OPERATING EXPERIENCE AND ECONOMIC ASSESSMENT OF COMMERCIAL AND INDUSTRIAL COOL STORAGE SYSTEMS - TVA CASE STUDY

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ABSTRACT

Thermal storage systems offer utilities a means to change the energy use patterns of both residential and commercial and industrial (C&I) customers by moving water-heating and space-conditioning loads from peak to offpeak periods. Benefits from investments in these systems include reduced capital investment in new generating capacity, reduced operating costs, and reduced risk associated with load growth projections and future environmental legislation.

This paper presents the results of a study undertaken to evaluate the performance of and quantify the potential economic benefits of C&I cool storage systems. The paper is organized into three major sections. Section one discusses the empirical data gathered from TVA's C&I Cool Storage Demonstration conducted during the summer of 1984. Section two discusses TVA's methodology for quantifying the potential economic benefits of these systems. Finally, the results are summarized with regard to future program activities.

INTRODUCTION

The situation facing the TVA power system at present is one common to many of our neighboring

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it is not needed until 2004 under the medium load forecast. Based on these projections and construction schedules, TVA will not, at present, need to make a decision on new capacity additions until 1988. Between now and 1988, TVA has a "window of opportunity" in which to refine, polish, and prepare its conservation and energy management programs to compete with the supply-side options. Within this "window of opportunity," TVA is planning to fully implement a demand-side management program, to refine its information-gathering techniques, to continue expanding and improving its arsenal of analytical and forecasting tools, to demonstrate new and promising technologies, and to form a portfolio of conservation and energy management programs that are ready to be phased in as power system needs dictate. TVA considers its conservation and energy management activities to be the most flexible option available to deal with the myriad of uncertainties that face the utility today. In that context, TVA is moving decisively in these program areas.

1984 C&I COOL STORAGE DEMONSTRATION PROJECT

One program area that holds particular promise is load management storage technologies. TVA initiated a field demonstration in 1982 to test the performance of cool storage systems. The cool storage systems included in the demonstration were designed to reduce peak electrical loads during the cooling season by storing cooling capacity during offpeak periods. Each system included a Thermaster thermal storage unit which stored cooling capacity by building ice on coils immersed in a water tank. The coils functioned as the evaporator for a conventional refrigeration system using R-22 and an air-cooled condenser. Chilled water was circulated around the ice to a duct coil to supply cooling to the conditioned space. The refrigeration system was controlled by a time-of-day electric meter and was allowed to operate only during offpeak periods. An ice-thickness control shut off the refrigeration system when the ice buildup reached a predetermined thickness, normally 2-1/2 inches. Chilled water delivery to the load and associated pump operation were allowed at any time as determined by the space thermostat. No auxiliary cooling was available during normal operation, so space temperatures increased if the cool storage system could not meet the cooling load.

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Tennessee, and Merita Thrift Store and West End Furniture Store in Knoxville, Tennessee. System design parameters are shown in Table 1.

TABLE 1

COOL STORAGE SYSTEM DESIGN PARAMETERS

Site	Rated Cool Storage Capacity (ton/hr)	Estimated Design Cooling Load (ton)	Compressor Size (hp)
Madison County Health Center	360	45*	60
Merita Thrift Store	48	7**	7.5
West End Furniture	48	9**	7.5

*Estimated from design data
**Estimated from monitoring data

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Each cool storage system was monitored by an 8-channel, solid-state data logger. Instrument readings were stored at 15-minute intervals by the data logger and transmitted daily to a central computer by telephone. Six measurement points were monitored for each of the three cool storage systems:

Building electrical load (kWh)
Compressor electrical load (kWh)
Ambient dry-bulb temperature (^{O}F)
Chilled water supply temperature (^{O}F)
Chilled water return temperature (^{O}F)
Chilled water supply flow (gal)

The monitoring systems performed well, with all raw data collected at all three sites except for 4 days in early May at West End Furniture Store.

The three cool storage systems operated as expected for most of the monitoring period. Each system showed onpeak compressor operation for several scattered days during the 3-month period. The few days of onpeak operation for each system did not appear to significantly affect overall results and were probably due to maintenance activities.

Test results indicated a seasonal COP of approximately 1.7 for the Madison County and Merita systems and approximately 1.0 for the West End system. The relatively low efficiency at West End resulted in a significant energy penalty.

Two factors are known to contribute to lower energy efficiency of cool storage systems as compared with conventional ones--heat gain to storage and reduced efficiency of the refrigeration equipment from lower refrigerant temperatures required to make ice. Direct measurement of these parameters was beyond the scope of this monitoring project. However, manufacturer's data for the compressor and condensing unit installed at Madison County showed approximately a 35-percent reduction in efficiency as suction temperature was reduced from 35 F to 10 F for typical condensing temperatures. The evaporating temperature must be substantially lower than 32 F for ice building systems since heat must be transferred to the refrigerant through a cylinder of ice with relatively low thermal conductivity.

Figures 1-3 show the electrical loads for the three systems for July 20-21. Also shown for reference in the figures is the TVA system load in GW (1,000 MW) for the 2 days. July 20 was a Friday and compressor operation was interrupted during the onpeak period. The Madison County system appears to have been controlled on Saturday, July 21, which is an offpeak day, but apparently the system reached a fully charged state and automatically cut off.

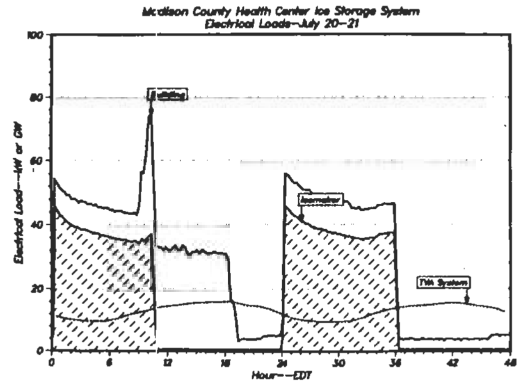

Fig. 1

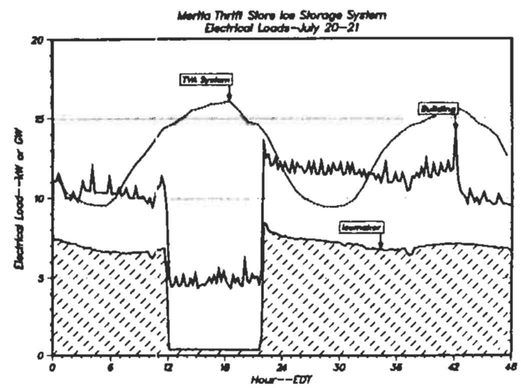

Fig. 2

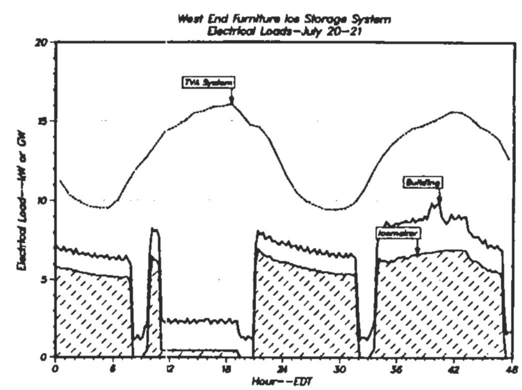

Fig. 3

ECONOMICS OF THERMAL STORAGE SYSTEMS

TVA justifies expenditures of power funds for programs that do not directly produce electricity by using the power credit methodology. The power credit methodology attempts to quantify the value of these programs with respect to future system load growth, future system expansion plans, and projected finances and rates.

DETERMINING PROGRAM BENEFITS

Over the years, TVA has developed models to quantify the cost effectiveness of conservation and energy management programs. TVA's methodology for determining the cost effectiveness of its conservation and energy management programs relies on estimating the present and future benefits and costs to the power system, the consumer, and society as a whole (power system and consumer).

The conceptual reasons why conservation programs are beneficial to the power system are fairly straightforward. However, computing the actual saving over the life of a given conservation investment is complex. First, the cost of generating electricity varies with the time of day, day of the year, and year being considered. Therefore, providing an accurate estimate of the value of the energy saving involves an hour-by-hour detailed simulation of power system operation. These estimates are made using TVA's system reliability and production costing programs that encompass information on future plan capital costs, fuel costs, operation and maintenance costs, maintenance schedules, plant capacity factors, and other relevant performance parameters.

Benefits for a conservation activity are measured by the marginal or avoided costs of reducing system output. The measure of benefits to the power system for increasing or decreasing output is the difference between the long-term marginal cost as compared with the long-term average cost. Benefits to consumers are measured by the reduction in electric bills as determined by reduced long-term average costs.

Long-term marginal cost is defined and measured by changes in system cost for changes in system output. TVA's staff has developed the models and procedures to estimate both the long-term marginal and average costs. Figure 4 illustrates the linkage of models utilized in developing marginal and average cost estimates.

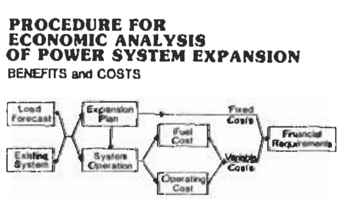

Fig. 4

In addition, precise estimates of future electric demand cannot be made with certainty. Compounding the difficulties involved in planning is the fact that past electric consumption trends are of questionable value for predicting future electricity usage. Regardless, TVA must plan to meet future system requirements for at least 20 years in advance, primarily because of the lengthy leadtimes (10 to 15 years) associated with completion of large generating facilities. Uncertainty concerning future demand and energy is factored into the planning process by evaluating generating requirements over a range of forecasts which are based on low, medium, and high load growth scenarios.

The true measure of the worth of cool storage systems is their benefit to society which is the sum of the benefits to the customer and the power system. The societal benefit provides an upper limit on the cost of these systems. Based on the analysis of the preliminary data collected from the 1984 demonstration, TVA estimates societal benefits of \$640/kW, \$400/kW, and \$100/kW for the high, medium, and low load forecasts, respectively. These values are for a 1990 installation and are stated in 1985 dollars.

CONCLUSIONS

In Figure 5, the rise in indoor temperature above control setpoints for a typical day illustrates that the cooling system at West End Furniture Store is inadequate to meet normal cooling loads. It was learned that this deficiency was not due to an improperly sized storage or icemaking subsystem, but rather to an undersized distribution system. West End has been scheduled for installation of a larger duct coil for the 1985 cooling season which should remedy this problem.

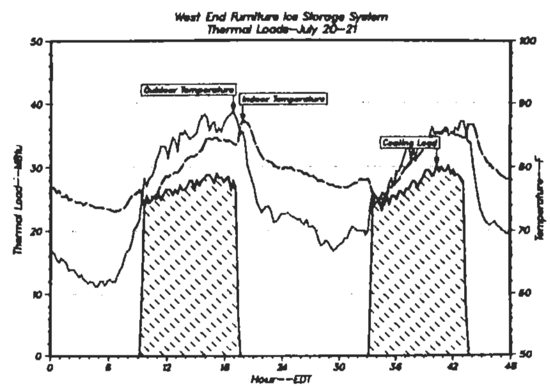

Fig. 5

The Merita Thrift Store system maintained proper indoor temperatures at setpoint levels. Although indoor temperature was not monitored at Madison County, the system did not show the constant chilled water circulation characteristic of an undersized system.

An undetermined effect of ice storage cooling in this test is the possible increase in the latent cooling delivered due to the unusually cold chilled water supply from the storage units. The resulting increased dehumidification capacity would allow warmer dry-bulb temperature settings to supply the equivalent comfort of a conventional system, possibly reducing the observed energy penalty of these storage systems. A modulating valve was installed at the West End site for the 1985 season to temper the supply temperature to that of a conventional system which should improve seasonal COP and reduce the energy penalty of the system.

Icemaking capacity of these systems could not be measured directly but appeared marginally sized for the control schedules used in the test. The icemakers generally ran the entire allowable period on design days rather than shutting off by ice thickness control before the end of the charging period.

The data clearly showed that cool storage systems effectively shift electric loads to offpeak periods and that energy performance is an area deserving further investigation. As a result, TVA is undertaking a Cool Storage Performance Test beginning the summer of 1985 at the Chattanooga Energy Use Test Facility laboratories to provide the information needed to assess the following performance parameters:

1. Effect of ice-building process on refrigeration performance
   Refrigerant condensing temperature
   Refrigerant suction temperature

2. Usable thermal storage in system
   Ice thickness (correlated to usable storage by onsite tests)

3. Thermal storage system heat gains for various ambient temperatures

Several systems, all from different manufacturers, will be tested and their performance compared with conventional systems to be able to adequately assess their potential benefit and saving to the end-use commercial customers.

REFERENCES

1. Tennessee Valley Authority, Division of Conservation and Energy Management, "C&I Cool Storage Demonstration Project Field Monitoring Report, May-July 1984," August 1984.

2. Sieber, R. E., "TVA's Marginal Cost Approach For Evaluating Demand-Side Conservation, Solar, and Load Management Technologies," presented at the EPRI Workshop on The Economics of Residential Ice Storage Systems, Tempe, Arizona, March 1984.

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