Title
Program Experience Report: Commercial Cool Storage

Authors
Piette, Mary Ann
Harris, J.P.

Publication Date
1988-10-01

LBL-25782
UC-95d

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Program Experience Report: Commercial Cool Storage

M.A. Piette and J.P. Harris

October 1988

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

ABSTRACT

This paper reviews, compares, and documents actual experience with utility and non-utility programs designed to encourage the use of commercial cool storage technologies. Over 50 utilities have reported some program activities regarding the use of cool storage. Many of these programs have begun only in the last year. At least a dozen utilities use cool storage in their own facilities. Of the 25 utilities currently offering rebates, seven of the programs started in 1987; the earliest programs began in 1981. The average payment for shifted demand is about $225/kW, with a range from $60/kW to $500/kW. Of the 23 utilities that do not offer rebates, the most common activity has been sponsoring demonstration projects. The scope of utility programs varies tremendously, ranging from sponsorship of a single demonstration site to aggressive marketing of well staffed programs. Based on design estimates from thirteen utilities, cool-storage systems shift an average of about 400 kW per site. Texas Utilities Electric Company and Southern California Edison have achieved the greatest load shift from cool storage: both estimate that over 30 MW of load shift from cool storage have been installed. Both utilities have aggressively marketed their cool storage programs.

The cost-effectiveness of cool storage to a building owner is highly dependent on the electricity rate schedule. Electricity rates may or may not be considered a program characteristic, but they are an important mechanism to encourage implementation of cool storage. The most innovative utilities separate electricity rates for the cool-storage system and the rest of the building, with the building and the cool-storage system individually metered. This arrangement provides separate energy performance data for the building and the cool-storage system, which could be extremely useful for performance analysis. At least one utility (Texas Utilities Electric Company) will consider adjusting electricity charges when operating errors occur. This practice lessens the customers financial risk associated with operating a cool-storage system.

Some utilities require specific calculation methods to be used in comparisons between cool storage and conventional technologies, while other utilities have not standardized analytical techniques. Further exploration into these methods is needed to help make comparisons of both estimated and actual performance results more valid among different buildings and among utilities. Results from studies of the cost-effectiveness of cool storage systems in actual buildings are mixed. Some have performed well, with short simple payback periods, while others have had severe problems. Further information is needed on the first-costs and operating costs of actual systems. Few systems have been in operation for more than five years; long-term performance data are needed to assess reliability.

PROGRAM EXPERIENCE REPORT: COMMERCIAl COOL STORAGE

M.A. Piette and J.P. Harris
Applied Science Division
Lawrence Berkeley Laboratory

INTRODUCTION

Commercial cool storage is a load-management technology that can be mutually beneficial to electric utilities and their customers. The technology involves shifting part or all of a building cooling system's compressor operation to off-peak hours when energy costs and demand charges are lower than during on-peak hours. There are currently about 1000 systems in the United States, located primarily in areas where utilities offer time-of-use (TOU) rates or significant peak-demand charges.

This paper reviews, compares, and documents actual experience with utility and non-utility programs designed to encourage the use of commercial cool storage technologies*. Such information will help guide future demand-side programs, and help utility planners anticipate program-related penetration rates (and other impacts) of demand-side resources. This work is a companion document to a larger report that discusses the technology itself (Piette et al., 1988a). This report is part of a series of program experience reports by the Lawrence Berkeley Laboratory (LBL) designed to synthesize current information on demand-side resources from both published and unpublished sources (Krause et al., 1988; Vine and Harris, 1988).

Utility demand-side program assessments can be described by their relation to two axes. One axis represents the depth of a study into an individual program, with the aim of understanding how a program's successes relate to specific features. The other axis represents the breadth of program descriptions in terms of comprehensively capturing the general scope of activities of numerous programs. Such information is drawn from surveys and often take the form of data bases (Sabo et al., 1988). This report includes elements of both modes or analysis. Past utility survey results were used to identify primary characteristics of cool-storage programs. In-depth information was collected for the larger-scale and long-lived programs.

An inherent difficulty with utility planning is that rate analysis and demand-side program planning are traditionally performed independent of each other. This report provides insights into specific issues encountered in load management programs as opposed to conservation programs. Load management programs, such as cool-storage programs, present problems associated with the overlap between rate design and program design.

The first half of this paper includes an introduction to the framework for program comparisons and a discussion of the data sources. We also describe the basic characteristics of cool-storage programs. The second half of the paper begins with a summary of significant activities in cool-storage programs. We discuss the results and various lessons learned from current programs, including data on the current capacity of shifted demand from cool storage for thirteen utilities. This is followed by a short section describing some of the difficulties with

*Some of the information below is not restricted to the commercial sector since many utility cool storage programs target industrial customers in addition to commercial customers.

current engineering methods to estimate load shift potentials, and some suggestions for improvement. We conclude with a summary of our findings and their implications.

OVERVIEW OF PROGRAM STRATEGIES

Methodology

Conceptual Framework. There are four types of barriers to energy-saving and load-management technologies: lack of information, substantial first-cost, technological development, and perceived risk (Vine and Harris, 1988). A well-rounded program should contain elements to address each of these barriers. Below we draw upon actual experiences from numerous utility programs. We discuss both those that have been aggressive in encouraging cool storage and a few that have recently been developed.

Data Sources. Information for this study came from numerous sources. We identified utilities with cool-storage programs from past demand-side activity surveys sponsored by the Electric Power Research Institute's (EPRI) (Sloane, 1985; George, 1986; Blevins, 1988). Newsletters from the International Thermal Storage Advisory Council provided information on the rebates currently offered by 25 utilities (ITSAC, Jan. 1988). We directly contacted many utility program managers to discuss their programs. Some of the material for this paper, being an extension of a larger project, includes information discussed in the technology report (Piette et al., 1988a). While drawing in some areas upon EPRI's "Cool Storage Marketing Guidebook", our primary focus is on issues not covered in the guidebook (McDonald and Davis, 1988).

Implementation Strategies and Program Characteristics

There are numerous mechanisms for encouraging the implementation of cool storage. We first discuss mechanisms most commonly used by utilities and offer examples in the sections that follow.

Rate Design. Electricity rates may or may not be considered a program characteristic, but they are an important mechanism to encourage implementation of cool storage. Rates that differentiate demand or energy charges by time-of-day encourage load shifting measures. The on-peak and off-peak price differential and the length of the on-peak period are important characteristics of the rates. Seasonal price changes also affect cost-effectiveness. High peak-demand charges encourage peak-shaving load management, which can include cool storage strategies. Some utilities are experimenting with special rates for customers with cool storage (Southern California Edison's (SCE) "Super-Off-Peak" rates are described below).

Demand ratchets exist in many commercial electricity rate schedules. Ratchets can be "unforgiving"--a single operating error during one hour may cause electricity bills to be higher for many months. As with other new technologies, there are inherent risks in the use of cool storage. Because of these risks, some utilities acknowledge the "shakedown" period associated with cool storage while building operators familiarize themselves with the equipment. Demand ratchets may be especially inappropriate with respect to cool-storage buildings (where demand rates do not vary by time-of-day) since in many cases errors with the operation of a cool-storage system that may induce a building peak demand may not be coincident with a utility's system peak. Utilities can reduce the risks associated with cool storage by offering a "forgiveness" clause to adjust electricity charges for one-time operating errors.

The issue of rate stability is also important. To quote McDonald and Davis, "If the utility cannot assure its customers that the TES (thermal energy storage) rate will be maintained for five to ten years, it has no business asking its customers to make these long-term investments".

Financial Assistance. Financial assistance helps alleviate the barrier of the increased first-cost of cool-storage systems over conventional cooling systems (see Table 1). The most common form of financial assistance for cool storage is the direct rebate. About 25 utilities currently offer direct rebates (also known as inducements or direct cash incentives) for cool storage (ITSAC, 1988). In almost every case, the first step in determining the rebate value is to estimate how much load (in kW) will be shifted by the cool-storage system. The sophistication and assumptions behind the calculation of the shifted kW differ among the utilities. Another form of financial assistance to lessen first-cost barriers is low-interest loans, which are currently offered by at least one utility (Wisconsin Electric, see Table 1). Financial assistance may also be provided to cover cool storage feasibility studies. There are currently six utilities that offer such funds. What have not been tried are utility backed performance guarantees--almost certainly a cheaper, higher-leverage strategy. Under such as agreement a utility may occasionally need to offer financial compensation to a building owner, but not every time.

Design Assistance. Design assistance typically starts with a field representative identifying a potential cool storage application. The utility may assist in the initial assessment of the potential cost-effectiveness of cool storage. These assessments vary from simple calculations to in-depth simulation studies. As mentioned, some utilities offer direct financial assistance to cover part or all of the cost of a detailed feasibility study (Table 1). Many utilities assist customers in finding proper engineering assistance.

Information Dissemination. EPRI's Cool Storage Marketing Guide contains numerous suggestions about how to provide appropriate information to decision makers in order to overcome hurdles to the use of cool storage technologies. Utilities must market their program, which can be accomplished through use of mailings or direct contact by field representatives. Newsletters about utility activities are a common mechanism to advertise a program. Some utilities sponsor design competitions and awards programs to generate case-study information.

The utility must educate potential participants about the technical characteristics of cool storage. Tutorial seminars are common mechanisms for providing technical information. Trade-ally marketing links the utility with design professionals such as architects and engineers. There are numerous sources of information about designing cool storage (see Piette et al., 1988a for an annotated bibliography on cool storage information). Much less information is available about the measured performance of actual installations.

Although the primary force behind the marketing of cool storage technologies comes directly from utilities, many other organizations promote cool storage. The International Thermal Storage Advisory Council (ITSAC) publishes a monthly bulletin (categorized as Advisory and Technical Bulletin newsletters) providing interested parties with the most current trends in the cool storage industry (ITSAC, 1986-1988). Demonstration projects sponsored by EPRI, along with various utility companies, offer customers concrete information on products and the performance of actual systems (Ayres, 1985; Piette and Wyatt, 1988b). The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has also been involved in publishing information on cool storage (ASHRAE TC 9.6, 1987). EPRI's recent marketing guidebook contains a list of 16 associations, societies, and institutes who provide information on cool storage (McDonald and Davis, 1988).

Research and Development. Many utilities have taken an active role in researching the performance of cool-storage systems and in aiding in the development of new products. Utility research often takes the form of demonstration projects with detailed submetering of working installations. For example, five utilities are testing new, packaged-rooftop ice-storage units designed for small commercial or residential customers. This is a new, large, relatively untapped market for cool storage. Results from many of these projects are being compiled for dissemination by EPRI. About a dozen utilities use cool storage in their own facilities. Research and development and information dissemination are closely linked. Continual effort must be made to inform interested parties of research findings.

The U.S. Department of Energy has also funded numerous projects regarding the use of cool storage, ranging from equipment testing to technical and program assessment studies (Comnes et al., 1988; Kammerud, 1987; Piette et al., 1988) Again we reference ASHRAE's Technical Committee 6.9, which sponsors research projects and conference sessions, and oversees publication of cool storage documents (ASHRAE TC 6.9, 1987).

In addition to utilities encouraging the use of cool storage, there are many other organizations and modes to promote cool storage, as described in the following three sections.

Tax credits. At least one state provides owners with tax credits for installing and using cool storage. During 1986, Hawaii passed a bill that provides a 15 percent state income tax credit for the cost of cool-storage systems. The tax credit applies to systems installed and in service after December 31, 1985 and before December 31, 1992 (ITSAC, Aug. 1986).

Energy Service Companies. Cool storage is an area being explored by energy-service or shared-savings companies (ITSAC, July 1987). There is little (if any) experience to date with cool storage under shared-savings contracts. The cool storage market appears viable for energy-service companies because, being a new technology for many HVAC engineers, it presents energy-service companies with the opportunity to become "experts" at designing, installing, and operating cool-storage systems. At least one cool storage manufacturer offers to lease, operate, and maintain its own systems (Teji, 1986).

Regulatory Codes. Most building standards in the United States address energy conservation more than peak demand savings or electric load shaping, but there may be greater emphasis on shifting and shaving peak demands in the future. For example, the California Energy Commission is considering the adoption of a commercial load management standard to address load growth in the commercial sector (Smith, 1987a). In general cool storage often fares well when standards allow for cost-based comparisons, i.e. when compliance can be achieved by comparing the operating cost (under the applicable rate schedule) of a proposed design versus a base-case building. Such is the case with the proposed Standard 90.1P (ANSI/ASHRAE/IES, 1987).

Under these circumstances design engineers must have the proper tools and information to analyze today's complex electricity rate schedules in conjunction with hourly building load profile data.

PROGRAM EXPERIENCE

Summary of Current Utility Activities

Commercial cool-storage systems have been installed in about 50 different utility service territories (Sloane, 1985; George, 1986; Blevins, 1988). Many utilities are just beginning their programs. Of the 25 utilities currently offering rebates (Table 1), seven of the programs started in 1987. The earliest programs began in 1981 (Table 2). Of the 23 utilities that do not offer rebates, the most common activity has been sponsoring demonstration projects. The scope of these programs varies tremendously, ranging from sponsorship of a single demonstration site to aggressive marketing of well-staffed programs.

In order to properly plan a program, a utility must first assess the market potential. For example, Florida Power and Light assessed the market for cool storage in their service area by surveying existing cool storage users and conducting focus groups with decision makers (Zeidler, 1986). The utility derived estimates of peak load that could be deferred in the year 2001 for 17 categories of new and existing commercial buildings. These estimates were based on the following utility program options: 1) doing nothing, 2) providing information, 3) guaranteeing performance, 3) providing low-interest loans, 4) guaranteeing paybacks, and 5) providing rebates.

In order to better understand decision makers, Potomac Electric Power Company (PEPCO) surveyed 373 developers and designers (PEPCO, 1985). They found that the most important criteria for selection of air-conditioning systems are first-costs, reliability, and space constraints. Space constraints and first-costs were viewed as the most significant disadvantages to cool storage. In response to a question about how PEPCO should promote cool storage, 82% and 73% requested information on programs and rate incentives, respectively. Technical training was recommended by 47% of the respondents and cash incentives were favored by 43%. In response to these results, PEPCO built cool-storage systems in two of their service centers. They do not offer cash incentives, but TOU rates are available to large customers.

Results from focus group and surveys of decision makers in New England differed from PEPCO's survey results. The top four factors motivating choices of space-conditioning equipment were (in order of importance): reliability, efficiency, safety, and lifetime (McDonald and Davis, 1988). First-costs were found to be less important.

The cost-effectiveness of cool-storage systems is often driven by the magnitude of demand charges. Commonwealth Edison Company in Chicago achieved significant penetration of cool storage without the use of rebates. Summer (June 15 through September 15) demand charges of \$13.34 per kW, and winter demand charges of \$10.43 per kW are applicable to most commercial customers. For large customers, over 500 kW, these demand charges are applied during the on-peak period, which lasts from 9:00 AM to 10:00 PM; energy charges are also TOU differentiated. For smaller customers the winter and summer demand charges hold, with an option on the TOU demand charge provision and no TOU energy charges. This is a long on-peak period; short on-peak periods are more conducive to cool storage economics. These rates became effective in October 1985.

Additional characteristics of Commonwealth Edison's cool storage program include substantial design assistance and information dissemination. The utility has sponsored numerous informational seminars aimed at engineers, architects, plant managers, and developers. The program staff feel that their success with cool storage has greatly benefited from a few dynamic figures in their region, especially the design engineers who have established a solid foundation for this technology in the Chicago area (Boumann, 1988).

By contrast, Jersey Central Power and Light Company (JCP&L) has utilized TOU rates and demand charges for many years, like Commonwealth Edison. Yet, unlike Commonwealth Edison, their rates had not proven sufficient to encourage the adoption of cool-storage systems (McDonald and Davis, 1988), probably due to less aggressive program marketing, fewer utility case studies, and the lack of the dynamic individuals that the Chicago area benefited from. To further encourage the use of cool storage their program now includes rebates, direct contact marketing through JCP&L representatives, advertising, a guidebook for designers, feasibility assessments, and subscriptions to ITSAC for its customers.

An example of an electricity rate specifically designed for cool storage is SCE's TOU-SOP (super off-peak) rates (Table 3). They include low off-peak electricity rates but high on-peak energy and demand charge. Individual meters are installed on the cool storage equipment (Smith, 1987b): therefore, the TOU-SOP rate applies to the load shifting equipment alone. The rest of the building is on a different rate schedule. The TOU-SOP rate has a short on-peak period, which allows the use of small cool-storage systems. Currently the TOU-SOP rate has a \$33.00/kW on-peak summer demand charge. This is one of the highest demand charges in the United States. Table 3 summarizes the TOU-SOP, and for comparison, shows a conventional TOU rate offered by SCE.

An important benefit of the TOU-SOP rate is that load profile data for the cool-storage system are available from the additional TOU meter. Many of the buildings using the TOU-SOP rates also use Energy Management Systems for building and systems control. Data from the EMS can, in theory, be used in conjunction with the cool storage meter to create detailed performance data that could provide valuable feedback on the installed technical and economic performance of the installed system (Campoy, 1987, Heinemeier and Akbari, 1987).

SCE is currently analyzing the cost-effectiveness of cool storage with the SOP rates compared to their conventional rates. During early 1988, electricity rates underwent changes that reflect SCE's efforts to retain customers. This caused a change in base case electricity costs, which reduced the cost-effectiveness of cool storage relative to the previous base case "conventional" rates. Although SCE's marketing of their "Off-Peak Cooling Program" is now a lower priority than in the recent past, they are continuing numerous research projects, including the development of an in-house computerized data base of all customer installations, and monitoring projects that span a variety of system types.

The 25 utilities that currently offer rebates for cool storage are listed in Table 1. Of the 14 utilities that offer a fixed rebate per kW shifted, the average is \$225/kW. The remaining 11 utilities calculate rebates based on various project characteristics such as the amount of kW shifted or the estimated payback period. Rebates may differ for new versus existing buildings. Maximum payments ranging from \$50,000 to \$300,000 dollars have been set by nine of the utilities, while no maximum levels have been set by the others.

One important distinction among utility cool storage programs is the method by which they calculate the load shift achieved by a cool-storage system. Some utilities require that feasibility studies follow standardized guidelines in specifying conditions for the base case to which cool-storage systems are compared. Pacific Gas and Electric Company (PG&E), for example, requires a computer simulation model that includes a 24-hour chiller load profile using an hourly simulation model with specified hourly weather data (PG&E, 1985). For new buildings, an average chiller efficiency of 0.7 kW/ton must be used. For existing buildings, the chiller efficiency is based on the type of chiller currently in the building. Motor efficiencies are also specified. The City of Palo Alto has a similar approach, prescribing specific guidelines for calculations, yet differing from those of PG&E, whose service territory surrounds Palo Alto's. For example, calculations for new buildings call for conventional chiller efficiencies from 0.7 kW/ton to 1.10 kW/ton, depending upon the size of the chiller. The rebate calculations used by SCE allow the design engineer more flexibility in defining the base case. Feasibility studies submitted to SCE are scrutinized by utility engineers and may be returned to design engineers for modifications if needed.

Texas Utilities Electric Company (TU-Electric), which includes Dallas Power and Light, Texas Electric Service Company, and Texas Power and Light Company, has a different approach. They run an in-house simulation analysis for each building. TU-Electric has produced more information about their experiences with cool storage than any other U.S. utility (Knipp, 1986; Mahoney, 1986; Poplett 1985). In addition to dissemination of information on the characteristics of the installed cool-storage systems, they have given strong consideration to the investment decision-making processes. The Knipp paper describes the utility's approach to marketing cool storage, which includes communication of thermal storage concepts to three major decision makers: 1) the developer/owner, 2) the engineer, and 3) the architect.

Program Evaluation

Few current cool-storage programs have been evaluated and many are too new to show definitive results. In this section we discuss the market penetration data reported from utilities, focusing on the three utilities with the largest reported megawatt (MW) shifts from cool storage.

The extent to which data are available on implementation of cool storage varies greatly among utilities. Table 2 shows a summary of estimated MW shift (as of early 1988) for thirteen utilities. The total installed MW shifts range from 30 MW for TU-Electric and SCE, the two most active utilities, to 0.3 MW for the City of Palo Alto, a small municipal utility whose program has just begun. To add some perspective on the size of this resource in relation to what has been achieved we reference an EPRI estimate on the potential for cool storage. Using the COMMEND model, Lann estimated that by the year 2000 cool storage can reduce the national commercial sector summer peak by 17 GW, or 10 percent (Lann, 1986).

Table 2 also shows an estimate of the number of buildings with cool storage for each of the 13 utilities. Commercial systems typically shift anywhere from about 25 kW to 3500 kW. The averages for each utility range from 67 kW/site (Northern States Power) to 857 kW/site (TU-Electric), with an overall average of 356 kW/site*. Across 13 utilities the average demand shift is 419 kW/site. Consistent with TU-Electric's high average kW load shift per site is the fact that

*We use the term "site" as opposed to "building" because some of the systems are industrial cooling applications, not commercial buildings.

they have a higher percentage of chilled water storage systems, versus ice storage systems, than most utilities. Chilled water systems tend to be the choice for larger systems.

Commonwealth Edison in Chicago has the third highest average kW load shift per site. As mentioned, their program is unique in that they have achieved significant penetration of cool storage (15 MW) without the use of rebates. Only two other utilities in Table 3, Carolina Power and Light and PEPCO, do not offer rebates. In considering the average kW/site for a utility one must look closely at the range of installations in a utility service territory. Included in Commonwealth Edison's 15 MW of installed system capacity is the world's largest ice storage system--Merchandise Mart. This 3.5 MW system represents 23% of the installed thermal storage capacity in this utility service area. In fact, the criteria that motivated the installation of the ice storage system were somewhat unusual for a retrofit. Mart's management was faced with growing cooling loads that, with the use of a conventional chiller, would have required an expensive renovation of the HVAC distribution system such as larger chilled water piping and modified ducting. The alternative was an ice storage system that supplied lower-temperature water, allowing the existing distribution system to deliver the necessary cooling (Brady, 1986).

Like many of the utilities in California (especially PG&E and SCE), Commonwealth Edison is not currently marketing their cool-storage program as aggressively as in the recent past, because of a current surplus of electricity. However, the program is well in place and design assistance continues to be available to interested customers. The program will likely be of value in the future as electricity demand continues to grow.

TU-Electric has perhaps the most extensive information on the approximately 30 MW of cool storage capacity installed in their territory. During 1984, cool storage was installed in 38% of the new office buildings greater than 50,000 ft^2 in Dallas Texas: this was up from 21% in 1982 and 30% in 1983 (Knipp, 1986). These percentages are clearly significant, but should be interpreted with caution since they represent only about a dozen large buildings. Construction rates have slowed in recent years, and cool storage is being installed in smaller buildings such as schools and churches. The program is presently active, with five to six full-time employees involved in marketing and design assistance. One of TU-Electric's many marketing tools is a package of one-page summaries for 38 installed and planned installations. Many of these summaries include an actual (measured) hourly whole-building load profile that provides an illustration of the demand reduction during the on-peak period.

TU-Electric's electricity rates include a ratcheted demand charge, which increases the financial risk of cool storage to the building owner because the ratchet is based on the highest summer peak demand. However, an important characteristic of the TU-Electric program is that the utility is willing to excuse certain operating errors, such as a one-time control set-point error. Their policy is to review each incident on a case-by-case basis, in terms of "forgiving" any demand ratchet that occurred during the on-peak hours of operation (McDonald and Davis, 1988).

Within the next year, SCE (one of the largest utilities in the U.S.) will most likely have more cool-storage systems within their service area than any other utility. The number of installations may climb to over 100, with an installed capacity totaling over 50 MW. TU-Electric's program, however, will probably remain the nation's most active in terms of staff effort, but new construction rates are slower in TU-Electric's service area. As described above, the cost-effectiveness of cool storage in SCE's territory has recently dropped because of a change in the standard TOU rates in comparison to the TOU-SOP rates. It is unclear how this change will affect the future penetration of cool-storage technologies in their service area.

HOW GOOD ARE PEAK-DEMAND SAVINGS ESTIMATES?

Since utility rebates and other cool-storage program services can amount to hundreds of thousands of dollars for a single large customer, there is a need for utilities to monitor their investments. The issue is three-fold: First, how are utility analysts calculating the initial rebate amount? Second, have other cost-effective load-shifting or load-reducing options been adequately considered? Third, is the system actually achieving the estimated demand shift?

To address the first issue, recall the above discussion describing the numerous assumptions that go into calculations of the amount of kW shifted. Since most utility rebates are based on the amount of kW shifted, there is an incentive for engineers to maximize the estimated demand shift. For utilities that base rebates on providing an acceptable payback time, there is an incentive by an engineer to maximize the estimated system cost in order to receive greater financial assistance. Standardization of performance and cost comparisons would clearly be of use to the utilities, and may also benefit building owners and operators, and design engineers. Standardization would allow a better understanding of both the assumptions used in performance projections and how to assess lower-cost solutions. Measured performance results comparing engineering predictions with actual system performance would also help in evaluating design methods. One possible method is to standardize cooling-load estimates by using the same calculation procedures required for state or local building performance standards, or ASHRAE Standard 90 guidelines.

This idea of using standardized cooling-load estimation methods could also address the second issue: the degree to which other cost-effective load-reducing technologies have been considered. Energy-efficient lighting systems and window treatments, for example, help reduce internally and externally generated cooling loads. Furthermore, utilities should offer rebates for peak reduction as well as peak shifting techniques. With the help of a data base of commercial building characteristics and cooling design data, a utility analyst could identify buildings whose cooling loads appear significantly higher than others with similar usage patterns. If a building's cooling load appeared significantly higher than others, based on some normalized value such as "peak tons/ft^2" or "average tons/ft^2", an analyst could explore methods for reducing the load. Given the final cooling-load estimate for a building, numerous system configurations could be evaluated to find the most cost-effective and reliable system.

Feasibility studies generally include a comparison of various options. High-efficiency chillers, direct and indirect evaporative cooling, or gas absorption chillers are alternatives to cool storage that should be considered by the customer and the utility. Many combined utilities, such as San Diego Gas and Electric Company, market gas cooling in addition to cool storage. Commercial gas cooling is a technology that appears to be gaining momentum. As of 1987, 28 gas utilities offered rebates for gas cooling, an increase of almost 50 percent over 1986 (Hopkins, 1988).

The utility has an interest in whether an installed cool storage system achieves the demand load shift that they paid for. The customer is interested in achieving financial savings from a system while maintaining comfort. However, few data on the actual performance of cool-storage systems are available. Results from the buildings that have been submetered are mixed (Piette and Wyatt, 1988b). Some have performed quite well, with short simple payback periods, others have had severe problems. Most customers with operational cool-storage systems do not have the information necessary to assess their electricity cost savings. For new buildings, submetering of cooling loads and system demand are required for performance assessment. At a minimum, hourly load data should be collected to analyze the load profile and the effect of the cool-storage system. With retrofits, however, electricity data can be compared to the "pre-retrofit" conditions to assess the impact of the cool-storage system. It is important to note that while in some cases a customer may not be achieving the level of dollar savings that was initially predicted, the utility may still be achieving the full demand shift they have estimated. This is because the utility is concerned with the utility system peak hour, while the customer is concerned with each hour of the year and the respective energy and demand charges for that hour.

SUMMARY AND CONCLUSIONS

Few studies have been conducted on cool-storage program experience. The cost-effectiveness of cool storage is primarily determined by the relationship between building loads and the electricity rate structure. In addition to informing potential cool storage users about technology options, utilities are providing financial incentives to encourage cool storage. Additional program features include design assistance and a variety of methods of information dissemination. Mechanisms for states to encourage cool storage include tax credits and building performance standards that acknowledge load management strategies or include cost-based (not energy-based) criteria for compliance with building energy codes.

Characteristics of Current Programs

- Over 50 utilities have reported some program activities regarding the use of cool storage. Many of these programs have begun only in the last year. At least a dozen utilities use cool storage in their own facilities.
- Of the 25 utilities currently offering rebates for cool storage, the average payment for shifted demand is about $225/kW. The range is from $60/kW to $500/kW.
- At least one utility (TU-Electric) considers adjusting electricity charges when operating errors occur. The utility thereby lessens the customer's financial risk associated with operating a cool-storage system.

Market Penetration Results from Current Programs

- TU-Electric and SCE have achieved the greatest load shift from cool storage. Both have estimated that over 30 MW of load shift from cool storage have been installed. Both utilities have aggressively marketed their cool storage programs.
- Based on design estimates from thirteen utilities, cool-storage systems shift an average of about 400 kW per site.

Implications for Program Design and Management

- The cost-effectiveness of cool storage is highly dependent on the electricity rate schedule. Ideally, utilities could design their rates to enhance cost-effectiveness.
- The most innovative rates offered today consist of separating the electricity rate schedule for the cool-storage system from the rate for the rest of the building. The building and the cool-storage system are individually metered. Furthermore, this arrangement provides separate energy performance data for the building and the cool-storage system, which could be extremely useful for performance analysis.
- Utilities should provide "one-time" adjustments to electricity charges for newly installed cool-storage systems to excuse first-year operating errors. Such a policy would lessen the perceived financial risks of cool storage.

- Results from analysis of decision-making criteria for choosing cooling equipment differ. The most important criteria appear to be: first-costs, reliability, size (in consideration of space constraints), efficiency, safety, and lifetime of equipment.

Areas of Uncertainty and Data Needs

- Some utilities require specific calculation methods to be used in comparisons between cool storage and conventional technologies, while other utilities have not standardized analytical techniques. Further exploration into these methods is needed to help make comparisons of both estimated and actual performance results more valid among different buildings and among utilities.
- Results from studies of the cost-effectiveness of cool storage systems in actual buildings are mixed. Some have performed well, others have had severe problems. Further information is needed on the first-costs and operating costs of actual systems. Few systems have been in operation for more than five years; long-term performance data are needed to assess reliability.

ACKNOWLEDGEMENTS

The work described in this paper was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. We thank Florentine Krause for his valuable assistance to this effort.

REFERENCES

ANSI/ASHRAE/IES, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings,* Third Public Review Draft, American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, Sept. 1987. Draft standard (90.1P) with three forms of compliance: prescriptive, system performance, and energy cost budget method. The latter method allows for the benefits of cool storage to be considered.

ASHRAE Technical Committee (TC) 6.9, Thermal Storage, *ASHRAE Handbook: HVAC Systems and Applications, Atlanta, GA,* Chapter 46, 1987.

Ayres, J.M. et al., "Performance of Commercial Cool Storage Systems, Volumes 1", EPRI Report EM-4044, prepared by Ayres Associates, Los Angeles, California, June 1985.

Blevins, R., forthcoming report on 1987 Demand Side Survey, EPRI research project 2884-1, 1988.

Boumann, E., Personal Communication, Commonwealth Edison Company, May 1988.

Brady, T. "Thermal Storage for the Merchandise Mart", *ASHRAE Journal,* Vol. 28, No. 11, Nov. 1986.

Campoy, L., personal communication, Sept. 1987. Discussion with former manager of Southern California Edison's Off-Peak Cooling Program.

Comnes, G.A., Pignone C., Kahn, E., and Warren, M., "An Integrated Analysis of Commercial Thermal Energy Storage." *Transactions of Power Systems Engineering Committee of The*

Institute of Electrical and Electronics Engineers, IEEE/PES 1988 Winter Meeting, New York, NY, Jan. 31 - Feb. 5, 1988; 88 WM 156-2.

Eder, E., "The Power Package: A Marketing Strategy for Conservation and Load Management Rebates Programs", *Proceedings of the Third National Conference on Utility DSM Programs: Demand-Side Management Strategies in Transition,* EPRI report EM-5452, Oct. 1987.

Krause, F., Gandhi, S., Vine, E., and Harris, J., "Experience with Alternative Lighting Program Designs", forthcoming LBL Report, 1988. See Appendices section.

George, S. S., "Commercial Customer Acceptance of Demand-Side Management Programs, Volume 3: Overview of Program Survey Database", Xenergy Inc., EPRI Project 2548, Draft Final Report, Sept. 1986.

Hassan, E.A., "Southern California Edison Company Cost-Effectiveness Analysis for the Off-Peak Cooling Program", Energy Management Division, SCE, July 1986.

Heinemeier, K.E., Akbari, H., "Capabilities of In-Place Energy Management Systems for Remote Monitoring of Building Energy Performance--Case Studies", *ASHRAE Transactions 1987,* Vol. 93, Pt. 2, LBL Report No. 23249.

Hopkins, M.E., personal communication, Oct. 1988. Discussion with M.E. Hopkins, (Manager, Special Demand Studies, American Gas Association) about the competition between gas cooling and cool storage.

International Thermal Storage Advisory Council, San Diego, CA. July 1986-Jan. 1988. ITSAC technical bulletins and advisory newsletters cover wide range of subject matter including: utility rate structures, electric load curve impacts, descriptions of various systems, case studies, and new research projects. ITSAC, Suite 401, 525 Balboa Ave. San Diego, CA 92117.

Kammerud, R., "Demand Limiting and Thermal Energy Storage in Buildings". Project underway (1987) to study thermal storage sizing, Applied Science Division, Center for Building Sciences, LBL. Sponsored by EPRI and the U.S. Department of Energy.

Knipp, R., "Marketing Thermal Storage", *Proceedings: International Load Management Conference,* Prepared by Synergic Resources Corporation, EPRI Report EM-4643, June 1986.

Lann et al., *The COMMEND Planning System: National and Regional Data and Analysis,* EPRI Report EM-4486, prepared by Georgia Institute of Technology, April 1986.

McDonald, C., and Davis, T., "Cool Storage Marketing Guidebook", prepared for EPRI, EM-5841, Research Project 2050-11, June 1988.

Mahoney, T.A., et al., "'Moving' on up' in Dallas", *Engineered Systems,* Jan./Feb. 1986.

Pacific Gas & Electric Co. (PG&E), *Thermal Energy Storage for Cooling,* May 1985. Commercial cool storage design guide for PG&E customers.

Pacific Gas & Electric Co. (PG&E), "1987 Incentives for Non-residential Customers", 1987, Program guidelines describing programs and procedures.

Piette, M.A., Wyatt, E., and Harris, J., "Technology Assessment: Thermal Cool Storage in Commercial Buildings", LBL Report No. 24852 (a).

Piette, M.A and Wyatt, E., "Measured Energy Performance of Commercial Buildings: An Update of BECA-LM", *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings* Vol. 3, Aug. 1988, LBL Report No. 25599.

Poplett, J., "Incentive Electricity Rates Spur Thermal Storage", *Energy User News,* June 10, 1985.

Potomac Electric Power Company, "PEPCO Polls Area Developers and Designers: Thermal Energy Storage", *Information Exchange,* Nov./Dec. 1985, Vol. 6, Issue 6.

Sabo, C.A., Norland, D., Gallagher, J.T., and Clinton, J.M., "Designing and Using a DSM Database in Utility Least-Cost, Integrated Planning", *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings,* Workshop Report, Conference Program and Abstracts Volume, Aug. 1988.

Sloane, B.D., "Survey of Commercial Sector Demand-Side Management Activities", Synergic Resources Corporation, EPRI Research Project 1940-12, EM-4142, July 1985. Survey of utilities conducted in 1984; 33 reported some activity regarding the use of commercial cool storage.

Smith, K., personal communication, Oct. 1987 (a). Discussion with K. Smith, Senior Economist, California Energy Commission, regarding the possibility of a load-management standard in California's future.

Smith, K., "The Influence of Utility Rates on Thermal Energy Storage", California Energy Commission, June 1987 (b).

Teji, D. S., *Thermal Storage Strategies for Energy Cost Reduction,* Urban Consortium Energy Task Force for the City of Phoenix, Public Works Department, Phoenix, Arizona, Jan. 1986.

Vine, E. and Harris, J., "The Experience of Energy Conservation Programs for New Commercial Buildings", *Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings* Vol. 5, Aug. 1988.

West, D., personal communication, Arizona Public Service Company, June 21, 1988.

Yokoe, J., personal communication, Pacific Gas and Electric Company, Feb. 1988.

Zeidler, P., "Estimating the Market Penetration of Cool Storage at Florida Power and Light", *Proceedings: International Load Management Conference,* Prepared by Synergic Resources Corporation, EPRI Report EM-4643, June 1986.

Table 1

Utility Incentives for Commercial Cool Storage Installations

Utility [1]	Inducement per kW Shifted	Maximum	Feasibility Study
Anaheim Public Utilities	$60	$50,000	$5000
Arizona Public Service [2]	$115-250	No Max	
Boston Edison	$200	No Max	
City of Austin Power & Light [3]	up to $300	No Max	
City of Denton Util. Dept. [2]	$200-350	No Max	
City of Palo Alto [4]	$350-425	$250,000	
Consolidated Edison Co.	$500	50%	
El Paso Electric Co. [5]	$200	No Max	
Florida Power & Light	$200		
Jersey Central Power & Light Co. [2]	$125-250	$200,000	
Long Island Lighting Co.	$300	$50,000	
Los Angeles Dept. of W.&P.	$250	40% or $150,000	
New England Elec.	$160	No Max	
Northern States Power	$175	No Max	
Oklahoma Gas & Elec. Co.	$200	$50,000	$500-1500
Pennsylvania Elec. Co.	$250	No Max	
Pacific Gas & Elec. Co.	$200	$150,000	
Public Service Elec. and Gas of NJ [2]	$125-250	No Max	
Riverside Public Utilities	$200	No Max	$5000
Sacramento Muni. Util. Dist.	$250	No Max	Limited No.
Salt River Project [2]	$115-250	$98,000	
San Diego Gas & Elec. [5]	$200-350	No Max	
Southern California Edison	$200	$300,000	up to $5,000
Texas Utilities Elec. Co. [2]	$125-350	No Max	
Wisconsin Elec. Power Co. [7]	$200	No Max	up to $5000

Source: ITSAC, Jan. 1988

Notes:

1. Numerous additional U.S. utilities have inducement plans under development or commission review.
2. Rebates based on number of kW shifted.
3. Rebates based on providing a 3 year payback.
4. Rebates based on whether new or retrofit project.
5. Rebates based on a negotiated payback.
6. Rebates based on number of kW shifted, whether new or retrofit project, and whether on flat or TOU rates. New construction rebates are based on installed tonnage.
7. Straight rebate offered, or five-year no-interest loan up to $750/kW.

Table 2

Estimates of Commercial Cool Storage Penetration in Thirteen Utility Areas

Utility	Estimated Total MW Shift		No. of Sites	Average kW/	Prgm Start	Source
	Installed	Committed	Installed	Site	Year	
Arizona Public Service Co.	2.3	6.8	28*	325	1985	West, 1988
Boston Edison	0.9		3	300	1987	Eder, 1987
Carolina Power & Light	0.8		2	400	1981	Blevins, 1988
Commonwealth Edison	15		25	600	1981	Blevins, 1988
City of Palo Alto	0.3		1	300	1987	Krause et al., 1988
Los Angeles Dept. of W.&P.	1.2		8	150	1987	Blevins, 1988
Northern States Power	0.4		6	67	1985	Blevins, 1988
Pacific Gas & Elec. Co.	8		36	222	1984	Yokoe, 1988
Potomac Elec. Power Co.	0.6	0.8	2**	300	1981	Blevins, 1988
Salt River Project	0.9		9	100	1985	Blevins, 1988
San Diego Gas & Elec.	4.8	11.6	47*	349	1981	McDonald and Davis, 1988
Southern California Edison	30	28	88*	659	1982	McDonald and Davis, 1988
Texas Utilities Elec. Co.	30	8.6	35**	857	1982	McDonald and Davis, 1988
Total	95.2	55.8	290			
Average (by total MW):				419		
Average (of 13 averages):				356		

* Number of buildings includes both installed and committed sites.

** Number of buildings includes installed sites only.

All values in the table are estimates based on feasibility studies.

Table 3

Comparison of Demand and Energy Charges for Conventional Time-of-Use and Super-Off-Peak Electricity Rate Schedules

	TOU-8		TOU-SOP	
	Summer	Winter	Summer	Winter
Demand Charge ($/kW/Month)				
On-Peak	13.25	N/A	33.00	N/A
Mid-Peak	2.05	0.00	0.90	0.45
Off-Peak	0.00	0.00	0.00	0.00
Non-TOU	2.70	2.70	2.70	2.70
Energy Charge ($/kWh)				
On-Peak	0.107	N/A	0.129	N/A
Mid-Peak	0.077	0.083	0.129	0.066
Off-Peak	0.050	0.050	0.046	0.050
SOP	N/A	N/A	0.037	0.037
Time of Use Periods				
Summer	July 1 - Sept. 30		July 1 - Sept. 30	
On-Peak Hours On-Peak Days	1 - 6 P.M. Monday - Friday		1 - 5 P.M. Monday - Friday	
Mid-Peak Hours Mid-Peak Days	8 A.M. - 1 P.M./6 - 10 P.M. Monday - Friday		10 A.M. - 1 P.M./5 - 9 P.M. Monday - Friday	
Off-Peak Hours Off-Peak Days Off-Peak Hours Off-Peak Days	All Other Hours Sunday - Saturday		6 - 10 A.M./9 - 12 P.M. Monday - Friday 6 A.M. - 12 P.M. Sunday - Saturday	
Super-Off-Peak Hours Super-Off-Peak Days			12 P.M. - 6 A.M. Sunday - Saturday	

Source: Smith, 1987b.

Notes:

Southern California Edison TOU-SOP effective January 1, 1988. Customer charges are $250/Month for both rates. TOU-8 is a standard SCE TOU rate.

N/A - Not Applicable.