February, 1988

DOE/IR/05106--T54

DE89 014913

THERMAL ENERGY STORAGE:

An Application Guide for Local Governments

A Technology Transfer Report From:

Energy Task Force
of the Urban Consortium
for Technology Initiatives

CITY OF PHOENIX

Conducted by

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PREFACE

The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. The Urban Consortium conducts its work program under the guidance of Task Forces structured according to the functions and concerns of local governments. The Energy Task Force, with a membership of municipal managers and technical professionals from eighteen Consortium jurisdictions has sponsored over 140 energy management and technology projects in thirty-five Consortium member jurisdictions since 1978.

To develop in-house energy expertise, individual projects sponsored by the Task Force are managed and conducted by staff of participating city and county governments. Projects with similar subjects are organized into *Units* of four to five projects each, with each Unit managed by a selected Task Force member. A description of the Units and projects included in the Eighth Year (1986-87) Energy Task Force program follows:

UNIT -- LOCAL GOVERNMENT OPERATIONS

Energy used for public facilities and services by the nation's local governments totals about 1.5 quadrillion BTU's per year. By focusing on applied research to improve energy use in municipal operations, the Energy Task Force helps reduce operating costs without increasing tax burdens on residents and commercial establishments. This Eighth Year Unit consisted of seven projects:

- **Baltimore, Maryland** -- *Sewage Sludge Conversion to Fuel by Acid Hydrolysis*
- **Baltimore, Maryland** -- *Full Scale Plant Demonstration: Inhibition of an Activated Sludge Process (Technology Transfer)*
- **Houston, Texas** -- *The Impact of Budget Incentives on Energy Management*
- **New Orleans, Louisiana** -- *Computer-based Training for Energy Management*
- **Phoenix, Arizona** -- *HVAC Equipment Replacement for Best Size and Efficiency*
- **Phoenix, Arizona** -- *Thermal Energy Storage: An Application Guide (Technology Transfer)*
- **Seattle, Washington** -- *Reducing Energy Consumption through Upgraded O&M Purchases (Technology Transfer)*

UNIT -- COMMUNITY ENERGY MANAGEMENT

Of the nation's estimated population of nearly 240 million, approximately 60 percent reside or work in urban areas. The 543 cities and counties that contain populations greater than 100,000 consume 50 quadrillion BTU's annually. Applied research by the Energy Task Force helps improve the economic vitality of this urban community by aiding energy efficiency and reducing energy costs for the community as a whole. This Year Eight unit consisted of seven projects:

- **Hennepin County, Minnesota** -- *Energy Enhancements in New Residential Construction*
- **Hennepin County, Minnesota** -- *Shared Savings in the Residential Market: Lessons Learned (Technology Transfer)*
- **Kansas City, Missouri** -- *An Energy-Based Economic Development Strategy*
- **New York, New York** -- *A City/Utility Partnership to Reduce Business Energy Costs*

- **Public Technology, Inc.** -- *Energy and Economic Development -- Phase II: Public/Private Financing*

- **San Francisco, California** -- *An Energy Plan for Mission Bay*

- **San Francisco, California** -- *Commercial Building Energy Assessment (Technology Transfer)*

UNIT -- ENHANCED ENERGY TECHNOLOGIES

Effective use of advanced energy technology and integrated energy systems in urban areas could save from 4 to 8 quadrillion BTU's during the next two decades. Urban governments can aid the capture of these savings and improve capabilities for the use of alternative energy resources by serving as test beds for the application of new technology. This Year Eight unit consisted of four projects:

- **Albuquerque, New Mexico** -- *Municipal Underground Storage Tanks: A Local Manager's Guide*

- **Denver, Colorado** -- *Waste-to-Energy Facilities: An Implementation Guide*

- **San Jose, California** -- *Energy Efficient Cooling Technologies: Pilot Applications and Conference Proceedings*

- **Washington, DC** -- *Energy Management for St. Elizabeth's Hospital: An Evaluation Guide*

UNIT -- UTILITY MANAGEMENT

Electric and gas utilities have a formal responsibility to provide stable supplies of energy at reasonable prices to all segments of a community's residential, commercial and industrial populace. By working closely with their utilities, local government staff can help to assure both supply and price stability. This Year Eight Unit consisted of five projects:

- **Chicago, Illinois** -- *Municipal Utility Franchise Renewal*

- **Columbus, Ohio** -- *Integrated and Computer-aided Database Management for Utility Network Planning*

- **Houston, Texas** -- *Electric Utility Franchise Guide (Technology Transfer)*

- **Memphis, Tennessee** -- *Energy Technology Transfer Strategies: Marketing and Economic Incentives*

- **Memphis, Tennessee** -- *Memphis Area Rideshare Handbook (Technology Transfer)*

Reports from each of these projects are specifically designed to aid the transfer of proven experience to staff of other local governments. Readers interested in obtaining any of these reports of further information about the Energy Task Force and the Urban Consortium should contact:

Applied Research Center
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1301 Pennsylvania Avenue, NW
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Acknowledgements

The originator of the project was Darshan Teji, Energy Conservation Manager for the City of Phoenix and Project Director for this project. The entire implementation work of this project was performed under his direction. Scott B. Wilkins was the Project Manager and provided the project management, engineering assistance and overall supervision of the project. John Kirby was the Project Engineer and was responsible for the composition of the project documentation. Paul Hudson was responsible for working with the Cooloff program that was incorporated as part of the text and Nidhi Chauhan provided valuable computer assistance. Special thanks go to the U.S. Department of Energy for providing the grant which made this project possible. Thanks for managing the grant go to Herbert Fivehouse, Chairman of the Energy Task Force of the Urban Consortium, and the staff of the City of Baltimore. Special thanks for assistance go to Unit Manager Anthony Laska with the City of New Orleans and to Richard Zelinski with the Public Technology, Inc.

Contents

Page

Page

Chapter 1 - Overview

ABSTRACT

Thermal energy storage technology is a comparatively new technology that is receiving attention throughout the United States and the World. The main object of this strategy is to lower the peak electricity demand by shifting the peak demand (KW) and energy use (KWH) from high demand hours to low demand hours. This strategy is receiving favor from the utility industry, with special rebates often available to those who install thermal energy storage systems.

In 1985, the Urban Consortium Energy Task Force formally approved funding for a project proposed by the City of Phoenix. The project selected was Thermal Storage Strategies For Energy Cost Reduction. This project was successfully completed with very interesting results and many lessons learned as a sideline. This project was implemented as a retrofit to the existing air conditioning system at the Century Branch Library of the City of Phoenix. In the conduct of this project, elaborate research on the technology was supported. Publications describing the latest relevant technology were studied, and several existing sites with similar applications were visited.

There are jurisdictions where the potential for similar applications exist, but practical implementation is constrained by the lack of guidelines and experience. The purpose of this project is to provide other jurisdictions with ready-to-use guidelines applicable to their own specific situations. The guidelines will help local governments begin the collection of appropriate information pertinent to their application. The manual will aid jurisdictions in performing both technical and economic evaluations which are necessary for

effective decision making. To simplify this evaluation process a computer program has been developed to help other jurisdictions in compiling the input data and converting it into useful result-oriented output. Individual jurisdictions will be able to derive benefits from this analysis for application to their particular situations.

PROJECT PURPOSE

The purpose of this project was to develop a useable guide for any jurisdiction who is considering thermal energy storage as an energy management measure. Thermal energy storage strategies provide savings through load management. The objective of load management is to shift portions of the electrical use from hours of peak demand to hours of the day that have less demand, as determined by the local utility.

With the successful completion of several thermal energy storage systems, the City of Phoenix has acquired useful knowledge in system design and control strategies, feasibility of retrofiting buildings and procedures for accurate cost/benefit analysis. The specific objectives of this report were as follows:

1. To bring thermal energy storage into the realm of standard retrofits to be considered for city buildings.
2. To transfer the technology of thermal storage to other local governments where the potential exists.
3. To provide a ready-to-use guide to assist local governments.

ORGANIZATION OF THE GUIDE

Four main chapters and four appendices comprise this guide. The major sections are organized as follows:

Chapter 1 -- provides an abstract and overview of the document.

Chapter 2 -- introduces the fundamental concepts of thermal storage to include; types of storage media, strategies for thermal storage and utility rates.

Chapter 3 -- details the step-by-step procedure to evaluate potential thermal energy storage applications.

Chapter 4 -- provides the complete background to use the computer analysis system Cooloff which will assist in the economic evaluation of potential retrofits.

Appendices-- provide a test program for the Cooloff program, input forms for the Cooloff program, a list of thermal energy storage manufacturers, and a bibliography for suggested reading.

Chapter 2 - Thermal Energy Storage Fundamentals

INTRODUCTION

This chapter is intended to provide enough background information to understand the basic terminology and theory associated with thermal energy storage. This background will prove useful in reading the text, and will also be helpful when dealing with engineers, architects, and contractors concerning thermal storage. This chapter is not intended to make the reader an expert in thermal energy storage. If more information is desired, the bibliography in the appendix contains suggested additional readings. A previous Phoenix report, Thermal Storage Strategies for Energy Cost Reduction provides a more in depth evaluation of thermal storage, however is not essential since this report alone is adequate to perform a preliminary analysis of thermal storage.

DEFINITION OF IMPORTANT TERMS

Demand. Demand is the rate at which energy is being consumed and is measured in kilowatts (KW). The terms demand, power, and capacity are often used interchangeably.

Energy. Energy is the amount of power consumed over a period of time. It is measured in kilowatt-hours (KWH).

Time-of-Use Rates. In time-of-use rates the utility company defines a time period during which building peak demand is measured for billing purposes. This is called the on-peak period or the on-peak hours. All other hours of the day are by definition off-peak.

Base Demand Load. Base demand load is defined as the power required to maintain building operation when no cooling (heating) demand is present. An accurate estimate of base demand load can be made by examining the monthly billing history of the building and noting the level of demand when neither heating or cooling was required.

Base Energy Load. The base energy load is the KWH per month used by the facility during the period when no cooling or heating is required.

Full Storage. Full storage means that the energy used to run the air conditioning or heating system is shifted entirely out of the period of peak energy consumption. The strategies for accomplishing the energy shift differ depending on whether a conventional rate or time-of-use rate is in effect.

Conventional Rate. Under the conventional rate there are no defined on-peak hours and a peak demand can occur at any time of day or night.

Partial Storage. The goal of partial storage is to have HVAC equipment run continuously at a steady power level without being influenced by the building demand or the time-of-day. Partial storage requires less equipment capacity than the other storage options and usually results in the fastest payback on investment.

Ratchet. Ratchet demand (KW) is equal to a specified percentage of the highest actual demand during the ratchet period. Most utilities will show both the actual measured demand and the ratchet demand on the billing. When estimating the base demand load of a building, be careful that it is the actual KW that is being used to make the estimate rather than the ratchet KW.

Thermal Storage Media. A thermal storage system requires a medium (usually water) to hold heating or cooling capacity for later use.

The storage medium and its vessel form a bank where thermal energy may be deposited or withdrawn as required. To be practical, a storage medium must have a high enough heat capacity (ability to store heat) that an inordinately large volume is not required. A practical storage medium must also be inexpensive per pound and commonly available. A latent or phase change medium must be capable of extensive freeze/thaw cycling with no deterioration.

COOL STORAGE MEDIA

For a number of practical reasons water dominates the field as a cool storage medium. Water is inexpensive, has superior heat transfer characteristics, has good sensible heat transfer (1.0 Btu/lb-deg F) and high latent heat capacity under phase change to a solid (ice, 144 Btu/lb-deg F). Water is capable of unlimited freeze/thaw cycling without deterioration. Also, conventional air-conditioning chillers and air-handlers already use water as a heat transfer fluid. Thus using water as the storage medium minimizes the problem of interfacing storage with air-conditioning equipment. The three major types of cool storage are chilled water, ice, and eutectic salts, with each type described below.

Chilled Water

Conventional air-conditioning systems in large buildings produce chilled water at about 44 degrees F. The water is circulated to cooling coils in air-handlers where it is used to cool air for the building. Cool storage can be added to the conventional system by providing a vessel to hold a large quantity of chilled water. In the resulting system the refrigeration equipment produces chilled water at 44 degrees F, as before. Now, however, the output goes first into chilled water storage and only later to the building.

The vessel to contain the chilled water may consist of a set of large tanks or a cast-in-place concrete container. The volume of storage required is generally large. Chilled water systems usually operate with a temperature difference of 10 degrees between supply and return. Since water holds 1.0 Btu/lb-deg F, it can hold only about 10 Btu/lb in a chilled water storage system. As an example of the size required, consider a full storage chilled water system for a ten story office building in Phoenix. The system would require approximately 4,320,000 pounds or 70,000 cubic feet of water. This volume is equivalent to half of one entire story of the building.

The unit cost of a chilled water storage vessel depends on the scale of the project. The cost varies from around $0.50/gallon for 150,000 gallons to $0.20/gallon for 2,000,000 gallons. The unit cost for any given installation will also depend on the type of storage vessel, its material, location and whether the storage is for old or new construction.

Advantages of Chilled Water. The advantages of chilled water storage stem from its similarity to conventional air-conditioning:

* Conventional chillers, piping and air-handling equipment can be used, meaning better selection and more competitive pricing.
* Engineering design firms are familiar with designing around a supply water temperature of 44 degrees F and can readily handle the project.
* The 44 degrees F output temperature allows the chiller to operate at normal efficiency. In fact the chiller efficiency may be slightly better than in a conventional system because storage shifts the primary cooling period to nighttime when lower ambient temperatures improve the performance of heat rejection equipment.
* Use of conventional equipment and controls makes chilled water storage more familiar to operating and maintenance personnel, and reduces the amount and complexity of training required.

Disadvantages of Chilled Water. Many of the disadvantages of chilled water storage stem directly or indirectly from its large storage volume requirement:

* Space must be found to locate the storage vessel.

* The storage vessel presents a large surface area for heat gains to storage.
* Large cast-in-place vessels require expert construction to avoid cracks and leaks.
* Maintenance to the vessel and water treatment are costly.

Ice Storage

Ice storage is the most popular form of cool storage with about 71 percent of the installed systems using ice. Its chief advantage over chilled water storage lies in its compact volume. Ice storage systems are smaller because ice holds 144 btu/lb, compared to 10 btu/lb for chilled water. In practice, ice storage takes only one-third to one-seventh as much volume as chilled water storage. Although the cost of ice storage and chilled water are usually comparable, ice storage is often chosen due to space limitations.

Modern ice storage installations use a number of methods to create and store ice. Ice makers are categorized according to whether they are static or dynamic. Static ice makers freeze and store ice in place around tubes or coiled piping. Dynamic ice makers freeze ice at one place and move it to be stored at another place.

Advantages of Ice Storage. The advantages of ice storage stem from its compact storage volume requirement:

* Space for storage can be more readily located in retrofit situations.
* Less space must be set aside for storage in new construction.
* The storage vessel presents a small surface area for heat gains from the surroundings.
* Maintenance to the vessel and water treatment are less costly.

Disadvantages of Ice Storage. The disadvantages of ice storage stem from the lower temperature required from the refrigeration equipment:

* Conventional air-conditioning chillers are not designed for ice making, leading to reduced selection options and possibly less competitive pricing in procurement of the equipment.
* The lower supply temperature reduces efficiency of the refrigeration cycle.
* The unconventional equipment will be less familiar to operating and maintenance personnel, and will increase the amount of training they require.

Eutectic Salts

Ice now has a challenger in the field of latent cool storage. Some systems now use a mixture of water and special salts which freeze at 47 degrees F rather than the 32 degrees F freezing point of water. The mixture is known as eutectic salts and comes packaged in stackable plastic containers. Water flows around the outside of the containers to freeze or thaw the eutectic salts solution as required. The manufacturer claims that the salt solution stabilizes after a few freeze/thaw cycles and shows no further changes in properties over thousands of additional cycles. The eutectic salt concept combines important advantages over ice and chilled water storage. Freezing eutectic salts requires water at 42 degrees F so that normal air-conditioning chillers and air-handlers can be used, which is the primary advantage of chilled water storage. At the same time, latent heat transfer keeps the storage volume much smaller, about one-third the size of chilled water storage, which is the main advantage of ice. These salts can be an attractive alternative to ice or chilled water, especially in retrofit situations where space may be limited and the existing chillers may not be capable of making ice. The disadvantage of eutectic salts is the high price of the storage media, compared to water, however the total system price can in some cases be comparable to ice or chilled water storage.

HEAT STORAGE

The standard material for heat storage is ceramic brick. Electric resistance heating elements heat the brick to temperatures of 800 degrees F to 1800 degrees F for storage. A forced-air furnace houses the brick and controls dissipation of heat from the brick during discharge of storage. Heat storage furnaces have established a market in Europe but are still rare in the U.S. The high first cost compared to conventional equipment and the relative lack of utility incentives for heat storage account for its rarity. Also inadequate information about computing operational savings has caused a lack of interest.

Alternate furnace designs show that cheaper materials can be used. In particular crushed rock ($10/ton versus $500/ton for ceramic brick) has been tested and showed a 25 to 50 percent reduction over ceramic brick furnaces. Other storage media being evaluated include pressurized water and concrete building floor slabs.

THERMAL STORAGE STRATEGIES

The majority of storage installations operate by one of three simple control schemes: full storage, demand limiting, or partial storage. Other strategies are usually variants or hybrids of these three basic modes of operation. The definitions given are not standard, so other labels may be found in other literature. The examples used to illustrate thermal storage strategies will be cool storage examples, however the definitions apply equally as well to heat storage. The objectives of cool storage and heat storage are the same and the control schemes used to operate the two types of storage are conceptually the same.

Observe the dramatic difference between daytime hours and nighttime hours. Also note how the cooling power is concentrated during the daytime and how much the cooling demand contributes to the peak electrical demand of the building. Now consider the various ways which thermal storage could be used to improve the load distribution of this building.

To begin the comparison of the different storage strategies an hourly electrical load profile for a hypothetical building is presented in Figure 1.

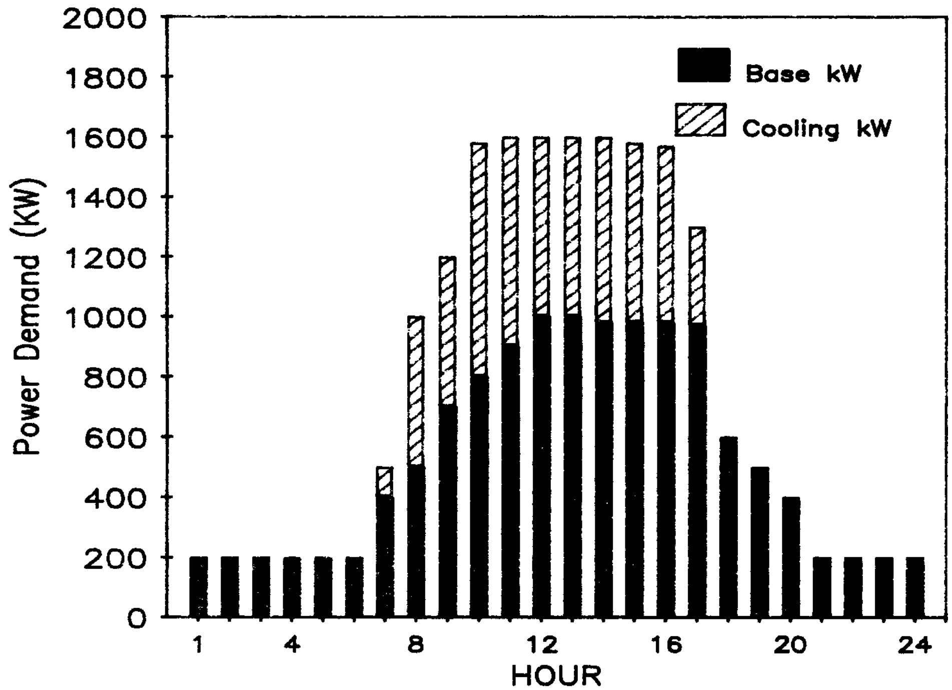

Figure 1 - Building Power Demand with No Storage

Full Storage

Full storage seeks to minimize the cost of cooling a building by moving the use of energy for cooling entirely out of the period of peak energy consumption. Figure 2 shows the building load profile using full storage.

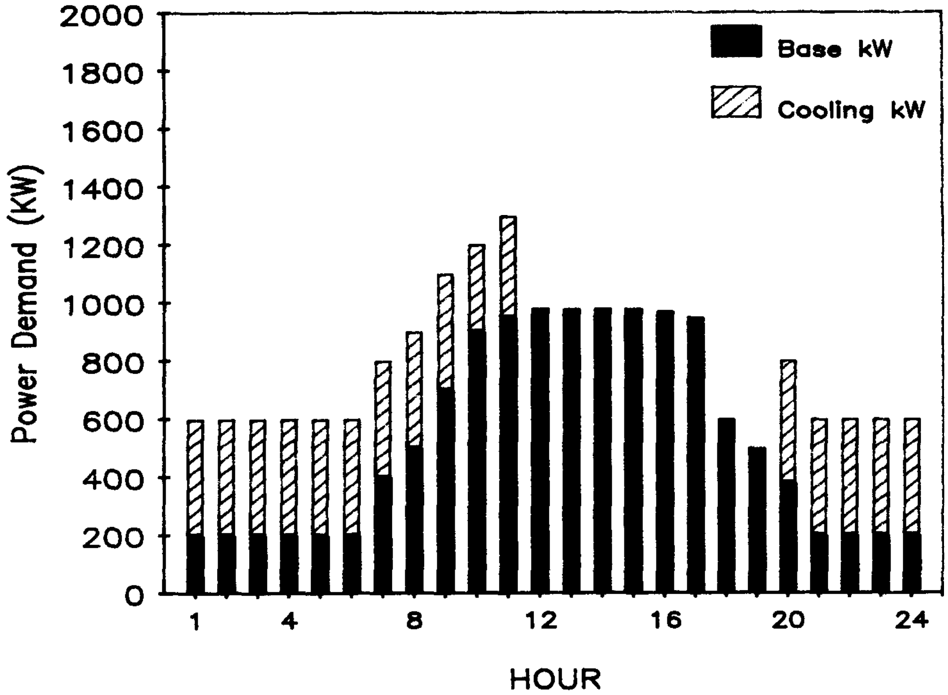

Figure 2 - Building Power Demand with Full Storage

Note that the cooling load does not add to the building's peak demand and in most cases the cooling equipment is not permitted to operate during specified times where utility rates are their highest.

Advantages of Full Storage. The following advantages are characteristic of full storage:

* Maximum reduction in utility bill;
* Controls are simple and inexpensive;
* Controls are easy for equipment operators to understand and maintain;
* Well suited to use of existing refrigeration equipment.

Disadvantages of Full Storage. The following disadvantages are characteristic of full storage:

* Requires large storage capacity and large cooling equipment capacity;
* Highest first cost;
* Largest space requirement for equipment and storage;
* Controls do not directly monitor building demand; errors due to unexpected building use or clock drift are possible.

Demand-Limiting Storage

The larger storage required in full storage can be reduced considerably by adopting a more sophisticated method of controlling the level of output of the refrigeration equipment. Demand-limiting uses the extra space for cooling power which is available during the shoulder periods of building use. The shoulder periods are periods of intermediate demand levels where it is possible that refrigeration equipment could be operated at part load without setting a peak demand level. By allowing the cooling equipment to operate over a greater number of hours and meet part of the cooling load directly, this strategy reduces the capacity requirements of the storage and refrigeration equipment.

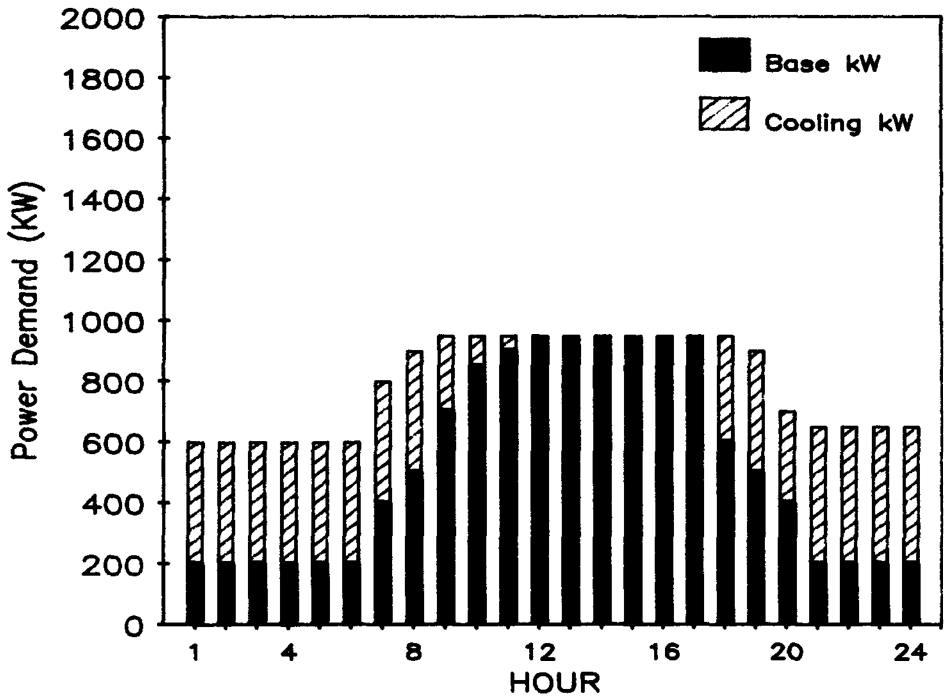

Figure 3 - Building Power with Demand Limiting

Looking at Figure 3 it can be seen how demand-limiting works. The refrigeration equipment operates at full load during nighttime hours to cool the storage tank. In the morning the building power demand begins to increase and the operation of the refrigeration equipment is cut back in stages, to keep the total building power demand below a specified level. This level is the base load peak power demand which the building experiences, thus cooling makes no contribution to the peak demand for which the building will be billed.

Compare Figure 3 with Figure 1 and observe how the demand profile of the building has been flattened. The peak demand of the building has been held to the base load peak. Just as in full storage the demand charge for the building has been lowered to the minimum possible level. Demand-limiting storage makes the most sense under conventional rates where lowering demand counts, but shifting energy use does not.

Advantages of Demand-Limiting Storage. The following advantages are characteristic of demand-limiting storage:

* Maximum possible reduction in peak;
* Less refrigeration capacity and less storage than full storage, because more time is available for compressor operation;
* Controls monitor building demand directly, less prone to allow accidental demand peaks.

Disadvantages of Demand-Limiting Storage. The following disadvantages are characteristic of demand-limiting:

* Controls are more complex and costly;
* Does not shift entire energy demand for cooling off-peak;
* Controls are more difficult for building equipment operators to understand and maintain.

Partial Storage

Partial storage, or load-leveling, simplifies thermal storage controls to the maximum possible extent, and minimizes the capacity requirements for refrigeration equipment at the same time. Partial storage seeks to run the cooling equipment at a steady rate over 24 hours, and ignores what is happening in terms of the utility rate or the building power demand.

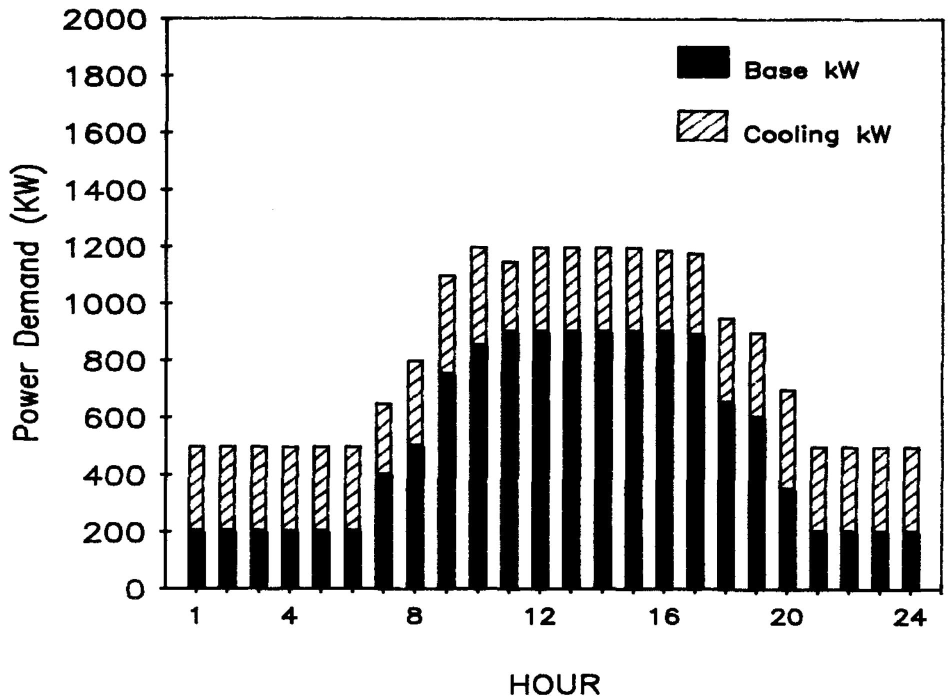

Figure 4 - Building Power Demand with Partial Storage

The electrical load profile for partial storage is shown in Figure 4. Observe how the cooling equipment draws steady power, and ignores the time of day, cooling load of the building, and the power demand of the building. Comparing Figure 1 with Figure 4, it can be seen that partial storage significantly reduces the peak demand of the building, but not to the extent it was reduced under full storage or demand-leveling.

Advantages of Partial Storage. The following are the advantages of partial storage:

* Minimizes required capacity of the storage and refrigeration equipment;
* Minimum first cost, comparable to the cost of a conventional system with no storage;
* Usually the fastest payback on investment;
* Minimum space requirement for equipment;

Disadvantages of Partial Storage. The following are the disadvantages of partial storage:

* The primary disadvantage is that utility bills are not reduced to a maximum extent. Partial storage typically saves 40 to 60 percent as much as full storage.
* To operate efficiently the system must have ideally-sized refrigeration equipment. This somewhat limits partial storage to situations where new equipment is being installed. Also new equipment cannot be oversized by conventional "safety margins" or savings will be drastically reduced.
* When using ice-storage, savings can be limited by the difference in capacity between water-chilling and ice-making modes. Water chilling capacity (and kw) is typically 50 to 100 percent greater than ice-making capacity and this tends to move energy and demand back on-peak.

THERMAL STORAGE AND UTILITY RATES

Thermal storage seeks to reduce an energy bill through load management. Load management is not energy conservation in the direct sense of saving kilowatt-hours. Load management saves money by changing the time of energy use rather than by reducing total energy consumption. Thermal storage is load management because, in general, storage does not reduce the consumption of energy, it simply shifts the consumption to a time when lower rates are in effect. Electric utilities use their rate structure to encourage load management by their customers. This section will attempt to explain rate structures and how thermal storage can take advantages of them.

Structure of Electric Utility Bills

Utility bills are normally based on two fundamental quantities; the total energy consumed during a month (kilowatt-hours), and the peak rate of energy demand at any one time during the month (kilowatts).

These two numbers recorded by the electric meter are used to calculate what the customer will be charged. The utilities calculate the charges using a set of formulas known as the rate structure. Rate structures can be of two general types. If the charges for energy and peak demand are independent of the time of day when the energy was used, then the rate is called a conventional or block rate. If the charges for energy and peak demand depend on when the energy is used during a day, then the rate is termed a time-of-use rate.

Energy Charge

With a conventional rate, energy is priced in blocks. Each block is of a designated size or number of kilowatt-hours. The first block of energy has the most expensive price per kilowatt-hour and the customer pays this rate until the size of the block has been reached. The customer then moves on to the second rate block, which usually will have a lower price per kilowatt-hour, and so on until all of a month's energy use has been accounted for. Because the energy charge varies in blocks and declines with amount used, it is called a declining-block rate.

Under a time-of-use rate, energy is priced according to the time of day or the day of the week the energy is used. Typically the utility designates certain hours of the day to be on-peak hours. Energy used during these hours will be charged at a higher rate than the remaining hours in the day, which become off-peak hours. A time of day electric meter keeps track of the energy used on-peak and off-peak.

Demand Charge

There are three ways utilities commonly use to charge the customer for his peak demand:

1) The utility may apply a straight charge of so many dollars per kilowatt of peak demand recorded each month.
2) The utility may make the energy charge to the customer more expensive by expanding the size of the most expensive rate

block in proportion to the size of the peak demand. This feature is known as an expanding rate block.

3) The utility may use the customer's annual peak demand to set a minimum monthly demand to be used in computing bills. For example,the utility may stipulate that it will bill the customer for the greater of the following two demand levels, either a) the actual peak demand set during the present month or b) 80 percent of the highest demand set in the last 11 months. This feature is known as a demand rachet.

A conventional rate may use any combination of these three mechanisms of demand charges. A time-of-use rate typically charges the customer a straight rate for on-peak demand, but levies no additional demand charge for off-peak demand. A rachet feature may also apply, but the time-of-use rate does not use an expanding block feature.

Seasonal Rates

Some utilities also vary their rates according to the season of the year. Summer peaking utilities charge more for energy and demand during the summer when demand is high and less in the winter when it is low. Seasonal rates are an alternative to the demand ratchet as a means of increasing the cost of electricity during peak summer periods.

HOW THERMAL STORAGE REDUCES ENERGY COSTS

Thermal storage adds flexibility to the operation of primary heating and cooling equipment. Without storage, the operation of air-conditioning equipment or space heating elements are tied to the cooling or heating demands of the building at a given moment. The building dictates how much heating or cooling energy will be used during a given hour. With storage, the operation of the heating or cooling equipment is partly decoupled from the building requirements. Heating or cooling capacity can be generated and banked when the building load is low, and later withdrawn when the load is high. The building no longer dictâtes the timing of the energy use.

How Storage Affects Energy Charges

With a time-of-use rate, electrical energy is cheaper during some periods of the day. Shifting energy into an off-peak period reduces the cost of that energy. Thermal storage allows all or part of the energy to be shifted off-peak resulting in a savings. How much can be saved depends on the rate differential between on-peak and off-peak periods. With a conventional rate no savings in energy charges (kilowatt-hours) can be realized through storage because energy charges are independent of time.

How Storage Affects Demand Charges

Heating or cooling equipment typically account for 20 to 50 percent of the peak energy demand. Thermal storage allows all or part of this demand to be moved to a time when it does not contribute to setting the peak demand level of the building. Under a conventional rate the demand is moved so as to level out the building load over the day. This load-leveling is the only source of savings under a conventional rate. If an expanding block feature is used then part of the savings due to load-leveling will appear to be a savings in energy charges.

With a time-of-use rate the equipment demand is moved to the off-peak period where no charge for demand usually exists. If the utility uses a demand ratchet feature then storage reduces the demand charges for the building all year round, even during those months in which no heating or cooling is used.

Chapter 3 - An Application Guide

INTRODUCTION

This chapter presents a suggested procedure to assist a municipality in a logical, step-by-step analysis of thermal energy storage. After reviewing this procedure the municipality should have a working knowledge of thermal storage and should be capable of performing a feasibility study of any of its buildings. Thermal energy storage applications are somewhat limited, as will be seen in the following analysis, however the applications that seem favorable have the potential for substantial savings. Since the City of Phoenix has performed numerous feasibility studies of their buildings and completed five installations, highlights from these projects will be included in this procedure to assist in understanding each step.

1) CONSULT THE LOCAL UTILITY

There is a good reason for listing this first. If the utility does not promote thermal energy storage in some way, the project in most cases will prove uneconomical. Check to see if the utility offers cash incentives, time-of-use rates, preliminary feasibility studies, financing assistance or partial payment of engineering design costs.

Cash incentives usually take the form of a dollar amount per kilowatt demand shifted from on-peak hours. The time-of-use rate divides the day into on-peak and off-peak times which have an on-peak and off-peak energy and demand charge conducive to demand shifting. In most cases there is no demand charge for off-peak demand and a lower energy charge during that period. Some utilities will provide assistance with feasibility studies which are typically computer simulations using load approximations and their various rate structures. A utility may also offer financial assistance toward engineering design fees of the thermal storage system, or low interest loans for the purchase of thermal energy storage equipment. All of these incentives point to one thing, utilities are very concerned about expensive peak electricity which may require building new and very costly power generation facilities.

The City of Phoenix is serviced by two utilities, the Salt River Project and the Arizona Public Service Company. The Salt River Project offers $250 per kilowatt demand shifted from on-peak (12:00-10:00pm) up to 300 kw and $115 per kilowatt to 500 kw. They also offer a special time-of-use rate (E-32) which is used as the default rate for the Cooloff program in chapter 4. Arizona Public Service offers much the same incentive and also offers a 50 percent subsidy of engineering design fees for a thermal storage design.

It will be advantageous to meet the utility representative promoting thermal energy storage, if one exists. A good working relationship with the utility is essential with a technology of this type. If the utility is familiar with thermal energy storage, as both Salt River Project and Arizona Public Service are, much of the feasibility work may be accomplished by them.

An important question to ask the utility is what changes can be expected in the upcoming years. Most utilities have some idea of rate increases or rate changes several years forward. It will be reassuring to know that the rate structure will remain in effect long enough to pay off the new thermal storage system.

2) RANK BUILDINGS BY PRELIMINARY FEASIBILITY

Create a list of buildings ranked by superficial feasibility. First rank the buildings by the type of HVAC distribution system. Buildings with chilled water systems should receive highest priority. Buildings with centralized DX systems would rank next and those with multiple packaged DX units would be considered last. Next look at the location of the existing equipment and the site. Space restrictions will usually determine which type of thermal storage, ice or chilled water, to consider. An ideal situation will have the existing equipment room located near ground level with space for storage adjacent, either on grade or under a lawn or parking area.

Constraints to the immediate installation of thermal storage in many municipal buildings do exist. The air-conditioning compressors at most sites are not suitable for making ice, which is the preferred medium for cool storage in retrofit situations. Thus, the retrofit must often bear the additional cost of replacing refrigeration equipment, unless the replacement can be justified by other means, for example, age, obsolescence, or low efficiency. Locating space for storage in an existing high-rise building can also be a problem. Having the existing equipment on the roof of the building, as is often the case, makes the problem of locating storage particularly acute. Finally, most thermal storage installations have a high first cost. Utility incentives must be strong to produce an acceptable payback on the investment. The survey of city buildings in Phoenix showed that both cash incentives and time-of-use rates were necessary to create attractive paybacks on storage retrofits.

If an energy audit has been performed on municipal buildings, HVAC equipment types can easily be identified. The audit will also prove very useful in subsequent steps in this procedure. Remember, the utility may provide feasibility studies as part of their incentives, so be sure to contact them as soon as practicable.

3) ROUGHLY ESTIMATE THE COOLING AND/OR HEATING LOAD

A load estimate accurate to plus or minus 25 percent can be made from examining the operating log of the existing refrigeration or heating equipment or by analyzing the monthly electrical billing history of the building. If an energy audit is already completed, the cooling and heating loads have already been determined. In most cases a rough estimate of kilowatt demand and kilowatt-hour usage for heating and cooling can be calculated using the past year of monthly electric billing. The monthly statement should include total kilowatt-hours for the month, kilowatt demand, and the cost of that month's usage. By finding the month with the lowest usage it can be assumed that very little heating or cooling is used. If gas or other than electric fuel is used for heat, winter months should reflect a base load. This approach may not be effective for larger office buildings where cooling is used year round. Summer cooling can usually be estimated at 40-50 percent for office buildings. An estimate for the cooling/heating demand (kilowatt) and usage (kilowatt-hour) will be required when calculating the savings of time-of use rates over conventional rates. Since the City of Phoenix had already completed energy audits, that data was used to perform computer load simulations to obtain cooling and heating load profiles.

4) ESTIMATE SIZE AND COST OF THE THERMAL ENERGY STORAGE SYSTEM

Using the rough estimate of building loads calculated in Step 3, an approximate thermal storage size and cost can be obtained. One method is to take the design load from above and multiply it by a diversity factor (usually 0.85) and the number of cooling hours (occupied period plus precool period). The equation for the daily required ton-hours is:

System ton-hrs. = Design Load (ton) x Diversity x Number of Cooling Hours

If more accurate data is available, such as the hourly load profile for design day conditions, use this information to obtain a daily ton-hour thermal storage size.

Approximate System Costs. The approximate cost of each system type is given below.

Chilled Water - \$350-500 per ton (60-200 tons chiller capacity)
\$0.50 per gallon of storage over 100,000 gallons

Ice - $1200 per ton (1985 EPRI estimate for ice harvesters)

Eutectec Salts - $120 per ton-hour (salts and tank for greater than 2000 ton-hour)

The City of Phoenix has purchased two brine type ice systems (Calmac Manufacturing Corp.) at about $110 per ton-hour and three ice harvesters (Turbo Refrigerating Company) at approximately $250 per ton-hour. The Calmac systems have both been 200 ton-hour systems while the Turbo systems have been 340 ton-hours each. The ice harvesters replaced existing chillers while the brine systems utilize the existing chillers to make ice, which accounts for some of the cost variance. When the cost of a replacement chiller is subtracted out of the Turbo system price, a $120 per ton-hour cost is obtained. This will be discussed further when calculating paybacks.

5) ESTIMATE PAYBACKS

At this time it will be worthwhile to obtain some payback figures. This is accomplished by utilizing the estimated thermal storage system cost in the last step and figuring in the utility incentives and time-of-use rate from Step 1. The Cooloff program in Chapter 4 can be used to calculate savings from the information that has been developed to this point. It may be worthwhile at this time to go to Chapter 4 and compute the estimated savings for thermal storage. With the approximate system cost and the calculated savings a simple payback can be obtained by this equation:

$$\text{Simple Payback} = \frac{\text{Cost of Installed System}}{\text{Yearly Savings}}$$

Make sure the incentive is subtracted from the system cost prior to performing the payback calculation. Also if old equipment was to be replaced regardless of thermal storage, the cost of same-kind equipment replacement should be deducted to reflect the actual costs attributed to thermal storage only. This cannot be done if the equipment is newer and not in need of replacement.

6) DO A FULL ENGINEERING STUDY

On buildings that appear to have acceptable paybacks, a more thorough evaluation should be performed. An accurate estimate of the on-peak building load can be obtained by directly measuring the hourly energy consumption or the thermal output of the air-conditioning system. A recording power meter (measuring kilowatt and kilowatt-hours) will provide a continuous readout of both demand and energy usage. With this information the on-peak thermal storage ton-hours required can be estimated when measured on days which closely parallel design day conditions.

If ASHRAE design methods are used it is very important to calculate all of the loads carefully. Missing a number of small heat gains for cooling, especially latent (moisture) loads can compound over daily or weekly storage requirements. The computer load simulations will give acceptable results only if all of the heat gains are accounted for.

Determine the limits of available space for storage. Specify how the existing HVAC distribution system will be interfaced with storage. Compare the basic alternatives; chilled water, ice and eutectic salts. Contact thermal storage representatives to evaluate your sites and give a fairly accurate installed cost. Rework the potential savings with the Cooloff program or utility assistance and obtain a new set of paybacks. A life-cycle costing will give a more accurate payback analysis which may make the project more acceptable.

If a project is within acceptable economic limits, proceed with the design. If the municipality has capable engineers the plans and specifications can be completed in-house. If outside engineers are required, look for companies that have had previous thermal energy storage experience and check to see that the completed project is acceptable to the building owner. If there are no local engineers familiar with thermal storage, a search of near-by cites or out-of-state firms may be required.

7) OBTAIN COMPETITIVE BIDS

A list of thermal storage manufacturers is given in Appendix D. In reviewing the bids look for contractors who have completed successful thermal energy storage projects. If thermal storage is new to the area, look for contractors who are familiar with HVAC systems and in particular with the type (chilled water or ice) of system chosen. Be cautious of low bids, in many cases the low bidder is unfamiliar with this technology and may be unable to complete the job or will use unacceptable materials.

8) INSTALL THE SYSTEM

System installation is the culmination of all the work accomplished to this point. If possible install and test the system in the off-season. This will insure all the pumps, motors, fans and compressors are functioning properly. The true test, however, will come during the middle of the cooling season. Problems like lower amp ratings to circuit protection due to high ambient temperatures, higher than anticipated building loads, and uneven ice harvesting are all problems that will not surface until the unit is operating at full load. Insure that all the equipment and controls have a full one year warranty that will cover problems encountered during the first cooling season.

It will prove beneficial to check with the utility to see if they have some provisions for crediting an occasional breakdown which may require setting a momentary on-peak demand. This could prove quite costly especially if a rachet rate structure is in effect which could set the demand rate for the whole year. If the utility is indeed interested in promoting thermal energy storage, then special arrangements can be worked out for those few days that maintenance may require equipment operation during on-peak hours. Since this peak demand occurs so infrequently it does not cause on-peak problems for the utility. As another reminder, get to know the utility representative working with thermal energy storage. If a good working relationship is established, most problems can be worked out to the advantage of both parties. Energy management and load shifting are beneficial to both the utility and the municipality.

Adding Heat Storage

The above procedure refers mainly to cool storage, of which the City of Phoenix is most familiar. In hard winter climates, heat storage can often be added as an adjunct to a cool storage system by using special heat-recovery chillers. Large buildings which require a warm-up in the morning, followed by cooling in the afternoon, are ideal candidates. Combined heat/cool storage strategies have proven successful in improving the economics of thermal storage in colder climates.

Chapter 4 - The COOLOFF Computer Program

INTRODUCTION

COOLOFF is a computer program that facilitates calculating the economic benefits of using thermal storage for cooling commercial buildings. The COOLOFF program uses information readily available from utility bills and utility rate tariffs. A diskette containing the COOLOFF program can be obtained at no cost by sending a written request to the following address:

Energy Conservation Office
City of Phoenix
2631 South 22nd Avenue
Phoenix, Arizona 85009

Assumptions

The COOLOFF program uses a set of assumptions that greatly simplify thermal storage calculations without unreasonably sacrificing the accuracy of the final results. The basic assumptions are the following:

1. The size of the cooling load in a building is proportional to the amount of energy (KWH) used by the building in excess of the base load.
2. The shape of the cooling load profile is the same on each day of the cooling season as it is on the design day.

3. The percentage of cooling energy (KWH) and demand (KW) that is shifted off peak on the design day is the same for each day of the cooling season. This assumption represents a conservative approach in regard to how a cool storage system will effect the distribution of energy usage on days other than the design day.
4. The total energy (KWH) used for cooling after installation of a cool storage system will be the same as the total energy used for cooling before the installation of the system.

The above assumptions will result in slightly underestimating the actual savings of a proposed cool storage installation. The program user, therefore, can consider the results of the COOLOFF calculations as the minimum amount of savings that can be expected from a cool storage project based on the values used in the analysis.

Heating

The COOLOFF program does not calculate the economic benefits of using thermal storage for heating a building.

SETTING UP THE PROGRAM

The COOLOFF program is written in IBM BASICA and will run on a computer with a minimum of 64K Random Access Memory (RAM) and one 360K 5-1/4 inch disk drive. The program will output results of its calculations to a printer when requested.

Diskette Operation

On a computer using only diskettes, the COOLOFF program can be booted by two methods:

1) If the computer is off, simply insert the diskette in Drive A and turn on the computer.

2) If the computer is on, insert the diskette in Drive A and enter CO (upper or lower case).

Hard Disk Operation

Because the COOLOFF program software is not copy protected, a user can store the program on a fixed (hard) disk by using the copy command of the DOS operating system for transferring the program to a fixed disk.

Data Entry

The terms Enter, Carriage Return, and C/R are commonly used interchangeably to denote the same key on the standard personal computer keyboard. This manual will use only the term Enter for this particular key.

COOLOFF TEST PROGRAM

A test program has been included in the COOLOFF software to give the user the experience of running a cool storage analysis on a building and to verify that the program is operating correctly. Appendix A contains reproductions of the data tables generated by the test program.

The test program can be activated with the following commands:

1) Type CO to begin the COOLOFF program and display the rate selection menu on the monitor.
2) Select Option 1, Enter Cool Storage Cost Analysis Program.
3) Next, select the conventional rate structure for use in the analysis.

The COOLOFF program now lists all the conventional utility rates stored on the disk. Unless the user has already created other utility rates, the only rate listed at this time will be DEFAULT.CON.

Pressing the Enter key will automatically enter the default utlity rate data into program memory.

The COOLOFF program will next ask for the building name. Enter the name TEST. A message "Wait For Printout" will appear on the monitor, and after approximately fifteen seconds a data table will be displayed. The data in the table should be exactly the same as the data shown in Appendix A. Press the Enter key to display the second half of the data table, and again compare the numbers shown on the screen to the data displayed in Appendix A. If the numbers are the same, the COOLOFF program is working correctly.

Observe message "HARD COPY (Y/N)?" at the bottom of the screen. The letter Y (yes) should only be entered when the user wants a printout of the tables displayed on the monitor. Pressing the Enter key without first making an entry will automatically load the default letter N (no) into the program and bring the COOLOFF analysis menu to the screen.

Select Option 1 from the analysis menu -"Analyse for Partial Cool Storage". The first of five questions will now appear on the monitor requesting the information necessary to run the analysis. Default answers to each of the questions have been supplied for the test program. The default values can be used as shown by pressing the Enter key or changed to whatever value the user desires. Do not change the values at this time because the sample data tables in Appendix A are based on the default values supplied with the program.

After all the questions have been answered, the user is asked to verify the correctness of the data entered. If the Enter key is pressed without first making an entry, the program assumes that the answer is yes (Y) and begins the cool storage calculations.

In a few seconds a data table appears on the monitor showing the results of the partial cool storage analysis. The values in the table should be exactly the same as the values shown in the upper portion of the next page in Appendix A. Press the Enter key to display the lower half of the data table on the monitor.

Once again the user is offered a printed copy of the data table. Press the Enter key without making an entry and return to the analysis menu to select Option 2-"Analyse for Full Cool Storage". The user is presented a series of questions for which default values have been supplied. When the message "Entries Correct (Y/N)?" appears, press the Enter key to began the calculations for a full cool storage analysis.

After a few seconds a data table will appear on the monitor showing the results of the full cool storage analysis. The values in the table should be exactly the same as the values shown in the upper half of the third page of Appendix A. Press the Enter key to display the other half of the data table on the monitor. The COOLOFF program is running correctly if the values displayed on the monitor are identical to the values shown in Appendix A.

Select Option 3 from the COOLOFF analysis menu -"Analyse for Air-Conditioning Costs". Once again the user will be asked a series of questions for which default values have been supplied. When the message "Entries Correct (Y/N)?" appears, press the Enter key to began the calculations.

After a few seconds a data table will appear on the monitor showing the results of the COOLOFF analysis. The values in the table should be exactly the same as the values shown in the upper half of page four in Appendix A. Press the Enter key to display the lower half of the data table on the monitor.

Return the the main menu to select Option 4 -"Summary of Cool Storage Analysis". A data table identical to the one shown on the fifth page of Appendix A, will appear on the monitor.

Option 4 completes the cool storage analysis. The remainder of the selections on the main menu are self explanatory and can be explored by the program user at this time. The user can experiment in changing the variables of the program to observe the effects these changes have on the results of partial and full storage calculations, or return to the rate structure program to began entering the values that match a local utility rate structure.

Running a time-of-use cool storage analysis is identical to the above procedures except that time-of-use utility rate option is selected at the beginning of the program.

CREATING A UTILITY RATE STRUCTURE

Thousands of utility rates exist in this country, but most of these rates are generated from a few general rules called billing components. By using the billing compoments furnished in this program, the user can create a custom rate structure that will closely resemble a local utility rate structure.

A rate does not have to be created every time the COOLOFF program is run. Once a rate structure has been created, it is permanently stored on the program disk and can be used in future thermal storage analyses by entering its name into the program when requested.

Types Of Rate Structures

There are two basic types of rate structures: conventional and time-of-use. Conventional rates usually consist of a monthly service charge, a declining block strategy for the energy charge (kilowatt-hours), and a fixed price per kilowatt for the demand charge. Time-of-use rates differ from conventional rates by having certain portions of the day designated as on-peak; all remaining hours of the day are by definition off-peak. Utility companies charge higher prices for energy and demand during the on-peak hours in order to discourage heavy electrical usage during this period. The COOLOFF program, therefore, allows seperate energy and peak demand charges for on-peak and off-peak hours in the time-of-use rate structure.

Rate Input Forms

The conventional and time-of-use rate input forms are shown in Appendix B. Fill out these forms completely before making actualdata entries on the computer.

Conventional Rate Structure

Service Charge. The service charge may be called a "customer charge" or a "base charge" in some localities. In all cases it is the fixed charge added to the monthly bill and is not effected by the amount of kilowatt-hours used in the billing period.

Definition of Summer/Winter Rate Split. If the local utility tariff has different rates for usage in summer and winter, then the COOLOFF program user must enter the first and last month of the summer time-period. Use the first three letters of the appropriate months, and enter the months in their normal calender order (MAR must be entered before OCT).

Demand Charge. Some utility rates specify that there will be no charge for an initial amount of demand. That amount of free KW is accounted for by the COOLOFF program. If the utility rate being created does not have any free KW, then the program user should enter a zero.

At this point on the conventional rate input form the user is asked if a demand ratchet is to be incorporated into the utility rate structure. If the answer is yes, enter the ratchet percentage (as a whole number) and the months in which the ratchet is in effect. Use the the first three letters of the appropriate month and enter the months in their normal calender order.

Ratchet demand is equal to a percentage of the highest actual demand that occurred during the ratchet period, which in most locations covers the summer months when the demand for cooling is at a maximum. The demand charge of a utility bill will never be less than a specified percentage of the maximum demand that occurred in the ratchet period. Most utilities show both actual measured demand and ratchet demand on their bills. When estimating the base demand load of a building, be careful to use the actual, measured, demand for the building rather than ratchet or billing demand.

Energy Charge. The COOLOFF program allows up to four energy blocks to be created in the new rate structure. The first block can be expanded into three diferent sizes based on demand. When defining the block that represents all remaining KW, the user should enter the word ALL to represent all additional KW or KWH. The word ALL is converted to 1E+10 by the program and will appear as such in printed copies. Please note that the energy charge must be input in dollars; therefore, an energy charge of 7.5 cents per KWH is entered into the program as 0.075 dollars per KWH.

Tax. This is the local tax rate for utility bills, which must be entered as a whole number. The program will divide the number by one hundred to convert it into a decimal percentage.

Time-Of-Use Rate Structure

Service Charge. Same as in the conventional rate structure.

Definition of Summer/Winter Rate Split. Same as in the conventional rate structure.

On-Peak / Off-Peak Hours. The COOLOFF program needs to know the starting and the ending times of the on-peak period. Once the program knows the on-peak period, it assumes the off-peak period to be all the remaining hours in the day. The times entered must be in the four digit (military) format. For example, 10:30 pm must be entered as 2230. Another consideration the user should keep in mind is that the starting time of the on-peak period must be earlier than the ending time.

Demand Charge. Enter the on-peak demand charge per KW. The COOLOFF program assumes that there is no off-peak demand charge when a time-of-use rate is in effect. If a summer/winter rate split is specified by the user, the program will request seperate on-peak demand charges for the summer and winter seasons.

Energy Charge. The on-peak and off-peak charges per KWH must be entered in dollars. For example, a charge of 7.5 cents per KWH should be entered as 0.075 dollars per KWH.

Tax. This is the current local tax rate for utility bills. The tax rate should be entered as a whole number. The program will divide the number entered by one hundred to convert it into its decimal equivalent.

Data Entry.

After the utility rate structure forms have been completed, enter CO to bring the COOLOFF rate selection menu up on the monitor and choose Option 1, Create a New Utility Rate.

Next, select Option 1, Conventional, when asked to choose a rate structure.

Default values will appear in the data entry windows as a guide to the user. These default entries can be retained by pressing the Enter key or they can be changed by entering the desired parameter in place of the default entry. The data is entered in the same order as it is shown on the rate input forms.

After all the information for the a new utility rate structure has been entered into the COOLOFF program, the entered values are displayed on the monitor for review. If erroneous data entries are found during the review, the program user need only enter the line number associated with the incorrect value and the COOLOFF program will automatically return to the data entry mode for that parameter.

Printed Copies

After the user is satisfied that all the data entries are correct, the message "Do you want a hardcopy? (Y/N)" will be placed on the monitor. Entering the letter Y (yes) instructs the program to print a copy of the data entered. Pressing the Enter key without designating a letter is interperted as entering N (no) and the program continues to the next step.

File Names

File names for the utility rate structures created by the user must follow all the rules for DOS (Disk Operating System) files. File names should be eight characters or less and must not contain any special symbols (as defined in the DOS manual) or blank spaces. After entering a file name, the user is returned to the COOLOFF main menu.

CREATING A BUILDING DATA FILE

The building data input forms for a conventional utility rate and a time-of use utility rate are shown in Appendix C. It is a good idea to completely fill out both of these forms before starting a thermal storage analysis because the COOLOFF program requires all of this information for the analysis and it is convenient to have the data available in the same order it is requested by the program.

Time-of-Use Building Data Input Form

The first items of information requested on the Time-of-Use Building Data Input Form are the building name and the run title. A highly descriptive run title should be used, such as ENERGY COST WITHOUT COOL STORAGE or PARTIAL COOL STORAGE COST ANALYSIS, because these titles are vital for labeling the data tables created by the program.

The building base energy load is the next item of information requested. The base energy load (in KWH per month) is the amount of energy being used by the building when no heating or cooling is required. This value usually can be estimated by examining a billing history of the building.

The fraction of base load energy (KWH) consumed on-peak is calculated by estimating the amount of energy consummed on-peak daily and dividing it by the total daily base load (energy used both on-peak and off-peak). These quantities are derived from an hourly record of energy consumption of the building under study. On large buildings a local utility may have such information already available, but on smaller buildings a portable wattmeter with a recording chart probably will have to be used to acquire the necessary data.

The COOLOFF program requires seperate fractions of base load energy consumed on-peak if the utility rate has a summer/winter rate split. These fractions may differ because the utility company could designate different time periods as on-peak during the winter season. For example, a utility may specify the hours between 12 noon and

10 p.m. as on-peak during the summer, and the hours between 7 a.m. and 10 p.m. as on-peak during the winter season.

Specifying the first and last months of the cooling season is important because they directly affect the results of the cool storage analysis. Cool storage analysis will be simulated only between these months.

The fraction of cooling energy and fraction of heating energy used during on-peak hours can be derived from cooling and heating load curves of the building on a design day. The COOLOFF program makes assumption that these on-peak fractions will be the same on each day of the season in which they occur.

Use values from actual electric bills for the monthly energy (KWH) consumed by the building. Pick a year that is close to average in terms of degree-days, or take an average of several years to avoid basing the thermal storage analysis on an unusually cold or warm year.

Use the same utility bills to determine the on-peak demand for each month of the year. Be careful to enter the measured demand rather than the billing demand. The COOLOFF program automatically calculate the billing demand if the ratchet is in effect.

Partial Cool Storage Section

Base Demand Load. Base demand load is defined as the power required to maintain building operations when no cooling demand is present. An accurate estimate of base demand load can usually be made by examining the monthly billing history of the building and noting the lowest demand level that occurred during the year.

Down-Sizing Ratio On Capacity. The program assumes that a partial cool storage system will flatten the cooling energy profile of the building over a twenty-four hour period. Therefore, the fraction of cooling energy used on-peak is the number of on-peak hours in the day (typically 8 to 13 hours) divided by the total number of hours in a day.

The down-sizing ratio on capacity is calculated by dividing the refrigeration capacity required with partial storage by the refrigeration capacity required without any thermal storage.

Conventional Building Data Input Form

The first items of information requested on the conventional building data input form are the building name and the run title. A highly descriptive run title should be used, such as ENERGY COST WITHOUT COOL STORAGE or PARTIAL COOL STORAGE COST ANALYSIS, because these titles are used on subsequent printed copies and are vital for labeling the data tables created by the program.

The first and last months of the cooling season are important because they directly affect the results of the cool storage analysis. Cool storage analysis will be simulated only between these months.

Use values from actual electric bills for the monthly energy (KWH) consumed by the building. Pick a year that is close to average in terms of degree-days, or take an average of several years to avoid basing the thermal storage analysis on an unusually cold or warm year.

Use the same utility bills to determine the on-peak demand for each month of the year. Be careful to enter the measured demand rather than the billing demand. The COOLOFF program automatically calculate the billing demand if the ratchet is in effect.

Partial Cool Storage Section

Base Demand Load. This value may be estimated by examining actual utility bills for the building in the months when no cooling is required.

Down-Sizing Ratio On Capacity. The down-sizing ratio on capacity is calculated by dividing the refrigeration capacity required with partial storage by the refrigeration capacity required without any thermal storage.

Full Cool Storage Section

The building base load is the next item of information requested. As previously explained, the base energy load (in KWH per month) is the amount of energy being used by the building when no heating or cooling is required.

Running The Program

The COOLOFF program user is ready to run a cool storage analysis after the building data input forms have been completed and a local utility rate structure has been created.

COOL STORAGE ANALYSIS

Activate the COOLOFF program with the following commands:

1) Type CO to display the rate selection menu.
2) Select Option 1, Enter Cool Storage Analysis Program.
3) Next, select either the conventional or time-of-use option for the type of rate structure to be used in the analysis.

The COOLOFF program will now list the utility rates stored on the disk. Type the selected file name (without the extension) into the data entry window and press the Enter key.

From this point the user can refer to the building data input forms for the information required to run the program. The COOLOFF program periodically requires conformation that the data entries are correct. The default entry is the letter Y (yes), therefore the user need only press the Enter key to continue entering data. Answering no (N) to the enquiry will return the user to the beginning of that section of the program in order to reenter the correct values.

After the monthly peak demands have been entered, the COOLOFF program proceeds to calculate the monthly electric bill for the building being analyzed. This calculation requires less than a minute on personal computers, at the end of which a data table appears on the monitor listing various energy consumption and cost figures.

Referring to the first data table displayed on the monitor, the column entitled "KWH CONSUMED ON PEAK" gives the combined on-peak energy consumption of the building from base load and cooling load sources. The next column, "KWH CONSUMED OFF PEAK", represents the difference between the total KWH for the month and the on-peak KWH listed in the first column. The column "BILLED KW" contains the figures used to calculate the demand portion of the bill. The last column lists the monthly charges for electrical service based on the rate structure that was selected for the analysis.

Press Enter key to have the second data table appear on the monitor. The second table contains statistics describing the pattern of energy use of the building and allows the program user to gage how much potential there is for reducing energy costs. The second column, "% OF ANNUAL BILL", represents the total annual billing charge divided by the appropriate monthly charge, showing which months are most costly in terms of demand and energy usage.

The next column, "RATCHET PENALTY", lists the charges in each month's bill attributable to the ratchet clause in the utility rate. The column will contain a zero if the ratchet clause was not in effect for a particular month or if the utility rate selected did not contain a ratchet clause. The penalty figure is derived by first calculating the monthly billing charge using measured KW, then calculating the billing charge using the ratchet KW, and finally subtracting the first calculation from the second. The third column, "LOAD FACTOR", is a ratio derived by dividing the average demand for the year by the peak demand for a given month. This information is useful as a measure of demand variability. A building is considered more efficient as the load factor approaches unity because less power (KW) is required to produce a unit of energy (KWH). Consequently, most utility rate structures are set up so that the cost per KWH decreases as the load factor increases. The COOLOFF program translates this information into a meaningful dollar figure in column three by showing exactly how much additional money is added to the bill every month to pay for a load factor of less than one.

At the end of the second data table the user is asked "Do you want a hard copy?(Y/N)". Enter the letter Y (yes) if a printed copy of both data tables is desired. Pressing the Enter key without first making an entry is interpreted as entering N (no) and the program will return to the COOLOFF analysis menu.

The next step, after existing utility costs have been calculated, is to begin the cool storage analysis for the building. The first four options on the COOLOFF anaylsis menu are (1) Analyze for Partial Cool Storage, (2) Analyze for Full Cool Storage, (3) Analyze for Air-conditioning Costs, and (4) Summary of Cool Storage Analysis. For a complete cool storage analysis the user should proceed through each of these options in the order they appear.

The cool storage analysis is basically complete after Options 1 through 4 have been exercised. At this point the user may wish to change one or more of the program variables to measure the effect of various cool storage strategies. The COOLOFF analysis menu offers a full range of options to change any value used in the current analysis, start a new building analysis, or exit the program entirely.

Appendix A - Sample Cooloff Outputs

* ANNUAL BILLING CALCULATION *

UTILITY RATE: DEFAULT

BUILDING: TEST
RUN TITLE: TEST
DATE / TIME : 05-31-1988 / 15:54:25

MONTH	KWH CONSUMED	MEASURED KW	BILLED KW	CHARGE ($)
1 JAN	9280	45	45	$626.91
2 FEB	9200	45	45	$623.24
3 MAR	9920	45	45	$656.28
4 APR	9040	45	45	$615.90
5 MAY	10480	59.2	59.2	$913.01
6 JUN	13680	59.2	59.2	$1,071.60
7 JUL	15520	59.2	59.2	$1,162.79
8 AUG	17120	63.2	63.2	$1,262.43
9 SEP	14400	58.4	58.4	$1,103.22
10 OCT	14080	60.8	60.8	$1,099.56
11 NOV	12160	50.4	50.4	$775.42
12 DEC	8960	45	45	$612.23
ANNUAL	143840			$10,522.59

MONTH	% OF ANNUAL BILL	RATCHET PENALTY	LOAD FACTOR	LOAD FACTOR PENALTY
1 JAN	6.0	$0.00	0.29	$97.27
2 FEB	5.9	$0.00	0.28	$97.61
3 MAR	6.2	$0.00	0.31	$94.58
4 APR	5.9	$0.00	0.28	$98.28
5 MAY	8.7	$0.00	0.25	$227.00
6 JUN	10.2	$0.00	0.32	$204.40
7 JUL	11.1	$0.00	0.36	$191.41
8 AUG	12.0	$0.00	0.38	$200.45
9 SEP	10.5	$0.00	0.34	$195.25
10 OCT	10.4	$0.00	0.32	$209.71
11 NOV	7.4	$0.00	0.34	$101.51
12 DEC	5.8	$0.00	0.28	$98.62
ANNUAL	100.0	$0.00	0.31	$1,816.10

* ANNUAL BILLING CALCULATION *

UTILITY RATE: DEFAULT

BUILDING: TEST
RUN TITLE: PARTIAL COOL STORAGE
BASE LOAD KW = 30 DOWNSIZING RATIO = .7 SEASON = MAY TO NOV
DATE / TIME : 05-31-1988 / 15:43:43

MONTH	KWH CONSUMED	MEASURED KW	BILLED KW	CHARGE ($)
1 JAN	9280	45	45	$626.91
2 FEB	9200	45	45	$623.24
3 MAR	9920	45	45	$656.28
4 APR	9040	45	45	$615.90
5 MAY	11199.2	50.44	50.44	$904.11
6 JUN	15327.2	50.44	50.44	$1,108.69
7 JUL	17700.8	50.44	50.44	$1,226.33
8 AUG	19764.8	53.24	53.24	$1,342.86
9 SEP	16256	49.88	49.88	$1,151.88
10 OCT	15843.2	51.56	51.56	$1,139.96
11 NOV	13366.4	44.28	44.28	$812.24
12 DEC	8960	45	45	$612.23
ANNUAL	155857.6			$10,820.64

MONTH	% OF ANNUAL BILL	RATCHET PENALTY	LOAD FACTOR	LOAD FACTOR PENALTY
1 JAN	5.8	$0.00	0.29	$97.27
2 FEB	5.8	$0.00	0.28	$97.61
3 MAR	6.1	$0.00	0.31	$94.58
4 APR	5.7	$0.00	0.28	$98.28
5 MAY	8.4	$0.00	0.31	$177.38
6 JUN	10.2	$0.00	0.42	$148.23
7 JUL	11.3	$0.00	0.49	$131.47
8 AUG	12.4	$0.00	0.52	$131.13
9 SEP	10.6	$0.00	0.45	$138.82
10 OCT	10.5	$0.00	0.43	$150.28
11 NOV	7.5	$0.00	0.42	$77.90
12 DEC	5.7	$0.00	0.28	$98.62
ANNUAL	100.0	$0.00	0.38	$1,441.56

* ANNUAL BILLING CALCULATION *

UTILITY RATE: DEFAULT

BUILDING: TEST
RUN TITLE: FULL COOL STORAGE
BASE LOAD KW = 30 SEASON = MAY TO NOV
DATE / TIME : 05-31-1988 / 15:45:38

MONTH	KWH CONSUMED	MEASURED KW	BILLED KW	CHARGE ($)
1 JAN	9280	45	45	$626.91
2 FEB	9200	45	45	$623.24
3 MAR	9920	45	45	$656.28
4 APR	9040	45	45	$615.90
5 MAY	11075.2	30	30	$794.04
6 JUN	15043.2	30	30	$990.69
7 JUL	17324.8	30	30	$1,103.77
8 AUG	19308.8	30	30	$1,202.09
9 SEP	15936	30	30	$1,034.94
10 OCT	15539.2	30	30	$1,015.27
11 NOV	13158.4	30	30	$759.44
12 DEC	8960	45	45	$612.23
ANNUAL	153785.6			$10,034.80

MONTH	% OF ANNUAL BILL	RATCHET PENALTY	LOAD FACTOR	LOAD FACTOR PENALTY
1 JAN	6.2	$0.00	0.29	$97.27
2 FEB	6.2	$0.00	0.28	$97.61
3 MAR	6.5	$0.00	0.31	$94.58
4 APR	6.1	$0.00	0.28	$98.28
5 MAY	7.9	$0.00	0.51	$74.33
6 JUN	9.9	$0.00	0.70	$46.30
7 JUL	11.0	$0.00	0.80	$30.19
8 AUG	12.0	$0.00	0.89	$16.18
9 SEP	10.3	$0.00	0.74	$40.00
10 OCT	10.1	$0.00	0.72	$42.80
11 NOV	7.6	$0.00	0.61	$35.52
12 DEC	6.1	$0.00	0.28	$98.62
ANNUAL	100.0	$0.00	0.49	$771.68

*** COOL STORAGE ANALYSIS ***

UTILITY RATE: DEFAULT

BUILDING: TEST

DATE / TIME : Ø5-31-1988 / 15:47:2Ø

****

TOTAL ENERGY COSTS

Present Energy Bill	$ 1Ø,522.59				
Partial Storage Savings	$ -298.Ø5	OR	-2.8	%	LESS
Full Storage Savings	$ 487.79	OR	4.6	%	LESS

AIR-CONDITIONING ENERGY COSTS

With Existing Equipment	$ 1Ø,522.59				
With Partial Storage	$ 1Ø,82Ø.64	OR	-2.8	%	LESS
With Full Storage	$ 1Ø,Ø34.8Ø	OR	4.6	%	LESS

****

Appendix B - COOLOFF Data Input Forms

CONVENTIONAL RATE INPUT FORM

1. Service Charge: $________/ month

2. Summer Rates are from ________ to ________

3. Demand Charge (If rate split: Summer, else Year-Round value):

   From _______ through _______ there is no charge for first ______ KW of demand.

   All additional KW charge is $________ /KW

   Demand Charge (If rate split: Winter):

   From _______ through _______ there is no charge for first ______ KW of demand.

   All additional KW charge is $________ /KW

   Demand Charge (Year):

   Is there a ratchet? (Y/N) ________

   If Yes, then: First month of ratchet: (Enter a #) ____

   Last month of ratchet: " ____

   Enter ratchet percent ____ %

4. Energy Charge (Summer)

Number of blocks (1-4): ______

Block 1 KWH charge = $_______ /KWH Blocksize = __________

Block 2 KWH charge = $_______ /KWH Blocksize = __________

Block 3 KWH charge = $_______ /KWH Blocksize = __________

Block 4 KWH charge = $_______ /KWH Blocksize = __________

Is there an expanding 1st block? (Y/N): ______

If Y, then number of expansions for Block 1 (1-3) ____

For 1st ____ KW of demand, Block 1 expands by ________ KWH/KW

From ______ to _____ KW, Block 1 expands by _______ KWH/KW

From ______ to _____ KW, Block 1 expands by _______ KWH/KW

Energy Charge (Winter)

Number of blocks (1-4): ______

Block 1 KWH charge = $_______ /KWH Blocksize = __________

Block 2 KWH charge = $_______ /KWH Blocksize = __________

Block 3 KWH charge = $_______ /KWH Blocksize = __________

Block 4 KWH charge = $_______ /KWH Blocksize = __________

Is there an expanding 1st block? (Y/N): ______

If Y, then number of expansions for Block 1 (1-3) ____

For 1st ____ KW of demand, Block 1 expands by ________ KWH/KW

From ______ to _____ KW, Block 1 expands by _______ KWH/KW

From ______ to _____ KW, Block 1 expands by _______ KWH/KW

5. Tax Enter the current tax rate in percent: ______ %

TIME-OF-USE RATE INPUT FORM

1. Service Charge: $________/ month

2. Summer Rates are from ________ to ________

3. ON PEAK / OFF PEAK Hours (Summer & Winter)

   For Summer, ON PEAK hours are from _______ to _______ (4 digits)

   For Winter, ON PEAK hours are from _______ to _______ "

4. Demand Charge

   For summer, ON PEAK Demand Charge is $_____ /KW

   For winter, ON PEAK Demand Charge is $_____ /KW

   Demand Charge (Year):

   Is there a ratchet? (Y/N) ________

   If Yes, then:

   First month of ratchet: (Enter a #) ____

   Last month of ratchet: " ____

   Enter ratchet percent ____ %

5. Energy Charge

   For summer, ON PEAK Energy Charge is $______/KWH

   For winter, ON PEAK Energy Charge is $______/KWH

6. Tax Enter the current tax rate in percent: ______ %

BUILDING DATA INPUT FORM

Time of Use Rate

BUILDING NAME: ____

RUN TITLE: ____

Building Base Load, (KWH/Month) = _____________

If no summer/winter rate split:
Fraction of Base Load Energy Consumed ON PEAK: ________

If summer/winter rate split:
For summer, Fraction of Base Load Energy Consumed ON PEAK: _____
For winter, Fraction of Base Load Energy Consumed ON PEAK: _____

First Month of Cooling Season (#): _______

Last Month of Cooling Season (#): _______

Fraction of Cooling Energy Used During ON PEAK Hours: ______

Fraction of Heating Energy Used During ON PEAK Hours: ______

Month	Total KWH Consumed	Measured ON PEAK Demand (KW)
JAN	____________	___________
FEB	____________	___________
MAR	____________	___________
APR	____________	___________
MAY	____________	___________
JUN	____________	___________
JUL	____________	___________
AUG	____________	___________
SEP	____________	___________
OCT	____________	___________
NOV	____________	___________
DEC	____________	___________

****

Partial Cool Storage

Above Data plus:

Base Demand Load - No Heating or Cooling (KW): ________

Down Sizing Ratio on Capacity (Fraction): ______

****

Full Cool Storage & Operating Costs Without Cooling

Uses above data.

BUILDING DATA INPUT FORM

Conventional Rate

BUILDING NAME: ________________________________

RUN TITLE: ________________________________

First Month of Cooling Season (#): _______

Last Month of Cooling Season (#): _______

Month	Total KWH Consumed	Measured Demand (KW)
JAN	____________	____________
FEB	____________	____________
MAR	____________	____________
APR	____________	____________
MAY	____________	____________
JUN	____________	____________
JUL	____________	____________
AUG	____________	____________
SEP	____________	____________
OCT	____________	____________
NOV	____________	____________
DEC	____________	____________

****

Partial Cool Storage

Above Data plus:

Base Demand Load - No Heating or Cooling (KW): ________

Down Sizing Ration on Capacity (Fraction): ______

****

Full Cool Storage

Uses Above Data

****

Operating Costs Without Cooling

Above Data plus:

Base Energy Load - (KWH / MONTH) : ___________

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Appendix D - Manufacturers of Thermal Storage Equipment

1. CALMAC Manufacturing Corporation

   Manufacturers of brine-type ice banks, featuring spiral-wound mats of plastic tubing in cylindrical tanks. Available in 60, 90 and 100 ton-hour sizes.
   150 South Van Brunt Street, P.O. Box 710, Englewood, NJ 07631
   (201) 569-0420 (212) 586-5178

2. Turbo Ice Systems Company

   Manufactures high-efficiency, dynamic, ice-harvesting equipment. Packaged systems include ice-maker, storage tank and controls.
   P.O. Box 396 Denton, TX 76202
   (817) 387-4301

3. Transphase Systems Incorporated

   Manufactures containers of eutectic salts which provide latent cool storage of 44 btu's per pound at 47 degrees F. System design and installation services are offered.
   16552 Burke Lane, Huntington Beach, CA 92647
   (714) 893-3920

4. National Integrated Systems

Manufactures direct-expansion ice builders, featuring durable copper expansion coils, fiberglass-lined tanks and integral subcooling. System design and installation services are offered.
1700 West Katella Avenue, Suite 360, Orange, CA
631-4831

5. Baltimore Aircoil Company Incorporated

Manufactures classic direct-expansion ice builders, featuring steel pipe coils, galvanized steel tank and air-agitation to improve the uniformity of ice building. Twenty-one standard sizes from 120 to 950 latent ton-hours.
P.O. Box 7322, Baltimore, MD 21227

6. Chester-Jensen Companv Incorporated

Manufactures direct-expansion ice builders, featuring unlined steel tanks, 1 1/4 inch schedule 40 steel pipe coils, and air-agitation. Forty three standard sizes from 1,000 to 100,000 pounds of ice capacity.
Main Office and Factory, Fifth and Tilghman Streets, Chester, PA 19013
(215) 876-6276

7. Perma-Pipe

Manufactures direct-expansion ice banks. Unique tank design consists of a 40 foot long cylinder of spiral-welded, 1/4 inch steel, pressure rated at 125 psig for closed systems. The tanks are designed to lie horizontally and may be stacked three deep. Casing is suitable for direct burial. Coils are 1 1/4 inch black steel pipe.
7720 Lehigh Avenue, Niles, IL 60648
(312) 966-2150

8. Sullair Thermal Systems, Incorporated

Manufactures direct-expansion ice builders, with matching rotary-screw compressors, liquid refrigerant recirculation packages and custom microprocessor control systems. Design assistance and installation guidance provided. Will lease, operate and maintain total systems.
3700 East Michigan Blvd., Michigan City, IN 46360
(219) 874-1500

9. Thermal Storage Technology Inc.

Manufactures a phase change system with a latent heat of fusion of 92 btu per pound at 46 degrees F and a high efficiency heat exchanger.
909 South Santa Anita Ave., Suite G, Arcadia, CA 91006
(818) 447-0897 (818) 447-0898

10. Ditt Sigma Inc

Distributor for "Cryogel" ice ball storage system. A four inch plastic ball with dimples for expansion/contraction and filled with water.
1255 23 Rd Street NW Suite 450, Washington, D.C. 20037
(202) 659-4333

11. Reaction Thermal Systems Inc.

Manufacturers of a storge system using polyethylene containers filled with deionized water, a storage module, and a high efficiency shell and tube heat exchanger.
Lafayette, CA 94549
(415) 284-3828

REPORT AND INFORMATION SOURCES

Additional copies of this technology transfer report, "Thermal Energy Storage: An Application Guide for Local Governments: are available from:

Publications and Distribution
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
Washington, DC 20004

For more information on the principles, practice and experience from which this Guide is developed, please contact:

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