922609
MARCH	2809	65	55099	1516952	27.5	-1047862
MCCHORD	NA	NA	NA	NA	NA	NA
MCCLELLAN	6788	49	98973	3665655	37.0	-2823045
MCCONNELL	1263	65	24703	681986	27.6	-471675
MCGUIRE	3497	57	60148	1888272	31.4	-1376197
MINOT	1906	6	3173	1029169	324.3	-1002153
MOODY	1493	90	40309	806177	20.0	-463005
MT HOME	1802	13	6962	972972	139.8	-913699
MYRTLE BE	1477	57	25037	797639	31.9	-584485
NORTON	3276	66	64685	1769040	27.3	-1218336
PATRICK	6649	63	124679	3590374	28.8	-2528908
PLATTSBUR	1417	56	23791	765353	32.2	-562811
REESE	2078	70	43705	1122077	25.7	-749995
SCOTT	5546	151	250857	2994797	11.9	-859106
SEYMOUR JON	2101	53	33098	1134783	34.3	-853002
SHEPPARD	4161	54	67375	2246832	33.3	-1673231
TRAVIS	2033	62	38096	1097859	28.8	-773524
TYNDALL	4623	85	118014	2496226	21.2	-1491510
WURTSMITH	1476	36	16146	796824	49.4	-659364

The following 42 tables provide an economic analysis of each base studied broken down in regions. From this format it appears that some regions of the country tend to favor the use of thermal storage more than other areas. However, a regression analysis comparing regional areas and annual cooling degree days to $/kW-yr per base showed the resulting r-squared values to be about 0.1, indicating the correlation between these factors are weak. Therefore the effectiveness of thermal storage for the bases not studied cannot be accurately predicted from known parameters such as the base annual cooling degree days and/or the regional area of a base.

TABLE 4.18

ECONOMIC ANALYSIS OF REGION 2 NEW CONSTRUCTION SCENARIO
15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	24983	3.2	132667
MCGUIRE	26721	6.3	59642
K I SAWYER	2723	7.4	3061
PLATTSBURGH	14527	7.6	13950
HANSCOM	11267	9.7	-12883
WURTSMITH	6640	10.7	-14297
FAIRCHILD	3200	18.5	-31948
LORING	3114	22.1	-442267
ELLSWORTH	1406	48.5	-56184
MINOT	1715	53.3	-76878
GRAND FORKS	NA	NA	NA

TABLE 4.19

ECONOMIC ANALYSIS OF REGION 3 NEW CONSTRUCTION SCENARIO
15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	32343	4.9	118104
MARCH	27550	4.9	99705
TRAVIS	19048	5.1	64580
CASTLE	15570	5.8	42532
MCCLELLAN	49486	6.6	95469
BEALE	20059	7.7	15971
MCCHORD	NA	NA	NA

TABLE 4.20

ECONOMIC ANALYSIS OF REGION 4 NEW CONSTRUCTION SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	64690	2.3	400681
HOLLOMAN	60999	3.4	313849
KIRTLAND	110509	3.4	563427
DAVIS-MONTHAN	73442	3.8	349622
REESE	21852	4.6	86301
LUKE	27814	5.7	77003

TABLE 4.21

ECONOMIC ANALYSIS OF REGION 5 NEW CONSTRUCTION SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	22257	10.5	-44029
LOWRY	5745	18.4	-56745
MT HOME	3481	24.8	-56850
F E WARREN	280	48.5	-11173

TABLE 4.22

ECONOMIC ANALYSIS OF REGION 6 NEW CONSTRUCTION SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	104858	2.5	626510
CHARLESTON	66025	3.1	358563
LITTLE ROCK	22424	3.8	105737
LANGLEY	44263	4.9	224956
MCCONNELL	12352	4.9	44535
BLYTHEVILLE	23520	5.3	75938
MYRTLE BEACH	12519	5.7	35676
SEYMOUR JOHNSON	16549	6.1	40021
DOVER	15763	9.5	-15258
ALTUS	NA	NA	NA

TABLE 4.23

ECONOMIC ANALYSIS OF REGION 7 NEW CONSTRUCTION SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	14384	3.6	71181
GOODFELLOW	10504	4.9	37872
DYESS	18171	4.9	65518
KELLY	105752	5.3	335845
SHEPPARD	33688	5.9	87082
COLUMBUS	9275	6.2	21665
CARSWELL	18843	13.2	-87718

TABLE 4.24

ECONOMIC ANALYSIS OF REGION 12 NEW CONSTRUCTION SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	20154	3.6	99926
ENGLAND	38159	3.7	185473
MACDILL	36284	4.1	159880
TYNDALL	47032	4.7	178527
EGLIN	192883	5.1	650537
EGLIN	2718	5.2	9076
PATRICK	59220	5.4	185026
HOMESTEAD	28851	6.7	53039
BARKSDALE	18533	10.7	-39903
KEESLER	22909	19.7	-256089

TABLE 4.25

ECONOMIC ANALYSIS OF REGION 2 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	24983	6.0	62646
MCGUIRE	26721	11.8	-87223
K I SAWYER	2723	13.9	-14542
PLATTSBURGH	9007	14.2	-50879
HANSCOM	11267	18.1	-108085
WURTSMITH	6640	20.0	-76272
FAIRCHILD	3200	34.7	-83742
LORING	3114	41.4	-102451
ELLSWORTH	1406	90.9	-115815
MINOT	1715	100.0	-156925

TABLE 4.26

ECONOMIC ANALYSIS OF REGION 3 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	32343	9.1	-19488
MARCH	27550	9.2	-18281
TRAVIS	19048	9.6	-20809
CASTLE	15570	10.8	-36240
MCCLELLAN	49486	12.3	-189637
BEALE	20059	14.5	-119478
MCCHORD	NA	NA	NA

TABLE 4.27

ECONOMIC ANALYSIS OF REGION 4 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	64690	4.3	269378
HOLLOMAN	60999	6.3	134062
KIRTLAND	110509	6.4	233206
DAVIS-MONTHAN	73442	7.0	108443
REESE	21852	8.6	-972
LUKE	27814	10.8	-62816

TABLE 4.28

ECONOMIC ANALYSIS OF REGION 5 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	22257	19.7	-248353
LOWRY	5745	34.5	-149194
MT HOME	3481	46.6	-132526
F E WARREN	280	90.9	-23033

TABLE 4.29

ECONOMIC ANALYSIS OF REGION 6 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	104858	4.8	393581
CHARLESTON	66025	5.8	180461
LANGLEY	44263	6.4	92064
LITTLE ROCK	22424	7.1	31211
MCCONNELL	12352	9.2	-8509
BLYTHEVILLE	23520	9.9	-32824
MYRTLE BEACH	12519	10.6	-26363
SEYMOUR JOHNS	16549	11.4	-48240
DOVER	15763	17.8	-146035
ALTUS	NA	NA	NA

TABLE 4.30

ECONOMIC ANALYSIS OF REGION 7 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	14384	6.7	26310
DYESS	18171	9.2	-12518
GOODFELLOW	10504	9.2	-7236
KELLY	105752	10.0	-158075
SHEPPARD	33688	11.1	-87671
COLUMBUS	9275	11.6	-28468
CARSWELL	7985	24.7	-129183

TABLE 4.31

ECONOMIC ANALYSIS OF REGION 12 REAL SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	20154	6.7	37223
ENGLAND	38159	6.8	63505
MACDILL	36284	7.7	29485
TYNDALL	47032	8.8	-15624
EGLIN	192883	9.6	-217099
EGLIN	2718	9.7	-3232
PATRICK	59220	10.1	-94226
HOMESTEAD	28851	12.5	-115471
BARKSDALE	18533	20.0	-212876
KEESLER	22909	36.9	-650822

TABLE 4.32

ECONOMIC ANALYSIS OF REGION 2 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	24983	12.0	-87401
MCGUIRE	26721	23.6	-401935
K I SAWYER	2723	27.7	-52263
PLATTSBURGH	9007	28.3	-178438
HANSCOM	11267	36.2	-312090
WURTSMITH	6640	40.0	-209076
FAIRCHILD	3200	69.4	-194728
LORING	3114	82.8	-231416
ELLSWORTH	1406	181.8	-243597
MINOT	1715	200.0	-328453
GRAND FORKS	NA	NA	0

TABLE 4.33

ECONOMIC ANALYSIS OF REGION 3 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	32343	18.2	-314328
MARCH	27550	18.4	-271106
TRAVIS	19048	19.2	-203785
CASTLE	15570	21.7	-205035
MCCLELLAN	49486	24.7	-800580
BEALE	20059	28.9	-409725
MCCHORD	NA	NA	0

TABLE 4.34

ECONOMIC ANALYSIS OF REGION 4 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	64690	8.7	-11983
HOLLOMAN	60999	12.6	-251195
KIRTLAND	110509	12.8	-474410
DAVIS-MONTHAN	73442	14.1	-408369
REESE	21852	17.1	-187984
LUKE	27814	21.5	-362430

TABLE 4.35

ECONOMIC ANALYSIS OF REGION 5 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	22257	39.3	-686191
LOWRY	5745	69.0	-347298
MT HOME	3481	93.2	-294688
F E WARREN	280	181.8	-48445

TABLE 4.36

ECONOMIC ANALYSIS OF REGION 6 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	104858	9.5	-105552
CHARLESTON	66025	11.6	-201187
LANGLEY	44263	12.9	-192705
LITTLE ROCK	22424	14.2	-128489
MCCONNELL	12752	18.4	-122173
BLYTHEVILLE	23520	19.8	-265887
MYRTLE BEACH	12519	21.2	-159303
SEYMOUR JOHNS	16549	22.9	-237371
DOVER	15763	35.6	-426273
ALTUS	NA	NA	NA

TABLE 4.37

ECONOMIC ANALYSIS OF REGION 7 UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	14384	13.4	-69842
DYESS	18171	18.4	-179738
GOODFELLOW	10504	18.4	-103896
KELLY	105752	20.0	-1216475
SHEPPARD	33688	22.2	-462143
COLUMBUS	9275	23.2	-135895
CARSWELL	7985	49.4	-326347

TABLE 4.38

ECONOMIC ANALYSIS OF REGION 12 UPPER LIMIT RETROFIT SCENARIO
15% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	20154	13.3	-97140
ENGLAND	38159	13.7	-197855
MACDILL	36284	15.4	-249932
TYNDALL	47032	17.7	-431662
EGLIN	192883	19.3	-2076319
EGLIN	2718	19.4	-29605
PATRICK	59220	20.2	-692621
HOMESTEAD	28851	25.0	-476564
BARKSDALE	18533	40.0	-583532
KEESLER	22909	73.8	-1496678

TABLE 4.39

ECONOMIC ANALYSIS OF REGION 2 NEW CONSTRUCTION SCENARIO
30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	49965	4.8	185310
MCGUIRE	60148	8.4	8536
K I SAWYER	6625	9.1	-3947
PLATTSBURGH	23791	8.6	-1552
HANSCOM	27577	11.8	-91630
WURTSMITH	16146	13.2	-75026
FAIRCHILD	6400	27.7	-123089
LORING	7608	27.1	-141571
ELLSWORTH	2811	72.7	-180518
MINOT	3173	86.5	-247429
GRAND FORKS	NA	NA	NA

TABLE 4.40

ECONOMIC ANALYSIS OF REGION 3 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	64685	7.3	78960
MARCH	55099	7.3	64569
TRAVIS	38096	7.7	31573
CASTLE	31140	8.7	-4961
MCCLELLAN	98973	9.9	-134898
BEALE	40117	11.6	-122857
MCCHORD	NA	NA	NA

TABLE 4.41

ECONOMIC ANALYSIS OF REGION 4 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	129379	3.5	651302
HOLLOMAN	121998	5.1	422228
KIRTLAND	245671	4.6	959351
DAVIS-MONTHAN	146885	5.6	423611
REESE	43705	6.8	72862
LUKE	55628	8.6	-5787

TABLE 4.42

ECONOMIC ANALYSIS OF REGION 5 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	44513	15.7	-321572
LOWRY	11490	27.6	-219146
MT HOME	6962	37.3	-200186
F E WARREN	559	72.7	-35900

TABLE 4.43

ECONOMIC ANALYSIS OF REGION 6 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	250857	3.2	1337079
CHARLESTON	132050	4.6	513581
LANGLEY	88525	5.1	298036
LITTLE ROCK	45090	5.7	128359
MCCONNELL	24703	7.4	28448
BLYTHEVILLE	47040	7.9	27576
MYRTLE BEACH	25037	8.5	450
SEYMOUR JOHNS	33098	9.1	-20828
DOVER	31527	14.2	-179975
ALTUS	NA	NA	NA

TABLE 4.44

ECONOMIC ANALYSIS OF REGION 7 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	28769	5.3	91081
DYESS	36342	7.4	41852
GOODFELLOW	21007	7.4	24192
KELLY	211504	8.0	107209
SHEPPARD	67375	8.9	-25554
COLUMBUS	18549	9.3	-13965
CARSWELL	15970	19.8	-179499

TABLE 4.45

ECONOMIC ANALYSIS OF REGION 12 NEW CONSTRUCTION SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	40309	5.3	128191
ENGLAND	76317	5.5	231555
MACDILL	88552	5.0	306828
TYNDALL	118014	5.6	339056
EGLIN	458191	6.5	926087
EGLIN	5436	7.8	4086
PATRICK	124679	7.7	104032
HOMESTEAD	62743	9.2	-43582
BARKSDALE	37066	16.0	-277489
KEESLER	45817	29.5	-963302

TABLE 4.46

ECONOMIC ANALYSIS OF REGION 2 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	49965	9.0	-24755
MCGUIRE	60148	15.7	-432061
K I SAWYER	6625	17.1	-56756
PLATTSBURGH	23791	16.1	-180134
HANSCOM	27577	22.2	-377237
WURTSMITH	16146	24.7	-260952
FAIRCHILD	6400	52.0	-278470
LORING	7608	50.9	-322122
ELLSWORTH	2811	136.4	-359413
MINOT	3173	162.2	-487568
GRAND FORKS	NA	NA	NA

TABLE 4.47

ECONOMIC ANALYSIS OF REGION 3 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	64685	13.7	-333816
MARCH	55099	13.8	-289387
TRAVIS	38096	14.4	-224594
CASTLE	31140	16.3	-241275
MCCLELLAN	98973	18.5	-990217
BEALE	40117	21.7	-529203
MCCHORD	NA	NA	NA

TABLE 4.48

ECONOMIC ANALYSIS OF REGION 4 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	129379	6.5	257395
HOLLOMAN	121998	9.5	-117133
KIRTLAND	245671	8.6	-31312
DAVIS-MONTHAN	146885	10.6	-299926
REESE	43705	12.8	-188956
LUKE	55628	16.2	-425246

TABLE 4.49

ECONOMIC ANALYSIS OF REGION 5 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	44513	29.5	-934544
LOWRY	11490	51.7	-496492
MT HOME	6962	69.9	-427213
F E WARREN	559	136.4	-71477

TABLE 4.50

ECONOMIC ANALYSIS OF REGION 6 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	250857	6.0	638293
CHARLESTON	132050	8.7	-20726
LANGLEY	88525	9.7	-100641
LITTLE ROCK	45090	10.6	-95220
MCCONNELL	24703	13.8	-130682
BLYTHEVILLE	47040	14.9	-298711
MYRTLE BEACH	25037	15.9	-185665
SEYMOUR JOHNS	33098	17.1	-285611
DOVER	31527	26.7	-572308
ALTUS	NA	NA	NA

TABLE 4.51

ECONOMIC ANALYSIS OF REGION 7 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	28769	10.0	-43532
DYESS	36342	13.8	-192256
GOODFELLOW	21007	13.8	-111132
KELLY	211504	15.0	-1374551
SHEPPARD	67375	16.7	-549815
COLUMBUS	18549	17.4	-164363
CARSWELL	15970	37.0	-455530

TABLE 4.52

ECONOMIC ANALYSIS OF REGION 12 REAL RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	40309	10.0	-59917
ENGLAND	76317	10.3	-134349
MACDILL	88552	9.5	-84357
TYNDALL	118014	10.6	-243397
EGLIN	458191	12.2	-1676821
EGLIN	5436	14.6	-32837
PATRICK	124679	14.4	-733722
HOMESTEAD	62743	17.3	-549112
BARKSDALE	37066	30.0	-796408
KEESLER	45817	55.4	-2147500

TABLE 4.53

ECONOMIC ANALYSIS OF REGION 2 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
GRISSOM	49965	18.0	-474894
MCGUIRE	60148	31.4	-1376197
K I SAWYER	6625	34.2	-169919
PLATTSBURGH	23791	32.2	-562811
HANSCOM	27577	44.4	-989251
WURTSMITH	16146	49.4	-659364
FAIRCHILD	6400	104.0	-611429
LORING	7608	101.7	-709017
ELLSWORTH	2811	272.7	-742759
MINOT	3173	324.3	-1002153
GRAND FORKS	NA	NA	NA

TABLE 4.54

ECONOMIC ANALYSIS OF REGION 3 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
NORTON	64685	27.3	-1218336
MARCH	55099	27.5	-1047862
TRAVIS	38096	28.8	-773524
CASTLE	31140	32.5	-747663
MCCLELLAN	98973	37.0	-2823045
BEALE	40117	43.4	-1399945
MCCHORD	NA	NA	NA

TABLE 4.55

ECONOMIC ANALYSIS OF REGION 4 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
CANNON	129379	13.0	-586689
HOLLOMAN	121998	18.9	-1272906
KIRTLAND	245671	17.3	-2154160
DAVIS-MONTHAN	146885	21.1	-1850363
REESE	43705	25.7	-749995
LUKE	55628	32.3	-1324087

TABLE 4.56

ECONOMIC ANALYSIS OF REGION 5 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
HILL	44513	59.0	-2248056
LOWRY	11490	103.4	-1090805
MT HOME	6962	139.8	-913699
F E WARREN	559	272.7	-147715

TABLE 4.57

ECONOMIC ANALYSIS OF REGION 6 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
SCOTT	250857	11.9	-859106
CHARLESTON	132050	17.3	-1165669
LANGLEY	88525	19.3	-954948
LITTLE ROCK	45090	21.3	-574319
MCCONNELL	24703	27.6	-471675
BLYTHEVILLE	47040	29.7	-997898
MYRTLE BEACH	25037	31.9	-584485
SEYMOUR JOHNS	33098	34.3	-853002
DOVER	31527	53.3	-1413020
ALTUS	NA	NA	NA

TABLE 4.58

ECONOMIC ANALYSIS OF REGION 7 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
LAUGHLIN	28769	20.1	-331989
DYESS	36342	27.6	-693916
GOODFELLOW	21007	27.6	-401112
KELLY	211504	30.0	-4549751
SHEPPARD	67375	33.3	-1673231
COLUMBUS	18549	34.7	-486646
CARSWELL	15970	74.1	-1047024

TABLE 4.59

ECONOMIC ANALYSIS OF REGION 12 UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

BASE NAME	ANNUAL SAVINGS ($)	PAY BACK (YR)	NPV (YR)
MOODY	40309	20.0	-463005
ENGLAND	76317	20.5	-918429
MACDILL	88552	18.9	-922609
TYNDALL	118014	21.2	-1491510
EGLIN	458191	24.3	-7254481
EGLIN	5436	29.1	-111958
PATRICK	124679	28.8	-2528908
HOMESTEAD	62743	34.5	-1632389
BARKSDALE	37066	60.0	-1908376
KEESLER	45817	110.8	-4685068

The bases that are designated as "NA" means that the electrical rate for that base will not support thermal storage. In most cases, these bases have a ratchet rate that is based on a peak demand level set in the winter months. Therefore the air conditioning load has a minimal effect on the demand peak. A break out of the specific electrical structures for each base is delineated in Appendix A of this report.

V. Results and Recommendations

Overview

This chapter consolidates the results of both the qualitative data and the quantitative data researched in this study. In addition, some recommendations based on these results are offered. Finally, recommendations for future study of this research are given.

Qualitative Results

The qualitative portion of this thesis addressed the following issues:

1. Validity of thermal storage.
2. Effectiveness of thermal storage.
3. Type of thermal storage system most appropriate for most Air Force applications.
4. Type of facility suitable for thermal storage.
5. Maintenance requirements of thermal storage.
6. Available incentives offered by utility companies to encourage thermal storage.

Validity. From the literature search, thermal storage was found to be not only a valid but also an effective technology in areas conducive to its use. The consensus of all the expert opinions researched in this study strongly endorses the validity of ice thermal storage systems. Since these opinions refer to ice systems in general and explicitly address applications concerning new construction, replacement and retrofit systems, a generalization of these opinions to Air Force applications is appropriate. Thus the technology supporting ice thermal storage is valid and therefore suitable for Air Force use.

Effectiveness. The case studies examined in this study demonstrate the effectiveness of thermal storage systems. These cases document significant dollar savings and short payback periods realized from the different applications offered. Additionally, the initial investment costs in these cases were shown to be competitive with conventional air conditioning systems costs. These cases show ice thermal storage to be a very effective technology in areas of high electrical demand and time of use rates.

Because of the diverse locations and electrical rate structures associated with Air Force bases, the potential benefits of thermal storage is certain to some Air Force bases where others may not be suitable for thermal storage. Therefore the effectiveness of thermal storage in Air Force applications varies from base to base. The determination of which bases are suitable for thermal storage is addressed in the quantitative portion of this chapter.

Types of Systems. This research revealed the overall best suited system available on today's market to meet Air Force requirements is the package ice storage system. Factors such as flexibility, ease of installation, expansion capabilities, warrantability, ease of design, and on site-space requirements were some of the qualitative factors used in choosing this type system over other types. In the classification of packaged ice storage systems there is an assortment of different systems such as ice harvesters, ice on tubes, glycol median systems, etc. The type of packaged ice storage system is not specifically recommended in this study since each system can be justified according to the situation, and that decision is deferred to the design engineer at each specific installation.

Type of Facility. In order for a facility to be a good candidate for thermal storage, the following criteria should be considered:

1. The facility has a sharp peak load coinciding with the installation's peak electrical demand.
2. The installation's electrical demand charge is high.
3. The facility has a well defined occupancy schedule.
4. The facility is separately metered, or at least has its own chiller to cool it (for monitoring performance).
5. The installation will strongly support the project.
6. The facility has space available for installing the cooling system.
7. Experienced contractors are available locally. (17:17)

Among competing applications, first consideration should be given to those facilities that are under design. This consideration allows the thermal storage system to be part of the original design of the facility. This allows the designer to fit the thermal storage system to the facility's original design and it gives him more flexibility in the layout and specific type of thermal storage system to use. One design option that is available for the new construction alternative that may not be applicable for existing applications is cold air distribution. The benefits of this design allows the air handling system to be smaller than conventional systems since the air temperature is colder thus requiring less air capacity than conventional systems. This results in lower initial and operating equipment costs.

Other good applications for thermal storage are those facilities that have air conditioning systems that are in need of replacement. Since these systems require replacement, the differential cost between a thermal storage system and a conventional system will be comparable to the initial cost of the new construction application. The only extra cost for the cold storage system is the storage tank and installation (3:13).

Retrofit applications require careful consideration. This is due to the excessive initial costs that can accompany this alternative. This is evident in the quantitative evaluation of this study in that the retrofit alternatives almost unanimously have an undesirable payback period. Thus retrofit options should be the last alternative to be considered for thermal storage.

Maintenance Requirements. According to the literature review and the parties contacted in this study, ice thermal storage systems do not require special maintenance or operational training apart from the normal requirements associated with a new conventional air conditioning system. Therefore implementation of these systems in the Air Force should not impart an undo strain on the maintenance shops to sustain these systems. It should be again pointed out that this study focused primarily on packaged ice systems. From a maintenance standpoint these systems are usually more attractive than the custom built systems because of the warrantability of the packaged systems. This is due to a single source providing the packaged system.

Incentives. When available, incentives provide an excellent means of reducing the initial cost of thermal storage systems. This study did not focus on the areas where utility companies were offering incentives, rather the legal implications determining if the Air Force could exploit these incentives were studied. By examining the typical requirements of a government contract and similar types of contracts already being used by the government, it was determined that these incentives are legal for Air Force use.

Quantitative Results

The quantitative portion of this study determined the market potential of packaged ice thermal storage systems for CONUS Air Force bases. By querying numerous bases in each region of the CONUS about their electrical rate structure and electrical demand requirements, a data base was developed showing which regions and which bases studied are most conducive for thermal storage.

Caveat. Since the quantitative results of this study are based on data that represents a snapshot of a base's electrical rate structure and demand load, verification of these results is recommended before programming actions occur. This is important since many utility contracts are negotiated annually. Thus the rate structure that enabled possible amenable savings from thermal storage in this report could be modified to the detriment of load deferment savings.

Also, it should be noted that if the Air Force Energy Conservation Incentives Program is reinstated, an interest rate of seven percent should be used in lieu of the ten percent used in this study in determining the NPV of the TSS's.

Regional Results

Although the correlation between climatic data and potential savings associated with thermal storage is weak, some helpful conclusions can be drawn by comparing the regions with each other. The following tables summarizes the percentage of bases studied within a particular region that have a simple pay back period range of less than three years, five years and ten years:

TABLE 5.1

REGIONAL PERCENTAGES NEW CONSTRUCTION SCENARIO 15% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	9	45
3	0	29	86
4	17	83	100
5	0	0	0
6	10	50	90
7	14	43	86
12	0	40	80

TABLE 5.2

REGIONAL PERCENTAGES REALISTIC RETROFIT SCENARIO 15% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	0	9
3	0	0	0
4	0	17	83
5	0	0	0
6	0	10	60
7	0	0	43
12	0	0	60

TABLE 5.3

REGIONAL PERCENTAGES UPPER LIMIT RETROFIT SCENARIO 15% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	0	0
3	0	0	0
4	0	0	17
5	0	0	0
6	0	0	10
7	0	0	0
12	0	0	0

TABLE 5.4

REGIONAL PERCENTAGES NEW CONSTRUCTION SCENARIO 30% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	9	36
3	0	0	71
4	0	33	100
5	0	0	0
6	0	20	80
7	0	0	86
12	0	0	80

TABLE 5.5

REGIONAL PERCENTAGES REALISTIC RETROFIT SCENARIO 30% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	0	9
3	0	0	0
4	0	0	50
5	0	0	0
6	0	0	30
7	0	0	0
12	0	0	10

TABLE 5.6

REGIONAL PERCENTAGES UPPER LIMIT RETROFIT SCENARIO 30% REDUCTION

	PAYBACK PERIOD		
REGION	< 3 YR	< 5 YR (% of bases studied)	< 10 YR
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
12	0	0	0

These tables indicate that from the bases studied, a hierarchy exists concerning the regional market potential for thermal storage. This hierarchy is as follows (see Tables 4.1 through 4.7 for bases in the following regions):

1. Region 4
2. Region 6
3. Region 7
4. Region 12
5. Region 3
6. Region 2
7. Region 5

Although causality cannot be presumed from this ordered list, an inference about the bases not studied can be made. Those bases that reside in region four are the most probable to benefit from thermal storage, where region five bases are the least probable to benefit from thermal storage.

Overall Results

The economic analysis performed in chapter four identifies the bases that are most likely to benefit from using thermal storage. This analysis has shown that thermal storage technology has good market potential for new construction and replacement applications. However, the retrofit applications did not show much economic potential. The following table depicts the overall potential annual savings for each option and application studied in this report:

TABLE 5.7

NEW CONSTRUCTION/REPLACEMENT APPLICATION POTENTIAL ANNUAL SAVINGS ($)

	PAYBACK PERIOD		
SHIFTED DEMAND	< 3YR	< 5YR	< 10 YR
15%	194531	850978	1538931
30%	0	807924	1818190

TABLE 5.8

RETROFIT APPLICATION/REALISTIC POTENTIAL ANNUAL SAVINGS ($)

	PAYBACK PERIOD		
SHIFTED DEMAND	< 3YR	< 5YR	< 10 YR
15%	0	16945	1086428
30%	0	0	1106999

TABLE 5.9

RETROFIT APPLICATION/UPPER LIMIT POTENTIAL ANNUAL SAVINGS ($)

	PAYBACK PERIOD		
SHIFTED DEMAND	< 3YR	< 5YR	< 10 YR
15%	0	0	169548
30%	0	0	0

These tables indicate that the Air Force could save as much as $194,000 per year by installing thermal storage systems on those bases indicated in this report to have a payback period of less than three years. Considering those bases deferring 15 percent of their cooling load conducive to thermal storage and having a payback period of less than five years, over $850,000 per year can be saved by installing systems on new construction and air conditioning replacement projects. This is particularly appealing since the initial cost associated with these applications can be competitive if not better than the conventional air conditioning systems the Air Force would normally use.

Recommendations

In view of the results shown in this chapter, it is the recommendation of this author that the following Air Force bases consider installing package ice thermal storage systems in all new facility designs with air conditioning requirements, and projects that require air conditioning replacement: Cannon AFB, Scott AFB, Charleston AFB, Grissom AFB, Kirtland AFB, Langley AFB, Holloman AFB, Laughlin AFB, Moody AFB, England AFB, Little Rock AFB, Davis-Monthan AFB, MacDill AFB, Reese AFB, Dyess AFB, March AFB, McConnell AFB, Norton AFB, and Tyndall AFB.

In addition, it is recommended that all the other CONUS bases not included in this report be analyzed for potential thermal storage implementation. Emphasis is added to those bases residing in regions four, and six. They are: Edwards AFB, Andrews AFB, Arnold AFB, Bolling AFB, Dobbins AFB, Pope AFB, Robins AFB, Shaw AFB, Tinker AFB, and Whiteman AFB.

Recommendations for Future Study

One area supporting future study of this thesis is identifying utility companies that are willing to offer the Air Force thermal storage construction incentives. This information could boost bases shown to have mediocre results in this report to have excellent payback periods where these incentives were found applicable. Another area that would be suitable for future research would be to conduct a case study on an Air Force base to determine the actual savings that can result from using thermal storage.

Conclusion

Thermal storage is a technology that can save the Air Force money. This study attempted to analyze the applicability of packaged ice thermal storage to the Air Force, and identify those CONUS bases that could best benefit from its use. One comment sticks out in this author's mind from an interview with an existing commercial user of thermal storage systems. This user said that he did not have much faith in thermal storage technology until he experienced the savings resulting from his system. He said he is convinced that the benefits he has seen from this technology could also be realized by the Air Force.

Appendix A: Electrical Rate Structure Calculations

Common Variables

OPR = On-peak demand rate in \$/kW
OFPR = Off-peak demand rate in \$/kW
OER = On-peak energy rate in \$/kWh
OFER = Off-peak energy rate in \$/kWh
M = Number of months thermal storage estimate to be operational per year
RM = Number of months per year ratchet is in effect
m = Number of months the peak demand exceeds the ratcheted demand
R = Ratchet percentage
S = Savings in \$/kW-yr by deferring peak demand to off-peak periods

---

Base Name: Altus AFB

Altus AFB's demand rate is set by contract each year. Therefore deferrment of peak load energy will not produce any dollar savings. Thermal Storage is not applicable in this case.

Base Name: Barksdale AFB

OPR = 5.00
ONPR = 5.00
OER = .029885
ONER = .029885
R = 0
M = 6

Calculations:

S = OPR x M   S = 30

Base Name: Beale AFB

OPR = 8.29
OFPR = 8.29
OER = .014430
OFER = .014430
R = 0
M = 5

Calculations:

S = OPR x M   S = 41.45

Base Name: Blytheville (Eaker) AFB

OPR = 12.11
OFPR = 10.61
OER = .035640
OFER = .035640
R = 0
M = 5

Calculations:

S = OPR x M   S = 60.55

Base Name: Cannon AFB

Demand Rates:

OPR = 7.76
OFPR = 7.76

Energy Rates:

R1 = .0330 ...First ratchet rate ($/kWh)

R2 = .0300 ...Second ratchet rate ($/kWh)

R3 = .0289 ...Third ratchet rate ($/kWh)

The energy consumed is based on the monthly demand peak

Demand peak x 230 ... first ratchet
Demand peak x 230 ... second ratchet if amount kWh is greater than first ratchet

R = 60%

M = 5
RM = 2

Calculations:

S = M x OPR + M x (R1 + R2) x 230 + RM x R x OPR + RM x (R1 + R2) x R x 230

S = 137.95

Base Name: Carswell AFB

OPR = 4.05
OFPR = 4.05
OER = .025000

OFER = .025000
R = 0
M = 6

Calculations:

S = OPR x M   S = 24.3

Base Name: Castle AFB

OPR = 11.07
OFPR = 11.07
OER = .015760
OFER = .015760
R = 0
M = 5

Calculations:

S = OPR x M   S = 55.35

Base Name: Charleston AFB

OPR = 17.30
OFPR = 11.3
OER = .020000
OFER = .020000
R = 0
M = 6

Calculations:

S = OPR x M   S = 103.8

Base Name: Columbus AFB

OPR = 10.36
OFPR = 10.36
OER = .004900
OFER = .004900
R = 0
M = 5

Calculations:

S = OPR x M   S = 51.8

Base Name: Davis-Monthan AFB

OPR = 8.25
OFPR = 8.25
OER = .038609
OFER = .038609

R = 66.7%
m = 7
RM = 5

Calculations:

S = OPR x m + RM x R x OPR   s = 85.264

Base Name: Dover AFB

OPR = 6.75
OFPR = 5.20
OER = .03220
OFER = .03220
R = 0
M = 5

Calculations:

S = OPR x M   S = 33.75

Base Name: Dyess AFB

OPR = 7.41 + 5.63
OFPR = 7.41
OER = .488000
ONER = .488000
R = 0
M = 5

Calculations:

S = OPR x M   S = 65.2

Base Name: Eglin 1 AFB

OPR = 6.32
OFPR = 6.32
OER = .019440 + .021690
OFER = .004060 + .020470
R = 0
M = 7
W1 = 4
W2 = 8
D = 22

Calculations:

S1 = OPR x M + M x (OER - OFER) x W1 x D   S1 = 54.466

S2 = OPR x M + M x (OER - OFER) x W2 x D   S2 = 64.691

Base Name: Eglin 2 AFB

OPR = 7.73
OFPR = 7.73
OER = .029700
OFER = .029700
R = 0
M = 7

Calculations:

S = OPR x M S = 54.11

Base Name: Ellsworth AFB

OPR = 1.65
OFPR = 1.65
OER = .012200
OFER = .012200
R = 0
M = 4

Calculations:

S = OPR x M S = 87.6

Base Name: England AFB

OPR = 7.30
OFPR = 1.65
OER = .075500
OFER = .075500
R = 100%
RM = 12

Calculations:

S = OPR x RM S = 87.6

Base Name: F. E. Warren AFB

OPR = 7.30
OFPR = 1.65
OER = .00000
OFER = .00000
R = 0
M = 4

Calculations:

S = OPR x M S = 29.2

Base Name: Fairchild AFB

OPR = 3.46
OFPR = 3.46
OER = .014400
OFER = .014400
R = 0
M = 5

Calculations:

S = OPR x M   S = 17.3

Base Name: Goodfellow AFB

OPR = 7.41 + 5.63
OFPR = 7.41
OER = .004800
OFER = .004800
R = 0
M = 5

Calculations:

S = OPR x M   S = 65.2

Base Name: Grandforks AFB

Not applicable for thermal storage because ratchet is based on peak loads that are set in winter months, therefore air condition load has minimal effect on peak.

Base Name: Grissom AFB

OPR = 9.99
OFPR = 9.99
OER = .016777
ONER = .016777
R = 75%
m = 4
RM = 8

Calculations:

S = OPR x m + RM x R x OPR   S = 99.9

Base Name: Hanscom AFB

OPR = 6.43
OFPR = 6.43
OER = .027770
OFER = .006700
R = 0

M = 4
W1 = 4
W2 = 8
D = 22

Calculations:

S1 = OPR x M + M x (OER - OFER) x W1 x D S1 = 33.137

S2 = OPR x M + M x (OER - OFER) x W2 x D S2 = 40.553

Base Name: Hill AFB

OPR = 6.1
OFPR = 6.1
OER = .026968
OFER = .026968
R = 0
M = 5

Calculations:

S = OPR x M S = 30.5

Base Name: Holloman AFB

OPR = 19.0
OFPR = 19.0
OER = .022035
OFER = .022035
R = 0
M = 5

Calculations:

S = OPR x M S = 95

Base Name: Homestead AFB

OPR = 6.25
OFPR = 6.25
OER = .039520
OFER = .032720
R = 0
m = 7

Calculations:

S1 = OPR x m + D x W1 x (OER - OFER) x m S1 = 47.939

S2 = OPR x m + D x W2 x (OER - OFER) x m S2 = 52.128

Base Name: K I Sawyer AFB

OPR = 8.74 ...first 3000 kW
OFPR = 8.48 ...remaining kW
OER = .32 ...in $/kW using 33 1/3 of max
OFER = .32 ...same as above
R = 60% ...does not come into effect therefore ignore
M = 4

Calculations:

S1 = OFPR x M + .333 x .32 x W1 x D S1 = 43.297

S2 = OFPR x M + .333 x .32 x W2 x D S2 = 52.675

Base Name: Keesler AFB

OPR = 3.25
OFPR = 3.25
OER = .042870
OFER = .042870
R = 0
M = 5

Calculations:

S = OPR x M S = 16.25

Base Name: Kelly AFB

OPR = 8.00
OFPR = 6.65
OER = .000 Data not supplied, assume no TOU rate
OFER = .000
R = 0
M = 5
m = 3

Calculations:

S = OPR x M + OFPR x m S = 59.95

Base Name: Kirtland AFB

OPR = 8.43
OFPR = 8.28
OER = .064952 - .035381
OFER = .0505 - .035469
R = 75%
M = 3 RM = 8 M = 3 RM = 2
W1 = 4

W2 = 8
D = 22

Calculations:

S1 = OPR x M + RM x R x (OFPR) + OFPR + M x OER x W1 x D
+ RM1 x OFER x W1 X D
S1 = 93.702

S2 = OPR x M + RM x R x (OFPR) + OFPR + M x OER x W2 x D
+ RM1 x OFER x W2 X D
S2 = 104.154

Base Name: Langley AFB

OPR = 8.327
OFPR = 8.327
OER = .025384
OFER = .025384
R = 90%
m = 4 RM = 8

Calculations:

S = OPR x m + RM x OPR x R S = 93.262

Base Name: Laughlin AFB

OPR = 8.160
OFPR = 8.160
OER = .004810
OFER = .004810
R = 80%
m = 7 RM = 5

Calculations:

S = OPR x m + RM x OPR x R S = 89.76

Base Name: Little Rock AFB

OPR = 17.195
OFPR = 15.015
OER = .025340
OFER = .024050
R = 0
M = 4
M1 = 1 ...number of off-peak months that TTS is in effect

Calculations:

S1 = OPR x M + M1 x OFPR + M x (OER - OFER) x D x W1

S = 84.249

S2 = OPR x M + M1 x OFPR + M x (OER - OFER) x D x W2

S2 = 84.703

Base Name: Lorin AFB

OPR = 3.76
OFPR = 2.01
OER = .057569
OFER = .045413
R = 0
m = 3
D = 22
W1 = 4
W2 = 8

Calculations:

S1 = m x OPR + m x (OER - OFER) x D x W1 S1 = 14.489

S2 = m x OPR + m x (OER - OFER) x D x W2 S2 = 17.698

Base Name: Lowry AFB

OPR = 6.15
OFPR = 3.75
OER = .024800
OFER = .024800
R = 75%
m = 5
RM = 3

Calculations:

S = m x (OPR - OFPR) + RM x R x (OPR - OFPR) S = 17.4

Base Name: Luke AFB

OPR = 11.14
OFPR = 11.14
OER = .035000
OFER = .035000
R = 0
M = 5

Calculations:

S = OPR x M S = 56.00

Base Name: MacDill AFB

OPR = 6.750
OFPR = 6.750
OER = .061310
OFER = .039640
R = 0
m = 9
D = 22
W1 = 4
W2 = 8

Calculations:

S1 = OPR x m + D x W1 x (OER - OFER) x m S1 = 77.913

S2 = OPR x m + D x W2 x (OER - OFER) x m S2 = 95.075

Base Name: McChord AFB
Not applicable for thermal storage because ratchet is based on peak loads that are set in winter months, therefore air condition load has minimal effect on peak.

Base Name: March AFB

OPR = 10.976
OFPR = 2.1
OER = .030820
OFER = .030820
R = 0
M = 5

Calculations:

S = OPR x M + OFPR M S = 65.38

Base Name: McClellan AFB

OPR = 8.10
OFPR = 6.70
OER = 0 Data not provided, assume no TOU rates
OFER = 0
R = 0
M = 6

Calculations:

S = OPR x M S = 48.6

Base Name: McConnell AFB

OPR = 13.04
OFPR = 13.04
OER = .053900
OFER = .053900
R = 0
M = 5

Calculations:

S = OPR x M   S = 65.2

Base Name: McGuire AFB

OPR = 8.91
OFPR = 8.91
OER = .063710
OFER = .049180
R = 0
M = 5
W1 = 4
W2 = 8
D = 22

Calculations:

S1 = OPR x M + M x (OER - OFER) x W1 x D   S1 = 50.943

S2 = OPR x M + M x (OER - OFER) x W2 x D   S2 = 57.336

Base Name: Minot AFB

OPR = 1.85
OFPR = 1.85
OER = .005060
OFER = .005060
R = 0
M = 3

Calculations:

S = OPR x M   S = 6.0

Base Name: Moody AFB

OPR = 7.5
OFPR = 7.5
OER = .033000
OFER = .033000
R = 100%
RM = 12

Calculations:

S = RM x R x OPR   S = 90

Base Name: Mt Home AFB

OPR = 3.22
OFPR = 3.22
OER = .020467
OFER = .020467
R = 0
M = 4

Calculations:

S = M x OPR   S = 12.88

Base Name: Myrtle Beach AFB

OPR = 11.3
OFPR = 11.3
OER = .02000
OFER = .02000
R = 0
M = 5

Calculations:

S = M x OPR   S = 56.5

Base Name: Norton AFB

OPR = 11.068
OFPR = 2.096
OER = .030740
OFER = .030740
R = 0
M = 5

Calculations:

S = M x OPR + M x OFPR   S = 65.82

Base Name: Patrick AFB

OPR = 6.25
OFPR = 6.25
OER = .039060
OFER = .035110
R = 0
M = 9
W1 = 4
W2 = 8

D = 22

Calculations:

S1 = OPR x M + M x (OER - OFER) x W1 x D   S1 = 59.378

S2 = OPR x M + M x (OER - OFER) x W2 x D   S2 = 62.507

Base Name: Plattsburgh AFB

OPR = 5.756
OFPR = 5.756
OER = .064800
OFER = .033922
R = 0
M = 5
W1 = 4

W2 = 8
2
D = 22

Calculations:

S1 = OPR x M + M x (OER - OFER) x W1 x D   S1 = 42.366

S2 = OPR x M + M x (OER - OFER) x W2 x D   S2 = 55.953

Base Name: Reese AFB (similar to Cannon AFB)

OPR = 9.10
OFPR = 9.10
OER = .009600
OFER = .009600
R = 60%
RM = 2   M = 5

Calculations:

S = RM x R x OPR + M x OPR + M x OER x 230 + RM x R x OER x 230

S = 70.11

Base Name: Scott AFB

OPR = 16.32
OFPR = 4.505
OER = .042400
OFER = -.01380
R = 0
M = 4   M1 = 8   M2 = 5
W1 = 4

W2 = 8
D = 22

Calculations:

S1 = OPR x M + M1 x OFPR + M2 x (OER - OFER) x W1 x D

S1 = 126.048

S2 = OPR x M + M1 x OFPR + M2 x (OER - OFER) x W2 x D

S2 = 150.776

Base Name: Seymour Johnson AFB

OPR = 10.5
OFPR = 10.5
OER = .029620
OFER = .029620
R = 0
M = 5

Calculations:

S = M x OPR S = 52.5

Base Name: Sheppard AFB

OPR = 5.19
OFPR = 5.19
OER = .026834
OFER = .026834
R = 80%
RM = 8 m = 4

Calculations:

S = RM x R x OPR + m x OPR S = 53.976

Base Name: Travis AFB

OPR = 8.923
OFPR = 8.923
OER = .015700
OFER = .015700
R = 0
M = 7

Calculations:

S = M x OPR S = 62.461

Base Name: Tyndall AFB

OPR = 3.35 + 2.97
OFPR = 2.97
OER = .041130
OFER = .024530
R = 0
M = 8
W1 = 4
W2 = 8
D = 22

Calculations:

S1 = OPR x M + (OER - OFER) x W1 x D x M S1 = 62.246

S2 = OPR x M + (OER - OFER) x W2 x D x M S2 = 73.933

Base Name: Wurtsmith AFB

OPR = 8.02
OFPR = 8.02
OER = .041270
OFER = .017760
R = 0
M = 3
W1 = 4
W2 = 8
D = 22

Calculations:

S1 = OPR x M + (OER - OFER) x W1 x D x M S1 = 30.267

S2 = OPR x M + (OER - OFER) x W2 x D x M S2 = 36.473

Appendix B: USACERL Technical Report E-89/13

MARKET POTENTIAL OF STORAGE COOLING SYSTEMS IN THE ARMY

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.

---

[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 1986).

[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-8571, 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.

---

[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,

---

[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	17056	24697	8505600	161674	403904	169455	344
04 23	17500	24697	8697600	165324	408767	169455	352
05 23	23155	24697	10809600	205468	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	525615	187271	461
10 23	26419	26010	11750400	214480	493381	178239	452
11 20	19085	26010	8659200	158056	410441	178239	333
12 22	17587	26010	9696000	176631	437489	178239	392
Total	266561	309284	134362400	2498910	5767271	2119900	

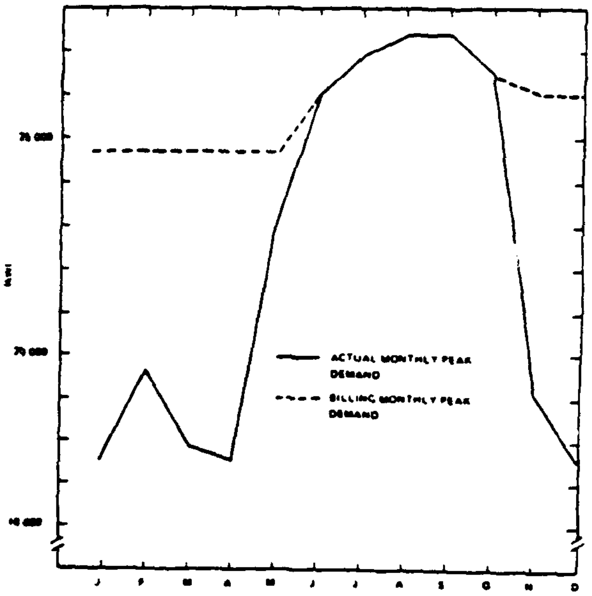

Figure 1. 1986 monthly actual and billing demand of Fort Stewart.

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 ($8.69) 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.

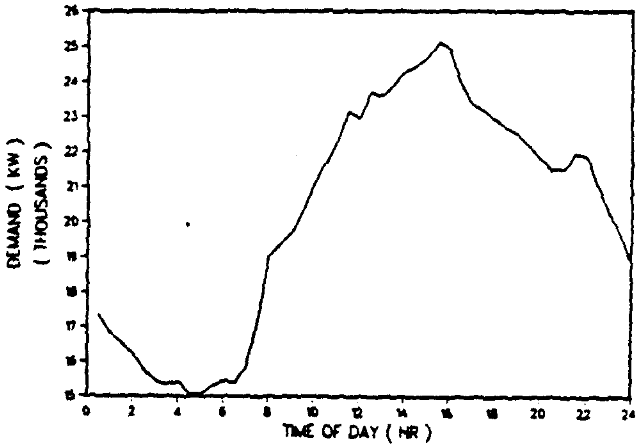

Figure 2. Hourly demand profile of Fort Stewart on 20 June 1984.

---

[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

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

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

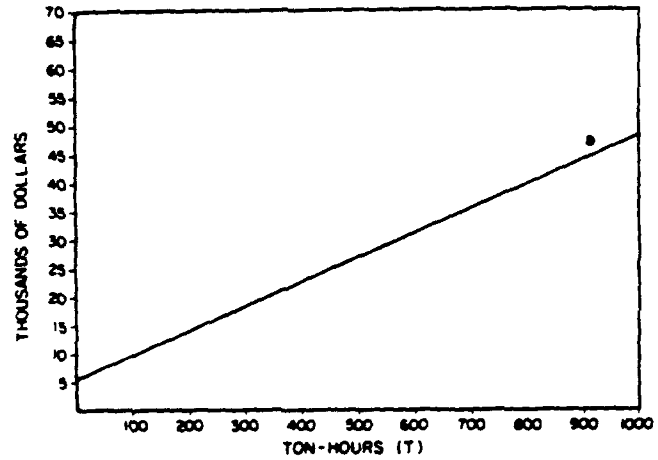

Figure 3. Cost of storage tank as function of storage capacity for ice-on-coil diurnal ice storage cooling system.

---

[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.

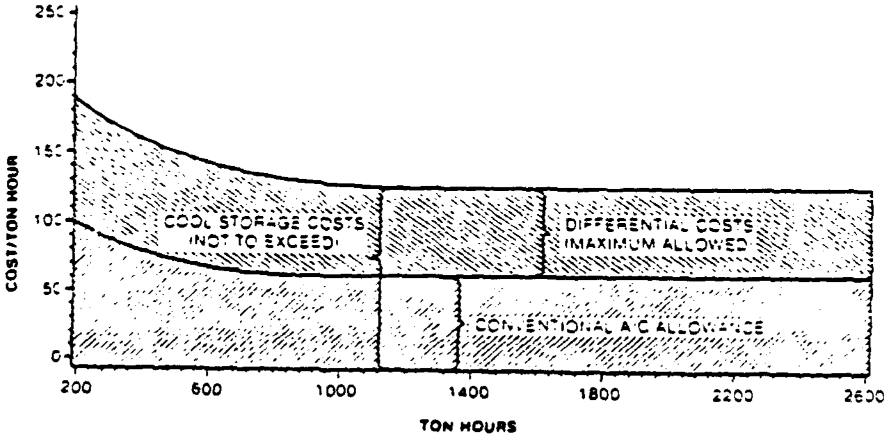

Figure 4. SCS system costs as a function of capacity.

---

[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.

---

[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

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

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.

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

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

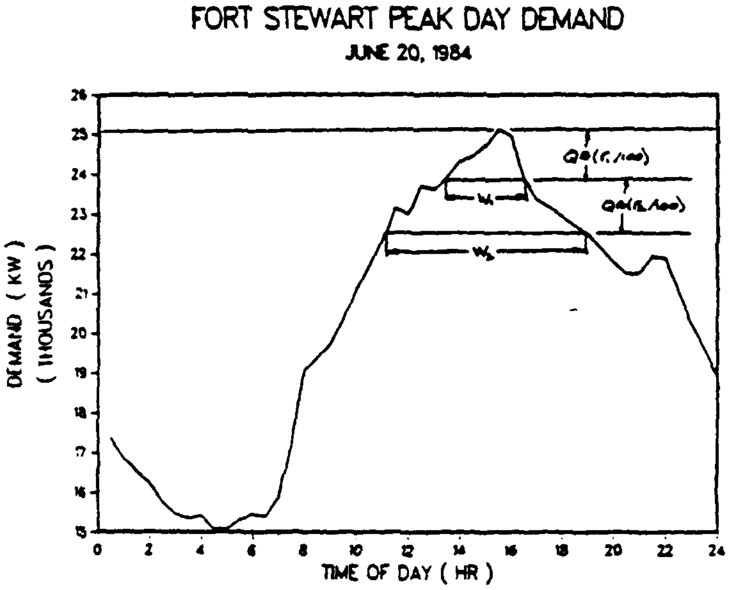

Figure 5. Daily peak demand profile.

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

---

[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 I: 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

					Demand Charge		Annual Ratchet Factor		Annual
	Post	State	Power Company	Pk Dem kW	$/kW D_1	$/kW D_2	F_1	F_2	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	68961	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

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

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

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

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

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

The required storage capacity is

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

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

For a new construction/replacement application,

$$\begin{aligned} C &= 80 \times 5841 \\ &= \$467{,}280. \end{aligned}$$

For a retrofit application,

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

and

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

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),

$S = P \times D \times F$
$= (29,203 \times 0.10) \times 6.69 \times 11.65$
$= \$227,600$/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

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

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

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

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

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

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

and

$C = 300 \times 11,681$
$= \$3,504,300$ (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 Can 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, No Profit/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 Med 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	81	[illegible]
10 %	0	0	[illegible]

Retrofit Application/Upper Limit

Shifted Demand	Payback Period < 3 Yr	< 5 Yr	< 10 Yr
5 %	0	0	81
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 iee 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.

---

[18] G. A. Reeves.

[19] M. A. Piette, E. Wyatt, and J. Harris.

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)

	New Construction Replacement Application		
Shifted Demand		Payback Period	
	< 3 Yr	< 5 Yr	< 10 Yr
5 %	457	3140	6700
10 %	753	4727	12252
	Retrofit Application/Realistic		
Shifted Demand		Payback Period	
	< 3 Yr	< 5 Yr	< 10 Yr
5 %	0	457	3555
10 %	0	0	4305
	Retrofit Application/Upper Limit		
Shifted Demand		Payback Period	
	< 3 Yr	< 5 Yr	< 10 Yr
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.

---

[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.

REFERENCES

Case Studies, STEP Storage of Thermal Energy for the Peak (Arizona Public Service Company, 1987).

"Chapter 46: Thermal Storage," in *1987 ASHRAE Handbook HVAC Systems and Applications* (ASHRAE, 1987).

Dorgan, C. E., "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).

Electrical World, Directory of Electrical Utilities 1987-1988 (McGraw Hill, 1986).

Facilities Engineering and Housing Annual Summary of Operations: Volume I: Executive Summary (Department of the Army, Office of the Assistant Chief of Engineers, 1987).

Hersh, H. N., *Current Trends in Commercial Cool Storage*, EPRI EM-4125, Project 2036-13, Final Report (EPRI, July 1985).

Hull, J. R., R. L. Cole, and A. B. Hull, *Energy Storage Criteria Handbook*, CR 82.034 (Naval Civil Engineering Laboratory, October 1982).

Kedl, R. J., and C. W. Sohn, *Assessment of Storage Technologies for Army Facilities*, Technical Report E-86/04/ADA171513 (USACERL, May 1986).

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

Piette, M. A., E. Wyatt, and J. Harris, *Technology Assessment: Thermal Cool Storage in Commercial Buildings*, LBL-25521, UC-95d, Lawrence Berkeley Laboratory (January 1988).

Reeves, G. A., *Commercial Cool Storage Design Guide*, Electric Power Research Institute (EPRI), EM-3981, Project 2036-3, Final Report (EPRI, May 1985).

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

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

Sohn, C. W., and J. J. Tomlinson, *Design and Construction 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).

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

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* (U.S. DOE, 1988).

Utility Inducement Programs for Cool Storage, ITSAC Technical Bulletin (ITSAC, August 1988).

Weijo, R. O., and D. R. Brown, *Estimating the Market Penetration of Residential Cool Storage Technology Using Economic Cost Modeling*, Battelle, PNL-6571, UC-202 (PNL, September 1988).

CONTRACT
FOR THERMAL ENERGY STORAGE FEASIBILITY STUDY

DISTRICT CONTRACT NUMBER _____
Revised February 12, 1990

THIS AGREEMENT is made and entered into on _________ by and between the SACRAMENTO MUNICIPAL UTILITY DISTRICT ("DISTRICT"), and ___________ _________________, ("OWNER").

This Feasibility Study is a part of the Thermal Energy Storage Program offered by DISTRICT. The Thermal Energy Storage Program also offers a Construction Rebate and Performance Payments to owners who install thermal energy storage in their air-conditioning systems. A Feasibility Study can used to complete the calculations needed to qualify for a Construction Rebate and Performance Payments. DISTRICT will provide up to $10,000 for a Feasibility Study.

The parties agree as follows:

1. The term of this agreement shall be from __________________ through _____ ____________.

2. OWNER agrees to hire a mechanical engineer ("Consultant") to provide OWNER with a Feasibility Study Report to determine if utilization of a thermal energy storage system is technically and economically feasible at _________________ ____.
OWNER expressly acknowledges that OWNER is solely responsible for the selection, recruitment, retention and supervision of the Consultant. OWNER expressly indemnifies, waives and releases DISTRICT, its directors, officers, agents and employees from and against any and all claims, loss, damage, expense and liability that may arise out of the contractual or other relationship established between OWNER and Consultant. OWNER expressly acknowledges that DISTRICT involvement and interest in the Thermal Energy Storage Feasibility Study is limited to payment for the Feasibility Study to reduce summer peak demand for electricity upon DISTRICT's system by using thermal energy storage as an energy conservation measure. OWNER holds DISTRICT, its directors, officers, agents and employees harmless from all claims arising out of any agreements entered into by OWNER on its own behalf to conduct such Feasibility Studies.

3. Consultant will determine the feasibility of thermal energy storage for the facility described above. OWNER agrees that the study will meet the DISTRICT's Requirements for a Thermal Energy Storage Feasibility Study, which are included as Appendix A. Owner agrees that Consultant will detail his findings in two phases:

a. A brief Preliminary Report stating, for both partial storage and full storage thermal energy storage systems, approximate: (1) equipment and installation costs above those of a comparable conventional HVAC system; (2) yearly rate benefits; and (3) utility benefits including a Construction Rebate and Performance Payments. District reserves the right to cancel this Contract after completion of the Preliminary Report and District payable in such event will under no circumstances exceed $3,000.

b. A Final Report as described in the DISTRICT's Feasibility Study Requirements.

4. _______________ is designated Contract Manager for OWNER. OWNER may change Contract Manager at any time by notifying DISTRICT.

5. The Program Manager for the Nonresidential Thermal Energy Storage Program is designated DISTRICT Contract Manager. DISTRICT may change Contract Manager at any time by notifying OWNER.

6. The DISTRICT shall pay OWNER for the cost of the Feasibility Study after OWNER meets the requirements of this Contract. The District's total payments to OWNER shall under no circumstances exceed the lesser of: (a) $10,000; or (b) the total amount billed to OWNER by Consultant on Consultant's invoices for the Preliminary Report and the Final Report. OWNER may invoice DISTRICT for work done on the Preliminary Report and District payment for the Preliminary Report shall not exceed the lesser of $3,000 or the amount invoiced OWNER by the Consultant.

7. DISTRICT reserves the right to approve or reject all Feasibility Study Reports.

8. OWNER shall: (1) submit any request for payment in triplicate; (2) state the DISTRICT Contract number on the invoice; and (3) include a copy of OWNER's invoice from Consultant. OWNER agrees that the invoices provided by the Consultant will show hours worked, rate per hour and all other expenses. DISTRICT agrees to tender payment to OWNER within thirty (30) days of receipt and approval of all uncontested invoices as specified herein. OWNER shall send the request for payment to:

Sacramento Municipal Utility DISTRICT
P. O. Box 15830, MS-27
Sacramento, CA 95852-1830
Attention: Accounts Payable

9. OWNER may terminate this Contract at any time upon giving 15 days notice in writing to DISTRICT Contract Manager. Upon such termination, OWNER waives all claims to compensation and/or reimbursement for expenses under this agreement and DISTRICT shall have no liability therefor.

10. DISTRICT may terminate this Contract at any time upon giving 15 days notice in writing to OWNER. In such event, OWNER agrees to use all reasonable efforts to mitigate its expenses and obligations hereunder. DISTRICT agrees to pay OWNER for all reasonable expenses incurred under this Contract prior to notice of termination and shall pay OWNER for all reasonable expenses incurred as a result of termination. The sum of all expenses paid to OWNER as a result of DISTRICT's termination of this Contract shall not exceed DISTRICT's maximum obligation under this Contract.

11. OWNER agrees to allow the use of DISTRICT's electric meter data for the Feasibility Study, where such meter data exists.

12. Written communications regarding this Contract shall be sent to:

Sacramento Municipal Utility District
Energy Services Department
P. O. Box 15830, MS-73
Sacramento, CA 95852-1830

Attention: Nonresidential Thermal Energy Storage Program Manager

13. Other than as specified herein, no document or communication passing between the parties hereto shall be deemed part of this agreement.

14. OWNER shall indemnify, defend and hold harmless the DISTRICT, its directors, officers, agents and employees against all claims, loss, damage, expense, and liability asserted or incurred by other parties, including, but not limited to, DISTRICT's employees or OWNER's employees, arising out of or in any way connected with the performance of this Contract and caused by the acts, omissions, intent or negligence, whether active or passive, of OWNER, its agents, employees, and suppliers, and excepting only such loss, damage or liability as may be caused by the intentional acts or the sole negligence of DISTRICT.

15. The sizing, design, selection, construction, installation, use and/or operation of a thermal energy storage system is the sole responsibility of OWNER. DISTRICT makes no representation as to the reliability, efficiency or sizing of any thermal energy storage system or associated equipment that may be installed as a result of the Feasibility Study provided under the terms of this Contract.

16. DISTRICT EXPRESSLY DISCLAIMS ANY AND ALL WARRANTIES, EXPRESSED OR IMPLIED, WITH RESPECT TO GOODS AND SERVICES PROVIDED UNDER THIS AGREEMENT. OWNER AGREES TO DEFEND, INDEMNIFY AND HOLD DISTRICT HARMLESS AGAINST ANY AND ALL CLAIMS OF ANY KIND WHATSOEVER ARISING OUT OF OR IN ANY WAY CONNECTED WITH THE SIZING, DESIGN, SELECTION, CONSTRUCTION, INSTALLATION, USE AND/OR OPERATION OF ANY THERMAL ENERGY STORAGE SYSTEM ANALYZED, DESIGNED AND/OR DESCRIBED IN THE FEASIBILITY STUDY PROVIDED UNDER THE TERMS OF THIS CONTRACT.

17. SIGNATURES FOR FEASIBILITY STUDY CONTRACT

OWNER AUTHORIZATION

BY: ____________________________ TITLE: ______________________
PRINTED NAME

____________________________ DATE: ________________
SIGNATURE

DISTRICT AUTHORIZATION

BY: ____________________________ TITLE: ______________________
PRINTED NAME

____________________________ DATE: ________________
SIGNATURE

APPENDIX A

FEASIBILITY STUDY REQUIREMENTS

THERMAL ENERGY STORAGE PROGRAM
RULES, REQUIREMENTS AND GUIDELINES FOR FEASIBILITY STUDIES

Revised February 15, 1990

The Sacramento Municipal Utility District (SMUD) will provide up to $10,000 for a feasibility study for thermal energy storage. The GENERAL RULES discuss the procedure for participating in the Thermal Energy Storage Feasibility Study Program and the amounts that may be obtained *for a feasiblity study. Report contents* and format are discussed under FEASIBILITY STUDY REQUIREMENTS. The SUGGESTED REPORT FORMAT (page 6) is not mandatory, but a thorough report should include everything shown. Feasibility study reports must be accurate and complete.

I. GENERAL RULES

A. SMUD will provide funds for a feasibility study for thermal energy storage. The study must analyze ways of reducing summer peak period demand for electricity through the use of thermal energy storage for cooling. All funding will be provided under the standard SMUD contract for a thermal energy storage feasibility study and SMUD will only contract with facility owners.

B. SMUD will cover the cost of a feasibility study up to an amount not to exceed the lesser of: (1) the total amount invoiced by the consultant performing the study; or (2) $10,000.

C. SMUD's payment for a feasibility study will be made in two installments; (a) up to $3,000 after a preliminary report has been completed and (b) the balance, up to a maximum of $10,000 as provided in I.B, above, after the final report has been completed and accepted by SMUD. The reports and associated invoices must be approved by SMUD before payment will be made.

D. Feasibility studies may be performed for either new construction or *retrofit projects.*

E. To participate, an owner must apply for funding and execute a feasibility study contract with SMUD. An application will consist of: (1) two copies of SMUD's standard feasibility study contract form, signed by the owner; and (2) a brief cover letter describing the project. Owners will be responsible for filling out and submitting the application to SMUD, but SMUD staff can help with the application. SMUD will review the application. SMUD will approve the application by signing the contract form, and the owner will then be accepted for participation in the Thermal Energy Storage Feasibility Study Program.

F. Contracts will be processed in the order received. A limited amount of money is available and feasibility studies will be funded on a first-come, first-served basis. SMUD reserves the right to reject any request and/or application filed for participation in the Thermal Energy Storage Feasibility Study Program.

G. The feasibility study must analyze and present findings on two TES options: (1) partial storage, which is sometimes referred to as "load-leveling thermal energy storage"; and (2) full storage. The feasibility study findings may be used when applying for a construction rebate if the findings meet SMUD's requirements for participation in the Thermal Energy Storage Construction Rebate Program. The findings can also be used when applying for performance payments if the findings meet SMUD's requirements for participation in the Thermal Energy Storage Performance Payment Program.

II. FEASIBILITY STUDY REQUIREMENTS - THE PRELIMINARY REPORT

The first phase of the feasibility study will be a brief preliminary report of one or two pages. The preliminary report will compare the thermal energy storage system to a conventional HVAC system, giving approximate values *for:* (1) equipment and installation costs for thermal energy storage and conventional systems; (2) yearly rate benefits for the thermal energy storage system; and (3) utility benefits for the thermal energy storage system, including a construction rebate and performance payments.

III. FEASIBILITY STUDY REQUIREMENTS - THE FINAL REPORT

The consultant completing the feasibility study must provide a final report. The requirements for the final report are:

A. The facility studied must be clearly identified in the report.

B. The final report must be performed, signed and stamped by a professional Mechanical Engineer, licensed and registered by the state of California. The final report must contain a signed statement by the engineer certifying that the calculations comply with the requirements listed in this document.

C. The final report must be a complete, typed, bound professional report. It will have a title page stating: (1) the name and location of the project; (2) the owner's name, address and phone number; (3) the engineer's name, address and phone number; and (4) the date of completion.

D. **The final report must contain:**

1. **An executive summary that explains the results of the study in nontechnical terms. The executive summary must contain a table showing: (1) the cost of a conventional HVAC system; (2) the cost of the TES system; (3) demand reduction for the TES system; (4) the amount of the construction rebate; (5) yearly cost savings for the TES system; (6) and the payback period for the TES system. This information must be provided for both the partial storage and full storage options.**

2. **A one-day summer <u>peak</u> load profile for the facility. The load profile must be based on a summer design day whose outdoor design temperatures shall be those listed in the 0.5% summer dry bulb and the 0.5% wet bulb columns for cooling based on percent-of-year in ASHRAE publication SPCDX, Climatic Data for Region X, Arizona, California, Hawaii, and Nevada, 1982.**

3. **An optimum size for the full storage and partial storage options. The optimum sizes must be based on first cost, cost savings and simple payback.**

4. **Descriptions of the TES systems considered in the study, including discussions of storage medium, mode of operation and control strategies.**

5. **Cost estimates for the TES system and a comparable conventional HVAC system. Cost estimates must be broken down into major components and installation costs. If the TES system provides cost savings for piping, pumps, ducts, fans and electrical service, these costs must be included in the cost estimates.**

6. **A table showing monthly demand and energy changes and cost savings for the TES systems.**

7. **Monthly peak day and average day weather data and a discussion of the methodology used to obtain monthly demand and energy data for the thermal energy storage and conventional systems.**

8. **Preliminary schematics for the TES and conventional systems.**

9. **A description of the methodologies used to determine the load profile, the monthly peak demand savings and the monthly usage changes. The methodology used to determine the peak day and average day outside air temperatures must be clearly described.**

E. Each appendix must be identified with a tabbed cover sheet clearly identifying its contents.

F. The storage capacities developed in the study must be adequate to maintain building comfort during peak design conditions.

IV. HOW TO OBTAIN MORE INFORMATION

Call 916-732-5397 for information, or write to:

Sacramento Municipal Utility District
P.O. Box 15830, MS-73
Sacramento, CA 95852-1830
Attention: Nonresidential Thermal Storage Program Manager

V. PAYMENT

Payment will not be made until the owner has been accepted for participation in the Thermal Energy Storage Feasibility Study Program. To receive payment for either the preliminary report or the final feasibility study report, the owner will be required to *submit copies of the report* and a request for payment:

A. Provide two copies of the report. SMUD will review the report and payment will be made after the report and the request for payment have been approved by SMUD. The submittal for the final report shall contain: a bound copy and a reproducible master. Send the submittal to:

Sacramento Municipal Utility District
P.O. Box 15830, MS-73
Sacramento, CA 95852-1830
Attention: Nonresidential Thermal Storage Program Manager

B. The request for payment shall state SMUD's contract number and shall contain: (1) a copy of the owner's invoice; and (2) a copy of the consultant's invoice showing hours worked, rate per hour and all other expenses. Send the request for payment to:

Sacramento Municipal Utility District
P.O. Box 15830, MS-27
Sacramento, CA 95852-1830
Attention: Accounts Payable

VI. REJECTION OF CONTRACTS

SMUD reserves the right to reject any requests and/or applications submitted for participation in the Thermal Energy Storage Feasibility Study Program.

SUGGESTED REPORT FORMAT
THERMAL ENERGY STORAGE FEASIBILITY STUDIES
SACRAMENTO MUNICIPAL UTILITY DISTRICT

The outline shown below is that of a typical feasibility study report. It is not a mandatory report format.

A. Title page
B. Table of Contents
C Project Summary Sheet and Certification Statement
D. Executive Summary containing: findings; a table summarizing the *findings*; and conclusions and recommendations
E. Introduction
    1. TES concepts
    2. Scope of work
F. Site Review and Field Audit
    1. Description of facility including type of facility, gross area, conditioned area
    2. Space limitations for storage tanks
    3. Owner/occupant agreements, lease periods, etc.
G. Building cooling requirements
    1. Cooling load profiles
        a. Cooling design day
        b. Design day frequency
        c. Average monthly load profiles
    2. Electrical load profiles
        a. Cooling design day profile for cooling
        b. Average monthly load profiles for cooling
        c. Total design day facility load profile
H. Utility rate structure and performance incentives
I. Cooling equipment sizing
    1. Conventional system
        a. Compressors, cooling towers, pumps and, where applicable, fans
        b. System performance data, including operating points and electrical demand
    2. TES systems
        a. Optimal tank size
        b. Equipment sizes
        c. System performance, including operating points and electrical demand
        d. System schematics
J. TES operating strategies
K. Economic Comparisons
    1. Equipment cost and total cost
    2. Annual operating cost
    3. Construction rebate
    4. Economic analysis for TES systems
L. Conclusions and Recommendations
M. Appendices, including weather data

Bibliography

1. Andreasen, Finn. Maintenance Supervisor. Telephone Interview. Bolar Pharmaceutical Company, New York NY, 18 June 1990.

2. Bosiger, Tom. Representative of Turbo Refrigerating Company. Telephone Interview. Turbo Refrigerating Company, Dayton OH, 14 June 1990.

3. Cler, Gerald L. & Chang W. Sohn. *Market Potential of Storage Cooling Systems in the Army*. September 1982, USA-CERL Technical Report E-89/13, U.S. Army Corps of Engineers.

4. Department of the Air Force. *Passive Solar Handbook Vol I*. Technical Guide, Architectural Energy Corporation, Bolder CO.

5. Dorgan, Charles, E. "Cold Air Distribution Makes Cool Storage the Best Choice," *ASHRAE Journal*, 31: 20-26 (May 1989).

6. Fiedler, Bob. "Thermal Storage Systems Slash On-Peak Demand," *Heating/Piping/Air Conditioning*, 60: 45-52 (August 1988).

7. Herberling, LtCol Michael E. Class handout distributed in CMGT 524, Contracting For Engineers. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 26 March 1990.

8. Knebel, David, A. and Steve Houston. "Thermal Storage Retrofit," *ASHRAE Journal*, 31: 34-42 (May 1989).

9. Lawson, Scott, H. "Computer Facility Keeps Cool with Ice Storage," *Heating/Piping/AirConditioning*, 60: 35-44 (August 1988).

10. MacCracken, Cal. "The Current State of Thermal Storage Changes Day by Day," *ASHRAE Journal*, 31: 18-20 (May 1989).

11. Makie, E.I. and W.R. Richards. *Design of Off-Peak Cooling Systems*, handout distributed in the ASHRAE Professional Development Seminar. Los Angeles CA, 16 May 1989.

12. Pearson, Fredrick, J. "Chilled Air Approaches the Office Building Market," *ASHRAE Journal*, 31: 28-30 (May 1989).

13. Redding, Bob. Chief of Hotel Maintenance. Telephone Interview. Worthington Hotel, Fort Worth TX, 15 June 1990.

14. Reeves, G.A. *Commercial Cool Storage Design Guide: Final Report*, EM-3981 Research Project 2036-3. Electric Power Research Institute, Palo Alto CA, May 1985.

15. Reid, Crowther & Partners, Ltd and George Reeves Associates, Inc. *Stratified Chilled-Water Storage Design Guide: Final Report*, Projects RP2036-19 and RP2732-13. Electric Power Research Institute, Palo Alto CA, May 1988.

16. Seidler, Bob. Supervisor of Building Services. Telephone Interview. Christian Broadcasting Network, Norfolk VA, 25 June 1990.

17. Sohn Chang W. and John Tomlinson. *Design and Construction of an Ice-in-Tank Diurnal Ice Storage Cooling System for the PX Building at Fort Steward, Ga.* July 1988. USA-CERL Technical Report E-88/07. U.S. Army Corps of Engineers.

18. Thomas, Laura H. "A Case for Packaged Thermal Storage Systems," *Engineered Systems*, 5: 36-40 (December 1988).

19. Thomas, Laura. Product Manager of Thermal Storage Telephone Interview. York International Corp, York PA, 15 June 1990.

20. Thumann, Albert. *Plant Engineers and Managers Guide to Energy Conservation* (Third Edition). Lilburn GA: Fairmont Press, Inc., 1982.

21. Wendland, Ronald, D. "Cool Storage: A Technology Update," *ASHRAE Journal*, 31: 30-32 (May 1989).

Vita

Captain David B. McCormick [redacted]. He graduated from Warren Central High School in Vicksburg, Mississippi in 1975 and attended Mississippi State University, graduating with a Bachelor of Science in Mechanical Engineering in June 1981. Upon graduation he began work with International Paper Company in Redwood, Mississippi as a Mechanical Design Engineer. In November 1982 he entered Officer Training School at Medina Air Base, Texas. On February 15, 1983, he received his commission into the Air Force and was stationed at Altus AFB, Oklahoma. At Altus AFB, he served as the Base Mechanical Design Engineer until July 1985 when he was reassigned to Misawa Air Base, Japan. At Misawa AB, he served as Project Engineer for one-and-a-half years, attended Squadron Officers School in Residence, and served as the Chief of Contract Management for two years and Chief of Resources and Requirements for the last four months of his tour. During this period he helped construct the multi-million dollar bed-down of two F-16 Squadrons. In the summer of 1989 he was reassigned to the School of Systems and Logistics, Air Force Institute of Technology, to earn a Master of Science degree in Engineering Management.

[redacted]

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1990

3. REPORT TYPE AND DATES COVERED
Masters Thesis

4. TITLE AND SUBTITLE
Applicability of Thermal Storage Systems to Air Force Facilities

5. FUNDING NUMBERS

6. AUTHOR(S)
David B. McCormick, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEM/DEE/90S-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Thermal storage is a technology that shifts the electrical demand for air conditioning from on-peak to off-peak periods. This is accomplished by chilling a storage medium during off-peak periods, storing this medium in an insulated container, and using it during on-peak periods to provide cooling. The result of this action is a lowered electric bill.

This study approaches this issue from both a qualitative and a quantitative stand point. The qualitative portion addresses the general validity and effectiveness of thermal storage. The quantitative portion determines the specific market potential of packaged ice thermal storage systems for the 51 CONUS bases studied based on three initial cost scenarios. These scenarios include new construction/replacement applications, realistic retrofit applications and upper limit retrofit applications. In addition, an economic analysis was performed on each base using simple payback and net present value techniques. The results of these analysis show the Air Force can save up to $850,000 per year by shifting base cooling demand loads by 15 percent for those bases showing a payback period less than five years. Based on these results, the climatic regional areas of the CONUS are prioritized according to their thermal storage market potential.

14. SUBJECT TERMS
Thermal Storage, Cold Storage, Demand Load Shifting,
Ice Storage Systems, Latent Storage, Thermal Energy Storage

15. NUMBER OF PAGES
195

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102