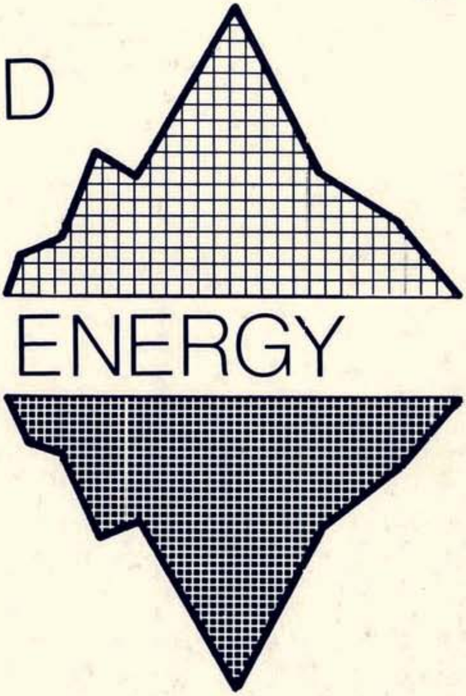
# PEAK-LOAD PRICING and THERMAL ENERGY STORAGE



sponsored by

Division of Energy Storage Systems
U.S. Department of Energy

Chemical and Electrical Systems Program
Argonne National Laboratory

Energy Resources Center
University of Illinois-Chicago Circle

July 15-17, 1979

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## CONTENTS

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# CONFERENCE ON PEAK-LOAD PRICING AND THERMAL ENERGY STORAGE: WELCOME AND OPENING REMARKS

by

**E. Gale Pewitt**
**Acting Director**
**Argonne National Laboratory**

As Acting Director of Argonne National Laboratory, which is a co-host for this conference on Peak-Load Pricing and Thermal Energy Storge, I welcome you.

I extend a welcome also in the name of the other co-sponsors: Energy Storage Systems of the Department of Energy, and The Energy Resources Center of the University of Illinois-Chicago Circle campus.

I also extend a special welcome to those participants from other countries, some of whom were involved in, or witnessed, the introduction of thermal storage in Europe over twenty years ago, and who will share their knowledge of thermal energy storage technology and load management strategies employed to reduce the use of oil and increase the use of native coal.

Let me explain how Argonne National Laboratory became interested in thermal energy storage. Argonne was formed in 1946, and was assigned the mission to develop peaceful uses of atomic energy. There were (and still are) programs in physical and environmental research that supported the nuclear power technology development. One of the physical research studies was the feasibility of thermally regenerated electrolytic cells, the heat being supplied with reactor heat. This concept turned out to be very inefficient; however, it was recognized that the molten salt system that was used with lithium/sulfur couple would be highly desirable as a battery. For the last ten years, this system has been developed, and is now in the first prototype stage. This development is being carried out with the participation of a number of battery firms. Applications are for load leveling on utilities and electric vehicles.

We are involved in "near-term" battery development. We are in charge of the battery development for the Electric Vehicle Act, through which we are pursuing battery systems utilizing advanced lead acid, nickel/iron and nickel/zinc. In addition to these chemical storage systems, we also have current activities in mechanical storage: underground pump hydro and underground compressed air storage.

We have a systems analysis group, under the direction of Dr. Joseph Asbury, which has looked at the performance and economics of all storage systems for different applications, with particular emphasis on utility storage. This particular group has advocated thermal energy storage for the last few years, and has been instrumental in planning this conference. All of our storage activities are under the direction of Dr. Paul Nelson.

As I view the printed program, this conference is based on the following related premises:

- First, that TES is a desirable technology that can, to some extent, reduce foreign oil dependence which threatens to compromise our political independence.
- Second, that heat storage can be an actuality today, in some regions of the country. Indeed, the technology we call "near-term" is already commercialized, and is in its third generation of development in Europe.
- Third, with respect to peak-load pricing, rate reform has clearly begun. Cost-of-service rates can be encouraged and applied to accelerate TES commercialization to the benefit of both the consumer and the electric utility.

- Fourth, that sufficient penetration of TES in the U.S. requires the coexistence of carefully designed rates, a favorable regulatory environment, utility decision-makers with initiative, additional vendors and responsible marketing, and R&D that will result in cool-storage and more versatile systems.
- Finally, that the participants present at this conference, have the ability to influence, in a positive way, the course of TES and the development of advanced TES systems for future space-conditioning needs.

In conclusion, after reading the history of nations (including the United States) it seems that millions of people can become simultaneously impressed with one delusion, run after it awhile, and then, just as suddenly, fix their minds on another idea. The energy situation is one where there is no unanimity of opinion in the U.S., on its causes, what it is, what to do about it, or whom to blame. It seems to me, that without commenting on its net merit, the pursuit of TES by DOE, EPRI and private utilities, to ameliorate one small part of the present situation is not a commitment to a strange, new view that will later be found to be untenable; nor is it a blue-sky hope that can't be realized, if deemed appropriate. It is, I think, a reasonable approach that deserves serious consideration, followed by some decision-making.

It seems that there is now a relatively good knowledge-base on TES as an effective load-management tool, and that its economic, institutional, regulatory and commercial aspects are somewhat understood. Doubtless, it would be desirable to know more than we do, but we are rapidly approaching the time when we must face the implications of the knowledge we already possess, and accept responsibility for using this information as best we can. If that time is now, I hope the participants of this conference will turn thought and words into responsible actions for the good of us all.

# I. European Experience With Thermal Energy Storage

# THE BRITISH EXPERIENCE WITH THERMAL ENERGY STORAGE

by
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## I Introduction

Electricity will contribute an increasingly important role towards the total national energy demand in the future, especially when the finite supplies of oil and gas become depleted. Although the long term availability of electrical energy is assured, it is prudent to discourage profligate and wasteful use of this premium form of energy.

Controlled and managed growth of electrical utilization with increasing emphasis on wise, efficient and effective applications is now paramount. This applies just as much to industrial and commercial applications as to the residential uses. Because electricity cannot readily be stored like fossil fuels, it is necessary to search for methods which improve the load factor thus equalizing the demand on generation plant. Apart from the obvious commercial benefits of providing an improved return on invested capital, load management can result in more efficient use of generation plant and the primary energy from which electricity is produced. Load management can result in lower real costs of electricity, which can be differentially passed on to those customers who assist in the attainment of the overall broad objectives by their judicious use of electricity.

While these concepts are accepted and recognized by professionals concerned with electricity supply, customers will not be motivated unless deliberate planned action is taken. Even then, response will be slow since the ultimate objective is dependent upon the individual decisions of many thousands of customers related to new building of homes and offices, and the construction of plants and machinery when existing equipment reaches the end of its useful life.

There are no simple solutions. If the management of energy supply and usage is to be more sophisticated in the future, compared with the past, then it will take much careful thought, time and effort.

There are two fundamental and interlinked criteria which influence customers in the direction of sensible load management:

1) Time-of-day pricing, or the introduction of off-peak tariffs at preferential rates. This is particularly relevant to residential applications. Similarly, time-of-year pricing can be introduced for those large commercial and industrial customers on maximum demand tariffs.
2) Thermal energy storage devices and controls to satisfy customer needs for space and water heating. Close collaboration with equipment and hardware manufacturers has been essential to ensure that the right products are developed, and that they are available for purchase by customers at the right price in sufficient quantity to satisfy the stimulated demand.

This paper describes some of these aspects of Britain's experience with thermal energy storage directed towards load management.

## II Electricity Tariffs Directed Towards Load Management

In England and Wales the Control Electricity Generating Board is responsible for the generation of electricity and its supply in bulk to the 12 Area Boards, whose function it is to provide supplies to customers in their area. While the Electricity Council has certain overall responsibilities, each of the 12 Boards is financially independent. Therefore the CEGB has to devise a tariff under which its bulk supplies are sold to the Area Boards, who vary in size and in their overall load characteristics.

The Bulk Supply Tariff of the CEGB has two functions. First, it must bring in sufficient revenue to enable the Generating Board to meet its financial obligations and secondly it needs to indicate to the Area Boards the avoidable generation and main transmission costs of different load patterns.

The cost of generating electricity depends largely on the characteristics of the electricity demand. The peak portion of this demand has to be covered by a relatively inefficient plant which operates only for short periods and is therefore particularly expensive in fuel costs. The distribution system has to be dimensioned to transport peak power, and when the energy content of the load peak is small the distribution system is poorly utilized.

For continuity of the electricity supply at all times of the day and year, the system planners must ensure that the installed generation and distribution capacity will be capable of meeting the peak load in all except emergency conditions. They must also consider the load characteristics in deciding on the right type of plant to be installed so that electricity can be produced in the most economic way. It follows that if some means can be found to reduce the peaks of the electricity demand, the generating and distribution equipment can be used more efficiently.

Historically the electricity undertakings in the United Kingdom have always encouraged the use of electricity away from peak time. They achieved this in various ways—by special agreements with industrial consumers, entitling them to lower demand charges for loads supplied outside the winter daytime peak periods; by general tariffs which encouraged the continuous use of the supply throughout the year once the capacity and fixed charges attributable to the supply had been recovered; and by the promotion of a wide range of uses of electricity amongst different types of customers to achieve maximum diversity. In 1950, Area Boards were recommended to offer special terms for off-peak supplies.

The development of underfloor heating systems and storage radiators suitable initially for high street premises such as shops, offices and public buildings, added impetus to the need for off-peak pricing suitable for a growing number of smaller customers, and in 1952 one Area Board published a day-night tariff for residential and other small consumers. By 1956-57, most Boards were offering off-peak tariffs at cheaper rates with supply through a separately metered circuit controlled by a time switch which provided supplies for 12 hours at night and for a 3-hour midday boost. The number of customers so connected in 1956-57 was below 50,000 and with installed off-peak load of only 300 MW and unit sales of some 300 million kWh. The principal load supplied in this way was floorwarming in both commercial and domestic premises.

By 1966-67, all Area Boards had introduced a range of off-peak tariffs, which included not only the 15-hour rate described, but also a cheaper 11-hour rate giving availability for 8 night hours plus a 3-hour midday boost; and an even lower night-only rate, (i.e., with no midday boost) suitable for commercial and industrial premises where there was no need for comfort conditions to be maintained in the evening. These off-peak rates were about half of the standard domestic kWh rate.

The great impact of this successful off-peak development resulted in 1969 and 1970 in the temporary emergence of a system peak demand in the afternoon hours when the boost period in these tariffs added the increased storage load to normal demands. This led to a reappraisal both of the tariffs and of the design of storage equipment. Storage radiators with improved insulation and output characteristics began to be produced, requiring no daytime boost. It was then decided that the time was ripe for a change in the emphasis in off-peak load develoment. In 1969, day/night (two-rate) tariffs were introduced as an alternative to the previous system of having both normal and off-peak tariffs in one consumer's premises. The advantages were that the lower night rate applied to all consumption—not just for storage appliances on separate circuits; and some daytime diversity would be restored so as to avoid having to invest in peaking plant to meet an incremental off-peak load. Finally in 1970, Boards withdrew the old off-peak tariffs except from customers already contracted to them.

**Table I. Average Retail Rates (Pence/kWh) in Residential Tariffs—England and Wales (All Figures in 1976-77 Prices)**

| | 15-Hour (12-Hour Night) plus Boost) | 11-Hour (8-Hour Night plus Boost) | 8-Hour (Night Only) | Running Rate in Standard Residential Tariff |
|---|---|---|---|---|
| | (1) p/kWh | (2) p/kWh | (3) p/kWh | (4) p/kWh |
| 1956-57 | 1.25 | —— | —— | 1.43 |
| 1966-67 | 0.93 | 0.83 | 0.76 | 1.69 |
| 1976-77 | 1.41 | 1.27 | 1.14 | 2.28 |

Above Off-Peak Rates Expressed as a Proportion of Standard Residential Tariff Running Rate in Column (4)

| | % (1) | % (2) | % (3) | % |
|---|---|---|---|---|
| 1956-57 | 87 | | | |
| 1966-67 | 55 | 49 | 45 | |
| 1976-77 | 62 | 56 | 50 | |

By 1976-77, the only off-peak rate generally available to new customers was the 8-hour night rate incorporated in Area Boards' White Meter tariff—the name by which the standard 2-rate (Day/Night) tariff was promoted. All other kWh meters are normally black, and the twin cyclometer dial type of meter was introduced in white to provide a distinctive feature. A subsequent development introduced on October 1, 1978 is described later in this paper. The progression of all these off-peak rates in the average standard domestic tariff is summarized in Table I.

In parallel with residential off-peak load development, work proceeded on the development of off-peak load in industry. This was achieved primarily by persuading industrialists to exploit the advantages of maximum demand tariffs, which enabled additional supplies to be taken at low running rates at any time, provided there was little or no addition to the customer's own maximum demand. This had the effect of stimulating longer utilization times for industrial demand, especially during night-time but also throughout the year. There were also many special agreements drawn up to meet the needs of certain industrial processes, with particular emphasis on the encouragement of their use away from winter peak hours.

The standard maximum-demand type of industrial tariff is still the main stay of industrial electricity load development, and successive improvements to its form have tended to obviate special agreements.

Progressive changes have taken place, but by 1976-77 the standard pattern throughout England and Wales was of demand charges higher in winter than at other times of year, and cheaper running rates at night than during the day. The price of additional night-time energy for a six hour period ranged down to about half the average overall price paid by many industrialists. Thus the price of night energy has been broadly maintained in real terms. This has been achieved by improving the structure of the tariff so as to give the customer the opportunity of taking supplies at times of lowest cost, and by improved thermal efficiency which has offset the increased real cost of fossil fuel.

Thus it can be seen that over the last twenty years the inducements offered for off-peak industrial load development have been improved, consolidated, and standardized. Industrialists are now made very well aware of the nature of electricity supply costs, and are better able to make informed judgements related to investment decisions on electroproduction techniques and equipment.

## III Thermal Energy Storage Product Development

The creation of the customer demand for storage radiators in Britain was a classic marketing exercise. Storage radiators were not new heating appliances but it was not until the early 1960's that they were considered suitable as a major appliance for the stimulation of off-peak energy sales. The Electricity Supply Industry took the lead in evolving a domestic storage radiator which could be sold in volume to the population at large.

The Electricity Supply Industry collaborated closely with the manufacturers of storage heaters to ensure the availability of their products, sized and designed to meet both customer requirements and the load management objectives. Such cooperation has continued and this has undoubtedly been encouraged by the purchasing power of the Area Boards. Almost uniquely compared with other countries the historical practice in the United Kingdom, which still continues today, has been for the utilities to promote and sell through their own high street retail shops all types of electrical appliances. These include cookers, washing machines, refrigerators, freezers and small appliances. This appliance marketing activity was extended to include storage radiators. It is a most useful adjunct in support of the energy marketing and load management objectives.

The marketing problem was how to sell metal boxes full of bricks to the public as central heating. An investigation of the potential finally produced the formula which was used for a number of years, namely, ''Start Central Heating from £50''. Obviously the £50 was inflated in later years but the essential message was the same—when starting central heating there is no need to make the major investment necessary with other systems. From 1966 a great deal of effort was put into the promotion of storage radiators both as an energy concept and as an appliance concept. Media advertising, including television commercials, was used to help with the problem of competing with gas, oil and solid fuel. The success of the exercise was reflected in the volume sold. At the beginning of the sixties there were no installations of domestic storage heaters. In 1964 sales were 190,000 a year rising to some 501,000 storage radiators in 1970. By this time the industry had achieved the job of marketing storage radiators on behalf of the entire electrical trade and the total annual market in England and Wales reached a peak of 740,000 in 1972.

The advertising and promotional formula was well tried and tested over the years, essentially in two parallel themes on television. First there was an energy commercial running through the Summer and Autumn on the basis of Electrical Central Heating. At the same time two annual promotions, one in the Spring and one in the Autumn saying ''Go to your Electricity Board Shop and buy Storage Radiators and Obtain this or that Premium Free''. The overall slogan was ''Cheap to Buy, Cheap to Install, Cheap to Run.''

Storage radiator technical developments took place in stages. At the outset there were eleven-hour radiators, requiring an eight hour charge overnight with a three hour midday boost. By the end of the 1960's, the midday valley on the load curve had been filled. This led to the development of the eight hour High Capacity storage radiator. From 1968 this was promoted with the same degree of success as its predecessor. The customer satisfaction rate also exceeded the 95% level, which is extremely high. Later developments included the use of a fan to boost the heat output at the end of the day, while more recently the damper controlled radiator achieved a predominant share of the market.

Styling changed over the years of development. In the early days, storage radiators were more bulky than today and generally there was a tendency to use conventional paint work. In recent years wood grain has gained popularity and storage heaters have been designed to be slimmer and less obtrusive. The Electricity Supply Industry through its own Appliance Testing Laboratories suggested improvements to storage radiators and determined methods for evaluating their safety and performance. These are used by manufacturers now to describe their storage radiators.

A satisfactory product at the right price and in the right volume was combined with the right promotional program. This resulted in storage radiators constituting a major role in energy and appliance sales. At one stage the Electricity Boards enjoyed a market share of some 70%, although it should be emphasized that the Electricity Supply Industry has wider interests than those of the electrical trade in promotion of off-peak heating equipment.

During the early 1960's gas warm air started to impact on the new homes market, and as it grew the market share of electric floor warming began to decline. The Electricity Supply Industry responded with a specification for what is now known as Electricaire and boldly placed an order for 20,000 units. A major task was to persuade house builders and architects to modify their designs to accept Electricaire as an alternative to gas warm air systems. Electricaire was launched in 1966 and then together with other heating systems, electricity achieved 29% of all central heating installations in homes in the UK.

**Table II. Consumers, Load and Sales in England and Wales on Off-Peak (Restricted Hour of Day/Night) Tariffs**

| Year | Number of Consumers (Thousands) | Installed Off-Peak Load GW | Energy Sales TWh |
|---|---|---|---|
| 1956-57 | 40 | 0.3 | 0.3 |
| 1966-67 | 825 | 5.6 | 6.6 |
| 1976-77 | 2,600 | 17.0 | 17.5 |

The results in terms of off-peak load development were appreciable and are summarized by the growth in the number of customers with off-peak space and water heating systems. This is shown in Table II which although including all small users relates mainly to residential homes.

**Table III. Households Owning Off-Peak Electric Central Heating**

| Year | Millions | % of all Households |
|---|---|---|
| 1956-57 | —— | —— |
| 1966-67 | 0.6 | 3.6 |
| 1976-77 | 2.3 | 12.6 |

Over the 20 years reviewed, the use of off-peak electricity, especially for domestic space and water heating, has been built-up from the smallest beginnings to the extent that one dwelling in eight now has off-peak central heating. A proportion of these homes also has off-peak central heating. The growth in ownership of domestic central heating has been as shown in Table III.

The breakdown in terms of heating system based on 1978 figures is as follows:

| | |
|---|---|
| Storage Radiators | 1,651,000 |
| Electricaire | 354,000 |
| Floor Warming | 306,000 |
| Total Storage Heating Systems | 2,311,000 |

**Table IV. Average Annual Electricity Consumption Per Consumer**

| Year | Domestic kWh | Farm kWh | Commercial kWh | Combined Premises kWh |
|---|---|---|---|---|
| 1956-57 Total | 1650 | 6200 | 7240 | 4150 |
| 1966-67 Total | 3420 | 10020 | 14930 | 10260 |
| (including off-peak) | (250) | (750) | (1480) | (530) |
| 1976-77 Total | 4150 | 12150 | 22800 | 14250 |
| (including off-peak) | (760) | (1250) | (2500) | (1100) |

It is easier to record the results of off-peak development on residential users because of homogeneity but the effects on other small users have also been significant. Table IV shows the growth in average consumption for non-industrial consumers, and the contribution to this overall average made by the off-peak component. While this component trebled its contribution to the average consumption per domestic user, it almost doubled for the other classes shown. By 1977, off-peak sales represented 15% of sales to non-industrial consumers.

## IV Effect on System Characteristics

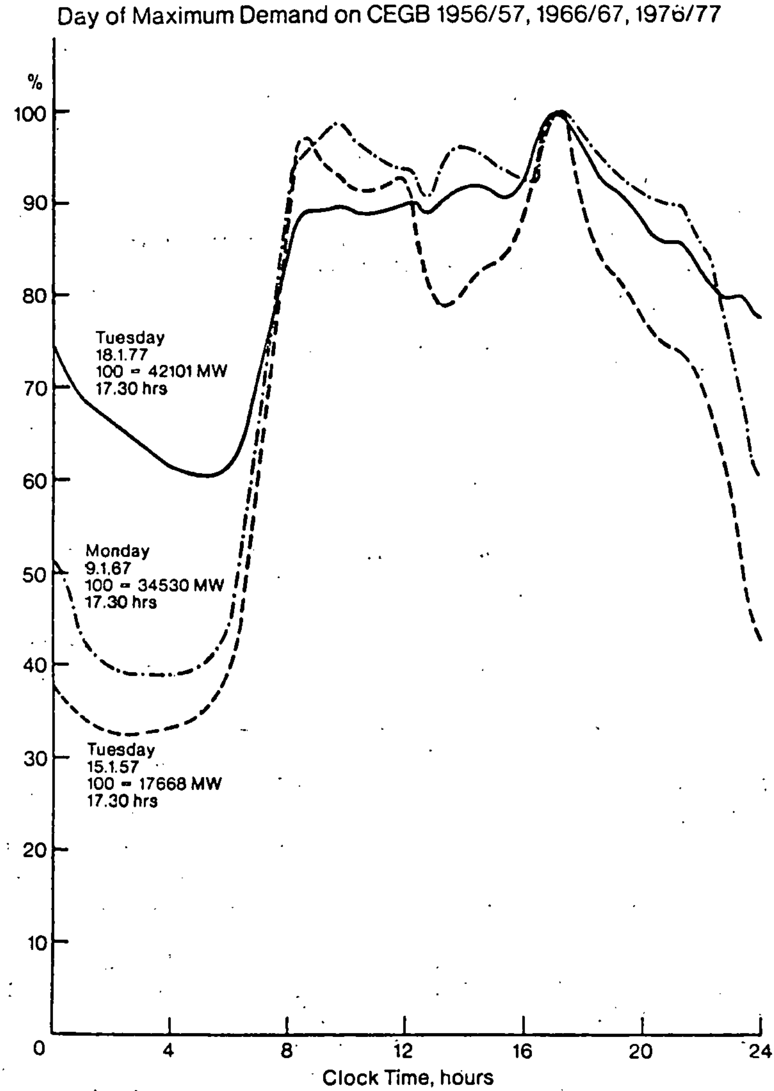


Figure 1

**Overall**

The overall effect of the development of off-peak load over the last 20 years is illustrated in the change of the shape of the total system demand curve. Figure 1 shows the load curve for each peak day in the three years under review, with the maximum demands (which all occurred in the half-hour ended 17.30 in mid-January) scaled to 100%.

**Table V. Improvements in Annual System Load Factors**

| Year | Annual System Load Factor | Proportion of Total Energy Supplied at Night* |
|---|---|---|
| | % | % |
| 1956-57 | 48 | 19 |
| 1966-67 | 52 | 22 |
| 1976-77 | 57 | 25 |

*Between 2300 and 0700 daily throughout the year.

The most notable feature of the changed demand curve is of course the filling up of the night valley, where the demand at 0200 hours has doubled relative to system peak since 1956-57. The consequent improvements to annual system load factor, and in the proportion of total energy supplied during the night hours, are given in Table V.

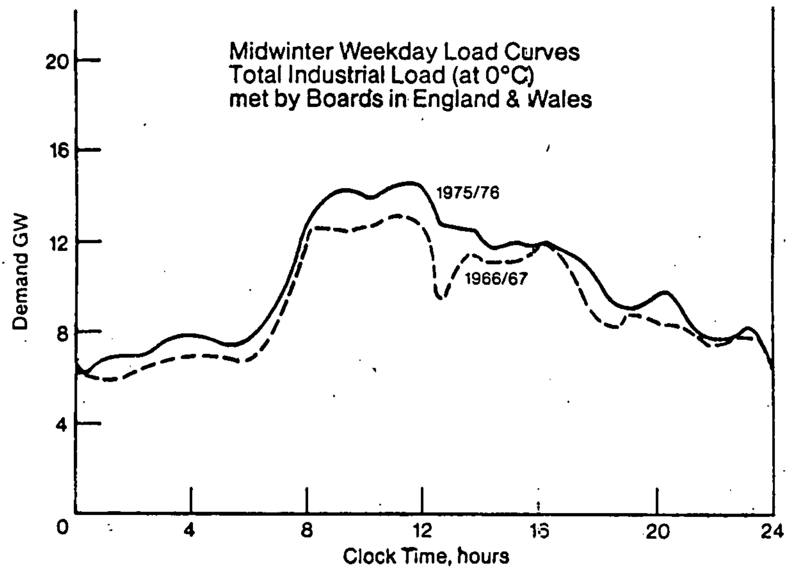


Figure 2

**Industrial**

Figure 2 shows how the total industrial demand at 0°C on winter weekdays moved between 1966-67 and 1975-76, when the growth in kWh sales was 20%. Results from load analysis of consumers with demands above 1MW, who take over 70% of all industrial electricity supplied, show their group load factor to have increased from 45% in 1961-62 to 70% in 1975-76, and their effective load factor at various half-hours during the day improved substantially over this period.

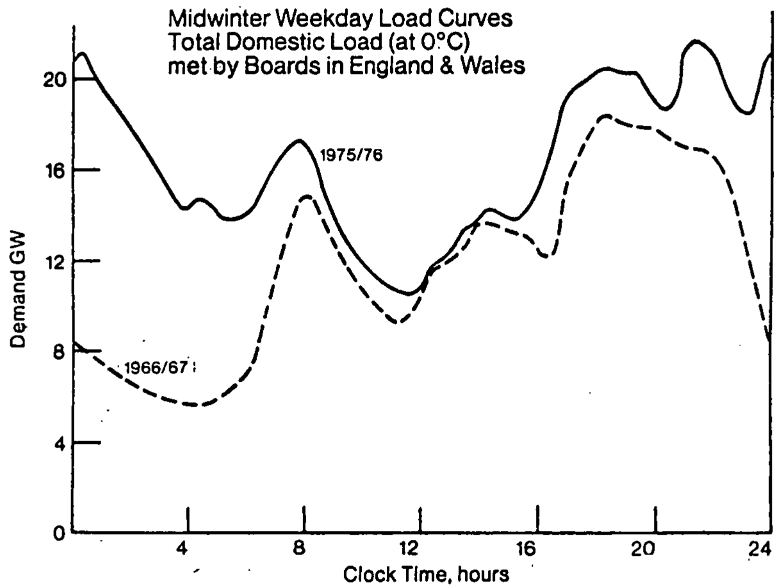


Figure 3

**Residential**

The very marked change in the residential class demand curve is apparent from Figure 3, which shows the extent of the filling of the night valley, as well as the increased late evening load. This is due to the various changes that have taken place in the home use of electricity, most notably in storage space and water heating. Other changes in living patterns will almost certainly have also made some contribution to the evening load characteristics (e.g., growth in ownership of electric kitchen and laundry equipment, and home entertainment).

**Commercial**

The contribution to the overall improvement in system characteristics by commercial users is also worthwhile, though less easy to illustrate in aggregate, because of the smaller size of this grouping and its fragmented character, ranging from shops and offices to public buildings of all kinds. For the larger buildings, tariff inducements result in load control more akin to industrial practice, while smaller establishments are in a similar category to dwellings. The storage heater was developed in the first instance for use in commercial buildings, and as storage systems have developed they have retained their hold in this particular market.

## V Thermal Storage Heating Devices

**Storage Radiators**

The storage radiator consists basically of a heating element in a suitable solid refractory heat storage medium, encased in special insulation and protected by a metal case. Thermostatic controls select the level at which the heater will be charged. A thermal cut-out disconnects the supply in the event of the case temperature exceeding the safe limit.

The storage medium will have a high heat capacity per unit of volume, electrical stability at high temperature, resistance to disintegration after repeated heating and cooling, and thermal conductivity suited to the radiator design.

The insulation will have to withstand the high temperatures reached by the core without fatigue or disintegration resulting from constant heating and cooling. It will have a reasonably constant leak factor to permit, as far as possible, a consistent rate of dissipation of stored heat from the core. In practice the temperature of the case gradually falls from its highest, at the point of supply cut-off, to its lowest prior to the commencement of the next charge period.

To assess the storage heater loading necessary to meet the design day heat loss of a room, account is taken of the internal incidental gains from domestic appliances, human activities, and solar incidence. In the UK, a factor of 0.72 has proved reliable. Thus a 24 hour heat demand is 24 = 36kWh. Then, the factor 0.72 is applied, i.e., 36 × 0.72 = 25.92 kWh, say 26 kWh. A storage radiator with a charge acceptance of 26 kWh would satisfy this heating requirement. The input rating of a heater for this situation would be 26/8 = 3.25 kW with an acceptance factor of 95%, which would be met by a standard 3.375 kW heater.

The technology of the storage radiator has introduced a number of new terms, and these are categorized as follows:

### Charge Acceptance

Apart from the effects of its location in a room the efficiency of a storage radiator depends on the amount of heat it absorbs during the charging period (usually 8 hours) and this is known as the charge acceptance. This is defined as the quantity of heat which a storage radiator can absorb and emit, and is given in kWh.

### Acceptance Factor

This represents the actual charge acceptance compared with maximum possible charge acceptance based on an 8 hour charge. Ideally the radiator should take 8 hours to become fully charged, but in practice this is rarely possible. So a 3 kW rated element supplied continuously for 8 hours theoretically provides 24 kWh of heat. If the actual charge acceptance is 20 kWh, then the acceptance factor will be 20/24 = 83.5%.

### Net Storage Capacity

This expresses the energy in kWh retained within the radiator at the end of an eight-hour charge period and which can be emitted during the subsequent 16 hour discharge period.

### Retention Factor

The ratio of net storage capacity to the 8 hour charge acceptance. If the charge acceptance is 20 kWh and the net storage capacity is 15 kWh the retention factor will be, 15/20 or 75% readily indicating the storage capabilities of the radiator.

### Half Life

This is defined as the time in hours for the output to fall to 50% of maximum heat output. Thus the longer the period before the heat output drops to 50T, the more even the heating effect. From this it will be seen that the element kW rating of a storage radiator cannot be directly related to the hourly heat loss of a room as is the case with direct-acting heaters.

### Ratings

Various models of the basic storage radiator are available from UK manufacturers with input ratings of 2 kW to 3.375 kW.

**Dimensions**

Starting from slim models 125 mm in depth, 500 mm in height and 700 mm in length to average sizes of 225 mm in depth, 600 mm in height and 850 mm in length.

**Storage Fan Heaters**

A storage fan heater has a refractory core containing heating elements similar to those of a storage radiator but it is quite different in the remaining design features and application. A storage fan heater has air passes in the refractory blocks to facilitate the passage of air by means of an integral fan. Also, the heater has a very high level of thermal insulation which only permits a relatively low emission of radiant heat at all times. When the fan is operated manually, or more usually by temperature or time control, heated air is discharged until the predetermined room temperature is achieved. In this way a storage fan heater provides controlled heat combined with economic operation.

The case emission amounts to about 10% of the heat stored and frequently is sufficient to remove the chill from the heated area. The core is charged overnight for the period allowed by the tariff, as with storage radiator. Most of the charge is then available during the daytime period for heating, as dictated by the demands of the room thermostat controlling the fan.

Because of the closer control of heat output possible with this type of heater, the running costs can be more economical and the heater itself can be housed inconspicuously, making the most economical use of floor space. It is frequently possible to stub-duct some of the heat through a wall or partition into an adjacent area or office. The additional cost of a higher-rated element would be more than offset by the savings produced. It would certainly be cheaper than installing separate lower-rated models in each room.

**Ratings**

Storage fan heaters are available from UK manufacturers in the input range 2 kW to 6 kW.

**Dimensions**

Shape is similar to storage radiators but larger.

**Electricaire**

Electricaire is a generic term used in Britain to describe central storage warm air space heating systems using a restricted hour electricity supply tariff. Electricaire is usually associated with a system of ducting, for air distribution, terminating at supply registers in the rooms or areas to be heated.

The heart of an Electricaire system consists of a well-insulated high temperature core heated by electric elements. Air passes through ducts in the core by the action of a fan. It is heated and mixed with cool incoming air within the fan chamber, resulting in an evenly mixed output without hot and cold zones in the air stream. A damper regulates the column of air which is allowed to pass into the core and at the same time ensures that the temperature of the final air output remains at a predetermined level over the major part of the heating period.

Store temperatures of up to 800°C are obtained within the unit, but are regulated by a charge controller or thermostat. This determines the quantity of heat put into the unit overnight. To prevent any overheating on the outside of the core a limit-thermostat is fitted and there is a further over-temperature device in the air stream to limit the maximum outlet air temperature. The warm air output from the mixing box is subsequently directed into a plenum box, which acts as a distribution chamber so constructed that it supports the weight of the heater. From the plenum box, ducts are led to the supply registers.

The stub duct system is the simplest form of warm air distribution arrangement, apart from direct discharge of the unit into the room. When using a stub duct arrangement, the Electricaire unit should be sited as centrally as possible in the space to be heated. Such a system is then often inexpensive and easy to install, the stub ducts frequently only penetrating the adjacent wall. The advantages of Electricaire are flexible design, low maintenance costs and clean, quiet operation. No special fuel or internal/external pollution problems arise and the system can give a manually selected rapid warm up or can operate under thermostatic control. See figure 4 — page 28.

**Dimensions**

The dimensions of the approved models are generally 610 mm square on a plenum of the same size fixed either below floor level or, for some stub ducted systems, above floor level, when the plenum chamber will add 305 mm to the height of the unit. The units will fit into a cupboard or compartment 762 mm square to 838 mm square. Other shapes and sizes are available which offer flexibility of interior design. Height depends on the rate capacity and varies from 1250 mm for a 6 kW model to 1650 mm for a 15 kW model.

**Floor Warming**

A storage system employing special elements to warm insulated concrete floors using mainly night time electricity. The system takes up no floor or wall space whatsoever. Since there are no mechanical parts involved it is extremely reliable. Almost any type and size of dwelling can be heated as each system is custom built.

**Installation and Design**

A floor slab which is to be electrically warmed would normally be insulated completely with 25 mm thick polyurethane slabs or equivalent, above the damp-proof course, across the base and around its perimeter. The design engineer should carefully consider the various methods of floor construction and floor finishes acceptable with floor warming.

Usually an electric floor warming installation would be connected to a restricted hour tariff supply, which would limit the charge period available to the floor elements by means of a time switch. Thereafter, two methods of control are available.

1) A simple room thermostat control which varies the degree of charge given to the floor.
2) A refinement on the room thermostat method to control the whole installation by means of inside and outside thermostats linked together to take account of the thermal inertia of the building and thus vary the degree of charge more precisely.

The system itself requires very little maintenance and this is usually confined to the thermostats, which may require occasional checking. As a general guide electric floor warming systems consume between 1500 and 2000 kWh per kW of calculated loss.

Obviously, the higher the degree of thermal insulation in the house the lower the electrical consumption of a floor warming system.

It should be emphasized that electric floor warming systems continue to be sold and installed in appropriate circumstances. Typical installations are found in custom-built residential homes, large apartment blocks, churches, schools and commercial office buildings. It is worthy of mention that Britain's first all-electric hospital, which is at present under construction in Peterborough, incorporates electric underfloor warming. The hospital is scheduled for completion towards the end of 1979. In some situations off-peak floor warming is applied to provide the background heating requirements of a building, and with top-up under design day conditions provided by additional direct-acting appliances operating on day rate tariffs.

**Bulk Storage Hot Water**

This system might be considered when adequate space is available to house large capacity well-insulated hot water storage tanks which are connected to an electrode boiler. The water can then be heated overnight during the restricted hour tariff period or, with appropriate controls, on a maximum demand tariff. The heat stored in the water is then dissipated during the daytime by circulating the water through a small bore pipe/radiator system. The electrode boiler is a special appliance in which the metal lining of the water container and all associated metal work are earthed and connected to the neutral connection of the electricity supply.

The phase connection is taken to an electrode immersed in the center of the water; current flows through the water heating it up in the process. The electrode can be raised or lowered into the water to determine the resistance of the path through the water and thus the rate of heating related to the current flow.

Protection of the heaters by control thermostats and overload devices is essential to ensure safety and minimize consumption.

For large commercial buildings, UK utilities continue to promote the concept and process of integrated environmental design, which has now been incorporated within the strategic approach to the commercial market for eight years. Consequently, where and when it is economical in capital costs and energy-effective in running costs, we recommend the use of bulk water storage as the heat reservoir for large air conditioned buildings in which the refrigeration plant also operates in the mode of an internal source heat pump. This bulk water storage is then topped up under severely cold weather conditions using the cheaper night time electricity. Variations on this approach are tailored to swimming pool applications, coal mine pit head cleansing facilities and similar applications, and in each case either electrode boilers or immersion heaters are exploited to heat the central bulk hot water storage vessel using off-peak energy.

**Other Devices Developed But Not Being Commercially Marketed**

Storage radiators, storage fan heaters, Electricaire systems and floor warming are still being promoted and installed in Britain at the present time. To a lesser extent bulk storage hot water systems are applied selectively.

There are two other TES developments which are no longer being pursued in Britain, namely the thermal storage wall and Centralec.

An Electricity Council Research Center development of the Electricaire system has been the ''thermal-storage wall''. It was envisaged that this would be used in houses in which floor space is at a premium for although the overall thickness of the wall is greater than a partition wall, no other floor area is required.

Basically, the wall is a high mass, low-cost, warm air central heating system which distributes heat through ducts and grills in similar fashion to an Electricaire installation. The system consists of four main parts:

1) A core, which is made of concrete blocks designed to permit the passage of warm air and which has the required thermal and structural properties.
2) Insulation on all six sides, with plasterboard finish to the rooms.
3) A power unit, consisting of two fans, heating element, mixing damper and controls. This unit can be mounted into the wall, either from an end or from a side.
4) Distribution ducts and grilles.

The wall surface is finished with a conventional material, such as plasterboard, which can be painted or papered in the usual way, since the average surface temperature will not exceed 30°C (86°F). Decorations will not be affected, nor will furniture placed close to the wall be damaged.

Although the wall surface will be at its maximum design temperature at about 0900 hours, its temperature will generally be a little above that of the air in the adjacent rooms, and this provides some radiation which improves the quality of the environment. Nevertheless, the main heating is by warm air.

The air entering the wall is passed through a filter to remove dust, and the fan motors are specially mounted to reduce noise and vibration. A feature of the power unit is ease of accessibility.

The thermal storage wall concept was never taken beyond trial research installations largely because of problems associated with custom building into houses during construction.

**Table VI. Characteristics of Thermal Storage Media**

| Material | Temperature Range | Storage Ratio | |
|---|---|---|---|
| | °C | kWh/m$^3$ | kWh/ft$^3$ |
| Water | 94-49 | 53 | 1.5 |
| Fire-clay | 750-150 | 364 | 10.3 |
| Olivine | 750-150 | 495 | 14.0 |
| Allow Cast-Iron | 750-150 | 674 | 19.1 |
| Feolite | 750-150 | 614 | 17.4 |

Considerable research effort has been aimed at finding competitive electrical hot-water radiator-systems, and this has involved the study of the merits of various systems of storage, heat transfer and distribution. Table VI shows the comparative storage characteristics of various media.

Apart from the inferior storage ratio of water, there are advantages in its use, principally because of its simplicity and because it can be used for both storage and distribution; design procedures can also lead to acceptably-sized storage vessels.

The case for using a solid storage media is strong and development in this sphere took the form of modifications to a standard Electricaire unit. Heaters of this type were for some years after 1971 marketed by the Electricity Supply Industry under the name of "Centralec". The principle on which the heater operates is similar to an Electricaire unit, but instead of the heated air being discharged into the dwelling, it is passed over an air-to-water heat exchanger and recirculated within the heater. The heated water is then pumped round a conventional small-bore hot-water radiator system. Input control is achieved by a core sensor. A thermostat sited in the outlet of heat-exchanger and set at the required flow temperature, controls the operation of the fan and thus the heat-output of the unit. The fan may be simply switched on or off by the circuitry arranged to vary the fanspeed. The latter method provides closer control but at a capital cost premium.

A large-scale field trial was run in 1969-70 with 100 units to obtain a viable sample for detailed running-cost and performance data; to obtain cost data and experience of installation; to prove the reliability of the heater components and design; and to provide personnel with practical experience of "wet" systems.

Subsequently, Centralec units were generally marketed by the Area Electricity Boards between 1971 and 1973. While the installation of Centralec units was straightforward and only a small number of minor mechanical faults occurred, promotion was discontinued because the capital costs proved to be uncompetitive both with other electrical systems and with comparable output fossil fuel fired boilers. The resultant small volume of production aggravated and destroyed the commercial economic case for Centralec.

## VI Control Aspects of Thermal Energy Storage Systems

There are three control aspects based on experience in Britain which warrant consideration. These are:

1) Time based control for load control locally on the customer's premises;
2) Weather sensitive controls for fine tuning of the input to thermal storage equipment (both space heating and water heating); and

3) A recently proven centralized utility control for providing switching signals over the power distribution networks to apparatus on the customer's premises.

**Time Based Control**

Customers who opt for the standard two rate tariff are provided by the utility with a twin digital dial kilowatt hour meter which records the kWh consumptions at each "time of day" price. On the customer's side of the twin register meter a timeswitch is used to automatically switch the supply during "off-peak" times to storage heaters and the hot water storage heater. An auxiliary switch incorporated within the timeswitch operates a rate register change-over mechanism incorporated in the kWh meter, and this switch is caused to make and break in synchronization with the main load switch within the timeswitch. In this way the thermal storage heating loads are constrained to charge only during the low rate period while other loads such as small and major household appliances and lighting have a continuous supply.

The timeswitch offers some advantages as follows:

- It is reliable, inexpensive, proven and popular with the customer because he knows precisely where he stands with regard to supply at any time.
- A scatter switching effect is produced by the tuning and setting differences.
- Since the switch is capable of direct operation on 100 amperes, the need for expensive and usually noisy contactors in the home is avoided.
- It is not susceptible to a general control failure which may occur with a centralized control system.
- A network can be fitted out gradually with controlled incremental capital expenditure, rather than incurring major initial capital expenditure.

In the event of failure of electrical supply, a spring reserve mechanism is immediately and automatically brought into play which maintains time standard to a high accuracy until the electricity supply is restored. This carry over facility is of 72 hours duration. A valuable feature is that the carry over facility is automatically exercised for ten minutes each day to ensure that the escapement is maintained in full working order.

The current handling capacity of the timeswitch is normally adequate for most residential applications but should a larger load require control, on single or three base systems, then the timeswitch can be used to control the coil of a suitable contractor.

**Weather Sensitive Control**

Trials carried out in Britain show that substantial reductions in consumption are possible, with improved load management through the use of suitable weather sensitive controls. A fundamental objective is to store only that amount of heat energy that will be required by the space heating system during the day. The amount of heat which has to be provided by any spaceheating system will depend upon several factors. Some are relatively constant and predictable for a given installation, such as building type and construction.

Some are fairly constant but initially unpredictable, such as the number and activity of occupants and their preferances. Some are variable and unpredictable, notably the weather.

There are two amounts of heat to be considered—the amount which is needed, and the amount which is stored. With simple storage radiators and underfloor heating, there is no really effective way of controlling output independently of input. It may be possible to vary the rate of heat-transfer out of the storage medium, but only to a limited extent. Even the larger fan-assisted heaters release up to 20% of their stored heat directly from the casing. It is therefore important to match the amount of heat needed to the amount stored for all types of storage heating. To keep losses to a minimum, it is desirable to store heat as quickly as possible, and as near as possible to the time it will be needed. In general, this means as late as possible.

The start and finish of the off-peak period can be defined by timeswitches in the customer's premises, or by remote control. Within the specified period, the actual load pattern for an installation will reflect the needs of customer and weather conditions, and also the type of control used to regulate the amount of energy being stored.

Thermostatic controls to regulate the amount of heat stored have a characteristic consumption pattern, which is a period of full on, followed by a period of cycling between on and off. This pattern will appear in the utility's system demand with overall consumption loaded towards the start of the off-peak period and a marked reduction towards the end. It is the opposite of the established objective of storing as late as possible.

An alternative to thermostatic control is an energy regulator of the "time-proportional" type. The percentage of the proportioning period for which the heater is on determines the percentage of energy being stored.

The proportional control operates by comparing two signals—one which changes according to the amount of heat required, and the other which changes with time. The heaters are turned on when one of the signals is greater than the other. The advent of micro-electronics has made it possible to generate signals which change slowly with time in almost any desired manner. Consequently it is possible to achieve any desired consumption pattern by the use of a proportional control incorporating this form of signal generation.

The required degree of customer control can be readily provided, and the amount of heat stored can also be automatically adjusted in response to outside or inside temperature. A central control can be used in conjunction with several appliances, or can be built-in to a single large appliance.

The pattern that developed in the UK was for the minimum demand "trough" to be towards the end of the off-peak periods, and simple backward charging control gives greatly improved levels of minimum demand.

A number of trials have been carried out using 'Pactrol' and similar controls on both residential and commercial installations of storage heating. In the residential homes the monitored performance showed average annual savings of 10% on energy consumption, and in the commercial buildings the annual consumption was reduced by 30-35% while maintaining satisfactory comfort conditions.

**Utility Control—Mains Signalling System**

Signalling over the power system distribution network for the remote control of loads and tariffs has been employed for many years.

While recognizing the availability of several other methods of communication control for load management such as ripple control, the London Electricity Board cooperated with GEC Measurements Ltd. of Stone in Staffordshire, England in the development of Cyclocontrol. This provides an efficient and reliable means of mains signalling which offers advantages over existing methods. Schemes installed in London control storage and water heating in blocks of apartments.

Improved cost effectiveness and simplicity of installation in comparison with ripple control techniques are the two most important features which commend Cyclocontrol. Static circuit transmitters and receivers provide effective control of remote loads, with selective control of up to 165 blocks of load. There are no tuning or attenuation problems of the type normally associated with ripple control systems. The modulation is small enough to prevent disturbances to sensitive loads such as fluorescent lights, yet large enough to be received at the extremities of large distribution networks without significant attentuation even in the presence of capacitive loads.

An entire 11 k/v/415 V distribution system having an 11 kV fault level of up to 300 MVA may be controlled from a single transmitter. The transmitter is conveniently connected to the 415 V side of a distribution transformer. For optimum signalling the distribution transformer should have a rating of at least 500 kVA and be sited as near as possible to the primary substation.

Cyclocontrol extracts power from the system in such a way as to modify the waveform of selected cycles of the mains supply. The receivers are simple assemblies consisting of a single printed circuit board and contractor.

Cyclocontrol is easy and comparatively inexpensive to install. Signalling is performed near voltage zero where the envelope power of the waveform is minimum. The transmitter does not have to handle large amounts of power. Current is drawn only for a fraction of a cycle and then only intermittently to form a code pattern. So the transmitter is very compact. In addition, no special coupling equipment is required since injection is through the low voltage side of a standard distribution transformer. These factors result in the signalling equipment being significantly cheaper than its ripple system competitors.

## VII. The New Economy 7 Tariff

Historically, British electricity prices in the post-World War II period have been stable in real terms, i.e., the average increase in price has approximately equalled that of the retail price index. The start of this decade saw an increase in the rate of inflation and attempts by Government to restrain prices in nationalized industries. The effect was for electricity prices to fall in real terms and at the same time our industry moved from profit to deficit.

In the last three years we have, with Government support, returned to making a relatively small profit but this has been associated with price increases greater than inflation. This rapid increase in the price to residential customers for electricity has resulted in our being in a most difficult competitive situation relative to the price of natural gas. The result has been a total fall off in our off-peak sales of some 24% during 1974 to 1978.

To counter this disturbing trend the Electricity Supply Industry in England and Wales has introduced a new tariff which was effective October 1, 1978. This new residential tariff which is called "ECONOMY 7" offers a very low night price which should be of great assistance to new as well as to many existing off-peak residential customers.

The night rate offered in the Economy 7 tariff covers seven night hours and is about 20% below the previous rates which were generally being offered by Electricity Boards throughout the country for night-time tariffs.

## VIII. Present Residential Promotional Activities

### The Medallion Award Scheme

For the past two years the Electricity Supply Industry in the United Kingdom has been promoting to the residential market the Medallion Award scheme which has been specifically adapted to foster the construction of energy saving homes by private speculative builders. The Medallion Award concept was developed in the United States a number of years ago for the promotion of all-electric homes, and it should be stressed that our present activities in the United Kingdom are essentially directed towards all-electric houses but with such high standards of thermal insulation that the running costs will prove to be economic to the ultimate house purchasers.

The Medallion Award is proof to the buying public that all-electric homes are an economic reality. By ensuring that set standards of insulation and electrical installation are met, the scheme offers homes with greater comfort and lower fuel bills. Medallion homes are highly competitive in running costs compared with fossil fuel based heating systems. Also they offer the simplicity, cleanliness and reliability of electricity. Living standards are considerably improved, giving these houses a competitive edge over houses built only to existing Building Regulation standards.

In order to provide customer re-assurance the Electricity Boards provide the builders of approved Medallion Award homes with a certificate to demonstrate that each approved development is being built to the Medallion Standards.

All-electric houses have always been cheaper and easier to build. Now, Medallion homes bring electricity to the forefront of the market, offering it as a competitive and comfortable alternative to fossil fuels.

No provision is needed for flues or hot water radiators and site work is considerably reduced with no heating pipes or fuel storage required. The money saved in these areas can be spent on cavity wall and roof insulation, so all the customer advantages of an energy saving modern home can be gained without pricing the house out of the market.

To the purchaser, the Medallion Award means that the homes are extra value for money. They are built with the needs of a modern family in mind and are economical, clean, comfortable and energy saving. National and local publicity support ensures customer awareness of the scheme, showing that electricity can offer a high standard of comfort without high cost. In these days of rising prices and concern for living standards, Medallion homes are already in popular demand and over 2500 have now been sold.

The Electricity Supply Industry has financed a major national advertising campaign to stress the benefits of the Medallion Scheme, and typical advertising features examples of Medallion sites throughout the United Kingdom.

A full range of publicity material is provided to builders of Medallion homes and further support is given in the spread of advertising in the local press, by point of sale boards and site office displays.

To help ensure that the builders' customers are completely satisfied with their Medallion homes the scheme includes a special after sales service. A representative of the local Electricity Board calls on all new purchasers to answer queries, explain the various budget payment schemes to spread running costs, and to make sure that the home owners know how to operate their heating systems correctly.

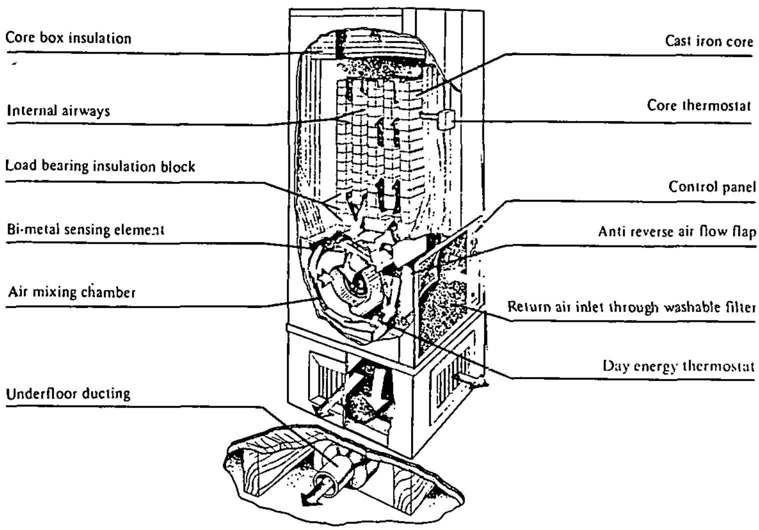


Figure 4

**Acknowlegements**

The writer wishes to acknowledge his thanks to the Electricity Council for permission to present this paper and also the support and cooperation of many colleagues.

# INTRODUCTION OF PEAK-LOAD PRICING IN EUROPE [1]

by

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## I Introduction

The purpose of this paper is to present a brief historical review of certain aspects of the European experience with peak-load pricing. As volumes could, and have been written on this subject[2], it is necessary to restrict the scope of this paper to subjects more likely to be of interest to the participants in this conference. The choice of what to attempt to cover and what to omit is in this case heavily influenced by this author's great ignorance of the experience of much of Europe. The decision to concentrate almost exclusively on Britain and France allows us to trace in more detail the evolution of some important ideas than would have been possible had a Grand Tour been attempted.

While we will treat France and Britain in separate sections, it is initially worthwile to examine the general circumstances that the electric utility industries found themselves in during the years immediately after the Second World War. In both countries, almost no new generating capacity had been added in the war years thereby placing considerable pressure on existing capacity. In both countries the governments had concluded sweeping reorganization of the industry. At almost the same time in both countries theoretical economic articles on tariff reform were published independently.[3]

The concepts proposed in these papers were implemented first in France, with the introduction of the Tarif Vert as an option for high voltage customers. The British introduced peak-load tariffs several years later but these were initially based on average cost principles rather than the marginal cost ideas used by the French. Marginal costs were eventually used (at least as a starting point) in Britain and the differences observable in the tariffs today are largely the result of significantly different cost structures in the two countries as well as those caused by the differences in industry organization.

These high-voltage tariffs were naturally first made available to industrial consumers and it was a considerable time later before residential and commercial customers could avail themselves of peak-load prices. The low-voltage peak-period prices were almost exclusively aimed at those customers with water and space heating loads where storage devices enabled a profitable shifting of load to the hours of cheaper electricity.

In contrast to the high-voltage tariffs, Britain was able, for largely institutional reasons, to offer residential peak-load tariffs before France. These tariffs have evolved considerably since their initial introduction as circumstances and technology changed. Unlike some other countries, the concept of load management has invariably been linked with tariff policy in both Britain and France and these residential peak-load tariffs generally offer either as an option or a requirement that certain appliances be controlled or restricted to the off-peak periods of the tariff.

The following sections will look in more detail at the French and British experience.

## II Peak-Load Pricing in England and Wales

Britain was drastically short of generating capacity in the immediate postwar years and on occasion suffered as much as a 30 percent excess demand. A vigorous construction program ensued and the Electricity Act of 1947 dramatically reorganized the industry. The industry as reorganized again in 1957 and for simplicity we will describe the resulting structure after that date, though from a tariff point of view no great misunderstanding will occur if this structure is assumed to exist from 1947.

**Industry Organization**

There are twelve Area Boards which purchase electricity from the Central Electricity Generating Board and distribute it to customers in their region. The Area Boards purchase power under the terms of the Bulk Supply Tariff and have considerable freedom on the nature of the tariffs that they offer to their customers. The action of the Area Boards are governed by a number of statutory requirements concerning financing and non-discriminatory pricing practices. The overall coordination of the industry is the responsibility of the Electricity Council which reports to the Secretary of State for Energy. The Generating Board has some additional responsibilities as a nationalized industry.[4]

**The Bulk Supply Tariff**

In recent years the Bulk Supply Tariff (BST) has been revised annually in both level and structure. It is a complex tariff with many subtle features not all of which will be explained here. The price per kilowatt-hour varies according to the time of day, with an off-peak rate in effect from midnight to 0800, a shoulder rate that applies at most other hours, and a peak energy rate that takes effect during the two half-hours of the actual system peak (retrospectively determined). Capacity charges are levied according to a complex formula that reflects both demand at the time of the generating system's peak as well as the area board's own peak demand. Area boards pay a basic demand charge, which is a rate per kilowatt of the area board's average demand during periods when the system is between 85 and 86 percent of its peak demand. The system peak demand is defined as an average of the three system peaks separated by at least ten days. A peaking capacity charge (rebate) is levied on the difference between the area board's basic demand and its average demand during the system peak demand. In addition there is an interruptible provision and until this year there was a very low night energy charge which had the feature of appearing as a negative marginal price.

The features of the Bulk Supply Tariff are much more important when considering the way area boards formulate their industrial tariffs than when considering residential tariffs. It is of interest to note however that the area boards will tend to behave as if they actually purchased power from a generating system with the cost characteristics defined by the BST.

**Residential Peak-Load Pricing**

In 1961[5] the area boards of England and Wales began an active campaign to promote the residential use of storage units for space heating. Radiators were supplied and metered on a separate circuit that was switched on by a clock control during hours of low system loads. These early storage units required a three-hour afternon boost which was beginning to cause problems by the late sixties. In 1969 a new tariff called the White Meter Tariff was introduced by all area boards which offered only an eight hour off-peak period. The previous restricted hour traffic with the afternoon boost was not available to new customers after 1970. Very recently a new tariff called the Economy Seven has been introduced which gives the boards more freedom in avoiding storage switch-on induced peaks.

In recent years the competitive advantage that electricity used to enjoy relative to gas and coal as a heating fuel has been eroded by the price of natural gas from the North Sea. This has caused area boards to closely examine the nature of their off-peak tariffs to ensure that they are as attractive as possible within the cost constraints.

## III Peak-Load Pricing in France

Immediately before nationalization there were about 1200 independent suppliers of electricity in France. The tariffs they had offered were often very inconsistent for similar customers in geographically adjacent locations. Tariff reform thus became an immediate and pressing task for the new organization (Electricite de France).

By 1955 EdF had developed marginal cost schedules, and in 1958 the Green Tariff was offered on an optional basis to high-voltage customers. After five years 88 percent of the eligible customers had selected it and by 1968 it was the standard tariff. During this period, uniform tariff increases took place but maintained the original ratios between periods and voltage levels. A tariff review was performed in 1971-73 which left the form and structure unchanged but based the levels on the new computations of marginal costs.

**The Green Tariff**

The Green Tariff is so named because of the color of the original report. There are five time periods in which prices vary: winter peak, winter shoulder, winter off-peak, summer shoulder and summer off-peak. The energy prices are different in each period. In addition there is a subscribed demand charge which is based on a concept called reduced power. The consumer subscribes to a level of maximum demand in each of the above periods subject to not being allowed to subscribe to less in periods when system demand can be expected to be lower than in the peak periods. These subscribed demands are combined in a formula to get the reduced power on which charges are made. Within the above structure there are five different price schedules which the customer can choose among. These have different weightings of the demand and energy charges and are so structured that it is in the customers own interest to select the correct tariff. These tariffs are tailored for customers with load factors[6] of over 5500 hours, between 3500 and 5500 hours, 800 to 3500 hours and less than 800 hours. There is one additional option designed for standby rates for emergency purposes which may be combined with some of the other tariffs. The Green Tariff contracts are for a five-year term, and the subscribed power levels apply for the duration of the contract. A customer's subscribed level may be increased at any time, in which case the new levels are binding for five years. If, in a given month, actual demand exceeds the subscribed level, the excess is billed at the rate of 70 percent of the annual charge per subscribed kilowatt. If the customer exceeds subscribed levels by a substantial margin, EdF will automatically increase the subscribed levels in the contract, thereby penalizing the customer for future years. In addition EdF maintains the right to install circuit breakers to limit actual demand to no more than 10 percent more than the subscribed level.

Unlike the Bulk Supply Tariff in England and Wales, which is wholesale tariff under which distributors buy electricity for resale to residential customers, the Green Tariff plays no direct role in residential rates. However, EdF does claim to use the hypothetical situation where the Green Tariff is used as a wholesale rate in forming the Universal Tariff.

**The Universal Tariff**

The reform of the lower voltage tariffs in France was a much more difficult task than that associated with formulation and introduction of the Green Tariff. The fact that only about 115,000 customers are on the Green Tariff compared with a potential 20 million for a revised low-voltage tariff is one reason. In addition there were numerous legal constraints on the relationship of any new tariff to the old one in terms of price level. This necessitated careful design and numerous compromises. After 5 years of work the Universal Tariff was introduced on an optional basis in 1965.

The previous tariff structure can only be described as a mess. Different uses were billed at different energy rates involving a multiplicity of meters and circuit-breakers. The new tariff sought in general to employ a single rate per kilowatt-hour but to differentiate the demand component according to use (and hence statistical diversity). This was done by extending the notion of subscribed demand enforced by a circuit-breaker. Circuit-breaker capacities can be subscribed at various fixed levels and a statistical relationship between this level and the expected uses is used to compute the charge. This does violate some of the objectives of presenting the consumer with individually correct incentives, but the simplification seems to be more than worthwhile. For all except the largest levels of subscribed demand the subscribed level is recovered largely thorugh a declining block structure where the blocks are determined by the subscribed demand.

In addition to the standard tariff there is an option offered to the Universal Tariff called the "double tariff". This allows cheaper energy charges between the hours of 2200 and 0600 but involves an increased fixed charge to cover the additional costs of a day/night meter. About 18 percent of all customers on the Universal Tariff have found it advantageous to take this option, and as expected, these are principally those with both storage space-heaters and water-heaters.

## IV Summary

Some form of peak-load pricing has been practiced in Britain and France for the last several decades. While the greatest gains in terms of cost saving have taken place at the industrial level, both countries have found it profitable to extend some form of time-of-day tariff to the residential consumer. The major loads which have been modulated in response to these price signals are those associated with storage heating. The storage devices are generally automatically switched on when the cheaper electricity is available. A recurrent problem which has prompted large numbers of thermostatically controlled loads are initially switched on. Staggered time periods are used in the newer tariffs to alleviate this problem and to avoid artificial system peaks. The French do not seem to be bothered by this problem at present.

## Bibliography


Walker, David L. 1975, *Design of Electricity Tariffs in England and Wales and Experience in Their Application.* In C.J. Cicchetti and W.K. Foell, eds, Energy Systems Forecasting, Planning and Pricing, Madison: Institute for Environmental Studies, University of Wisconsin.

——————, 1975, National Report for the United Kingdom, UNIPEDE, Conference on Electricity Tariffs, Madrid.

Requin, Andre & Lorgeau, Jean. 1975, *Experience with French Tariff Structures: Technical Means for the Implementation of Tariff Structures,* in Cicchetti & Foell.

Lorgeau, Jean. 1975, *Tariff Framing for Low Voltage Supplies in France. Theoretical and Practical Aspects of Developing the Universal Tariff.* UNIPEDE, Madrid.

Rouchon, J. 1975, *Experience in Restructuring Low-Voltage Tariffs: The Problems Involved in Introducing the Universal Tariff in France.* UNIPEDE, Madrid.

Electrical Times, 1978, 1979, *The Electricity Supply Handbook.* IPC Electrical Electronic Press Ltd., London.


[1] The contents of this paper are drawn from a number of published British and French works as well as the Rand book cited below. In addition the author has had a number of conversations with the commercial representatives of the Electricity Council and English and Welsh Area Boards, as well as personnel from the Direction des Etudes et Recherches and Etudes Economiques General of Electricite de France. The major objective of the research which led to these contacts concerns industrial response to peak-load pricing, but more general tariff matters were discussed. The study of industrial response is funded by contracts from The Los Angeles Department of Water and Power, The U.S. Department of Energy and the Electric Power Research Institute. Naturally, neither the Rand Corporation nor any of its corporate sponsors are responsible for any views expressed in this paper and the author is solely responsible for errors of omission or commission.

[2] A significant portion of this paper has been drawn directly from "Peak-Load Pricing: European Lessons for U.S. Energy Policy"; by Brider M. Mitchell, Willard G. Manning, Jr. and Jan Paul Acton; published by Ballinger (1978).

[3] Houthakker, H.S. 1951. "Electricity Tariffs in Theory and Practice." Economic Journal 61 (March): 1-25.

[4] An additional reorganization of the industry appears imminent. Since the change of government, it is not clear what direction such a reorganization may take.

[5] The Eastern Area Board actually offered a tariff with a small night day differential in 1952 for those willing to pay the additional metering cost.

[6] In Europe, load factors are often measured in hours of utilization. To convert to the ratio more commonly used in the U.S. it is only necessary to divide by 8760.

# ELECTRIC SPACE HEATING IN WEST GERMANY

by

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## I INTRODUCTION

The Federal Republic of Germany (West Germany) covers an area only about 70% larger than that of the State of Illinois. Its population is approximately 60 million. Nearly 52% of its energy supply is based on oil, 95% of which is imported. Hardcoal supplies 17.8%; natural gas, 14.9%; browncoal, 9.5%; and other, 5.7% (in 1977).

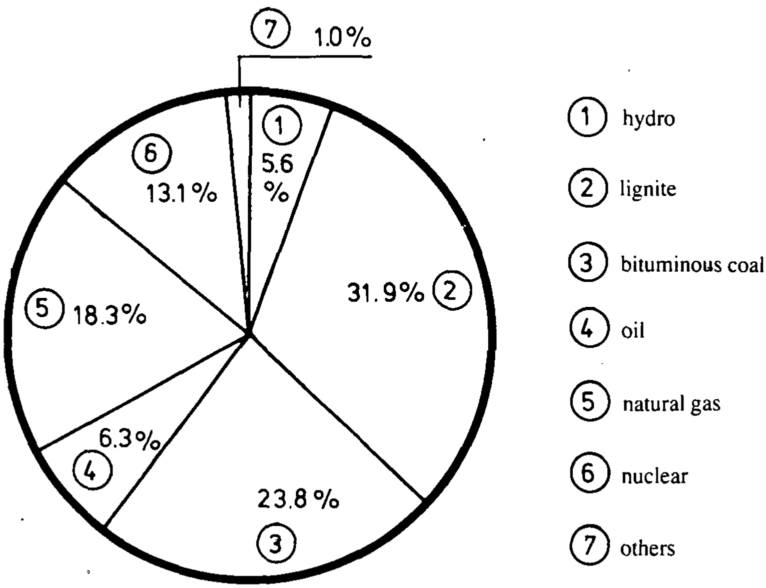


Fig. 1. Electricity Production by Fuel Type, 1977

Electricity is mainly generated from indigenous lignite and bituminous coal. About 15% is derived from nuclear energy. The net generating capability of the public utilities (excluding industry's captive power stations) amounted in 1977 to 67,000 MW (Fig. 1). The power supply utilities are not state-owned. Among their shareholders the municipalities and communities predominate. The largest utility in West Germany is Rheinisch-Westfälisches Elektrizitätswerk AG (RWE), Essen, which operates power plants and high-tension systems and supplies a very large area.

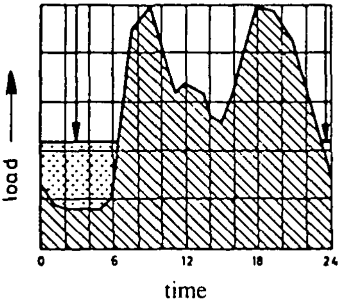


Fig. 2. Typical Daily Load Curve in the Mid-1950's.

In the mid-1950's, the peak-load in West Germany was around 12,000 MW. In winter, the daily load curve showed deep load troughs at night and in the early afternoon. Power stations were not optimally utilized (Fig. 2). (Air conditioning is practically insignificant in Europe and so the maximum load always occurs in winter.) It was at this time that the largest producer of electricity, Rheinisch-Westfälische Elektrizitätswerk AG (RWE), and other utilities gradually initiated practical trials of thermal storage heaters with the aim of improving utilization of the power stations. They had no idea what a rapid expansion in demand was to follow. In 1958 there were about 17 million households in West Germany, and it was reckoned that a market of at least 6% of all households must exist for thermal storage heating, i.e., 1 million complete installations. This was a target figure that appeared hardly attainable because initially it was extremely difficult to install even a few systems. Batch-produced heaters were not available. Each appliance was manufactured separately. Very low off-peak rates already existed, but heating with off-peak electricity was still much more expensive than heating with coal or oil (including the initial outlay).

RWE and other utilities installed, at their own expense, demonstration systems in households and schools and publicized the result in order to make the new technology known. An important step forward was the development of the fan-controlled thermal storage heater, which enables the heat released to be controlled as desired. A small manufacturer (Witte, Iserlohn) took up batch production and gradually a few hundred thermal storage heating systems were installed. The author, who at that time was responsible for thermal storage heating at RWE and who was chairman of the national committee established to promote thermal storage heating (HEA special committee), published almost three hundred articles at the time on this subject and presented just as many papers.

In addition to development work on thermal storage heaters, control equipment was developed for charging and discharging. The possibilities available to assure optimal thermal insulation of buildings were studied from the technical and economic aspects and specifications were drawn up on the correct dimensioning of the appliances and their proper use because setbacks were feared if errors were made.

Around 1960 a number of building companies in Berlin and Essen were, for the first time, prepared to equip large housing estates with thermal storage heating. The buildings received better thermal insulation than usual and were provided with double glazing. Technical and economic results were so good that this furnished the real breakthrough for thermal storage heating in West Germany. The experience gained and the efforts made by the authorities to alleviate atmospheric pollution in the cities induced the ministries in 1965 to recognize electric off-peak space heating as economic and suitable for use in subsidized housing. This led to a boom, particularly in the Ruhr area, but also in other parts of the country. Thousands of buildings and entire municipal areas were equipped with thermal storage heating.

Towards this end it was necessary to develop new cost-saving methods for supplying electricity to such housing areas. The local distribution networks have to provide about five times more electricity per household than in comparable housing estates without thermal electric space heating. This can be achieved with conductors of larger cross-sectional area and many small compact sub-stations. The installations of a distribution network providing about five times more electricity per household costs only about twice as much as a normal distribution network.

In some areas with a high concentration of thermal storage heating systems which originally could only be charged between 10 p.m. and 6 a.m., considerable effects were noted in the high tension transmission networks (110,000 V and 220,000 V) when night peaks were encountered. This is no problem as long as it is a local effect and as long as capacity is still available in the interconnected grid (380,000 V). On the other hand, it is necessary in such situations to provide large transformers solely for the supply of electricity for heating, or existing transformers have to be uprated and the costs involved are too high. It was for this reason, and especially in view of the situation in large housing estates, that the period 2 to 4 p.m. was additionally included for charging the storage heaters although at that time the network does not offer as much free capacity as at night. With ten charging hours the specific electricity demand of a household decreases, the local distribution network can be dimensioned for somewhat lower current capacity and load distribution in the high-tension network is improved—as long as free capacity is available in the afternoon.

Recharging in the afternoon also made it possible to adopt the principle of thermal storage floor heating. This is a very comfortable heating system which, however, requires a high degree of installation work as it has to be carefully adapted to the given circumstances. It is mainly for this reason that this system was not widely adopted in West Germany, just like the numerous attempts made with central heat storage systems (heat storage in water or solid blocks).

All the major manufacturers such as AEG, Siemens, Bauknecht, Stiebel and others had by then taken up the manufacture of thermal storage heaters in large production runs and promoted the sale of their products through intensive advertising. The appliances were of improved design and less expensive than previously and this led to a further increase in thermal storage heating which had now become a matter of course for many thousands of families.

## III MARKET DEVELOPMENTS

By 1967 only 1% of all West German dwellings were provided with thermal storage heating and both the power supply industry and the appliance manufacturers believed it would take many years to fill the existing load valleys. In addition, the commissioning of every new baseload power plant provides additional capacity for the connection of further thermal storage heaters. However, growth was much faster than anticipated. Especially at RWE, which had for many years made considerable efforts to promote thermal storage heating, the limitations became distinctly visible as early as 1970. The free capacity available at night was largely used up by thermal storage heating and in some areas, for instance in the Essen region, 10% of all households were soon heated with thermal storage heaters. In the early 1970's, RWE had to discontinue advertising thermal storage heating almost altogether while in other regions, where the sales promotion of this method of heating had not been as intensive, advertising was and will be continued.

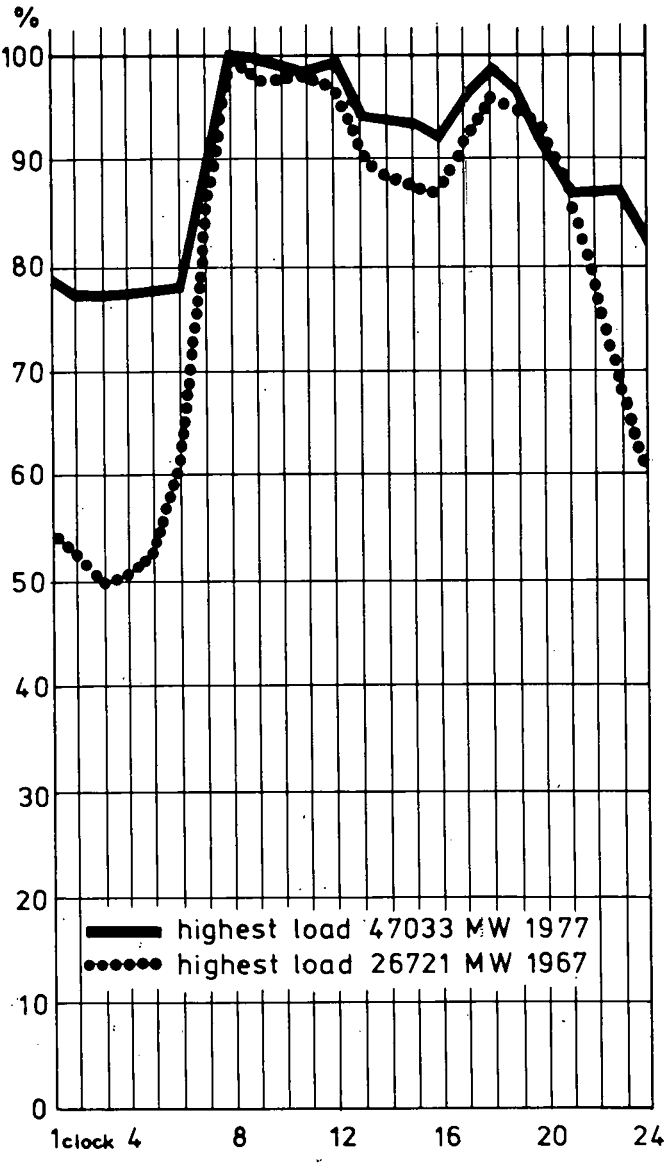


Fig. 3. Load Characteristics of Western Germany in Percent of the Highest Annual Load in 1967 and 1977 (VDEW).

In the entire territory of West Germany, too, it was found that the load valleys were quickly filled. Figure 3 shows a comparison of the situation in 1967 and 1977. In December 1967 load at night declined to 49.9% of the peak-load, but in 1977 to only 77%. While the load at night had almost tripled, the maximum day load was only 76% higher than in 1967.

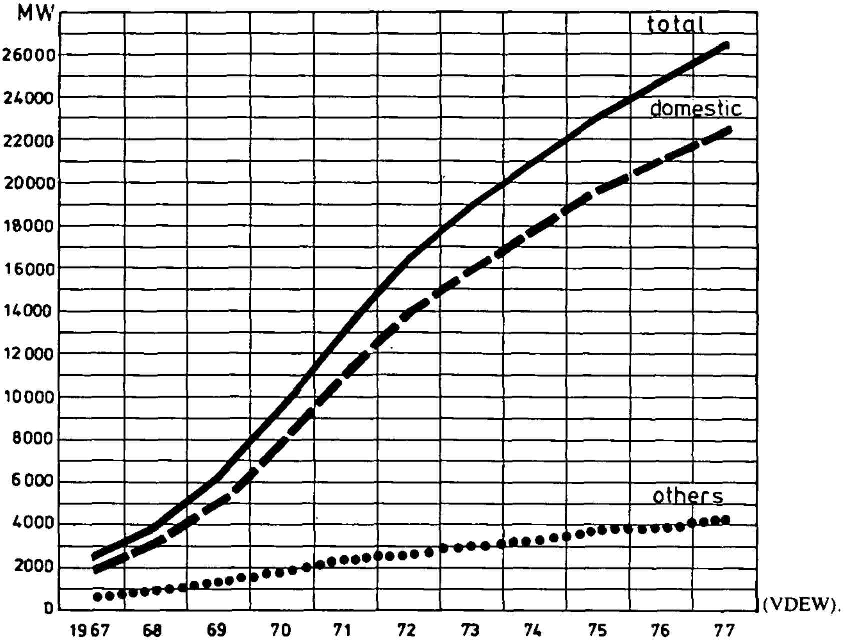


Fig. 4. Market Penetration of TES in West Germany

Naturally, considerable numbers of new thermal storage heaters and systems are being installed year by year and this will continue in the future. The governing factor is the annual increase in power plant generating capacity, about 50% of which can roughly be used for new thermal storage heating. One of the main problems facing the utilities now is to find the proper balance between the additional generating and transmission capacities and the wishes of the consumers. As a result of this trend, the growth rates for thermal storage heating declined somewhat from the mid-1970's as can be seen in Fig. 4. While the growth rates in the 1960's were 50% and higher, they are now approaching those for the general consumption of electricity. Nevertheless, 1,600 MW were added in 1977 for thermal storage heating and it can be expected that this rate of expansion will roughly continue. It should be noted that electricity growth rates today are of course smaller than in the 1950's and 1960's. For the next few years we anticipate in West Germany a general rise in load of annually about 5% corresponding to a growth in power generating capacity of about 3,500 MW (net generating capability in 1977 was 67,000 MW).

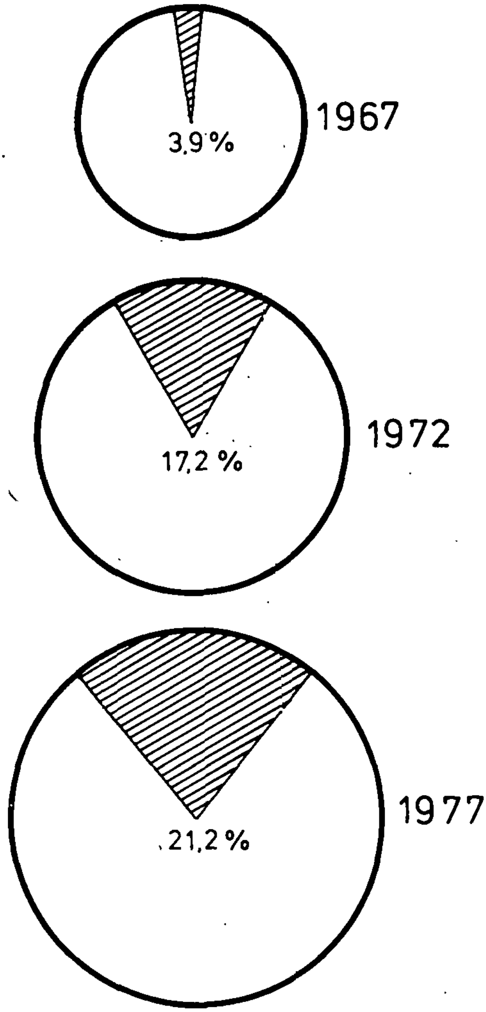


Fig. 5. Electricity Used for TES in Percent of the Whole Domestic Consumption in Western Germany (VDEW).

At 22,300 MW, households constitute the major share in thermal storage heating. In 1977 a total of 1.8 million or 7.4% of all dwellings had electric thermal storage heating. Of the rest of the connected load, agriculture accounted for about one-fifth; schools, churches and other public buildings for somewhat more than one-third; and trade and commerce for the remainder. In 1977 the share of thermal storage heating in the total electricity consumption of all households rose to 21.2% (Fig. 5).

If electric storage heating is divided into the various systems, it is found that thermal storage heaters designed for the separate heating of rooms predominate by far. Thermal storage heaters make up 93.9% of the entire connected load. Floor heating accounted in 1977 for 3.3% of the connected load. In addition, there are some combined heating systems which account for 2.8% of the aggregate connected load.

The consumption of electricity for electric thermal storage heating reached 18.3 billion kWh in 1977 and was thus 5.2% higher than in the preceeding year. The figure of 18.3 billion kWh corresponded to 7.2% of all electricity supplied by the supply utilities.

**Table 1. The Development of TES in West Germany***

| Year | Total Installed TES Load (MWe) | Number of TES Manufacturers | Production of TES Units ($10^3$Units) | Domestic Sales of TES Units ($10^3$ Units)** |
|---|---|---|---|---|
| 1960 | 100 | | | |
| 1961 | 300 | | | |
| 1962 | 500 | | | |
| 1963 | 800 | | | |
| 1964 | 1,000 | (No/Data Available) | | |
| 1965 | 1,500 | | | |
| 1966 | 2,000 | | | |
| 1967 | 2,350 | | | |
| 1968 | 3,800 | | | |
| 1969 | 6,200 | 21 | 547.2 | 545.1 |
| 1970 | 9,500 | 23 | 710.2 | 721.3 |
| 1971 | 13,200 | 23 | 861.6 | 783.5 |
| 1972 | 16,400 | 23 | 1,045.4 | 893.6 |
| 1973 | 18,800 | 23 | 682.1 | 500.7 |
| 1974 | 21,000 | 22 | 741.9 | 475.7 |
| 1975 | 23,100 | 19 | 560.4 | 439.1 |
| 1976 | 24,800 | 18 | 503.7 | 357.8 |
| 1977 | 26,400 | 14 | 531.9 | 404.4 |
| 1978 | ——— | 14 | 379.1 | 314.1 |

*Source: Hauptberatungsstelle für Elektrizitatsändwendung E.V. (HEA).
**Domestic Sales = Domestic Production + Imports − Exports

Obviously the manufacturers of thermal storage heaters were too optimistic in the 1960's in their view of the long-term prospects. Manufacturing facilities were established with capacity which was beyond that required to meet current demand, although such appliances were and are being increasingly exported to other European countries (Table 1). Some manufacturers have meanwhile discontinued production so that the recommendation should be made that manufacturing capacity should not be matched to the capacity available at night at the starting point but to the long-term growth in the general network load.

## IV Controlling TES Loads

In the early 1970's, the power supply utilities in Germany faced the problem of controlling the rate of growth in TES loads. It seemed appropriate for TES growth rate to equal approximately that of total system expansion. The legal status of this special supply of electricity furnishes a control mechanism. We use a special electricity supply contract (not a tariff) to which the consumer has no binding legal entitlement. When no network capacity is available for thermal storage heating or cannot be provided after the networks have been expanded, no such supply contract is offered. The prerequisite for the conclusion of such a supply contract is that an application is received for 30kW, for instance, for a single family home. The utility then looks into the question as to whether this capacity is available in the local distribution network and in the high-tension transmission network or whether it can be provided after system expansion, and then calculates an amount which the consumer has to pay as his contribution to the costs involved. Normally service connection costs of about $900 are incurred for the connection of a single family home with the usual electrification, that is without space heating. If the house is furnished with electric heating, the costs increase to about $1,400. These are only average figures, however. If a remote farm wants to install electric thermal heating and if an additional local network transformer becomes necessary or the cross-sectional area of the lines has to be increased, an amount of several thousand dollars may be involved which the consumer has to pay because the rate for heating current is so low (e.g. approximately 3¢/kWh and is not enough to cover investments by the utility in its networks.*)

The special supply contract for thermal storage heating naturally includes a price escalation clause in line with the price of bituminous coal.

It may be mentioned that numerous consumers use small convectors, radiant heaters or unit heaters for space heating (direct heating) under their normal household tariff. The general tariff terms in Germany stipulate that without any special agreement each household can make use of such heating appliances only up to a total of 2kW capacity. As the tariff rate is roughly twice as high as the off-peak rate, this type of electric heating fortunately is not of great significance especially since almost all houses and dwellings are provided with other comfortable and efficient heating systems operating mainly on oil or natural gas. However, if oil prices increase at a fast rate or in the event of an acute shortage of oil, it must be anticipated that such electric heaters will increasingly be used. This would have far-reaching consequences on the reliability of the power supply as loads are then liable to occur for which the capacity of power stations and lines is totally insufficient.

The German power supply industry is therefore endeavoring to ensure that the various types of electric space heating, i.e., direct heating, storage heating and heat pumps are employed in a controlled way so that sudden changes in consumer behavior, e.g., because of very low temperatures or changes in the energy market, do not lead to serious supply problems as occurred, for instance, in France early in 1979. This requires, however, that all sources of energy supply remain at all times fully operative and that sudden price increases as have just occurred for oil do not entirely upset equilibrium.

Let me now turn to the present energy situation which is causing a great deal of unrest in the world's energy markets and which is no doubt having and will have considerable consequences for heating with electrical energy.

After the first oil crisis in 1973, politicians in West Germany decided to substantially

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*At the time of the break-through of TES in Western Germany in 1963 prices were as follows:

| | |
|---|---|
| "off-peak"-electricity | (1.9¢/kWh) |
| light oil for domestic use | (18¢/gal) |

Today (July 1979) the equivalent prices are:

| | |
|---|---|
| "off-peak"-electricity | (3.2¢/kWh) |
| light oil for domestic use | ($1.12/gal) |

That is, the price of off-peak electricity has increased 1.6 times and the price of heating oil has increased 6.2 times over 1963 levels. The cost of TES heating is currently competitive with gas and oil and in the future is expected to be considerably cheaper.

reduce the country's dependence on oil—52% of West Germany's energy supply depends on imported oil—and to give priority to the use of indigenous coal and nuclear energy. It was at this time that in West Germany and its neighboring countries environmentalists and ideologists, who are against coal-fired power stations because of air pollution, more or less reject nuclear energy and hold that economic growth is wrong, began their activities. The power supply industry first thought to reduce this resistance by furnishing more information. In spite of all the efforts made, the energy debate has become more and more acrimonious. Ideological aims and unrealistic dreams (generation of energy from alternative sources) at present prevent realistic ideas from receiving priority and appropriate decisions for the future being made. This is due to the fact that the ruling coalition and the opposition are almost equally strong and both groups have to overcome considerable conflicts of opinion in their own organizations on questions relating to energy. Moreover, the environmentalists and similar groups have formd their own political parties so that the outcome of elections is more and more uncertain. The minimum consensus of national energy policy at present is roughly as follows:

1) Dependency on oil imports should be reduced (in fact, it is increasing).
2) Energy consumption should be reduced (in fact, it is increasing in all areas).
3) Electricity is to be preferably generated from coal (in fact, coal mining capacity can hardly be increased and environmentalists are against the additional burden of waste gas).
4) Nuclear energy should not be dispensed with (in fact, in political terms it is at present practically impossible to have a new power plant accepted).

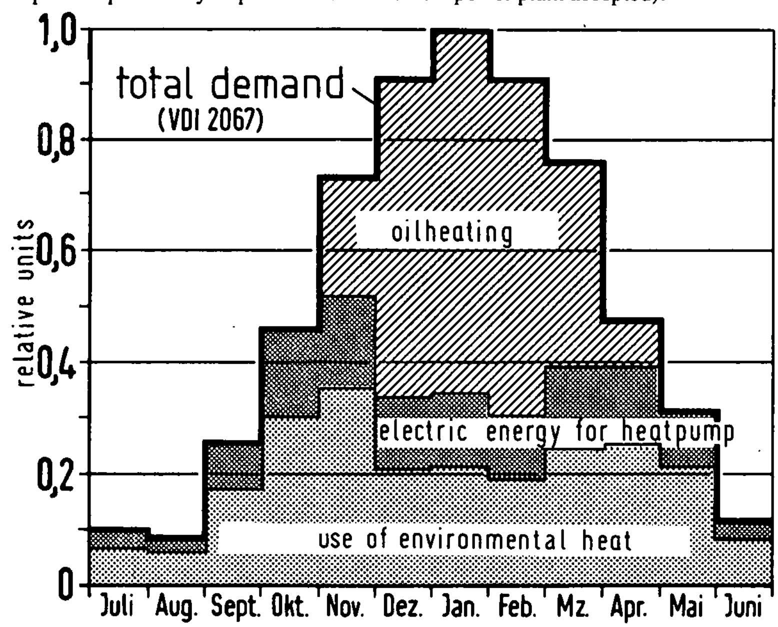


Fig. 6. Energy Consumption by a Bivalent Heating System

No one can say how these problems will develop in the next few years. In view of these circumstances the power supply industry has drawn conclusions for the heating of buildings. Apart from thermal storage heating, which will continue to have a substantial share of the market, the industry is promoting the use of the heat pump, particularly the dual-source heat pump. This means a combination of an electric heat pump system with a conventional heating system which is only used instead of the heat pump on very cold days (Fig. 6). Numerous appliances are available today from the manufacturers for a rapidly growing market.

The heat pump is designed to be able to meet the heat requirements of the building at outside temperatures down to about 3°C (37°F). In this range it is unsurpassed in economy. A single family home provided with good thermal insulation requires only a few kWh so that expensive supply networks are not necessary. Conventional oil-fired heating is then used only on about 20% of all heating days. The oil can be purchased at summer prices and coal can also be used. This combination of two heating systems is technically somewhat more complex than a standard system but offers overwhelming advantages in every respect:

1) The use of dual-source heat pumps in combination with oil-fired heating saves about 35% of primary energy compared with straight oil-fired heating and at the same time reduces the burden on the environment.
2) The heat pump as the electrical heating system is not in operation during the extremely cold weeks of the year when power stations have to supply the maximum load. While storage heating utilizes off-peak troughs, the dual-source heat pump utilizes free generating capacity outside the winter peak loads. It is thus possible for many such installations to be installed without it being necessary to build new power stations or high-tension networks which must be dimensioned to carry the annual maximum load.
3) To supply dual-source heat pumps, the local distribution networks need only carry 1/5 of the load required for the operation of thermal storage heating systems.
4) Oil consumption in the cold weeks of the year amounts to only 1/3 of the annual consumption of a normal oil heating system. This reduces the dependency on oil imports.
5) The operating reliability of two systems is better than that of only one system.

Now some remarks on the heat pump itself. Heat pumps are today available factory-made as standard models and are easy to install. There are three variants:

a) Ambient air as heat source (normal case);
b) The ground as source of heat (at a depth of 1.3 m pipes are laid over an area about three times the size of the housing area to be heated); and
c) Groundwater lakes or rivers as sources of heat.

In addition, it is possible to combine the heat pump with solar roof collectors for further recovery of heat and such combination already exists. Today this technology is by far not as important in practice in West Germany as electrical thermal storage heating but consumers, industry and politicians are showing increasing interest especially as a result of the most recent crisis in oil supply. Higher prices for primary energy will make this solution increasingly attractive for more and more consumers.

## V Summary

Electrical storage heating, especially in the form of standard fan-controlled appliances, has found widespread use in West Germany within a period of 15 years. It will enjoy a good market in the future, the volume of which will depend on the construction of new power plants.

The world-wide need to save primary energy, to make optimum use of existing power generating capacity and to reduce the burden on the environment will increasingly favor, as well, use of the dual-source heat pump system.

Finally, we shall also have to promote electric direct heating in the long run. This requires excellent thermal insulation of the buildings as in specific terms this is the most expensive electrical method of space heating because the consumer has to pay in full for all capital expenditure from the power plant to the service connection and for the cost of the energy supplied. Within a few decades it will no longer be possible to use fossil fuels for heating. Electric energy, and perhaps to some extent solar energy, will then be the only possibilities for heating buildings.

## References

Bortelmann/Flatow, *Handbuch der elektrischen Raumheizung*, 5, Edition 1975, 530 Seiten, Dr. Hüthig-Verlag, Heidelberg.

Stoy, Kalischer, Rinck, Eickenhorst, Schwindt, *Wärmepumpen, Nutzung der Umweltwärme zur Hausheizung*, 1978, 32 Seiten, RWE, Kruppstr. 5, 4300 Essen.

Kalischer, a.o., *Erfahrungen mit Elektro-Wärmepumpen zur Beheizung von Wohngebäuden*, 1978, 52 Seiten, Vulkan-Verlag, 4300 Essen.

Wehn, R., *Netzbau, Netzbetrieb und Betriebsergebnisse in Siedlungen mit elektrischer Speicherheizung*, Elektrizitätswirtschaft 1966, Heft 16, S. 515-518.

Piehl, E., *Essenber Oststadt- Siedlung Isinger Feld mit 1125 Wohnungen Allelektrisch Versorgt*, Zeitschrift Kommunalwirtschaft Heft, 2/1970, Deutscher Kommunal-Verlag GmbH, Dusseldorf.

# THE ROLE OF THE ELECTRIC UTILITY IN THE U.S. ENERGY FUTURE

by
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Last evening, President Carter outlined his new energy goals. These included (among many other things):

—A bold conservation program;
—Creation of an Energy Mobilization Board;
—A massive commitment of funds to develop oil substitutes from coal, oil shale, alcohol, unconventional gas and the sun, and
—A mandate that our nation's utility companies cut their use of oil in half and switch to other fuels, especially coal.

Anticipating the last point, several of my DOE friends have been searching in recent weeks for ways to encourage massive switches from oil-fired generation to other fuels. It is a baffling problem involving either—

(1) The abandonment of over 30 million kilowatts of oil-fired capacity, principally on the east and west coasts, and its replacement with nuclear or coal-fired capacity equipped with scrubbers, at a capital cost of up to $30 billion, or
(2) Switching half or more of our nations's oil-fired generation from oil to natural gas or synthetic fuels—again at many billions of dollars of capital cost if synthetic fuels are involved.

Either way, there will be difficult environmental issues to resolve—for neither coal-fired generation nor synthetic fuel plants are without their environmental impacts. Moreover, the whole operation will present enormous financial problems, particularly when only $5 billion is available to finance a switch.

For the latter reason, I intend to spend a good deal of my time this noon reviewing the financial problems of the U.S. electric power industry. In my opinion, these represent the most important of all constraints facing our industry:

—More important than environmental problems associated with coal-fired generation;
—More difficult to resolve than nuclear regulation and licensing delays.

My intention is, first, to review these financial problems in some detail and then, second, discuss conventional original cost utility rate regulation, third, its unsuitability in an inflationary environment and, fourth, what to do about it.

## I The Financial Problems Of The U.S. Electric Power Industry

The electric power industry is responsible for about one-fifth of all U.S. business plant investment and one-fifth of all new business plant construction. We require an even larger share of long-term financing—more than one-third of all new corporate financing by U.S. corporations other than financial and real estate institutions(over one-quarter by the investor-owned sector alone) and over half of all the new issue common stock. The figures for the last three calendar years are shown in Table 1.

**Table 1**

**Three-Year Annual Averages of Business Plant Construction Expenditures and New Money Financing**
(Billions of Dollars)

| | Total Construction Expenditures | Total Long-Term Financing | Total New-Issue Common Stock* |
|---|---|---|---|
| | (A) | (B) | (C) |
| Electric Utilities: | | | |
| Investor-owned | $ 20 (15%) | $12 (28%) | $3.6 (51%) |
| Government and co-ops | 8 | 5 | —— |
| | $ 28 (20%) | $17 (40%) | $3.6 (51%) |
| All other (except financial and real estate institutions) | 109 | 26 | 3.5 |
| Total | $137 (100%) | $43 (100%) | $7.1 (100%) |

*Included in column (B).

Note: These figures have been revised recently. Previously I have used somewhat lower estimates of the electric utilities' share, viz., 36% of total long-term financing and 50% of total new-issue common stock.

These figures are extremely large. But estimates for the next 15 years, 1978 through 1992 inclusive, are larger still. For this period, construction expenditures by the U.S. electric power industry, public and private, are estimated at $850 billion while our industry's new money needs will be in the $500 to $600 billion range. These average out to roughly twice current levels—over $50 billion a year of new electric plant construction and $35 to $40 billion of new outside financing annually.[1] This suggests that during the next decade and a half, U.S. electric utilities will continue to be responsible for at least one-third of all corporate financing, excluding that done by financial and real estate institutions.

The U.S. electric power industry's financing requirements now approximate one percent of GNP compared with only half a percent a decade ago. This increase in demand for capital funds is particularly significant—and disconcerting—in view of the increasing competition for such funds. This is further aggravated by the fact that corporate income taxes are levied on apparent rather than real earnings. The resulting overstatement of taxes during periods of inflation significantly reduces capital formation, according to Martin Feldstein and Laurence Summers of the National Bureau of Economic Research.[2]

**Lagging Savings Rates (Table 2)**

Compared with other industrialized countries, the rate of gross savings in the United

States is a relatively low 14% to 15% of GNP. On the other hand, since 1960 such rates for other industrialized nations have ranged between 20% and 37%. These foreign competitors of ours have modern industrial plants—in many cases, more modern than ours.

**Table 2. Savings Rates as a Percent of GNP**

| | |
|---|---|
| United States | |
| 1950-54 | 15.1% |
| 1955-59 | 15.6% |
| 1960-64 | 15.3% |
| 1965-69 | 15.8% |
| 1970-74 | 15.1% |
| 1975-78 | 14.0% |
| Other Nations—Range of Annual Savings Rates 1960 through 1978 | |
| France | 20 to 26% |
| Germany | 21 to 27% |
| Japan | 29 to 37% |

A few years ago, my friend, Mike Tenenbaum, retired President of Inland Steel, visited two Japanese steel plants. He compared one of them to Inland's Indiana Harbor Plant located near Chicago—a plant which, in several recent years, has produced more tonnage than any other U.S. steel mill. According to Mike, one of the Japanese plants (Nippon Kokan Keihin) in many ways was quite similar to Inland's Harbor Works:

—It was about the same age.

—It was located about the same distance from downtown Tokyo as the Harbor Works is from Chicago's Loop.

—It was about the same size as the Harbor Works. It was equally modern, in fact, the Japanese plant probably had a slight edge over the Inland plant.

The principal difference between the two, according to Mike, was that the Japanese plant had been declared obsolete and many of its major units abandoned—replaced by a brand new plant (Nippon Koken Ogishima) which is more environmentally acceptable and more efficient.

If we in the U.S. are to remain competitive, we have our work cut out for us. Clearly, our manufacturing industry will require substantially larger capital funds in the years ahead. All of this suggests that the U.S. electric power industry will have difficult sledding.

### Decline in Attractiveness of Electric Utility Securities

The electric power industry is at a growing disadvantage in its ability to attract capital. Throughout the last decade, there has been a steady reduction in electric utility credit standing. This, coupled with our industry's inability to offer a convincing outlook for future growth in earnings on common stock, has produced acute financing difficulties for many U.S. electric power firms. In my opinion, these difficulties are responsible for many of the recent deferments and cancellations of baseload generating facilities and for the lag in new orders for such facilities. Taken together these actions may jeopardize the supply of electric power in the late 1980's and early 1990's.

### Rating Reductions

The first three years of the 1970's saw reductions in credit ratings for about 30 electric companies. Nevertheless, as late as 1973 utility debt securities as a whole enjoyed relatively good ratings with roughly 90% of electric securities rated A or better.

Then came virtual disaster. In a single year, 1974, 43 major investor-owned electric power companies had their credit ratings lowered—30 by Standard and Poor's and 29 by Moody's—while only six such firms had their ratings raised.[3]

After 1974, the reductions continued, although at a more moderate rate. By 1978, the rate of decline appeared to have leveled off with increases matching reductions.

Nonetheless, things are far from what they used to be when AAA electric debt was the common synonym for a high-grade security. Today there are less than a handful of AAA electrics left. Moreover, with today's sharply rising interest rates and the resumption of coverage declines, the near-term outlook is not sanguine.

**Reduced Interest Coverages (Table 3)**

Before-tax interest coverage is defined as the number of time charges for debt service (interest and related items) are earned before provisions for income taxes. Prior to 1970, such coverages for high-grade electric utilities commonly ran in the range of four to five times higher. By the end of 1974, the average before-tax interest coverage of 128 major U.S. electric power firms had declined to 2.6, and even these low coverages included significant amounts of allowance for funds used during construction (AFUDC), a second-rate kind of earnings that do not provide cash which can be used to pay the interest it is supposed to "cover."[4]

While there was a temporary improvement in fixed charge coverages for our industry after the 1974 low point, the ratios have again declined in recent months and the decline now appears to be accelerating with the onset of higher interest rates.

**Table 3. Pre-Tax Interest Coverages for 50 Large Electric Utilities[5]**

| | |
|---|---|
| 1967 | 5.1 |
| 1968 | 4.7 |
| 1969 | 4.0 |
| 1970 | 3.3 |
| 1971 | 3.1 |
| 1972 | 3.0 |
| 1973 | 2.9 |
| 1974 | 2.6 |
| 1975 | 2.7 |
| 1976 | 2.8 |
| 1977 | 2.9 |
| 1978 | 2.85 |

Today, a number of firms in our industry have before-tax coverages significantly below three and are approaching the limit below which they can no longer issue bonds under the terms of their mortgages.

Inflation is the primary cause of the foregoing coverage declines and rating reductions. However, the adverse effects of inflation are exacerbated by:

—Failure to earn a return on massive investments in construction work in progress (CWIP), totalling roughly $50 billion.

—Inadequate internal cash generation resulting from the need to pay virtually all earnings out as dividends, to make up for the industry's inability to offer even modest prospects of future growth in earnings and stock prices.

—The continuing need to sell additional common stock at frequent intervals in amounts aggregating roughly $4 billion a year.

Unfortunately, much of this new issue stock must be sold for less than book value. Indeed, a recent study by the First Boston Corporation (April 25, 1979), showed that the common stock of 75 selected investor-owned electric utilities had an average market-to-book ratio of only about 87%. Since most new issue common stock is sold at discounts of 10 to 15% below the market, this implies that many electric utilities are realizing net proceeds equal to less than 75% of book value on their common stock offerings.

In its December 1974 report to the Federal Power Commission on "The Financial Outlook for the Electric Power Industry," the Technical Advisory Committee observed, "When large amounts of new stock must be marketed at substantial discounts below book value, it means that the amount the investor has historically put in the business exceeds the market value of his investment. As a result, some potential new investors may wonder what will happen to the future value of their investments.

"Selling common stock at substantial discount below book value translates into a direct reduction in the average book value of shares outstanding. Since electricity rates are generally based on book value, any reduction of the book value of outstanding shares results in a direct loss of capital to earlier shareholders. It is, in effect, a form of consumption of capital. It is discouraging to new investors since it raises the possibility that they too may suffer future losses because of failure of the company to earn a sufficient return to assure the preservation of capital.

"In fact, unless there can be a sufficient increase in the return on common equity to compensate for the dilution in book value resulting from marketing new-issue stock below book, there will be a permanent reduction in the earnings and dividend growth potential for all common stock."

These observations are as true as they were four years ago when Jack Glover and I first drafted them.

In concluding this discussion of financial problems, let me observe that of all the constraints affecting future electric power supplies, the financial constraints are the most serious. In the last analysis, these are really a form of regulatory constraint, a product of regulatory lag enhanced by the inflationary environment in which we live. In order to explain why this is true, let me turn to my second subject.

## II The Nature Of Conventional Original-Cost Utility Rate Regulation

Public utility rate regulation in the United States dates back to the 1870's when the Supreme Court declared that the government has the power to regulate prices charged by those businesses which "stand in the very gateway of commerce."

Since then, the rate-making formulas which guide our regulatory bodies have gradually evolved. Today, most states and other regulatory jurisdictions follow rules which comport with the original-cost investment principles laid down by Justice Brandeis in his famous 1923 dissenting opinion in the Southwestern Bell Telephone Case. In essence, the original cost doctrine proposed by Justice Brandeis allows the utility to recover the cost of operating expenses and taxes incurred during a "test period," often one long expired, plus a return on the depreciated cost of its investment sufficient to cover interest expenses actually incurred and to maintain the market price of its common stock at a figure approximating book value, although that book value often represents dollars invested years before when the value of those investment dollars was considerably higher than it is today.

There is no doubt that Justice Brandeis was not thinking about today's inflationary conditions when he wrote his famous dissent. A close reading of his opinion makes it quite clear that he regarded the dollar as a stable unit of measurement whose value had considerable integrity. He was not living in an inflationary environment and his dissent did not deal with the matter. However, his original cost doctrine is being widely applied throughout the U.S. in today's inflationary environment. Indeed, the principal characteristic of today's public utility rate regulatory procedures is that they are rigidly formulated. Rates established thereunder are based upon outmoded test periods and plant investment costs incurred for facilities acquired or constructed years before. As a result, like the activities of Alice and the Red Queen, regulatory proceedings today have a dream-like quality and often seem strangely unrelated to the real world.

## III Unsuitability Of Conventional Original-Cost Rate Regulation To An Inflationary Environment

Utility rate regulation, as it is practiced in the U.S. today, particularly original cost rate regulation, works quite well under conditions where prices are relatively stable and construction delays, not inordinate. Even then, however, it tends to discourage new plant investment. This is because, even under relatively stable price-level conditions, rates established under original-cost rate regulation rarely cover marginal costs and, what may be more relevant, periodic *increases* in prices almost always fail to cover periodic *increases* in marginal costs. This tends to induce a mix of capital, fuel and labor inputs which involves less than the optimum proportion of capital. In other words, management tends to be induced by the regulatory constraint to *under*-invest.

This is contrary to the conventional wisdom which mistakenly holds the opposite view. The tendency of conventional public utility rate regulation to induce under-investment is sometimes referred to as the negative Averch-Johnson effect.[6] The negative Averch-Johnson effect is particularly noticeable in an inflationary environment. Indeed, original-cost regulation was not designed for conditions like today's double-digit construction cost inflation coupled with decade-long (and ever-lengthening) construction lead times. Clearly, its long-run effect is discouraging the construction of high capital-cost facilities such as base-load generating plants today, and it will continue to do so. Indeed the negative A-J effect, so apparent today, seems to me to represent the most important of several reasons for the slackening of nuclear power plant expansion in recent years.

Why does conventional rate regulation discourage capital-intensive alternatives?

(1) **First, the rate of return allowed in rate cases never even approaches the marginal cost of money—even in normal times.**

Under conventional utility rate regulation, the rate of return allowed on plant investment is based upon average embedded costs of debt plus a bare-bones allowance for return on equity. Moreover, the actual earnings rates achieved during periods immediately following each rate case are almost always lower than those allowed because of the practice of trying rate cases and fixing electricity prices on the basis of historical test periods which are out-of-date before the rate order is signed.

Managers of regulated public utilities recognize this. As a result, they have little or no incentive to make any but minimal plant additions because the effect of each added increment of plant investment is to reduce earnings per share of stock. Only because of the legal requirements to provide adequate service are plant expansion projects authorized at all—and these are often financed with considerable difficulty.

(2) **Second, under original-cost regulation, the rate of return is applied to the historical cost of plant completed years ago. As a result, during inflationary periods, the resulting electric rates are always far below marginal costs.**

The net book value of Commonwealth Edison's 17,800 megawatts of electric generating facilities in service is about $150 a kilowatt. Even our nuclear generating facilities are carried on our books at a net figure of only about $160 a kilowatt.

These book figures are the only amounts included in rate base. They are substantially below the cost of a new plant. For example, our recently-completed oil-fired cycling capacity cost $258 a kilowatt. And the 6,600 megawatts of nuclear plant we now have under construction will cost nearly $800 a kilowatt—over five times the net carrying value of plant in service, either nuclear or fossil. And when all six of our new nuclear units have been placed in service, in the mid-1980's, our total investment in generating facilities will be $7 billion—nearly three times today's figure of $2½ billion after deduction of depreciation reserves.

Conventional original-cost rate regulation does not recognize new and higher construction costs until the related facilities are placed in service, perhaps years later. This substantially understates the true value of services provided, and tends to induce wasteful consumption—contrary to the objectives of the National Energy Act.

Understatement of prices and revenues also makes the financing of new long-lead-time facilities difficult.

Moreover, the wide disparity between the current costs of new capacity and the depreciated original cost of old capacity included in rate base gives both the public and the regulators an erroneous impression of the real cost of expanding electricity supplies—which will ultimately provide even further obstacles to the acceptance of needed new generation.

(3) **Third, under conventional rate regulation, as practiced in most jurisdictions, current rate levels do not reflect the large investments in construction work in progress, thus depressing real earnings and inhibiting financing.**

The $50 billion which the electric power industry has invested in construction work in progress now represents about 20% of the industry's utility plant investment.

We at Commonwealth Edison have $3 billion invested in such uncompleted construction, nearly a third of our total plant investment. This $3 billion is not included in rate base. Our customers pay no carrying charges on it. Instead, such carrying charges are capitalized through bookkeeping entries which credit earnings with something called, "allowance for funds used during construction." Such AFUDC credits represent second-class earnings which now comprise over 60% of our net income! They are not cash earnings. Instead, they represent hoped-for claims against future customers—to be collected over the thirty to forty year service lives of those facilities which are now under construction.

The immediate effect of the AFUDC approach is to hold down current rates, which is politically popular, but its long-run result will be higher rates in the future, due to the addition of large amounts of AFUDC to rate base. This will exacerbate future inflation and is likely to discourage further the investment in capital-intensive alternatives.

All three of these factors result in the main from the fact that conventional utility price regulation is unsuited to an inflationary environment because:

—it uses unrealistically low money costs, out-moded test years and prehistoric measures of plant investment values, and

—it disregards today's enormous investments in long lead-time construction projects.

Yet in today's environment, there are those who are grievously hurt by inflation—especially the poor and the aged. These necessarily seek relief wherever they can find it, and public utility rate proceedings represent one avenue which is open to them. However, public utility rates are not an appropriate vehicle for providing social welfare benefits. As Boiteaux once observed, these are matters for the legislature.

**The Consequences of Continued Regulatory Lag.**

If we do *not* succeed in controlling inflation, and if we persist in following inappropriate regulatory procedures, we will ultimately run out of cheap, abundant electricity supplies.

With orders for new nuclear units declining and with orders for base-load coal-fired operating units lagging, one must conclude that something is awry. I fear that a significant portion of that lag arises from a reluctance to commit large amounts of capital to a thankless endeavor. The ultimate result may well be failure to make timely decisions for installation of the more economic, but more capital-intensive, generating plants like coal and nuclear. Thus, we could well find ourselves dependent on scarce high-cost oil and gas for firing electric generation in the late 1980's, and to the extent this in turn runs afoul of national policy, we may find ourselves short on energy of any kind!

To sum it all up—conventional original cost rate regulation is inappropriate in an inflationary environment. It always results in inadequate rate levels. If electric rates persist at levels too low to enable us to finance needed electric plant expansion, we will have to cut back our construction program and ultimately run out of electricity. Then the government will have to use tax revenues to build the needed plant, and all of us will have to pay more taxes to make up for the failure to charge enough for electricity.

## IV What To Do About It? What Can We Do To Mitigate The Financial Problems Of The Regulated Electric Power Industry, Problems Which Arise From The Co-Existence Of Prolonged Inflation And Outmoded Rate Regulatory Procedures?

### Control Inflation

The obvious sensible solution is to get inflation under control. If that were done, solutions to many of our other problems would simply fall into place. However, this is easier said than done.

The sort of inflation we face today is different from what we studied in school. It has not been caused by material shortages or by overheating of the economy. Instead, today's inflation can be said to result from the institutionalization of expectations. More and more of our transactions are being covered by contracts or commitments (including the Social Security commitment) which provide automatic cost of living adjustments or other escalators. As a result, we now have a situation where inflation and unemployment can exist side-by-side. And the stubborn inflation which we have today seems peculiarly insensitive to general business conditions. Whether the outlook for the economy is good or bad, prices continue to rise.

In my opinion, we will only be able to slow down today's inflation when we recognize the need to improve overall productivity.

We must go forward with workable national plans to reduce oil imports, expand domestic energy supplies, apply strict cost-benefit tests to all forms of government regulation and otherwise improve productivity which is being stifled today by a growing burden of conflicting and often senseless regulations.

The application of cost-benefit tests to environmental, safety and other government regulations will be difficult, but such cost-benefit testing is essential if we are to mitigate the present inflationary spiral. Last year, 1978, compliance with environmental regulations (which were not in effect prior to 1969) cost the customers of Commonwealth Edison Company over $300 million, roughly one-eighth of total revenues. Moreover, such costs are expected to escalate sharply in the future as ever-more costly environmental controls are incorporated in new plants which are still under construction.

### Environmental Costs Often Exceed Benefits

The environmental statutes in America today are replete with the mandate to use "best available technology." Under this philosophy, businesses throughout the country are often required to incur environmental costs that are out of all proportion to the resulting benefits. Recently, we were forced to authorize a $200 million expenditure just to treat the run-off water from the coal piles, parking lots and station yards at a dozen of our fossil stations. This is a lot of money but we had no other alternative.

The essential problem is that most statutory references to the balancing of environmental costs and benefits seem vague and half-hearted. And those cost-benefit studies that are made are often overlooked or shelved.

Today, we as a nation seem bent upon an environmental protection course which can only be characterized as "Damn the expenditures, full speed ahead!"

At first blush, this may not seem totally bad. We Americans are noted for our determination to charge forward, regardless of the risk. However, there comes a time when we simply must ask where we are heading.

About a year ago, the Washington Post raised a warning flag. Here are three random and somewhat abbreviated statements from their April 5, 1978 editorial:

(i) ''environmental legislation . . . [is], essentially, a moral issue . . . But to say that is not a license to ignore the costs which have been rising steadily.''

(ii) ''Why is [economic productivity] . . . no longer rising as fast as it used to? There is now a good deal of evidence that part of the explanation is the large and rising investment in pollution abatement . . .''

(iii) ''Is that a reason for abandoning the environmental protections that have been written into the law over the past decade? Clearly not. But there is a certain danger . . .''

This morning, I will try to put a price tag on that danger—to estimate the costs of complying with those environmental rules which have been adopted since 1969, excluding however all such costs which would have been incurred in the normal course of business prior to 1969.

**Environmental Price Tag: $2 Billion Since 1969**

Here are the figures for Commonwealth Edison for the nine-year period, 1970-1978:

—We have spent over $600 million on facilities and equipment needed to comply with environmental rules.

—We have spent an additional $175 million to operate those facilities and equipment.

—We have lost about a half a million kilowatts of generating capability, worth $300 million, as a direct result of environmental restrictions.

—We have spent about $850 million to replace Illinois coal with low-sulfur fuels and to provide the fuel to power our pollution-control facilities and related items.

Thus, our environmental expenditures for the nine years total nearly $2 billion.

These figures are extremely large and there is little evidence that the resulting benefits are commensurate.

**Reasoned Approach Needed**

It is a shame that no comprehensive evaluation has been made of the benefits resulting from our nation's enormous environmental outlays. The only comprehensive study I have seen was made about two years ago by the University of Chicago and Argonne National Laboratory working together. That study showed the benefits resulting from power plant air emission control efforts in the Chicago area to be far less than the cost.[7]

In my opinion, it is time for a more reasoned approach to this whole area. Perhaps such expenditures should be required only where it can be demonstrated that the health and safety of the people are at stake.

It seems clear at any rate that, until we as a nation make a serious attempt to balance environmental costs and benefits, prices of all goods and services (including electricity) will continue to rise.

To sum up this matter of controlling inflation, it strikes me as unfortunate that we are unwilling to ensure the realization of our expectations for ever-higher living standards by increased productivity. Instead, we are prone to blame the other fellow and to let ourselves be guided into the cul-de-sacs of ''low growth'' by proponents of ''soft energy paths,'' while insisting, at the same time, that our incomes be continually adjusted upward so that we can acquire goods and services which in the past have been brought to us by making our traditional high-technology industrial machine work!

We cannot have it both ways, and if we try to do so we will find, as the Red Queen told Alice, that we must run very hard just to stay in one place.

**Rate Regulatory Reform**

While we are getting inflation under control, we must adopt new standards for the establishment of electric utility rates. These include (a) the use of forward-looking test periods as is now done by the FERC,[8] and (b) appropriate adjustments of rate base to reflect, in part at least, the effects of construction cost inflation—possibly, as a first step, including construction-work-in-progress in the rate base.

These two changes would help achieve one of the important objectives of the National Energy Act, namely the pricing of electricity at something more closely approximating long-run incremental cost. This would be eminently sensible from a national energy policy standpoint, as compared with today's regulatory procedures which substantially understate the real cost of producing electricity and thus encourage waste and make energy conservation more difficult.

These changes would also be sensible from a national economic policy standpoint. It is not inflationary to price electricity at its true cost, even if that means somewhat higher prices in the short run. This is because allowing utilities a minimum capital-attracting level of earnings will enable them to install the most efficient facilities which will,in the long-run, be the most economic. On the other hand, if electric rates do not recover costs, the unreasonably high amounts which electric utilities will have to pay to attract capital will discourage installation of efficient plant and equipment and will ultimately result in much higher electric rates, contributing to future inflationary pressures. Moreover, failure of rates to provide capital-attracting investment returns may prevent the installation of nuclear and coal-fired facilities and leave no alternative for the late 1980's or early 1990's but additional high-cost oil-fired generation—and the national imperative may then make that impossible.

An alternative course of action, not pleasant to contemplate, is that failing either to stop inflation or to adopt electricity pricing procedures which take account of inflation, our electric power firms will not be able to finance the needed expansion of electricity supply facilities.

The U.S. electric power industry is the most capital-intensive of all industries. Today it is taking about one-third of all the new-money financing requirements of the U.S. business sector, as shown in an earlier table. However, this portion cannot be maintained without adequate investment return. If the private sector of the electric power industry is to continue to attract this much new capital, there must be a clear prospect that an adequate return will be provided for the prospective investors. New capital funds cannot be conscripted in the U.S.—at least not yet.

Failure to provide adequate capital-attracting electric rate levels will mean that we must either finance our future electric supply facilities through taxes—in which case our tax bills will go up—or that we must go without the energy needed to maintain a healthy economy—which may be the course we ultimately choose.

In conclusion, let me remind you that ours is the only large nation in the world to have a privately-financed electric power system—except for Japan and the Ruhr Valley in Germany. All other nations have chosen to finance their electric systems with tax dollars.

If we as a nation are unwilling to pay as much for electricity as it costs to provide it, our needed electric facilities will have to be provided by government institutions and supported with increased taxes. Meanwhile, if inflation continues and electric utility earnings deteriorate further, I fear that we will enter the late 1980's short on electric supply facilities and then there will be a crash program to install additional oil-fired electric generation—which can only serve to further exacerbate our oil supply and balance-of-payment problems.

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[1]These estimates are based upon studies made three years ago. While there has been a moderate slow-down in the growth of electricity usage since then coupled with reductions in construction programs, these tendencies have been offset by higher construction cost escalation than had previously been assumed plus more costly environmental requirements. As a result, actual expenditures and financings in recent years have exceeded the estimates.

[2]M. Feldstein and L. Summers, "Inflation and the Taxation of Capital Income in the Corporate Sector," Working Paper No. 312, National Bureau of Economic Research, Inc., January 1979. For 1977, they estimated that inflation caused an excess tax liability of $32.3 billion on non-financial corporate source income, i.e. the income generated by non-financial corporations, their shareholders, and their lenders. "This excess tax on corporate source income was 54 percent of the corporate income tax liabilities of $59 billion and 35 percent of the combined corporate, shareholder and lender tax liabilities of $93 billion." (p. 28) Feldstein and Summers conclude that the effects of this inflation induced tax increase on the economy are the following:

1) A reduction in the rate of capital formation.
2) "A redistribution of investment away from the corporate sector and to residential construction and consumer durables." (p. 48)
3) "Within total corporate investment, existing tax rules will induce firms to invest more in inventories and less in equipment and structures." (p. 48)

[3]Report of the Technical Advisory Committee on Finance to the Federal Power Commission entitled, "The Financial Outlook for the Electric Power Industry," December 1974, pages 87 and 88.

[4]For some firms, AFUDC credits are not considered in computing the coverage ratio used to satisfy the requirements of the mortgage. For example, Commonwealth Edison's mortgage provides that no additional bonds can be issued if before-tax bond coverage, computed without regard to AFUDC credits, drops below 2.5.

[5]Source: Argus Research Corporation, "Argus Utility Scope," March 14, 1979.

[6]I lectured upon this subject at MIT nearly ten years ago. A paper based upon that lecture was published in 1971. See Gordon R. Corey, "The Averch and Johnson Proposition: A Critical Analysis," The Bell Journal of Economics and Management Science, 1971, pp. 358-373.

[7]The 1976 University of Chicago and Argonne National Laboratory study done under the direction of Dr. George Tolley showed that the benefits derived from Commonwealth Edison's expenditures of $117.4 million, primarily for low-sulfur coal, during the year 1974, amounted to only $57.5 million. We are nevertheless required under existing regulations to adopt ever newer and "better" technologies—and it is almost impossible to predict when the steady tightening of such requirements will taper off.

[8]18CFR Section 35.13

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## II. State -Of-The-Art Of TES Technology

# CONCEPT STATEMENT FOR DISTRIBUTED THERMAL STORAGE

by
James H. Swisher
Assistant Director
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U.S. Department of Energy

### Introductory Remarks

This morning we had the pleasure of hearing about the successful commercialization of customer side-of-the-meter thermal energy storage in Europe. This afternoon we will hear presentations on the status of advancing technology in thermal energy storage. Then tomorrow there will be sessions covering active demonstration projects, changes in electrical utility rate structures, and market projections for commercialization of thermal storage units in the U.S. From the point of view of the Department of Energy, this conference is very timely because it is being held at the same time that a commercialization venture is being considered seriously by the federal government.

The Department of Energy now has a well structured commercialization program under the direction of the Under Secretary. Our Deputy Under Secretary for commercialization, Jackson Gouraud, who had hoped to be here today, spends much of his time following commercialization activities. During the past several months, I have been privileged to chair a DOE task force on commercialization of customer side-of-the-meter thermal energy storage. Its purpose is to make judgments and recommendations on commercialization readiness. At the conclusion of the study, we will identify technical, economic, environmental, and institutional barriers to commercialization, and outline a federal program, if appropriate, to overcome these barriers. A publication is available on the first or concept phase of the study and the second or readiness phase is nearly complete. The remainder of the study will be completed in a matter of months and a final report issued. Our findings to date are the following:

- Cummulative oil savings of 40 million barrels of oil (0.2 quads) is possible by 1990.
- Payback times of 3 to 5 years for storage space and hot water heating are expected.
- Lower cost storage air conditioners are needed to reduce payback times.
- There are no serious technical or environmental barriers to commercialization.
- Electrical utility rate structures *must* be changed before large scale commercialization is possible.

After the task force completes the study, a decision will be made on whether to establish a DOE office and Resource Manager whose responsibility it is to implement a program to overcome commercialization barriers. Resource Managers have already been appointed in approximately a dozen areas, but this would be the first in energy storage technology.

In this afternoon's session, we will hear six invited papers. Two deal with storage air conditioning, two deal with storage heating, and the remaining two cover the scope of DOE's overall thermal energy storage program. I'm sure that each of the six speakers will have an interesting and informative message for us.

## I INTRODUCTION

More extensive use of customer-side-of-the-meter thermal storage (TES) in utility systems can beneficially alter the shape of the electric peak-load demand by filling the valleys in the daily load curves. These storage options consist of several low-cost methods of providing space heating and cooling or hot water to residential and commercial customers, while improving the utilities load curve. Installed on the customer's premises, TES systems store off-peak electric energy in thermal form for use during times of peak load. Significant national benefits can result from decreased consumption of premium fuels for peak power generation, more effective utilization of existing and new coal- and nuclear-fueled baseload plants, and possible reduction in the cost of electricity supply.

The benefits lie principally in the reduction in the use of premium fuels rather than reduction in the total energy consumed. The impact can be large where electricity is currently used for space conditioning and water heating. In addition, thermal storage can be used in combination with energy-saving devices such as heat pumps to achieve both kinds of benefits. These systems are also complementary to Annual Cycle Energy Systems (ACES) because the ACES store energy on a seasonal rather than daily basis. Since a large storage vessel is needed for ACES, it is more attractive for large buildings than for individual residences.

Timely commercialization of TES depends on the transfer of a large portion of the utility's storage-related benefits to the customer. Adoption of special electric rates or financing and/or ownership by utilities of the TES equipment are two possible strategies that could enhance the use of TES. Although utility ownership is feasible, the more likely path to increased use of TES is adopting new forms of peak-load pricing, such as time-of-day rates, demand charges and load management contract rates. All approaches require the approval of state regulatory commissions.

## II TECHNICAL DESCRIPTION

There are three candidate TES options for near-term commercialization:

- Electric Storage Heating
- Storage Air Conditioning
- Storage Water Heating

Optimal designs of these systems vary with climate, utility load characteristics, and thermal load characteristics.

**Electric storage heating** is a space heating system for buildings that incorporates, for example, resistively heated refractory bricks to store energy during off-peak hours for use during peak load hours. This form of space heating is widely used in England and Wales and in the Federal Republic of Germany. Based on European technology, TES for central furnace or individual room application is being developed and tested in the U.S. In a typical storage heating system, temperatures of the refractory brick or cast iron may reach 1200°F, but the insulated cabinet surface maintains a safe 140°F. Radiation from the cabinet supplies a continuous base heat output, while a thermostatically-activated fan exhausts air at 125°F to 140°F to maintain required temperature. Efficiencies for the heating system can be as high as 100 percent, if losses can be utilized to heat the residence.

**Storage air conditioning** systems being developed and tested in the U.S. incorporate ice storage tanks connected to the central air conditioning systems. An electrically driven compressor chills the water, forming ice, which acts as a heat sink for cooling purposes when the compressor is off. A water-level sensor controls the amount of ice formed to allow water to circulate fully for efficient heat exchange during the system discharge cycle. For residential applications, 150 to 300 gallons of storage capacity is required. Commercial buildings will need a larger capacity, and may use a chilled water rather than an ice-based system. Efficiencies for the cooling system can be greater than 90 percent, depending on the difference between day and night outdoor temperatures.

**Storage water heating** is another well-developed technology with extensive European use. Readily adapted to meet U.S. demands, these simple systems are currently being developed and tested in the U.S. While standard-size water heaters are usually adequate for interruptible service for four hours, larger, better insulated tanks are required for longer, diurnal storage applications. Water heater efficiencies approaching 100 percent are possible.

The following factors must be considered in commercializing these technologies:

- **Technical Risk** for TES is associated with equipment design and installation:
  —Design of reliable ice sensors and efficient ice making systems.
  —Compliance with standards for hot water heaters.
  —Lack of contractors' experience.
- **Economic Risk** to installation of TES mainly involves a rather long payback for storage air conditioning. Its economics are not as favorable as TES space heating or water heating.
- **Environmental Risk** of shifting to increased baseload capacity is a consequence of enhanced TES utilization. In addition, mining production of the mineral olivene, from which refractory bricks are made, would double U.S. production capacity. Storage air conditioning has the same risk of refrigerant leakage as any conventional unit. Land use considerations favor TES over competing options.
- **Institutional Risk** of installing TES involves five key issues:
  —Customer acceptance
  —Device control
  —Utility rates to encourage investment
  —Equipment certification
  —Limited number of vendors
  —Matching installed storage to the utility needs.

## III END-USE MARKET

**Table 1. Market Potential**

| | Estimated Capacity (GW) | | | |
|---|---|---|---|---|
| | 1976 | 1985 | 1990 | 2000 |
| Total Capacity* | 475 | 775 | 1050 | 1350 |
| Expected Growth | —— | 300 | 275 | 300 |
| Peaking Capacity* | 50 | 75 | 125 | 200 |
| New Peaking Capacity | —— | 25 | 50 | 75 |
| Penetration | | | | |
| Displaced conventional electric furnace demand | —— | 2-6 | 9-12 | 62-86 |
| Millions of installed customers | —— | 0.2-0.6 | 0.8-1.1 | 5-8 |

*Source: Based on data obtained from documents available from the National Electric Reliability Council (NERC):

1) "Seventh Annual Review of Overall Reliability and Adequacy of the North American Bulk Power Systems," NERC, July 1977.

2) "Fossil and Nuclear Fuel for Electric Utility Generation, 1977-1986," August 1977.

The potential market for TES are conversions from existing electric resistance heating systems, conversions from gas or oil where replacement of old equipment is necessary, and new homes. Estimates of the market potential for TES are presented in Table 1. While use of the storage devices in larger buildings is an attractive option, market potential estimates are not available for inclusion in the table.

Electric storage heating will serve electric space heating markets in service areas supplied by winter-peaking utilities, currently limited to the northernmost states. However, if the current trend toward electric heating continues, all areas of the country except the south eventually will experience peaks. Penetration will be greatest in those areas where oil and natural gas supplies are uncertain, unavailable or expensive. While deregulation of natural gas is permitting more new gas hookups than a few years ago, the total effect on market penetration of new electric space conditioning systems cannot be estimated at this time.

Storage air conditioning is applicable to markets where the utilities experience a summer peak. Penetration will be more rapid in areas with larger summer peaks, longer cooling seasons and a greater day-night temperature differential. Storage air conditioning can only be used on central air conditioning systems. Because of the need for large storage tanks, (a few hundred gallons for residential ice-making systems) the retrofit market may be limited.

Storage water heating will penetrate existing hot water markets, particularly in areas where oil and natural gas supplies are constrained. Current electric water heaters can be retrofitted for four hour storage capacity. Longer storage periods are only applicable to new or replacement markets.

Major competition for TES includes all utility storage options, solar energy, heat pumps and load management concepts, as well as conventional heating and cooling technologies.

The infrastructure for TES exists and is a complex system of distribution, local installation, financing and regulatory involvement. A classical example of marketing new technology, it involves extensive product information systems, national name brand reputations (i.e., Lennox, GE, Westinghouse), local business transactions, purchaser-obtained financing and local zoning and code regulations.

## IV CURRENT STATUS

Results of recent studies by Argonne National Laboratories[1] showed that TES systems were cost effective relative to conventional space conditioning and hot water equipment, but the benefit/cost ratios depend critically on the shape of the utility's seasonal and winter-peaking service areas. Storage was found to offer significant savings relative to conventional heat pump and direct resistance heating systems. Benefit/cost ratios for electric storage heating in these locations ranged from 3:1 to 6:1. Storage air conditioning is an effective load-leveling technology in summer-peaking service areas. However, the benefit/cost ratio, typically 1.6:1, is much lower than for storage heating. Storage water heating is cost effective in both summer- and winter-peaking service areas.

Examples of projected costs and paybacks for TES and representative competing technologies are shown in Table 2. These projections are estimates that will be refined during the next phase of the commericialization study.

**Table 2. Comparison of Customer TES and Conventional System**

| | Charging Capacity (kW) | Storage Capacity (kWh) | Installed Cost (June 1978 $) | Payback* Period (Years) |
|---|---|---|---|---|
| Central TES Heating | 25.0 | 140 | 1450-1750 | 2-4 |
| Central Electric Furnace | 15.0 | — | 600 | — |
| Central TES Cooling | 4.2 | 30 | 1950-2250 | 5-8 |
| Central Air Conditioning | 3.7 | — | 950 | — |
| TES Water Heating | 5.0 | 8 | 400-450 | 2-3 |
| Domestic Hot Water Heating | 5.0 | — | 160 | — |

*Payback Period = (Incremental Installed Cost)/(Levelized Utility and Customer Savings)

## V SUMMARY

Customer-side-of-the-meter TES consists of several low cost methods for providing space heating and cooling and hot water to residential and commercial customers. Utilization of TES could improve the electric peak-load demand, resulting in substantial national benefits, including:

- Decreased use of oil and natural gas
- More efficient use of coal- and nuclear-fueled baseload plants
- Favorable net environmental impact

All three TES candidates are in the demonstration phase of RD&D. While European experience is beneficial, some modifications are needed for utilization in the U.S. Electric storage heating will serve electric space heating markets where utilities experience winter peaks. Storage water heating is cost-effective in all service areas. The economics of storage air conditioning, applicable to summer-peaking utilities, is marginal except in a few service areas.

To realize the benefits from TES, key institutional barriers must be resolved:

- Certification procedures and standards
- Customer acceptance of TES
- Ownership of customer TES by utilities or consumer
- Approval of required time-of-day rates for TES
- Limited number of vendors
- Matching installed storage to utility needs.

Although minor concerns, other technical, economic and environmental issues that must be addressed include:

- Optimum design and installation
- Long payback for storage air conditioning
- Environmental impacts of increased baseload capacity and olivene production.

[1] Asbury, et. al., "Assessment of Energy Storage Technologies and Systems, Phase I and II," Argonne National Laboratories, for the Department of Energy, August 1976 and March 1978.

# AN OVERVIEW OF THERMAL ENERGY STORAGE FOR PEAK LOAD PRICING APPLICATIONS*

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## I INTRODUCTION

This paper discusses the application of customer-owned thermal energy storage (CO/TES) to utility load management. It addresses issues of concern to the potential customer faced with the decision of whether or how to utilize thermal energy storage devices in conjunction with heating and/or air-conditioning systems.

Four subject areas will be addressed, as outlined in Fig. 1: incentives, application options, system components subsystems, and the Department of Energy-Division of Energy Storage System's (DOE/STOR) program of technology development for thermal energy storage.

## II INCENTIVES

Incentives are required to induce utility customers to invest in CO/TES and to operate it in a manner which results in the achievement by the utilities of their load management objectives of oil and gas conservation and reduced cost of service. Four types of incentives which may be utilized are listed in Fig. 2. The most easily implemented and the one which will provide incentives both for investment and for operation is the utility rate structure. Utility rate structure options are described in other papers at this meeting. Other incentives include front-end subsidy by either the utility or by government (state or federal) in the form of tax subsidy, capital cost savings that result from the decrease in peak capacity requirement under some operating conditions, and such non-economic but important incentives as "conservation of natural resources" and "easing the energy crisis."

The magnitude of the rate differential between on-peak and off-peak rates, as determined by the utility rate structure, establishes the cost guidelines for CO/TES. This is illustrated by two simple examples shown in Fig. 3, one based on a differential energy charge and one on a differential demand charge. In each case, the value of CO/TES (expressed as installed cost) is \$10/KWH (\$3000/$10^6$BTU). Front-end subsidy or other capital cost savings would allow units costing even more than that to be economical. As noted, \$10/KWH is a reasonable cost for water storage.

The incentives must be sufficiently great as to overcome both economic and technological barriers as listed in Fig. 4. The two economic barriers, front-end cost and utility-controlled payback period, although related to each other, are perceived differently by different people, and thus either one can be a barrier. Overcomming the front-end cost barrier will be aided directly by a front-end subsidy.

*The Technology Barriers.* The newness of the technology and concerns about the effect on comfort will not be eliminated directly by providing incentives, but it is expected that the larger the incentive, the greater the interest in trying a new and possibly risky product. In addition, it is expected that educational and promotional campaigns will be carried out by the utility, by manufacturers of CO/TES, and by governmental and civic organizations.

* Research sponsored by the Division of Energy Storage Systems, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

## III APPLICATION OPTIONS

In order to have an impact on utility load management in the shortest time, it is necessary that CO/TES be utilized in a variety of customer applications. The options are summarized in Fig. 5. Application to both residential and commercial space heating and cooling, and to both new and retrofit systems will result in the fastest market penetration.

It is unlikely that a single TES technology or system will be optimum for all applications due to differences, for example, in storage temperature, in system size, and in the constraints associated with retrofitting. The temperature of storage will be dictated primarily by the limits of the heat source and the needs of the end-use system, with storage for radiant heaters, for example, requiring a higher temperature than storage for convective heaters. System size will affect the choice of storage technology in that larger systems (for commercial application) will tend to utilize the least expensive storage media, since the cost of the other components (container, insulation, controls) represents a smaller fraction of the total system cost. Retrofit of TES introduces special constraints including dimension and weight limits, and the need to match existing components (air vs hydronic, central vs distributed).

## IV SYSTEM COMPONENTS

Thermal storage system components include the storage medium, container, thermal insulation, heat transfer components (input and output), and sensors and controls. There are relatively few options in the selection of storage medium. Among sensible heat storage media, water, ceramics, and earth are potentially useful. Latent heat media include such phase-change materials (PCM) as ice, hydrated salts, and molten salts. There is an apparent thermodynamic advantage of using PCM in that storage is at constant temperature. However, because of the need for temperature differences in the input and output heat exchangers of any storage system, this advantage is only relative since it is always possible to design a sensible heat storage system with a total temperature drop equal to that needed for any given practical latent heat storage system. Differences relate to relative cost, size, simplicity, safety, etc.

Storage media (sensible and latent) have different practical operating temperature ranges as listed in Fig. 6 which limit their use to specific application systems. There are, for each storage medium, many design options for the associated system components. Thus, optimum systems using the same storage medium will reflect differences due to design innovations and operating and cost compromises with regard to the various design parameters; heat input and output rates; utilization of storage capacity, reliability, comfort, and retrofit constraints.

Latent heat storage devices using hydrated salts or molten salts have special problems and advantages. The problems include containment (encapsulation), heat transfer, and for specific salts, the problem of incongruent melting. Advantages of latent heat storage include reduced volume and weight.

CO/TES systems are currently commercially available or are being developed for all applications. Currently available are TES systems based on ceramic brick, and pressurized after or as storage media for use with resistance heaters for residential applications and systems using unpressurized water for commercial heating and/or cooling applications. However, even for those systems, cost effectiveness from the customer's viewpoint needs to be demonstrated under U.S. conditions, taking into consideration the rate structures and other incentives, installed cost including maintenance, climatic conditions, and comfort standards.

Systems under development include those for cool storage based on ice or hydrated salt as storage media and on water, molten salt, and earth for hot storage.

## V THE DOE/STOR PROGRAM

The Department of Energy-Division of Energy Storage Systems is sponsoring a program to develop thermal energy storage for building heating and cooling applications. A major element of that program is the development and demonstration of improved and advanced systems for application to off-peak electricity utilization. Figure 7 lists the goals of that program with regard to each of the storage media. During FY 1980, it is expected that work will be aimed principally in three areas: development of systems for residential cool storage (including improved systems using ice and advanced systems using other PCM) and the development of improved ceramic bricks for residential hot storage based on the use of resistance heat. In addition, smaller projects will address earth storage and water storage technology. In FY 1981, it is expected that the development of improved systems for water and ice storage for commercial building heating and cooling will be initiated.



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**THIS OVERVIEW WILL ADDRESS ISSUES FROM THE CUSTOMER VIEWPOINT**

- INCENTIVES
- APPLICATION OPTIONS
- STORAGE MEDIA AND SUBSYSTEMS
- DOE/STOR PROGRAM

*Research sponsored by the Division of Energy Storage Systems, U.S. Department of Energy under contract W-7405-eng-25 with the Union Carbide Corporation.

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Figure 1

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# CO/TES REQUIRES CUSTOMER ORIENTED INCENTIVES

- UTILITY RATE STRUCTURE
- FRONT END SUBSIDY
- OTHER CAPITAL COST SAVINGS
- NON-ECONOMIC INCENTIVES

Figure 2

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## THE MAGNITUDE OF THE RATE DIFFERENTIAL ESTABLISHES COST GUIDELINES FOR CO/TES

| ASSUMPTIONS | VALUE |
|---|---|
| \$0.015/KWH DIFFERENTIAL ENERGY CHARGE | \$10/KWH |
| 100 FULL TIME USES/YR | (\$3000/$10^6$ BTU) |
| 0.15 ANNUAL CHARGE | |
| \$4/KW-M) DIFFERENTIAL DEMAND CHARGE | |
| 5KW/40KWH STORAGE RATIO | \$10/KWH |
| 3 MONTHS/YR | (\$3000/$10^6$ BTU) |
| 0.15 ANNUAL CHARGE | |

(AT \$0.90/GAL, 300 BTU/GAL, WATER STORAGE COSTS \$3000/$10^6$ BTU

Figure 3

## INCENTIVES NEED TO OVERCOME CUSTOMER BARRIERS

- FRONT END COST
- LONG PAYBACK (UTILITY DEPENDENT)
- NEW TECHNOLOGY
- COMFORT IMPACT

Figure 4

## CO/TES IS NEEDED FOR A VARIETY OF UTILITY CUSTOMER APPLICATIONS

- RESIDENTIAL/COMMERCIAL
- HEATING/COOLING/COMBINED
- NEW/RETRO FIT
- SPECIAL REQUIREMENTS

Figure 5

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## STORAGE MEDIA DIFFER WITH RESPECT TO THEIR PRACTICAL OPERATING TEMPERATURE RANGE

| | | | |
|---|---|---|---|
| CERAMICS: | UP TO 1200°F | ICE: | 32°F |
| WATER: | 32–250°F | PCM: | VARIOUS |
| EARTH: | 40–150°F | | |

Figure 6

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## THE DOE/STOR PROGRAM AIMS AT IMPROVEMENTS IN EXISTING SYSTEMS AND DEVELOPMENT OF ADVANCED SYSTEMS

<u>IMPROVED SYSTEMS</u>

WATER
- MATERIALS OF CONSTRUCTION
- ANTI-BLENDING
- EFFICIENT CONTROL STRATEGY

CERAMICS
- LOWER COST (DOMESTIC) SUPPLY
- INCORPORATE HIGH TEMPERATURE PCMS
- INSULATION

ICE
- LOWER COST CONTAINERS
- MORE EFFICIENT ICE MAKERS

<u>ADVANCED SYSTEMS</u>

PCMS
- RESOLVE PCM PROBLEMS
- DEVELOP COST EFFECTIVE SYSTEMS
- DEVELOP COMBINED (H&C) SYSTEMS

EARTH
- DEVELOP TECHNOLOGY
- DEVELOP COST EFFECTIVE SYSTEMS

Figure 7

# CURRENT ACTIVITIES IN COOL STORAGE

by
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## I INTRODUCTION

Many northern electric utilities such as our have experienced load growth patterns that have caused some concern. Up until 1968 we were winter peaking, however, the winter peaks and the summer peaks were very close. The growth in both seasons seemed to be quite similar generally causing a leap-frogging situation where the winter's peak exceeded the previous summer's peak, etc. In 1968, our system definitely became summer peaking. It is interesting to note that our system load factor appeared to be at a maximum when the peaks were farthest apart. Weather sensitive loads such as air conditioning were seen as a major contribution to the change to summer peaking. In our part of the country air conditioning became a must for practically every small commercial customer during the 1960's. About the same time, residential air conditioning showed increased acceptance. Additionally, our Public Service Commission was advocating a concept of time-of-use or off peak rates. Since most air conditioning applications are basically on peak in character, we had two good reasons to look to stored cooling. Stored cooling possibly could provide a method of stunting the growth of summer peaks and provide the customer with a less expensive means of maintaining comfort when faced with time-of-use rates. In 1975, I was given the assignment of providing a simple, inexpensive demonstration of stored cooling for residential customers.

## II STORAGE SYSTEM DEVELOPMENT

In contemplating cool storage it became apparent that cool storage has a problem that heat storage does not. The purpose of TES is to control electrical demand by shifting the time energy is used. In the case of heat storage, a kWh moved from one period to another will require 3,413 Btu's of storage capacity. In the case of cooling, shifting one kWh requires 8,000 Btu's of storage capacity with an air conditioner with an EER of 8. In other words, load shifting using storage for cooling requires over twice the storage capacity as heating for each unit of electric load reduction.

The Milwaukee area has a relatively high humidity level in the summertime. After spending a few summers there, one could easily get the idea that the phrase, "It's not the heat, it's the humidity," originated in Milwaukee. Historically, our summer design conditions were 95F DB and 76F WB. Currently, we are limited to 89F DB by code. Many of our residential air conditioning users complained of lack of humidity control even though temperatures were well within comfort limits. Since water freezes at 32F, and water any warmer than 45F to 50F would be of little value in controlling humidity, the usable temperature range of water for cooling storage, we felt, was limited to 35F to 50F. Since our normal maximum day requirements may equal the equivalent of 8-10 hours of calculated heat gain, using water for off peak cooling could require approximately 800-1,000 gallons per ton of cooling load. This size storage device, we felt, was out of the question in the existing residential market. The existing home market is important because at the time less than 15% of residential customers had central air conditioning. The obvious option within the price and size constraint was to look to ice. Ice offered several advantages over water. The high heat of fusion of ice (144 Btu/1 lb.) coupled with only a 6F rise in water temperature (from 32F to 38F) reduces storage space requirements to 1/10 of that required for water. Less than 100 gallons of water, frozen into ice would meet the 8-10 ton hour/ton of load storage requirement. A second important advantage of using a phase change, is the availability of all the energy at a constant temperature. For humidity control, this is very desirable.

Thermal energy storage utilizing ice is an ancient practice. In northern climates, Mother Nature was utilized to freeze the ice in the winter. Ice formed on lakes, streams, and ponds was harvested by sawing it into blocks. The blocks of ice were then stored in heavily insulated "ice houses" to be used for domestic refrigeration of foods in summer. As late as the 1950's, some fishing resorts in northern Wisconsin still practiced this ancient art rather than use the more modern refrigerator. In some remote areas, it probably still is done.

In the twentieth century, with the advent of mechanical refrigeration equipment, "manufactrured" ice houses came on the scene. Water was frozen into ice using mechanical refrigeration and then delivered by wagon or truck to customers; "ice boxes" where perishable foods were stored. This industry still exists for the specialty ice products such as ice cubes or block ice for parties, picnics, campers, etc.

In recent years, there was renewed interest in the Annual Cycle Energy System (ACES), developed by Harry Fischer. This system utilizes an extremely large storage tank for ice; for a typical residence, approximately 1,800 cubic feet for static ice storage. The primary function of this system was to provide space heating in the winter by extracting heat from water turning it into ice. The ice is then stored to provide "free" cooling for the summer. This system appears to have great potential where the heating loads and cooling loads are so balanced to utilize the ice. In our part of the country, the heating load will provide enough ice to cool 7 or 8 residences. Further developments in the area of annual cycle or longer cycle systems led to the development of the ice maker heat pump.[1] The developments in these areas were not quite what we were looking for in our application of stored cooling to a residence.

We examined the current practice in the manufacture of commercial ice. Since the emphasis in this industry is more on production than on energy efficiency, some of the methods employed impose a considerable penalty on the energy efficiency if used for space cooling. The other area we investigated was the present practice of stored cooling utilized in many commercial establishments particularly in the mid-south area of our country. We found many commercial customers, particularly those with relatively large cooling loads for very short durations such as churches and theaters, using commercially-available ice makers for storage of air conditioning. We found several manufacturers active in this market for 40 years and more. The major reason for these installations was to conserve capital spent on refrigeration equipment by substituting ice banks. A typical example might be a church with a 100 ton cooling load for 3 to 4 hours a week. The installation may consist of 400 ton hours of ice bank storage and a 10 or 15 ton refrigeration machine. At the time many of these installations were made, the storage equipment was cheaper than the refrigeration equipment. Additionally, utility rates with demand charges provided a savings in operating cost when compared to a direct expansion system to do the same task. We found this technology to be well developed with adequate performance, but equipment size did not fit into the constraints imposed by application in the residential market.

Our solution was to build our own. Fifty dollars worth of copper tubing, a thirty-five dollar cattle watering tank, a few dollars worth of plastic plus a few evenings in the workshop produced our first ice maker. This ice maker froze water into ice in a cylinder around the evaporator rather than on plates as most commercial ice banks then available did. We found it was very easy to make ice. We found it not quite so simple to fully utilize the ice at a constant temperature. The concern that the commercial ice bank manufacturers exhibited in the design of their system's water circulating patterns to obtain uniform melting, appeared to be justified.

The horse trough ice bank was not acceptable as a piece of furniture in a customer's basement and the lack of uniform melting of this ice did not provide 100% capacity at a constant temperature as we had hoped for. The solution to both of these problems was solved simultaneously. Working with a local manufacturer of domestic water heaters, we had them build the same type of configuration for ice making as we had in our cattle tank, but vertically in a 120 gallon water heater tank. The appearance of this device was more acceptable to the residential customer. It could fit down a basement stairway. This vertical configuration also solved the problem of having ice in storage usable at a constant, low temperature approaching 32F.

In our experimentation, we found that the temperature drop across the cooling coil that would be placed in the plenum above the residential furnace to be 12F to 15F. This required a water flow rate of approximately 1.6-2 gallons per minute per ton of cooling capacity. Since the ice storage tank did not freeze solid, but only about 80% of the water is turned to ice, we still had approximately 20 to 25 gallons of water to circulate. Since our flow rate was less than 2 gallons per minute per tank, this means it would take 10 minutes to move that 20 gallons of water completely through the tank. This apparently is slow enough so that stratification in the tank was adequate so the discharge water temperatures from the bottom of the tank only varied 2 to 3 degrees to the point where the last pound of ice was melting. This made the entire quantity of ice available at a good temperature for controlling humidity. The stratification in the tank produced a second problem. We did not get uniform melting. Typically, we found the ice at the top of the coil melting faster than the ice at the bottom of the coil. We also found the system itself took care of this problem rather well. Ice is not a good conductor of heat. The transfer rate from the refrigerant to the water will vary inversely with the thickness of the ice. Consequently, ice build up will be the fastest where the ice is the thinnest and vice-versa. Numerous partial thaw and refreeze cycles showed only minor differences in the thickness of ice from top to bottom of the coil. At no time did we block the flow of water with excessive ice build up at the bottom of the coil. We felt the prototype was satisfactory for some home demonstrations.

## III APPLICATION OF COOL STORAGE TO RESIDENCES

In our investigation of applications of cool storage in residences, two concepts were envisioned. One would be a full storage system where the compressor would make ice in the off peak-period to provide air conditioning during the on-peak period. This would require adequate storage to carry the cooling load of the on-peak period and adequate compressor capacity to fully charge the storage in the off-peak period.

A second approach would be a partial storage system. This system would have a compressor of smaller capacity than would be used in conventional cooling coupled with a storage system that would be smaller than required to handle the full on-peak period. Typically, we might find the storage and compressor to be approximately one-half of the size required for full storage. With a one-half storage system, there is no potential for ever seeing the full cooling load no matter what control malfunctions or what the customer does.

One of the problems one faces in residential cooling loads is that they are unpredictable. While they are strongly weather sensitive, activity within the house itself can affect the requirements. An afternoon tea or a late afternoon cocktail party with 20 guests on the hottest day of the year could make the storage capacity of a full storage system inadequate for the peak period on that particular day, even though it may be adequate on any other day of the year. If the occupant of that house was operating a storage system because of an off-peak rate availability, he may very well override the control on the compressor in the middle of the afternoon of that hottest day to provide cooling for his guests and as a consequence the utility would see the same or possibly even a higher load than if that customer had conventional cooling. The result on the utility would be the negation of load shifting benefits offered in an off-peak rate. If the same situation occurred to the structure with a one-half storage system, there is nothing the occupant would do to change the loading of the compressor which would already be running. As a consequence, the utility is assured to never having more than one-half as much load as a conventional air conditioner. The axiom "the best control of demand is control of connected load," is valid.

Though in the unusual condition cited, the one-half storage system may cause a slight temporary amount of discomfort from an occupant's standpoint, there are other advantages to the one-half storage system, particularly if it is to be controlled by radio or some other utility load management device. When the full storage system runs out of ice, there is absolutely no cooling available. When a partial storage system runs out of ice, there is still approximately one-half cooling capacity available. Since the storage on that special day would probably be exhausted by late afternoon, the partial capacity could provide some comfort until the weather sensitive portion of the cooling load disappears or the party is over. The partial system also has an advantage of having a lower first cost.

## IV ENERGY SAVING POTENTIAL WITH COOL STORAGE

At first glance, it would appear that cool storage would require more energy than cooling a structure in a conventional manner. In making ice, one encounters lower suction temperatures than one experiences in direct expansion cooling. There is a pump for circulating water that is not required in conventional cooling. The thermal storage device itself certainly has some losses. First appearances, however, are not necessarily so. If we are to do off-peak cooling at night for day time cooling loads, our ice maker will encounter lower condensing temperatures than conventional cooling. If we substitute a 25F suction temperature for the conventional 45F suction temperature, but the nights are cool enough to lower our condensing temperature from 115F to 90F, application of the theoretical limits of the Carnot cycle gives us the following results:

Conventional C.O.P.

$$\frac{505}{575 - 505} = 7.21$$

Storage C.O.P.

$$\frac{485}{550 - 485} = 7.46$$

Thus, we see that the theoretical availability of C.O.P. is not significantly different. In fact, Richard P. Bywaters and Jerold W. Jones [2] of the University of Texas at Austin predicted that in Austin, Texas an "estimated 10% reduction in air conditioning energy would result from the more efficient nighttime/daytime operation of AC/TES system."

It must be remembered that thermal energy storage generally is not an energy saving tool but a load management tool. Utilities recognize that not all kWh's are created equal. Cool storage was investigated to optimize this inequality. For summer peaking utilities, a break even on energy or a slight increase in energy for cool storage would be acceptable in light of its load management, peak shaving capabilities.

## V EARLY UTILITY DEMONSTRATIONS

We welcomed the opportunity to install a residential cooling system utilizing chilled water instead of direct expansion refrigerant. Since humidity control in our climate is a primary concern, we felt a lower cooling capacity and lower discharge temperature should reduce humidity in the home. With chilled water, this could easily be accomplished by reducing the fan speed enough so that the total cooling capacity was well below the design cooling load of the home. We accomplished this by installing a two-speed fan motor in the home's existing furnace, along with a thermostat with two stages of cooling. The furnace fan's speeds were chosen so that the high speed would provide the design cooling load capacity and the low speed would be well below that. When the thermostat first called for cooling, the water pump would be turned on along with the fan in low speed. If the house still experienced a rise in temperature, the second stage of the thermostat would close, changing the fan from low speed to high speed. When the second stage of that thermostat would be satisfied, the fan would revert to the low speed continuing to provide cooling and humidity control without overcooling the home. If the lower fan speed could satisfy the cooling load of the home under certain conditions, this method of control would provide longer running time than experienced in direct expansion systems with an associated improvement in comfort.

In 1975, we discussed the idea of residential stored cooling with many utilities around the country. Several showed great interest. The manufacturer who built the first prototype tank built another dozen. These were purchased by utilities from Austin to Boston. In April, 1976, we presented a paper on our work to the Conservation and Energy Management Conference of the Edison Electric Institute in Washington. The summer of 1976 saw residential cool storage activities in Boston, Milwaukee, Toledo, Indianapolis, Green Bay, Philadelphia and Austin, to name a few. A 1977 survey showed 24 utilities with cool storage projects. The two residential installations we made in Milwaukee were in operation for the summer of 1976. The first summer's performance of the two installations in Milwaukee is reported in Appendix A.

## VI MANUFACTURERS' ACTIVITIES

This activitiy by utilities encouraged one major air conditioning manufacturer to build 50 prototype ice storage tanks. Approximately one-half of the tanks were purchased by utilities and installations made.

## VII ELECTRIC POWER RESEARCH INSTITUTE PARTICIPATION

In 1976, the Electric Power Research Institute (EPRI) commissioned the Carrier Corp. to select 20 existing cool storage installations and completely monitor them to assess performance as well as utility impact potentials. Twenty of these installations are being monitored during the summers of 1978 and 1979. These monitored installations are basically residential and include some of the early utility experiments as well as installations utilizing the manufacturers' ice tanks. At this time, only preliminary data on this effort is available with a complete report expected this fall.

## VIII PERFORMANCE OF COOL STORAGE

Appendix A shows the electrical load profiles of a house with conventional cooling, the same size house with a half-storage system and the same size house with full storage. There is no question that our installation is demonstrating that comfort can be maintained and the air conditioning load shifted. While other factors do affect comparative temperature in a home, these figures tend to show that the two stage systems used on the storage devices have the capability of improving humidity control within a home.

## IX CUSTOMER ACTIVITIES IN STORED COOLING

As stated earlier, stored cooling for commercial customers has been practiced for many years. The trend towards time-of-use, load management or off-peak rates as well as utility demand charges has renewed interest in this practice. Equipment is still being manufactured for this market. Some of these installations involve a partial storage system where a compressor is utilized day and night. At night, ice is made or chilled water is stored for handling cooling loads the following day. In many installations, the compressor is also required but is supplemented by the storage. The papers, "Thermal Storage: It Saves, and Saves, and Saves,"[3] by Robert T. Tamblyn of Ontario, Canada, outlines potential savings in utility costs offered by storage in commercial structures.

Presently, there are three of our customers, in addition to our own company, utilizing cooi storage. One of these is residential, the other two industrial. Two of these installations are for space conditioning, one is for process cooling. Our company's installation is in a district service center with 9,000 $ft^2$ of office space. A partial storage system is employed using a nominal 24 ton compressor and 3,000 gallon static ice storage tank. This system went into operation in August of 1978.

One of the customers employing ice storage has a large residence. His system consists of two ice banks and two three-ton compressors. These ice banks are two of the 50 manufacturers' prototypes. This customer was one of the first 500 of our residential customers put on time-of-use rates. The potential cost savings were secondary, however. This customer was very unhappy with the comfort level in his home with a conventional cooling system due to poor humidity control. The ice bank system was installed in place of a proposed chilled water system in order to provide better humidity control. He is now enjoying superior comfort at lower cost.

One of the industrial customers uses stored cooling for providing 32F chilled water for a process. The compressor is 120 tons with about 32 tons of ice storage. This customer is also on a time-of-use rate.

The third installation employs a 230 ton ice maker heat pump with a 12,000 $ft^3$ storage tank. The ice makers are located over the storage tank so the harvested ice falls in. This system is used for both heat and cool storage on a weekly cycle rather than annual or daily cycle.

For heating, heat energy is extracted from the water by freezing it into ice. Some of this ice is used for cooling loads in internal spaces. If necessary, ice is melted evenings and weekends by adding energy to the ice tank. A solar supplement for melting ice is planned. In the summer, the system operates as a stored cooling system, making ice evenings and weekends for use during the 9:00 AM to 9:00 PM on-peak period, Monday through Friday. Because this customer normally operates two shifts, the weekly cycle was chosen. This system went into operation about a month ago.

## X FUTURE OF STORED COOLING

TES of any kind has a very limited future without financial incentive. Much of that incentive will probably be in the form of off-peak or time-of-use rates.

The three customers of ours employing ice storage are taking advantage of these rates. Their installations, however, exhibit something more important. Storage devices, rate incentives, but most importantly, creativity, are necessary ingredients. Storage devices and rate incentives alone will do little to foster growth in cool storage without the designer's imagination in putting them to work.

## REFERENCES

1. *Thermal Storage Applications of the Ice Maker Heat Pump.* H.C. Fischer, ASHRAE Transactions, 1977, Volume 83, Part 1.

2. *Power Reduction in Air Conditioning Systems Through the Use of Thermal Energy Storage.* R.O. Bywaters and J.W. Jones, Center for Energy Studies, University of Texas at Austin, April 28, 1975.

3. *Thermal Storage: It Saves, and Saves, and Saves.* R.T. Tamblyn, ASHRAE Transactions, 1977, Volume 83, Part 1.

# APPENDIX I

## REPORT OF RESIDENTIAL STORED COOLING FIELD DEMONSTRATION — SUMMER 1976

For the field demnonstration of residential stored cooling, three identical homes were selected in the same neighborhood. All homes have a calculated heat gain of 19,000 Btu's.

In house #1, air conditioning was already installed. In this home we are only monitoring the operation of that air conditioning system.

In house #2, there is a half storage system installed consisting of one A.O. Smith storage tank and a 1-ton compressor-condensor unit. This compressor can run any time the ice sensor in the storage tank calls for ice-making. Since the furnace fan was multispeed, a 2-stage thermostat was installed. The thermostat's first stage will turn on the water pump and the fan in low speed. If that cannot satisfy the cooling requirements of the house, the second stage of the thermostat will put the fan in high speed.

In house #3, we installed a full storage system consisting of two A.O. Smith storage tanks and a 2-ton compressor-condensor. The compressor is timeclock controlled so that it can only run between 9 p.m. and 7 a.m. weekdays, and all day on Saturday and Sunday. This house also has a 2-stage thermostat and a 2-speed fan motor.

### PROBLEMS ENCOUNTERED

Only minor problems within the two homes with stored cooling were encountered. In the half storage house (#2) a control was miswired causing the compressor to run continuously and freezing the tank into a solid block of ice. No detectable damage resulted from the over-freezing. In house #3, with full storage, the compressor was unable to fully charge the tanks with ice in 10 hours. During a period of consecutive days of 90 degree weather, there will be adequate ice for cooling the first day, the second day there will be only enough ice to handle the house until approximately 8 p.m., and the third day the ice may be gone as early as 6:30 p.m On August 20, the timeclock controlling the compressor was reset to allow the compressor to operate for 12 hours per night rather than 10. This improved the situation, but did not relieve it entirely. Another solution would be to install a larger compressor. Present compressor capacity averages approximately 2/3 of nominal rating.

### INSTALLED COSTS

House #2 Half Storage

| | | |
|---|---|---|
| Material costs | Refrigeration | $458 |
| | Storage | 800 |
| | Electrical | 69 |
| Labor costs | Refrigeration | 374 |
| | Electrical | 85 |
| Total costs | | $1786 |

| | |
|---|---|
| Estimaed cost of conventional system | $900 |

| | | |
|---|---|---|
| House #3 Full Storage | Refrigeration | $528 |
| | Storage | 1600 |
| Material costs | Electrical | 90 |
| | Fan motor | 52 |
| Labor costs* | Refrigeration | 607 |
| | Electrical | 105 |
| Total costs | | $2982 |
| Estimated cost of conventional system | | $975 |

*Labor cost on house #3 is abnormal due to this being the first one of its kind, causing some confusion on the part of the workmen. There should be little difference in labor between full storage and half storage.

The difference between stored and conventional cooling installations appears to be the cost of the storage equipment plus about $100.

## OPERATING ENERGY

Test Period 7-16-76 to 9-10-76

| House #1 Conventional | House #2 Half Storage | House #3 Full Storage |
|---|---|---|
| 868 kWh | 501 kWh | 1383 kWh |

These energy consumptions are not indicative of the system's true comparison but rather of the occupant's use of the system. The house with the full storage system (house #3) leaves the system on and the thermostat set at 75 degrees at all times. The other two homes use cool evening air to cool the house when possible, and sometimes forget to start the system until the house becomes uncomfortable. The net result is the house with full storage has comfortable temperatures and humidities at all times; the other houses sometimes take overnight to reach the same comfort level.

Examination of a warm week's operation indicates the difference is barely measurable.

Week of August 20 to August 27, 1976. Daily highs were: August 20, 85; August 21, 86; August 22, 91; August 23, 78; August 24, 77; August 25, 80; August 26, 87; August 27, 96.

| House #1 Conventional | House #2* Half Storage | House #3 Full Storage |
|---|---|---|
| 247 kWh | 168 kWh | 277 kWh |

*During this week, the occupants of house #2 were on vacation and spent considerable time away from home. During those unoccupied periods, the thermostat setting was raised or the system was off.

Additionally, we examine August 27, which was our system peak day. (Twenty-four hours, midnight to midnight).

| House #1 Conventional | House #2* Half Storage | House #3 Full Storage |
|---|---|---|
| 46 kWh | 33 kWh | 48 kWh |

*Part of the vacation week mentioned above.

The conclusion seems to be that the difference in energy consumption due to storage is small; probably in the 5% to 10% range.

## TIME-OF-USE ENERGY

From July 16 to August 20 the measured on-peak period was 7:00 a.m. to 9:00 p.m., Monday through Friday, all other hours being off-peak. The distribution on the basis of energy used was:

| House #1 Conventional | House #2 Half Storage | House #3 Full Storage |
|---|---|---|
| 22% off-peak | 47% off-peak | 91% off-peak |
| 78% on-peak | 53% on-peak | 9% on-peak |

From August 20 to September 10 the measured on-peak period was 7:00 a.m. to 7:00 p.m., Monday through Friday. The distribution on the basis of energy used was:

| House #1 Conventional | House #2 Half Storage | House #3 Full Storage |
|---|---|---|
| 52% off-peak | 67% off-peak | 95% off-peak |
| 48% on-peak | 33% on-peak | 5% on-peak |

It appears from examining the demand charts that not allowing the system to operate with a constant thermostat setting on a conventional system moves some energy from the on-peak to off-peak period since the air conditioner is not able to completely "catch up" until late in the evening or early morning.

## COMFORT CONDITIONS

Dry bulb and wet bulb readings were taken in each home weekly. These readings were taken between 3:00 and 5:00 p.m., during the warmest period of the day.

| | | House #1 Conventional | | | House #2 Half Storage | | | House #3 Full Storage | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Outdoor Daily High (Dry Bulb) | DB | WB | RH | DB | WB | RH | DB | WB | RH |
| 7-23 | 96 | 84 | 72 | 57% | 84 | 72 | 57% | 78 | 65 | 50% |
| 7-30 | 86 | Vacation | | | 77 | 66 | 56% | 77 | 64 | 50% |
| 8-13 | 76 | 79 | 66 | 51% | 78 | 65 | 50% | 76 | 63 | 49% |
| 8-20 | 85 | 79 | 67 | 54% | 82 | 67 | 47% | 76 | 62 | 45% |
| 8-27 | 96 | 82 | 69 | 52% | Vacation | | | | 66 | 51% |
| 9-3 | 85 | 83 | 69 | 50% | System off | | | 76 | 63 | 49% |

The conditions in house #3 with full storage were the most consistent. This is primarily due to the difference in the occupant's use of the various systems. However, the multi-stage cooling offers the potential of better control as is evidenced by conditions on days in the 70's and 80's.

All of the homes had warm air heating systems with perimeter baseboard supplies and two returns each on inside walls. In the conventional house, both returns were combination hi-lows. In the two-stage homes, one return in each was hi-low, the other being at the floor. Stratification of cold air was not objectionable in any of the homes at any fan speed used.

## CONCLUSIONS

The demonstration has shown that stored cooling is a viable alternative for reducing the system peak caused by air conditioning. The economics at this point are questionable since not one mass produces the equipment and a time-of-use rate has not been approved yet. The demonstration also indicates an improvement in comfort with two-stage cooling on a storage system as compared to conventional on-off air conditioning.

# STORAGE ASSISTED AIR CONDITIONING USING A NEW LOW-COST PHASE CHANGE MATERIAL PACKAGING CONCEPT

by
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## ABSTRACT

The realization of the promise of storage-assisted air conditioning for saving oil and money is dependent upon the successful development of a low-cost storage subsystem and the adoption of time-of-day electricity rates. This paper will describe the development of a low-cost storage component for air conditioning systems. Time-of-day rates are currently under consideration or have been adopted in 27 different states and consideration of these rates has been required by federal legislation.

The adoption of this low-cost thermal energy storage technology for storage-assisted air conditioning and other storage-assisted heat pump applications has the potential of saving 100 million barrels of oil over the next ten years and 12 million barrels of oil per year by 1985. These savings would accrue from a shift of the summer air conditioning peak electricity load from oil- and gas-fired peak electrical generators to the base load electrical generators fired by coal, nuclear and hydroelectric.

This low-cost air conditioning storage concept is based on hydrated salt phase change material, specifically a mixture based on sodium sulfate decahydrate and a new low-cost packing technology which uses a film laminate as the phase change material mixture's package and heat exchanger.

In this paper, the relative economics of various technological options for air conditioning storage are compared. It is demonstrated that this economic analysis leads to the necessity to develop a low cost film package and heat exchanger. An analysis of savings to homeowners based on current and planned off-peak rates is included. Since this is the first product developed utilizing this new low-cost material as a packaging film, it is anticipated that major improvements in both cost and performance specifically related to individual systems will be developed and implemented over the next ten years, with significant improvements coming in the next several years.

## I THE NEED FOR STORAGE ASSISTED AIR CONDITIONING

Eighty percent of the electric utilities in the United States experience a summer peak. Summer peaks are largely due to the use of air conditioners, i.e., the air conditioner's compressor during the period from late morning to late afternoon on the hottest days of the year. Since this peak load can be experienced over as few as 15 days by many electric utilities, considerable capital investment is required just to meet this 15-day demand.

If a portion of this compressor load on the electric utility can be shifted to the off-peak hours, i.e., 9 p.m. to 8 a.m., the need for new electric generating capacity to serve this summer peak can be reduced.

Storage assisted air conditioning systems can operate by taking the building's heat gain durıng the day and exhausting it to storage. This heat is then discharged at night by operating the air conditioner and exhausting the heat to the outside. The exhaustion of heat from the house to storage can be by fan only, thereby allowing all air conditioning compressor operation to be done off-peak. The air conditioner will operate at a higher efficiency during the night, often as high as 15-30 percent, depending on the lower nighttime temperature.

The adoption of this storage air conditioning technology could save an electric utility as much as $36-48 million in capital investment over the next ten year period. This is based on a typical utility with a shift of 150-200 mWe affecting 35,000 customers, If some of these savings are passed on to the consumers, they could be persuaded to adopt this technology.

Of equal importance is the fact that shifting the peak load from oil- and gas-fired peak electrical generators to the base load electrical generators fired by coal, nuclear and hydroelectric could lead to savings of as much as 100 million barrels of oil over ten years and 12 million barrels of oil per year by 1985. Time-of-day rates offering an incentive of greater than $.05 per kilowatt hour for shifting the load to the off-peak are required. Twenty-seven states have currently adopted some type of time-of-day rates and legislation has been passed requiring other states to investigate their adoption. With the adoption of time-of-day rates, the main problem becomes the development of cost-effective storage air conditioning systems.

## II ANALYSIS OF THE COST FACTORS OF STORAGE AIR CONDITIONING SYSTEMS

A storage system for air conditioning can be based on either the sensible heat of water or stones or the heat-of-fusion of a phase change material. The most common phase change material is ice. Other phase change materials, such as hydrated salts, extend the potential operating range from 32°F to 115°F. A sodium sulfate based system has been successfully operated with the transition temperature adjusted to 55°F.

The most important advantage of phase change materials is the isothermal nature of the transition temperature which makes it ideally suited for heating as well as cooling applications. Another advantage is the lower volume, as little as 1/5 the volume of an equivalent amount of water or 1/12 the volume of an equivalent amount of rocks. However, none of these advantages has any meaning if the phase change material is not cost effective.

**Table 1. Air Conditioning Storage Cost Comparison ($) 270,000 BTU's**

| | Volume $ft^3$ | Storage Medium | Heat Exchanger | Container | Total Systm Cost** | Distribution Installation (50% Markup) | Selling Price |
|---|---|---|---|---|---|---|---|
| Water* | 250 | 50 | 300 | 1000 | 1350 | 675 | 2025 |
| Rocks* | 600 | 550 | —— | 700 | 1250 | 625 | 1875 |
| Ice | 50 | —— | 190 | 905 | 1095 | 548 | 1643 |
| Hydrated Salts (Rigid Wall Pkg.) | 125 | 189 | 650 | 100 | 938 | 469 | 1408 |

* $\Delta T = 15°F$

**Materials and Labor

Table I compares the storage air conditioning system cost for 270,000 Btu systems. In this table it is shown that the cost for a delivered system can vary from $2025 for water down to $1408 for hydrated salts using standard packaging technology. The range of cost differences between hydrated salts, ice and rocks between $1408 and $1875 is not considered enough of an economic advantage, particularly when one considers the variations of potential manufacturing and distribution costs from region to region, to clearly recommend hydrated salts.

Careful analysis of the data in this table indicates that the heat exchanger is a major area of potential cost reduction for phase change materials. Historically, phase change materials have been packaged in rigid wall polyethylene containers 30 to 40 milli-inch thick. These containers serve as both the package and the heat exchanger. The cost of the rigid wall polyethylene container exceeds the cost of the salts and dominates the cost of the system.

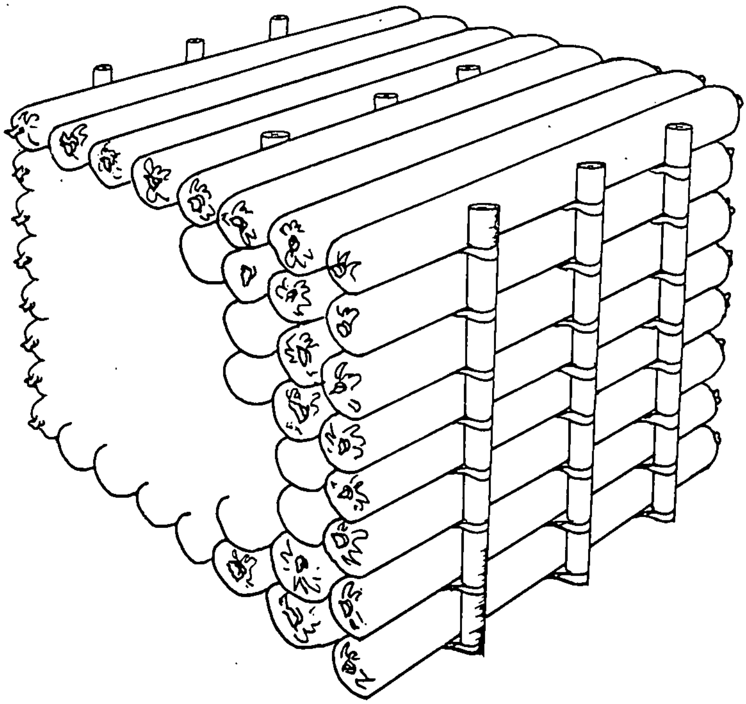
**Table 2**

| | Volume $ft^3$ | Storage Medium | Heat Exchangeer | Container | Total System Cost** | Distribution Installation (50% Markup) | Selling Price |
|---|---|---|---|---|---|---|---|
| Hydrated Salts (Film Pkg.) | 125 | 189 | 189 | 75 | 453 | 227 | 680 |

The Institute of Energy Conversion enlisted the assistance of the DuPont Company in the development of a low-cost package for the storage medium and the heat exchanger using polyester film and food packaging technology. Although other investigators have tried to develop low-cost packages for similar systems, the DuPont Company and the Institute, working together, divided the overall packaging problem into a number of individual issues and, after considerable investigation, developed a multi-layer laminate that has performed well. This packaging breakthrough has reduced the cost of the total system to a price affordable to the average consumer, as shown by Table 2.

One of the advantages of this packaging technique is that it has enabled the phase change material to be packaged using conventional manufacturing technology. This packaged thermal energy storage material is currently being fabricated in a facility adjacent to the University campus at rates up to one ton per hour. It is expected that the rate of fabrication can be increased to three tons per hour range within one year. This storage material is then assembled in the modules shown in Figure 1. Each of these modeules contains 10,000 Btu's in 200 pounds of hydrated salt. Using the present design rating of 50 Btu's per pound, it takes 27 of these modules to assemble a 270,000 Btu thermal energy storage system.

Figure 1



THERMAL ENERGY STORAGE MODULE
(PROTOTYPE DESIGN FOR STORAGE ASSISTED AIR CONDITIONING)

20" CUBE

64 - 20 INCH LONG BY 2 INCH DIAMETER "CHUBS"

10,000 BTU

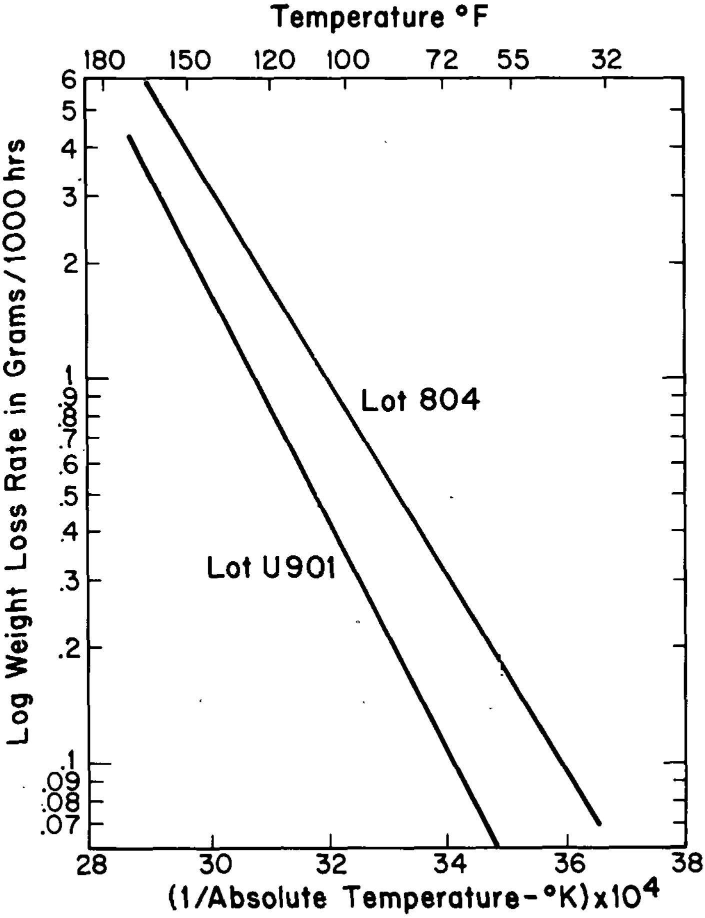
200 LBS.

50% AIR FLOW VOLUME

2,160 BTU/CU. FT.

Figure 2

## Effect of Temperature on Weight Loss Rate

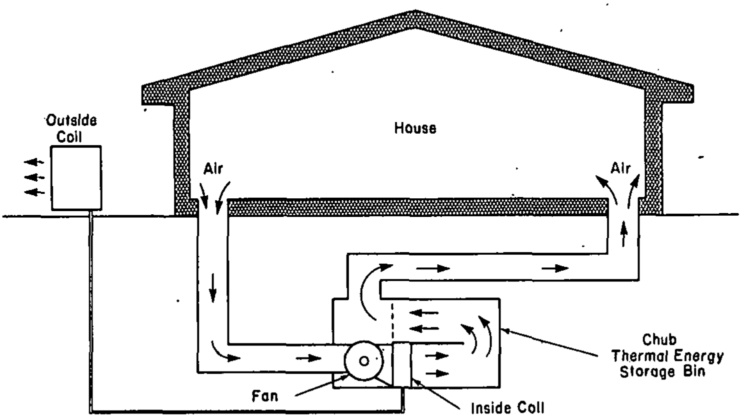



A major problem which was solved during the development of this package, in addition to obtaining package integrity under rough handling, was to obtain high moisture retention by reducing the moisture vapor transmission through the package. Figure 2 shows a curve of an accelerated life test indicating the effective weight loss rate at different temperatures. Lot 804 was one of the first R&D lots fabricated by the DuPont Company and can be extrapolated to a 3.7 percent loss in weight by water vapor transmission over ten years. This translates to an eight percent loss in thermal storage capacity due to water loss for formation of the decahydrate, when extrapolated out to ten years operation at room temperature. Lot U901 was the first qualification lot fabricated after the facility was started up at the University of Delaware. The weight retention performance of this material showed an improvement in moisture loss from 3.7 to 1.2 percent in ten years.[2]

# III SYSTEM TEST RESULTS

Figure 3

Storage Assisted Air Conditioning
(House Cooling Mode)




A thermal energy storage system using the low-cost packaging was first deployed in a full house configuration at the Institute of Energy Conversion field test laboratory, Solar One, at the University of Delaware campus. The schematic of the test configuration is shown in Figure 3. Air is drawn by a fan from the house during the day over the thermal energy storage bin and returned to the house after the heat has been removed by thawing the prefrozen storage material. At night the compressor is run and the heat is exhausted from the storage bin to the outside. Two modes of operation are used at night: 1) using circulation through the house and 2) using a bypass which allows the bin to be cooled independently of the house. Tests in the summer of 1978 used the bypass between the hours of 2 a.m. and 5 a.m. to further cool the bin. Some of the current tests are using the house as a whole, i.e., without the bypass. The utilization of the house rather than the bypass is designed to reduce the total cost of the storage system by eliminating a set of dampers.

TABLE III

OPERATING DATA

| Day | Date | Maximum Outside Temp. (°F)(4) | House Relative Humidity Min. | House Relative Humidity Max. | House Temp. (°F) Thermostat Set Point | House Temp. (°F) Observed |
|---|---|---|---|---|---|---|
| First Week | | | | | | |
| 1. | 8/8 | 88 | 52 | 64(1) | 76 | 75-78(1) |
| 2. | 8/9 | 88 | 52 | 61 | 76 | 75-78(1) |
| 3. | 8/10 | 86 | 52 | 62 | 76 | 76±.5 |
| 4. | 8/11 | 87 | 53 | 71(2) | 76 | 76±.7 |
| Second Week | | | | | | |
| 5. | 8/14 | 89 | 51 | 59 | 76 | 76±.3 |
| 6. | 8/15 | 89 | 52 | 62 | 76 | 76±.3 |
| 7. | 8/16 | 92 | 56 | 70(3) | 76 | 75-78(3) |
| 8. | 8/17 | 90 | 56 | 66(3) | 76 | 75-80 |
| 9. | 8/18 | 89 | 52 | 64(3) | 76 | 76±.7 |
| Third Week | | | | | | |
| 10. | 8/21 | 81 | 46 | 52 | 76 | 76±.5 |
| 11. | 8/22 | 85 | 48 | 52 | 76 | 76±.5 |
| 12. | 8/23 | 88 | 48 | 56 | 76 | 76±.5 |
| 13. | 8/24 | 88 | 48 | 61 | 76 | 76±.5 |
| 14. | 8/25 | 87 | 52 | 58 | 76 | 76±.5 |

cont.

| | | | | | | |
|---|---|---|---|---|---|---|
| Fourth Week | | | | | | |
| 15. | 8/28 | 87 | 48 | 56 | 75 | 75±.3 |
| 16. | 8/29 | 87 | 49 | 61 | 75 | 75±.3 |
| 17. | 8/30 | 87 | 52 | 60 | 75 | 75±.3 |
| 18. | 8/31 | 83 | 52 | 59 | 75 | 75±.3 |

(1) Adjustments being made in cycle cut-off temperatures.
(2) Temperature/Humidity Stress Test
(3) Forced into storage exhaustion
(4) Taken from NOAA Climatological Data

Table 3 summarizes the house's living space temperature and humidity during 20 days in 1978[3] in which the storage assisted air conditioning unit was tested.

The mode of operation for the summer of 1978 tests used the following operation sequence:

A: During daytime operations (9 a.m. to 10 p.m.), normal air circulation, controlled by thermostat, was used. When cooling was required, house air was carried through the normal air conditioning duct system and into the thermal energy storage bin. Heat was removed by melting the salts.

B. At 10 p.m. the storage bin was charged by causing air from the inside coil for the air conditioner to flow over the storage bin. Discharge continued until the temperature of the storage bin reached a preset point indicating that sufficient heat had been extracted from the bin to fully "charge" it, or until 9 a.m. if the preset temperature point had not been reached.

C. If the house required additional cooling during nighttime charge periods, dampeners were activated to divert cooling air from the inside coil of the air conditioner to the house thus bypassing the storage bins. In this mode of operation, charging of the storage bin and cooling of the house provided alternate uses for the output of the inside coil of the air conditioner.

A continuous record of relative humidity and temperature was made using a portable Bendix hydrothermograph. Figure 4 shows a chart of the temperature and humidity control during a typical day. Cooling from the storage and air conditioner of the house during that time period can be estimated from the small fluctuations of the temperature curve. The humidity curve indicates a low point of 52 percent at noon rising to just over 60 percent at 10 p.m., when the night charging cycle starts. This temperature and relative humidity behavior is characteristic of the normal storage assisted air conditioning operation over 13 days in August when no stresses or adjustments were made to the operating conditions.

The system was deliberately driven to exhaustion on Friday, August 11. Figure 5 shows the temperature and humidity. The purpose of this experiment was to observe the exhaustion of the storage capacity by monitoring the temperature excursion limit to get a signal indicating the exhaustion of thermal energy storage capacity. About 5 p.m., the temperature rose to 78°F and the humidity to 64° relative humidity. (The temperature and humidity were increased by running the electric clothes full of wet towels and venting the air into the house). From that point temperature gradually dropped back to 76°F and the humidity kept rising. Analysis of the date indicated that, under these conditions, evaporative cooling of the house was occurring. During the day, moisture was removed from the house air and circulated over the thermal storage packages in the bins. This moisture on the thermal energy storage components gradually built up in the form of droplets during the normal cooling day. When the system was driven to exhaustion, the house air circulating across the storage bin evaporated the moisture previously condensed, thereby maintaining the house temperature even in the face of rising humidity. This indicates that humidity change is a more sensitive measure of the thermal energy storage bin's exhaustion than temperature.

8/31/78

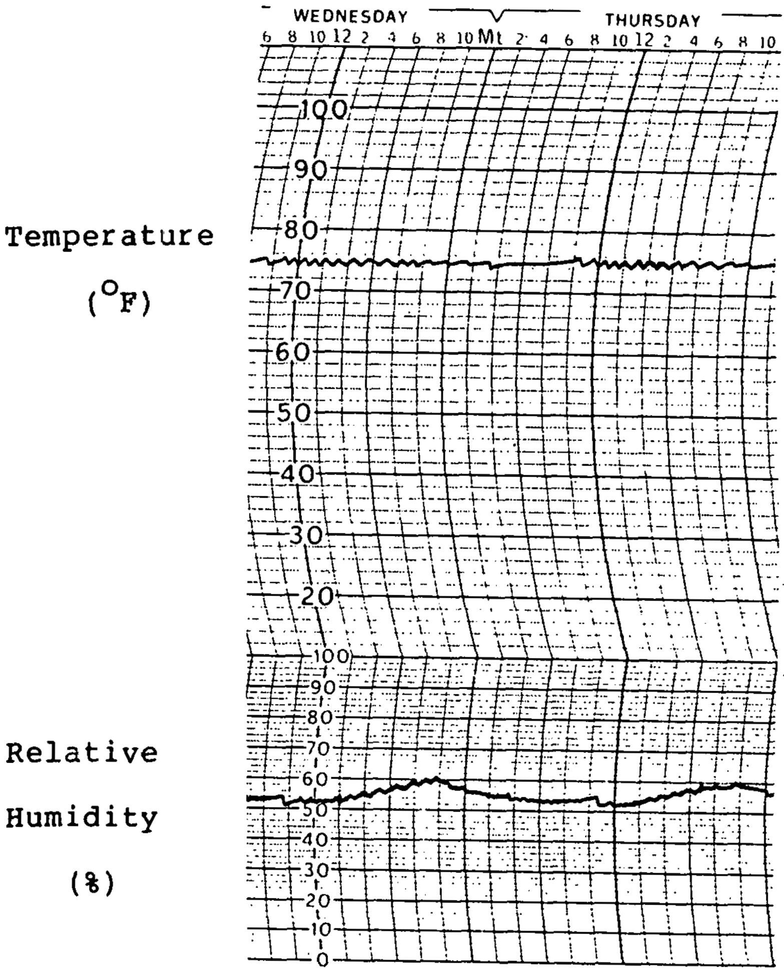



Figure 4. Recorded Temperatures and Relative Humidity
(Average Day)

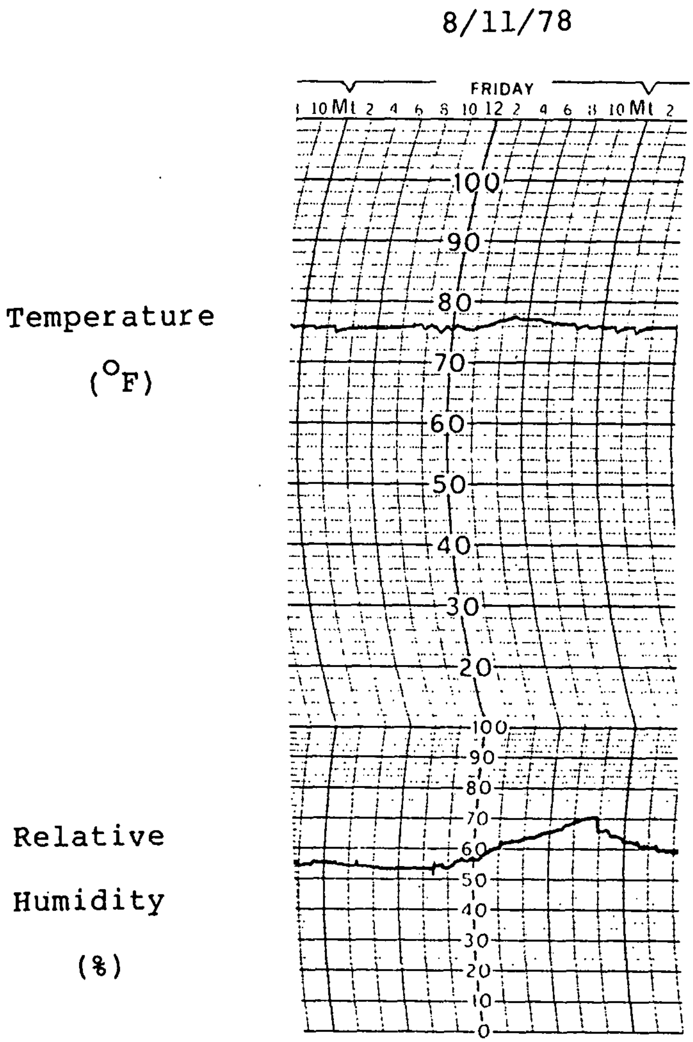



Figure 5. Recorded Temperatures and Relative Humidity
(Experimental Stress Conditions)

## V ECONOMICS OF A RESIDENTIAL STORAGE ASSISTED AIR CONDITIONING SYSTEM

**Table 4. Air Conditioning Electric Power Requirements**

| | Without Storage 85% on-peak 15% off-peak | Storage Air Conditioning |
|---|---|---|
| Compressor (kWh) | 3,000 | 2,160* |
| Circulating Fan (kWh) | 480 | 1,060 |
| Total Kilowatt Hours | 3,480 | 3,220 |
| Total Kilowatt Hours: | | |
| Off-Peak | 522 | 2,592 |
| On-Peak | 2,958 | 600 |
| Total Annual Cost (On-Peak—10.3¢/kWh) (Off-Peak—1.3¢/kWh) | $ 311 | $ 95 |
| TOTAL ANNUAL SAVINGS | —0— | **$216** |

*Off-peak; due to nighttime COP differential of 1.4.

The predicted performance of an operating system is summarized in Table 4. The primary assumption is that a 3 kilowatt compressor would be operated for 1000 hours during the season. The utilization of storage assisted air conditioning has an estimated reduction in total kilowatt hours of 8 percent due to the higher compressor efficiency, using the lower outside heat rejection temperatures at night.

An additional important bonus over the possible energy savings is the fact that the electricity use can be shifted from the oil- and gas-fired peak load generators to the coal, hydro and nuclear base load generators.

The adoption of this technology could save electric utilities collectively as much as $12 billion in capital investment cost over this coming 10-year period. By passing on some of these capital and operating costs, savings to the consumer could be $216 per year for a total investment of about $700 per year. The actual savings will depend on the total kilowatt hours over the cooling season and off-peak cost differential per kWh.

It is estimated that a 270,000 Btu storage bin can be installed for $680 total cost which could give a payback in less than four years. When one also considers the possibility of tax incentives to encourage this type of installation, the economics to the consumer become extremely favorable. Utilizing an on-peak/off-peak differential rate of $.09 per kilowatt over 3000 kilowatt hours, one can achieve a total annual savings of $216. A rate differential of 8.9 and 8.8 c/kWh is incorporated in experimental rates 1E2 and 1E3, effective December 31, 1978, by the Commonwealth Edison Company in Chicago, Illinois. Compressor kilowatt hours per season can be as low as 1500 to as high as 7500 in various regions of the country. The savings to the consumer depend on the intensity of the season and on the off-peak rate which can be as low as a penny. At a $.05 rate differential in the Mid-Atlantic region, annual savings can be estimated to be about $105 per year.

When the savings of $105 to $216 are compared to the $680 storage system cost, one sees a payback of four to eight years. This payback can be significantly reduced if tax incentives similar to the solar tax rebate and the energy conservation tax rebate are applied to this system.

## VI COMMERCIALIZATION

The first full-house test results with the low-cost laminate packaging were obtained in the summer of 1978 in the University of Delaware test house. Plans for this summer include applications testing in ten different structures, including residential and commercial buildings. Based on these results and increased field testing in the summer of 1980, full product introduction could occur as early as the summer of 1981.

The original development of this concept and the summer of 1978 field test was sponsored by Delmarva Power & Light, Pennsylvania Power & Light and Baltimore Gas & Electric. Field tests for the summer of 1979 are currently sponsored by these three electric utilities, plus Atlantic City Electric, Florida Power Corporation, Pacific Gas & Electric, and Tampa Electric. As a result of this enthusiastic support from electric utilities, field tests should be further extended for the summer of 1980.

If market penetration can be achieved at a rate equal to that achieved by England (note paper "The British Experience" by John Platts, this conference) this storage technology could be used to save 100 million barrels of oil per year by 1990, which is seven percent of the national goal on oil savings.

Storage air conditioning is one of a group of new technological developments which can make a measurable contribution to the solution of our energy consumption problem by conserving oil, gas and economic resources.

# HEAT (CERAMIC) STORAGE: STATE-OF-THE-ART

by
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Director of Engineering
TPI Corporation

## I Introduction

Heat (Ceramic) Storage technology, as has been expressed earlier this morning, is not new. Its development has been a product of necessity since World War II in England and Western Europe.

However, the technology is new in the United States due to the manner in which it must be applied and made useful to the American consumer. Developing this new technology has been the goal of TPI Corporation since 1976.

In 1976, American Electric Power Company contacted TPI relating their necessity in finding a manufacturer that would have an interest in developing and testing electrical thermal energy storage (TES) heaters. TIP well understood the possible benefits to the utilities and consumers in developing and marketing such a unit. With AEP's guidance, TPI entered into a license agreement with Creda International Ltd., a Division of Tube Investments. With this agreement, the technological expertise developed in England would benefit the American development of TES systems.

A learning period then occurred in which the English technologies were reviewed and their applications to the American market evaluated.

From this study it was determined that the basic concept of heat storage within a ceramic was sound both functionally and economically.

However, it was also determined that operational features must be developed to apply the storage concept to the American consumer's style of living and the utility's desired load characteristics.

Within England and Western Europe we found that:

1) The homes were not heated during the nighttime hours.
2) The outside temperature variations from daytime highs to nighttime lows were not as great as within the United States.
3) Air conditioning was not being used in conjunction with TES and the American consumer enjoyed cooling his home during the summer months.
4) The TES units as developed in Europe required the home owner to manually set desired storage levels for the next day.

We felt that the American consumer would not accept a system which was not totally automatic.

From these differences we determined that a TES system to be accepted in the United States must be designed with the following features:

1) The unit must provide the capability to maintain the structure at a comfortable level at night.
2) The unit must be able to forecast and store the next day's heat requirements as close as possible to prevailing weather conditions.
3) The unit must be able to produce enough air to accommodate a comparable split system air conditioner.
4) All of the preceding items must be accomplished automatically in order that the homeowner can set his thermostat and not have to make daily operational changes.

To complete our goal, these systems had to be designed in acceptance with the National Electrical Code and Standards for Safety as set forth by Underwriters Laboratories.

One problem which also had to be overcome was obtaining materials and controls which already enjoyed UL listing and which were equal to the English product in composition or operation. This was an especially hard task since the TES device operating or storing at temperatures up to 1400°F. This has not been done as routinely in the past as one might imagine.

Therefore our basic design criteria was established except for one extremely important detail; that is, accomplish all of this at as low a cost as possible.

## II Design (Core)

The core within the TPI TES Unit is composed of bricks of olivine. Olivine has been determined to be the most feasible because of its heat storage capabilities and its relative abundance.

Some of the other materials used in England have been cast iron, Feolite or Magnetite, soap stone and many others.

Olivine is found in abundance in the states of North Carolina and Washington. In North Carolina, the reserve is estimated at 1.2 billion tons.

Specifically, Olivine is approximately 43 to 45% $SiO_x$, 43 to 45% MgO and other materials such as $Al_2O_3$, $Fe_2O_3$, CaO, etc. The specific heat is approximately 0.265 Cal/g°C. One olivine brick as used weighs approximately 16.5 pounds. For the central TES furnace unit 2376 pounds of brick make up the storage core.

Within the core eleven nichrome elements, totaling 30 kW input, are used to obtain the final temperature of 1350°F in a fully charged condition.

Thermal overload safety devices are incorporated for any abnormal conditions rendering the input in an off position.

## III Insulation

With temperatures of 1350°F within the core, some exotic insulations had to be used to maintain an outside case temperature of 140° to 160°F.

The core sits on a base of vicuclad or vermiculite. Two sides also have vicuclad boards. On the outsides of the vicuclad and the back of the core a ceramic type of insulation, developed and used during the Apollo space missions for reentry heat shields; is used.

On the outside of this material a mineral wool is used. One 3/4 inch thick board of the ceramic material is equal to 4 inches of the mineral wool. These combinations of insulations render the outside case temperatures well within the maximum allowable by UL standards.

The insulating valves are also critical in another aspect of operation. It lowers the static case emissions or amount of energy emitted within the installation area.

## IV Sensing and Operation

The next point of interest is the manner in which the 240 kilowatt hours of energy is obtained and controlled.

For our purposes we shall use an eight hour off-peak period. Other periods of longer duration can be used. However, let the start of the period be at 11 o'clock at night and end at 8 o'clock in the morning.

At 11 o'clock at night a thermistor senses the outdoor temperature and sends a signal to the logic panel. At the same time a temperature reading is made in the core and its signal sent to the logic panel. From these two signals an evaluation is made within the logic panel determining the charge for the next day. This evaluation is continuous and should a cold front move in, the amount of energy to be stored will be increased.

The logic panel is designed in such a manner that the charge will be leveled all during the charge cycle and will be complete at the end of the period or at 8 o'clock in the morning.

## V Damper Section

The next important operational feature is the air distribution of the system. The supply of air to the structure is maintained at 140°F by a mixed air thermostat.

This sensing device in turn controls two sets of damper systems. One set supplies air to the core area and the other provides a core bypass system.

The air enters the lower plenum section from the structure return duct. The outlet air thermostat determines the percent of air which must pass through the core and mix with the bypass air to obtain the 140°F outlet. When the core temperature is 1350°F, the core dampers are open a small percentage and bypass dampers almost 100 percent. As the core temperature decreases, the core dampers opening increases and bypass decreases. This sequence continues until almost 100 percent of the air is passing through the core.

In combining the damper system with the core we have the following air movement. Air moving through the core damper, up through the ducts designed in the bricks, back down the front brick ducts and out into the mixed air chamber for supply to the structure.

This procedure is followed for the sixteen hour on-peak period as commanded by the structure thermostat.

## VI Night Heating Section

In order to maintain a comfortable structure temperature during the night, an electric furnace is coupled with the storage unit.

The night heating furnace is a regular resistance type unit having the air handler for both storage unit and night heating system located in its lower position.

This type of arrangement places the storage section within a negative pressure. The negative pressure is critical as it eliminates air leakage from the core during system operation. If the core were placed under a positive pressure, the filtration would be great, resulting in high energy losses.

The night heating section is controlled from the same structure thermostat as the storage unit. However, during operation of the night heating section the storage core dampers are in the closed position. The bypass dampers are in the full open position allowing the air to move directly into the night heating section and over the open coil resistance elements providing the required heat.

## VII Control Section

The control sections are integral in operation to each other. The logic panel is a four channel device actuating time delay relays. Each time delay relay has a 15 second delay in its operation. In the event of a power outage the inputs to the heating core elements are reenergized in 15 second intervals preventing the full load from being energized at one time.

The night heating unit also has an emergency switch circuit which allows it to be energized in the event that the storage falls short of the required heat. Also a summer/winter lock-out switch is provided within the system.

All these systems have been designed to provide to the consumer an automatic operating system which does not require daily manual operation. With the combined operation of the preceding systems, the consumer is provided comfort conditioning that is equal to any presently marketed system. The design criteria have been met in that the structure is maintained at the desired temperature for 24 hours a day. The storage system automatically determines the next day's energy needs through constant monitoring of temperatures. The plenum bypass and blower systems have increased air volumes to accommodate air conditioning.

All of these systems are completely automatic providing a total package to the consumer which does not require anticipation of the next day's storage requirement or manual operation. Weekend trips can be taken with a set temperature maintained.

## VIII Other Systems

The present system can also have additions such as night set back, set back with freeze control and can be operated by ripple control, radio control, or time of day operation.

The system can be used as back up to solar systems or heat pumps. In essence TES technology is ready for the American consumer. There are advances on the boards for tomorrow which will render an even greater advance in storage technology. This generation of unit will be available during the next year.

## IX Room Radiator Units

One type of storage unit which we have not covered is the individual room type. The storage principals of this unit and the central system are the same. However, there are functional differences. The room unit can be of the dynamic or static type. The dynamic unit will produce energy by both dynamic and static emission.

The input is approximately 6 KW with the availability of lower inputs. The room units lend themselves to off-peak or time-of-day operation with only minor changes to the accessory control packages. They also lend themselves readily to the conversion market replacing direct resistance, oil or glass heating systems. The units can be controlled individually or from a centrally located thermostat. The individual room control allows the user to completely turn off any room desired thus decreasing energy usage.

## X Application

Regardless of how advanced our technology may be in respect to conforming the storage system to our mode of living, a strong word of caution is in order at this point.

Conventional heat loss calculations and unit sizing are not adequate. The storage capacity must be matched against the structure loss for the lowest average day temperature in respect to the on-peak period. This lowest average day temperature should be obtained from the nearest class A airport or reporting station within the area.

## XI Summary

The years of technology development in England and Western Europe have been utilized to form the basis of the TES unit in America. Advances on these technologies have been made as necessitated by the American style of living and market environment. Future designs will refine these technologies. TES units utilizing ceramic cores are available for consumer purchase rendering benefits to the consumer and the utility and a solution to some of our country's energy problems.

# STATE OF THE ART
# HEAT (PCM) STORAGE

by
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## ABSTRACT

Phase change materials (PCMs) designed for various temperature levels are being developed by or for commercial manufacturers for use in storing heat from solar, electric resistance, or electric heat pump condensers. Both air and liquid transfer fluid systems are described in the paper with primary focus on the latter using PCMs melting at around 115°F.

Heat storage in phase change materials in this country and perhaps the world has been pioneered chiefly by Dr. Maria Telkes starting in the 1940s at the Massachusetts Institute of Technology and later at universities in New York, Pennsylvania, Delaware and Texas and in associations with private firms such as Calmac, Curtiss-Wright, Cryotherm, Melpar, American Standard, Royal Industries, Kay Laboratories, Dow Chemical and Allied Chemical.

What few people know is that her research has included the analysis of every possible salt hydrate and their eutectics which she has compiled in a so-far unpublished work. Many people know her only as the Glauber salt lady and indeed she has spent a great deal of time trying to tame, in a practical way, this cheapest, yet most difficult of salt hydrates.

She will be the first to agree that her work has been inadequately subsidized, that sufficient engineering support was not available, and that the integration into systems was incomplete. Thus, salt hydrate thermal storage, the so-called "eutectic" salts, have unjustly gotten a black eye. Most of this criticism, ironically, has been directed toward Glauber salt which changes phase at too low a temperature (89°F) for hot water and the vast majority of space heating systems.

Salt hydrates have been the focus of most of the work primarily because of cost, but also because of higher volumetric heat of fusion, safety, and lower volume change during fusion. Paraffins have been a popular alternative suggestion but have not been commercialized because of these reasons.

Let me set straight two misconceptions regarding salt hydrates: first, many of them which are called "eutectics" are really not eutectics because they do not involve a mixture of two or more compounds; and second, salt hydrates that "go bad" and cease providing the original heat of fusion do not decompose in the sense of oxidation or other chemical reactions.

Regarding the word "eutectic," I suggest that we treat it as we have the word "brine" and simply broaden its meaning because the public cannot live by initials as the government does. Brine originally referred to sodium and calcium chloride mixtures with water, but because of its broad use as an anti-freeze, the word brine is now defined by ASHRAE to include all anti-freeze including ethylene and propylene glycol. Eutectics in plates for cold storage is a broadly used industry word and thus the meaning in the sense of heat of fusion compounds is already well established and should remain so, whether or not they are true eutectics.

The decomposition of the salts is primarily a physical matter in that the wrong hydrate or the anhydrous material becomes formed. In other words the water goes to the wrong location or perhaps even evaporates. For example with sodium thosulfate the normal compound, which I call our friend, is the Pentahydrate, five moledules of water. The enemy, which has very little heat of fusion, is the dihydrate with two molecules of water. When this forms there is extra water which appears as a weak saturated solution on the top. However, by reheating the mass above 150°F everything is melted and pentahydrate can be reformed, a truly reversible process.

**Resistance Heat.** Load levelling with PCM heat storage can be done either with resistance heat or heat pump condenser heat. Since resistance heat can cover a very wide range of temperature, PCMs lose their renowned size advantage in this case but they retain one very important advantage, low losses. Their poor thermal conductivity becomes an advantage: when an internal heat exchanger is used.

Where hydronic heating systems are used requiring 150°F or more to distribute the heat to the rooms, heat pumps become impractical unless there is a source of heat close to room temperature. A resistance-heated, liquid transfer tank and heat exchanger four feet in diameter by four feet high holding 400,000 Btus is available from our company with a fusion point at 150°F and can be installed outside the house for easy retrofit. Thus for a price of around $2500 an off-peak electric system can be installed in a fossil-fueled hydric heated home. The salt used is trisodium phosphate, the most successfully used of all heating eutectics, which we began adapting in 1957 to provide temperature stabilized shipping containers for the Polaris program.

**Heat Pump.** For an air duct system capable of handling air conditioning, a 115°F tank of the same size is also available using sodium thiosulfate at the same cost provided the air conditioner is also converted to off-peak ice storage which requires a liquid coil in the duct. However, at this temperature heat pump condenser heat may be used at only moderately higher cost since the air conditioning compressor may be used for the heat pump. Electric usage will be cut by a factor of two to three by the use of a heat pump compared to resistance heat.

Phase change materials for heating are also available at 135, 97, 89 and 81 deg. F consisting of hydrates of sodium acetate, disodium phosphate, Glauber salt and calcium chloride respectively. Most actively investigated has been Glauber salt because of its low cost. Unfortunately Glauber salt drops out 15% anhydrous sodium sulfate salt when it melts and for it to refreeze, this precipitate must be mixed uniformly with all the other salt.

**89°F Storage.** This problem has been attacked in different ways: a thixotropic gel by Maria Telkes now being exploited by her former employer, the University of Delaware; tumbling in a rolling drum by General Electric Company, an idea also proposed by Karl Boer and William Shurcliff; and a honeycomb crust by Maria Telkes at American Technological University now licensed to Valmont Energy Systems, Valley, Nebraska. All of these have been designed to use air for heat transfer. The University of Delaware uses a chub, or flexible sausage casing developed by Dupont Company, as a container. Valmont uses a twenty pound self-stacking plastic tray. Both of these are in preliminary field testing, not yet released for general marketing. Massachusetts Institute of Technology is using Cabosil as a gel agent in hollow radiant ceiling tiles. Solar, Inc. also used self-stacking trays. OEM Products has a liquid system.

To date little important test data is available. The University of Delaware claims 50 Btus per pound, M.I.T. 30, and tests by the National Bureau of Standards of Solar, Inc., equipment showed about 60 after 5 cycles. On the other hand, General Electric reports full theoretical value close to 100.

**81°F Storage.** Dow Chemical is marketing experimentally their calcium chloride dihydrate bagged in crystalline form with instructions on how to add water to form the hexahydrate which has a fusion point at 81°F. Additives to prevent subcooling are included in the dihydrate.

PSI Corp. and their sales agent, Texxor, are purchasing Dow's 81°F salt and encapsulating it in plastic tubes. Calmac is supplying tanks with internal plastic tube liquid heat exchangers into which Dow's salt can be mixed and pumped on site.

The most feasible application for PCMs with fusion points in the 81 or 89°F range is for feeding heat pumps with solar or waste heat since space heating generally requires higher air temperatures than can be achieved from the heat exchanger associated with these salts. Since this talk is referring to heat storage as opposed to cool storage and thus to taking heat from condenser side of the heat pump, not the storage of heat or cool fed to the evaporator, my main emphasis will be on higher temperatures.

**115°F Storage.** Sodium thiosulfate pentahydrate, or "hypo" as it is commonly called because of its use as a photographic fixative, has a fusion point of 118°F in the pure photographic grade and 113 to 115°F in the lower cost heat storage grade which contains about 1% sodium sulfate as supplied by Allied Chemical Company. Calmac has developed a bulk tank system with internal plastic tube liquid heat exchanger and submersible stirring pump which under joint testing programs by Calmac and Allied Chemical has given complete stability of the salt in over 10,000 cycles. If the pump should fail, heating the salt to over 150°F reestablishes the original condition. Limited commercial sales are planned for late 1979 of 360,000 Btu units. Performance tests under ASHRAE 94-77 test standards have been monitored by the National Bureau of Standards.

In California and Japan programs using additives such as sodium acetate have given apparent stability without pumping. Thermal Energy Storage, Inc., taking over work by Kay Laboratories in San Diego, reports independent cycling tests by the University of California in 1978 and verified there was no degradation of the chemistry of the sodium thiosulfate with time and charge/discharge cycles. They also plan to begin commercial sales late this year. Present tanks being tested hold 250,000 Btus.

The problem in using PCMs can be listed as the three-Ss, the three-Cs, and the three-Vs: Stratification, Subcooling, Shipping cost, Corrosion, Conductivity, Cost, Volume change, Volume total, and eVaporation (pardon). While it is not appropriate to go into all the detail here, it appears that the bulk storage system with internal liquid heat exchanger simplifies many of these problems over the encapsulation techniques.

**Efficiency.** Stagnation heat loss tests on our bulk storage tank with only 2 inches of insulation have shown less than 5% loss in twelve hours when fully melted and less than 2% loss in twelve hours in partially charged conditions. This self-insulating property of bulk PCM storage is perhaps its greatest advantage allowing only minimal insulation and outdoor above-ground location even in cold climates. A considerable part of the eight to one volume advantage over water tanks and the seventeen to one advantage over rock beds is in the savings in insulation volume, and even the water tank and rock bed losses are far higher.

**Conclusion.** In summary I come to the following conclusions:

1. PCM heat storage has finally matured thanks largely to the support of the U.S. Department of Energy.
2. Many firms will be offering PCM storage products at many different temperatutre levels using both air and liquid for heat transfer.
3. As with any other energy product, independent testing and certification to approved standards is essential to prevent inferior grade products from further damaging the name of "eutectics".
4. PCM systems will soon be offered that should have life equal to that of the other equipment or better.
5. PCMs, particularly with internal heat exchanger systems, show promise of providing high thermal efficiency combined with small size.
6. While continued research is required, if the government and utilities want load levelling from thermal storage, PCMs will be ready to do the job reliably.

# AN OVERVIEW OF THE DOE THERMAL STORAGE PROGRAM*

**by**
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**Division of Energy Storage Systems**
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## ABSTRACT

The Thermal Energy Storage Program of the U.S. Department of Energy promotes energy savings and fuel substitution by developing and helping to commercialize technologies for storing heat or cold. The sources of energy include industrial and utility waste heat as well as primary sources such as solar, geothermal, nuclear, and fossil fuels. The primary energy sink involved in the storage of "cold" is winter-chilled air. The program emphasizes applications which possess a potential near-term impact and those which relate to solar and other dispersed energy technologies. These applications include seasonal storage for building heating and cooling; daily storage for active or passive solar and conventional heating and cooling; heat storage for solar thermal electric power generation; and storage for recovery of industrial or utility waste heat.

The program has a budget of $8.2 million for FY 1979. Program management for policy, planning, and budget issues is provided by Division of Energy Storage Systems within the Office of Assistant Secretary for Energy Technology. Detailed project management is provided by field organizations, including PNL for seasonal storage, Oak Ridge National Laboratory for low-temperature storage, NASA-Lewis Research Center for high-temperature storage, and Sandia Livermore Laboratory for thermochemical storage and transport. The program includes a diverse range of individual projects, from analytic studies of thermochemical pipelines, through benchscale laboratory investigation of individual phase-change materials, to large-scale field testing of aquifer storage.

## I INTRODUCTION

Thermal energy storage includes the range of technologies which retain heat energy (or cold) during one period in time for use during a subsequent period. As with other storage devices, thermal storage is needed for many practical energy systems because of a frequent disparity between the time of energy availability from thermal sources and the time of energy demand by thermal loads or end-users. In solar energy systems, thermal storage satisfies an inherent need to provide energy on demand in spite of regular periods of non-availability at night and during inclement weather. In this application, thermal storage is an enabling technology which links a renewable energy source to established patterns of energy use. Other applications of thermal storage, while less obvious, could result in capture of "waste" thermal energy for later use as a supply of heat for industrial processes or for space heating and cooling. The two major goals of thermal energy

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*Adapted from a paper by C.J. Swet (DOE-STOR), John Gahimer (DOE-STOR), and W.R. Standley (TRW, Inc.), presented at "Commercialization of Solar and Conservation Technologies: Symposium-Workshop," Clean Energy Research Institute, Miami, Florida, December 11-13 1978.

storage, more efficient use of existing energy systems and displacement of scarce fossil fuels as primary energy sources, are in direct support of the National Energy Plan (NEP) and the National Energy Act (NEA). This paper describes the technologies and applications of the thermal energy storage program in DOE, including potential paths to commericialization for three selected activities.

## II THERMAL ENERGY STORAGE

Thermal energy storage is a generic title spanning the class of technologies in which a storage device accepts and returns energy in the form of heat. The process is analogous to other, more familiar methods for storing energy, including electrochemical batteries for electric energy and flywheels for mechanical energy. A device for thermal storage may become "hot" and serve as an energy *source* at the time of use. Alternatively, thermal storage includes the accumulation of "cold", in which case the device becomes a thermal energy *sink* at the time of use typically in air conditioning and refrigeration. Like any storage device, thermal storage is an interface technology which enables the coupling of otherwise incompatible energy sources and end-users, as depicted in Figure 1.

The various technologies may be categorized according to the thermo dynamic basis of operation. The three categories, involving sensible heat, heat effects during changes of phase, and thermochemical heat, are shown in Figure 2.

- Energy storage as sensible heat is accomplished by raising or lowering the temperature of the storage medium. This form of storage is historically the most familiar, with tanks of hot water and beds of hot rocks used in a variety of applications, including active and passive solar-thermal systems. Energy storage density depends on the heat capacity of the medium and a maximum acceptable temperature swing with typical values of the order of 10 to 100 Btu per pound. Major disadvantages of this technology are that stored heat is generally returned at an ever-decreasing availability (temperature level) and that storage densities are relatively low. It has the advantages of low cost and simplicity. Most commercial-sized thermal storage systems employ sensible heat devices.
- Energy storage involving a phase change in the storage medium makes use of latent heat effects of melting, vaporization, or other changes in the physical state of aggregation of the medium. The storage of winter ice for use during the summer is an historical example of this technique. Energy storage densities are generally greater than those for sensible heat storage, resulting in a potentially lower system cost. Another advantage is that stored heat is returned at nearly constant availability (temperature level). Phase change storage technologies are significantly less advanced than those for sensible heat. Continued development is expected to verify the lower cost and higher performance potential of phase change materials for energy storage.
- Energy storage via thermochemical heat of reaction makes use of a change in chemical composition of the storage medium. The chemical system employed must exhibit rapid, reversible kinetics involving a large endothermic or exothermic heat effect. The chemical changes in the storage medium must be totally controllable, either through easy physical separation of reactants and products or through the need for a catalyst. An advantage to the thermochemical approach is that it allows storage at ambient temperature with essentially no time-dependent heat losses. In addition, the attainable energy storage densities are potentially an order of magnitude higher than either sensible heat or phase change methods. It has potential applications in long-distance transport of large quantities of energy. The controllable nature of the energy release allows matching energy availability (temperature level). Phase change storage technologies are significantly less advanced than those for sensible heat. Continued development is expected to verify the lower cost and higher performance potential of phase change materials for energy storage.

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Thermal storage may also be categorized by area of application. Four categories provide a framework for discussing the program in more detail:

- **Building heating and cooling** include projects for seasonal storage in community and other large-scale applications; phase change and chemical heat pump projects for solar applications; and projects which involve storage of heat and cold derived from off-peak electricity to accomplish electric load leveling on the customer side of the electric meter.
- **Industrial process** applications for thermal storage include projects for cogeneration and for capture and re-use of waste heat to improve net thermal energy efficiency.
- **Electric power generation** includes projects for both conventional and advanced solar-thermal power generation.
- **Heat transport** includes projects for delivery of energy from a central source (such as a nuclear or a concentrating solar thermal plant) to end-users, or from a distributed source (such as multiple solar collectors) to a central storage and conversion facility. The thermochemical approach is particularly appropriate for heat transport because it operates at ambient temperature, reducing or eliminating thermal losses.

Figure 3 shows the relevant combinations of energy source and storage technology for each application area. For seasonal storage, the primary approach is sensible heat storage in heated or chilled water in underground aquifiers, with secondary emphasis on surface ponds and earth as the storage medium. Daily storage for active solar heating and cooling systems is being developed through chemical heat pumps; the most advanced of these is based on a cyclic dilution and concentration of sulfuric acid. For passive solar systems, concepts involving phase-change storage in building materials are under investigation. For electric load-leveling, the approach is to verify the suitability of sensible heat storage units that are widely used in Europe and to develop advanced technologies for use with heat pumps and air conditioners. In solar-thermal power applications, sensible and phase-change heat storage systems are being developed for buffering and daily needs. Thermochemical methods are being explored for long-duration storage and for transport in distributed collector solar systems. All of the industrial retrofit projects are expected to use sensible or latent heat storage.

## III DOE ROLE IN DEVELOPMENT OF THERMAL STORAGE TECHNOLOGIES

Federal involvement in the R&D process is appropriate when the development of a specific technology supports national energy goals but the private sector is not yet actively involved. Thermal energy storage offers the two benefits sought by the NEP and NEA:

- Energy savings from improved efficiency in existing systems.
- Displacement of scarce fossil fuels as primary energy resources in favor of long-term and renewable resources.

The development of thermal storage within the private sector will not occur within the desired time frame. For that reason, a Thermal Energy Storage Program exists within the DOE Division of Energy Storage Systems. The detailed technical management of individual project areas is delegated to several field laboratories. This organization is illustrated in Figure 4 and Figure 5. Authority for technical management and procurement is assigned to lead laboratories, as follows:

- The **low-temperature** thermal energy storage subprogram is managed by Oak Ridge National Laboratory and includes sensible and latent heat technologies at temperatures below 250°C.
- The **high-temperature** thermal energy storage subprogram is managed by the NASA-Lewis Energy Research Center and includes sensible and latent heat technologies at temperatures above 250°C.
- The **seasonal** energy storage subprogram is managed by Pacific Northwest Laboratory and includes the Aquifier Storage Subprogram.

The annual budget authority for energy storage programs during FY 1978 and FY 1979 is shown in Figure 6, with the portion allocated to thermal storage shaded for emphasis. The distribution of funds among the various thermal storage project areas is shown in Figure 7. Budget authority funding represents dollars committed rather than those actually spent.

## IV DOE PROGRAM COORDINATION

Thermal energy storage is an enabling technology, rather than a primary energy source or a means of converting energy to useful work. Its development cannot proceed independently of energy source and end-use technologies. A major facet of the development program and a key responsibility of the Program Manager is coordination with other programs in DOE, as well as with other public and private agencies.

The Thermal Program interfaces with numerous divisions within Energy Tehchnology, Conservation & Solar Applications, Resource Applications, and the Office of Energy Research as shown in Figure 8. Joint funding of projects is a common tool for achieving a coordinated effort. At the present time, approximately 40 percent of the funding for thermal storage projects managed by this program is cofunded from other DOE divisions.

A less formal vehicle to enhance program coordination is the multi-agency forum at which various agencies and private firms involved in energy storage can exchange information. The 1977 Interagency Coordination Meeting on Energy Storage involved DOE, NASA, DOT, DOD, NSF, DOI (USGS), DOC (NBS), and EPRI. In addition, the annual Thermal Energy Storage Contractors' Review provides an open forum for discussion of program thrusts and individual projects.

## V THE DOE THERMAL ENERGY STORAGE PROGRAM

The program emphasizes those applications which have been demonstrated to possess a potential near-term impact, as well as those which accelerate the market penetration of solar energy technologies. The Thermal Energy Storage Program is discussed below by applications areas, i.e., building heating and cooling; industrial process heat recovery; generation of electric power; and thermal energy transport.

## VI BUILDING HEATING AND COOLING

Heating and cooling of homes, offices, stores, and other buildings represent a large fraction of our national energy consumption. During 1977, heating, cooling, and hot water for residential and commercial buildings accounted for approximately 19 quads of energy (3400 OE), primarily as natural gas and petroleum distillates. These prime fuels are high-quality energy sources, whereas the need in heating applications is for low-quality thermal energy, i.e., low-temperatures on the order of 80°F to 160°F. The use of fossil fuels is thus an accommodation to logistic, economic, and environmental factors, not a technological requirement. Alternative energies which are both available and applicable to building heating and cooling are solar-thermal, reject and cogenerated heat from utilities and industry, and ''energies of opportunity'' such as winter cold. Each one exhibits a time mismatch with the desired end-user, however, so that thermal energy storage is needed to use these energy sources effectively. Storage requirements include seasonal, weekly, daily, and buffering applications which represent durations of months, days, several hours and a few hours, respectively.

### Seasonal Storage for Building Heating and Cooling

The energy recovered from waste heat and cogenerated heat from industry and utilities is generally available throughout the year. Seasonal-duration thermal storage allows the capture and use of a far greater fraction of this energy than simple supply-on-demand. Similarly, the cold air of winter is an ''energy of opportunity'' which can be stored until summer and used for air conditioning. Finally, seasonal storage for solar-thermal applications will allow use of smaller solar collectors sized to gather thermal energy over an entire year, especially during the summer. In this case, cost-effective seasonal storage may expand the solar heating market to regions where it is presently of marginal economic interest, and reduce the need for back-up heat sources.

Seasonal storage of thermal energy requires a very large thermal mass to retain the energy needed for an entire heating or cooling season. For both district systems and large buildings, initial studies indicate that a low cost thermal mass of this magnitude will probably involve natural structures such as aquifiers (underground, water-bearing geologic formations), constructed ponds and earth, rather than manufactured devices such as water tanks and rock beds. The primary focus of the seasonal storage effort is developing technology for aquifier storage and conducting large-scale technical demonstrations. Cooperative funding with a West German project is being used to acquire information about seasonal storage in ponds. Thermal storage in damp earth has also been studied for single-dwelling applications. Future versions of chemical heat pumps are also expected to be attractive for small-scale seasonal storage applications.

### Aquifier Storage

Seasonal storage of thermal energy in aquifiers takes advantage of naturally-occurring, porous rock formations which contain large quantities of water and which are commonly tapped as a source of water for household and irrigation purposes. They represent a natural alternative to large man-made storage facilities, requiring only drilling and pumping operations to be linked with the energy sources and end-users on the surface. The concept involves withdrawal of water from the aquifier, heating (or chilling) the water using an existing energy source and reinjecting the water into the aquifier, as shown in Figure 9. Reversing the water flow allows recovery of the heat (or cold) on demand. The concept is attractive for near-term applications because the technologies for well-drilling and production are established; aquifier storage will require no breakthroughs, only the solution of specific engineering problems.

A major investigation of aquifier storage at JFK airport in New York was cosponsored by DOE and New York State ERDA. As shown in Figure 10, winter-chilled air would be used as an ''energy of opportunity'' to produce cold water which is stored in an aquifier and subsequently withdrawn for summer air conditioning. Engineering studies are underway and the detailed geology of the aquifier is being determined through test drillings.

A second major demonstration of aquifier storage, under study at Bellingham, Washington, is part of a project to capture industrial waste heat from an aluminum plant for use in a district heating system.

Experimental support work includes operation of wells at Auburn University and at Texas A&M that are intended to provide data for cyclic storage of heated (Auburn) and chilled (Texas) water. The testing will check predictions of analytic models describing the efficiency of injection and withdrawal in a known aquifier system. In addition, the work will provide hands-on experience with the engineering problems associated with the processes. Analytic studies include modeling efforts at Lawrence Berkeley Laboratory; an economic analysis at Oak Ridge National Laboratory, and a generic environmental impact analysis at ORNL. Hydrogeologists are conducting a parametric study in the A region to determine the suitability of various types of aquifiers for thermal storage. The objective of these supporting studies is to increase understanding of the basic processes which will affect the use of aquifiers for thermal storage, including mechanisms of energy loss, mechanical and hydraulic effects, and environmental impacts.

For the future the Pacific Northwest Laboratory expects to issue a competitive procurement in August of 1979, the object of which will be to demonstrate the seasonal storage of thermal energy in aquifiers. Government funding of this cost shared effort is expected to reach $40,000,000.

**Daily Storage for Building Heating and Cooling**

Solar-thermal heating and cooling systems need thermal energy storage to meet building demands during periods of darkness, inclement weather, or intermittent cloud cover. Rock beds and water tanks are mature technologies for storing thermal energy. Latent heat (phase-change) and thermochemical (chemical heat pump) technologies require further development. Daily storage technologies include not only active and passive solar-thermal systems, but also customer-side-of-the-meter storage of heat and cold derived from off-peak electricity to accomplish utility load leveling. The principal application for chemical heat pumps is in active solar-thermal systems, while phase-change materials are being developed for active and passive solar systems, and for customer-side-of-the-meter storage.

**Phase-Change Materials**

The development of phase-change materials for both active and passive solar-thermal applications includes projects for modular storage units (macroencapsulation and bulk containment) and storage in building materials (microencapsulation).

Phase-change materials can be macroencapsulated in metal cans and plastic CHUBS (sausage-like containers) which are in turn arranged to form a storage module. Bulk containment in storage modules can provide both structural form and integral heat exchange for the bulk phase-change material. Both methods are being developed for active solar-thermal heating and for storage of heat or cold from off-peak electricity. Macroencapsulation projects are underway at Dow Chemical Company and the University of Delaware. Bulk containment projects are underway at General Electricity and the University of Dayton, using Glauber's Salt and form-stable polyethylene, respectively. The objective is to develop packaging for storage modules in an active solar-thermal system at a system cost goal of $5/kWht by FY 1981.

Incorporation of phase-change materials into building materials, such as concrete blocks, is directed as passive solar-thermal applications and storage of heat or cold from off-peak electricity. A procurement to develop advanced building materials will be issued during 1980.

Supporting effort in this area focuses on identification and evaluation of improved materials, and analytic modeling of the mechanism of nucleation and crystallization, and analytical-physical modeling of thermal transport mechanisms.

### Customer-Side-of-Meter Storage for Electric Load Leveling

For a number of years, European electric customers have been reducing daily peak-load electricity demand through storage of thermal energy from off-peak periods to on-peak times. The state-of-the-art devices are resistance heaters imbedded in a suitable thermal mass. The DOE effort attempts to verify the domestic acceptability of these European devices and to apply technologies to this end-use. Phase-change materials are a primary new candidate for this application, especially with heat pumps and air conditioners.

## VII INDUSTRIAL RETROFIT FOR RECOVERY OF REJECT PROCESS HEAT

Approximately 40 percent of the total energy demand in the United States is used in industrial applications. Both energy savings and displacement of fossil fuels can result from capture and re-use of reject process heat from industries. In many cases, this energy may be re-used within the industrial facility to improve the net process efficiency. Thermal energy storage is needed for those applications where there is a time or rate mismatch between heat availability and heat demand. In other cases, the heat may be exported to a district heating system, reducing residential fuel consumption.

The DOE program has identified over 20 application areas for industrial heat recovery with thermal energy storage. Five specific industries were selected for detailed study, namely: pulp and paper, primary steel and iron, primary aluminum, food processing, and cement.

### Pulp and Paper Industry

Conducted by Boeing Engineering and Construction (BOECON), Weyerhaeuser, and SRI, this case study of a Weyerhaeuser plant at Longview, Washington identified an application for buffering storage of steam which would increase substitution of ''hog fuels'' (wood wastes) for fossil fuel. The application is shown in Figure 11. It includes the calculated steam requirements and illustrates the potential reduction in plant fossil fuel requirements; this technology will be transferred to the paper and pulp industry in FY 1980.

### Primary Steel and Iron Industry

This study was conducted by Rocket Research Company in conjunction with Bethlehem Steel and Seattle City Light. Conceptually, reject heat from the electric arc furnace fume stream would be accumulated in a solid storage medium of slag or scrap steel materials capable of withstanding the nearly 3000°F temperature. As shown in Figure 12, stored energy would raise steam which would drive a turbine to generate electricity, reducing the peak load demands of the plant.

### Primary Aluminum Industry

The study was conducted by Rocket Research Company in conjunction with Intalco Aluminum Corporation and Bonneville Power Administration. It focused on the use of reject heat from the aluminum smelting process for district heating in the nearby communities of Ferndale and Bellingham, Washington. The concept involves either buffering and daily storage in water tanks (Figure 13) or seasonal storage in a doublet-well aquifier system.

### Food Processing Industry

Conducted by Westinghouse Electric Corporation in association with the H.J. Heinz Company, this study focused on daily storage of low-temperature thermal energy to recover reject heat from food processing operations for preheating makeup water for food processing and cleanup operations. The concept, as shown in Figure 14, was based on typical processing facilities for canned foods (Pittsburgh, PA) and frozen foods (Lake City, PA). A demonstration effort is scheduled for FY 1981.

**Cement Industry**

The study was conductd by Martin-Maritta Aerospace in conjunction with the Portland Cement Association. Sensible heat from the exhaust stream of the plant's kilns would be stored in solid, sensible-heat materials such as cement clinker, granite, or limestone. Heat would be withdrawn from storage to raise steam which would drive turbines to generate peak-load electricity for the plant. Energy storage provides the heat necessary to generate electric power during periodic kiln shutdowns for maintenance.

These five studies are the first phase of the DOE program to promote recovery and reuse of industrial reject and process heat through thermal storage. Further effort includes retrofit of thermal storage into a food processing plant starting in 1979, with operation planned for 1980. Plans to retrofit thermal storage to a pulp and paper plant have been modified because of the discovery that a similar installation already exists (see discussion of commercialization efforts). Finally, an aluminum refinery retrofit will be designed in 1979 and 1980; construction will proceed to a target operating date during 1983. The goal of these demonstration projects is to verify 3-year payoff for industrial heat recovery. The program will enhance technology transfer through issue of a detailed commercialization document once the individual demonstrations are complete.

## VIII GENERATION OF ELECTRIC POWER

Development of solar-thermal power generation will require high-temperature thermal subsystems to provide buffering and daily storage. Thermochemical storage has potential applications for long-duration storage. High-temperature thermal storage added to existing coal-fired power plants could supply peaking power to displace oil-fired peak-load capacity. However the maturity level of these technologies is below that for building heating/cooling and industrial reject heat recovery; the time frame for potential implementation is the late 1980's to 1990's.

**Utility Applications for Peak-Load Following**

The concept for using thermal storage to achieve utility peak-load following is illustrated by Figure 15. This project is a cooperative effort involving DOE, EPRI, and TVA. A system study contract awarded to General Electric and scheduled for completion during 1979 will produce a comparative evaluation of conceptual designs for mid-term applications. The results of the study will be used to compare thermal energy storage with other energy storage concepts, coal plants, and load management/rate design techniques to identify the most effective means of dealing with peak power demands.

**Solar-Thermal Power Generation**

The development of solar-thermal electric power involves coupling high-temperature solar collection technology to a thermal power cycle, such as a Brayton or Rankine cycle. A stable supply of power requires a thermal energy storage system capable of driving the power cycle during brief periods of cloud cover (buffering), during the night (daily cycling), and during periods of inclement weather. In addition, long-duration storage of thermal energy would allow solar systems to meet seasonal power demands. High-temperature storage as sensible and latent heat is the prime candidate for the buffering and daily applications, while thermochemical storage technology is being developed for longer durations. The objective of this element of the DOE Thermal Storage Program is to assess and develop storage technologies on a schedule compatible with the development of solar-thermal electric power systems. A comprehensive development and demonstration program plan is being prepared by NASA-Lewis Research Center with input from Sandia Livermore Laboratory, Jet Propulsion Laboratory, Solar Energy Research Institute, Aerospace Corporation, and PRC Energy Analysis Company, for the DOE Division of Energy Storage Systems and the Division of Central Solar Technology. The plan correlates development of thermal storage with solar-thermal system requirements and milestone schedules for 1980 to 1985; elements of the plan are given in Figure 16. A draft plan is under review by DOE and publication of the plan is scheduled for fall 1979.

Three applications are emphasized for high-temperature sensible and latent heat technology development. First, daily storage is needed for central receiver (power tower) plants in peaking and intermediate service. Analytic and laboratory efforts will examine alternatives to present baseline storage systems and a technology demonstration is scheduled for 1982. The second application is daily storage in small power systems which are part of a solar total energy system concept. Laboratory studies, computer simulations, and an intermediate-scale demonstration will be conducted during 1979. The third application is thermal buffering storage for repowered (existing plant retrofits) steam-Rankine power systems. During 1980, procurements will be initiated for development and demonstration of this concept by 1982. The cost goal for short duration storage is $20/KWhe.

Thermochemical storage for solar-thermal power applications is directed toward long duration applications. Ongoing advanced system studies and laboratory investigation of promising chemical reaction systems will lead to a 1981 decision on weather to proceed with a subsystem development and test activity which could be complete by 1984. Second generation systems will also be pursued and will lag the first generation program by about 2 years.

## IX ENERGY TRANSPORT

Thermochemical energy transport in pipelines is a concept for non-electric transmission of energy from central energy sources such as solar and nuclear plants. The concept uses reversible chemical reactions, similar to thermochemical energy storage but involving transmission, rather than accumulation, of the chemical reactants. The basic features of the system are shown in Figure 17, although a practical system will certainly be more complex. The advantages to thermochemical versus electrical transmission include direct transmission of high-quality heat energy without thermal loss and inherent storage capability which allows the source to operate at steady conditions while the load fluctuates in time.

The energy transport program emphasizes systems studies and component development for open-loop and closed-loop pipelines, and transmission in distributed solar thermal systems. The concept of thermochemical pipelines is an early stage of development, and has a cost goal of $0.005/kWht for heat transmission over distances of 100 miles by 1990.

### Closed-loop Pipeline

High temperature closed-loop pipelines involve chemical systems which accept and return heat energy at the temperatures typical of advanced nuclear reactors and concentrating solar collectors. The methane-steam reaction ($CH_4 + H_2O = CO + 3H_2$) is a mature technology which is adaptable to this purpose. During 1979 a duplex steam reformer will be interfaced with a high temperature experimental facility at KFA Julich, as part of a joint U.S.-German project. The test represents the energy input portion of a concept which originated in Germany and is known as EVA-Adam, as shown in Figure 18. A second activity in the high-temperature pipeline program will assess the feasibility of interfacing a pipeline with a central receiver solar energy source.

Activity during 1979 and 1980 on low-temperature, closed-loop pipelines will focus on establishing the feasibility of using the benzene/cyclohexane reaction for energy transport. This system has the advantage of interfacing with near-term nuclear and solar plant designs. Market characterization studies will be conducted and alternate chemical systems will be investigated, starting in 1980.

### Open-Loop Pipeline

An open-loop energy pipeline involves a net transport of material in addition to energy because the return loop is eliminated. The concept is thus restricted to chemical systems where the end product is a fuel or other commodity material. Technology development for a coal gasification based system could provide an alternative to baseline coal gasification systems. Conceptual studies of interfacing open-loop thermochemical pipelines with advanced solar concepts will start in 1980.

## X COMMERCIALIZATION ACTIVITIES

The ultimate goal of this program is commercialization of all appropriate thermal energy storage technologies. Successful development efforts will culminate in site-specific demonstrations which verify the technical and economic feasibility of the thermal storage system.

### Pulp and Paper Industry

A 1976 conceptual study identified over 20 industrial processes which were appropriate for conservation of energy through thermal storage. Five specific cases were selected for a more detailed analysis. Early in 1978, the team of Boeing Engineering and Construction, Weyerhaeuser Corporation, and SRI International examined thermal storage applied to the pulp and paper industry. Their study recommended the use of variable-pressure steam accumulation to allow substitution of wood waste (''hog'' fuel) for fossil fuel in generating process steam. While searching for an industrial partner to participate in a site-specific demonstration of the technology, BOECON discovered that at least one U.S. company was already using the concept for steam demand swing smoothing with excellent results, but had not disclosed the technique to the industry-at-large. Under DOE funding the study results and the experience of the existing units will be documented in a commercialization package and distributed to the pulp and paper industry-at-large. The decision to employ thermal energy storage for this purpose will be made by industry executives and planners, based on their own standards for capital return.

### Seasonal Storage in Aquifiers

The commercialization of thermal energy storage in aquifiers is proceeding through activities which are expected to lead to fully integrated, site-specific technical demonstrations. A procurement notice will be released by ORNL in August, 1980 and will result in up to eight contracts to develop feasibility studies and conceptual designs for fully integrated demonstrations. At the end of this stage those contractors will be condensed to a group of approximately five participants who will take their designs to construction, startup, and operations. We expect applications on a broad geographic basis. DOE is also funding two studies of hot water storage in aquifiers for the purpose of district heating. Each study leads to a decision on whether to pursue a demonstration project. The first involves the use of reject heat from a primary aluminum refinery near Bellingham, Washington (by Rocket Research Company/Intalco Aluminum/Bonneville Power Administration). The second involves capture of cogenerated heat from electric utilities in Minneapolis-St. Paul, Minnesota (by General Electric-TPO/Studsvik). Additional regional field tests will be developed to demonstrate the heating applications of aquifier storage at two to five sites by 1984. Successful tests will be documented and widely publicized to accelerate transfer of this technology to the private sector.

## Electric Load Leveling

One approach to the use of energy storage to accomplish customer-side-of-the-meter load leveling uses off-peak air conditioning to "charge" a storage module with "coolness," then uses the module rather than the air conditioning unit to provide on-peak climate control. A joint project involving the University of Delaware and DuPont has established the technical feasibility of packaging a "coolness-storing" phase-change material (Glauber's salt) in inexpensive "CHUBS", sausage-like casings which provide physical packaging and surface area for heat exchange. DOE funding will be employed to demonstrate quality control through long-duration, cyclic life tests.

Other, near-term approaches to providing thermal storage for building heating and for domestic hot water are presently being demonstrated on several utility grids by the DOE Division of Electric Energy Systems. This activity is monitored by a DOE Commercialization Task Force, which will assess present commercialization strategies and recommend future directions.

## XI SUMMARY

The DOE Thermal Energy Storage Program emphasizes near-term (1985) approaches to energy conservation and displacement of natural gas and oil. In addition, it provides for development of technologies which will allow use of renewable resources such as solar-thermal energy during the mid-term (1985-2000) and of advanced energy storage and transport techniques during the far-term (beyond 2000). In all cases, its goal is to contribute to the establishment of a stable, efficient national energy supply through advancement of those concepts which are technically feasible, economically attractive, environmentally sound, and socially beneficial.

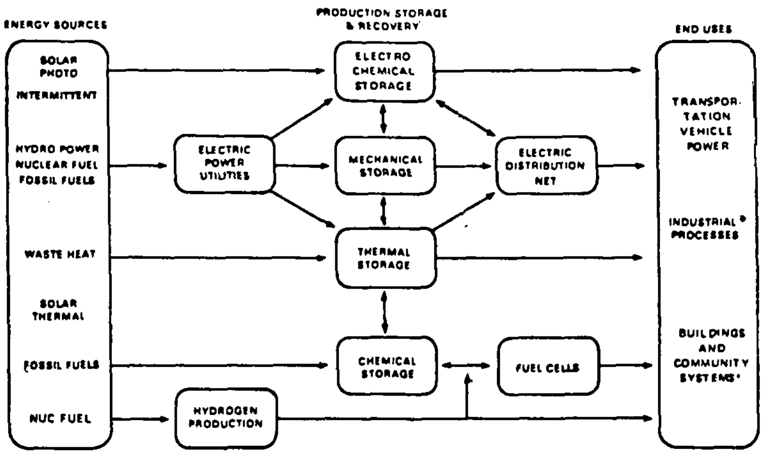



Figure 1. Energy Sources, Storage Systems, and End-Uses

- SENSIBLE HEAT: $Q = C_p \cdot \Delta T$
- LATENT HEAT: (PHASE CHANGE) $Q = \Delta H_{\text{VAPORIZATION}}$
  $Q = \Delta H_{\text{FUSION}}$
  $Q = \Delta H_{\text{TRANSITION}}$
- THERMOCHEMICAL: (HEAT OF REACTION) $Q = \Delta H_{\text{REACTION}} = \underset{\text{PRODUCTS}}{\Sigma M_p h_p} - \underset{\text{REACTANTS}}{\Sigma M_r h_r}$

Figure 2. Thermodynamic Mechanisms for Thermal Energy Storage

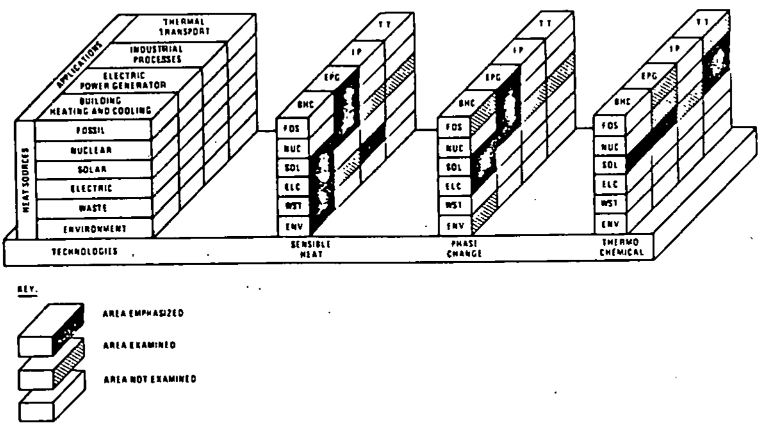



Figure 3. Thermal Energy Storage: Sources, Applications, and Mechanisms

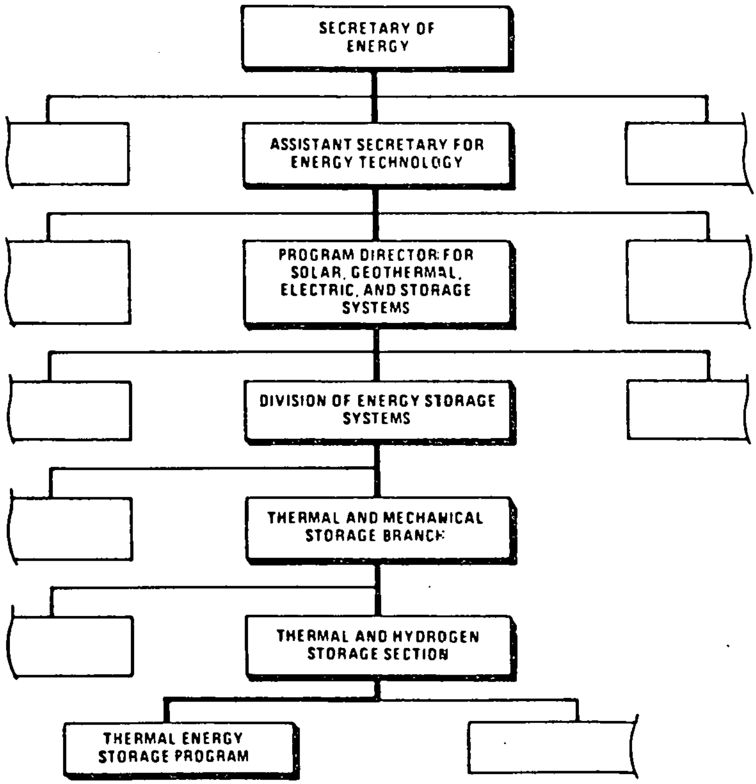



Figure 4. Organization of the DOE Thermal Energy Storage Program

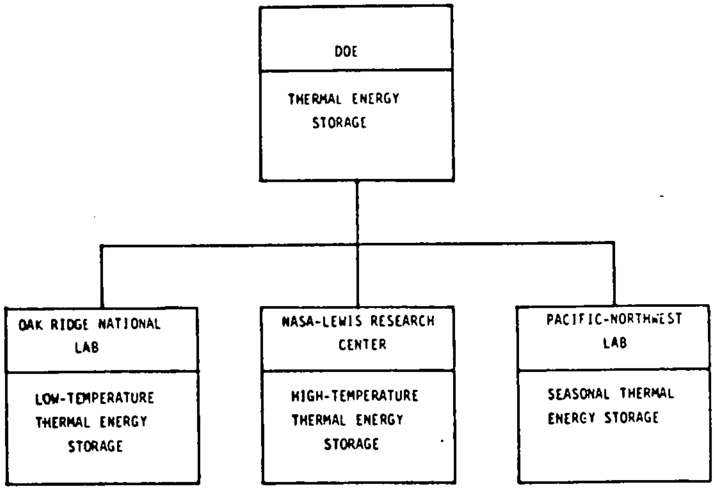
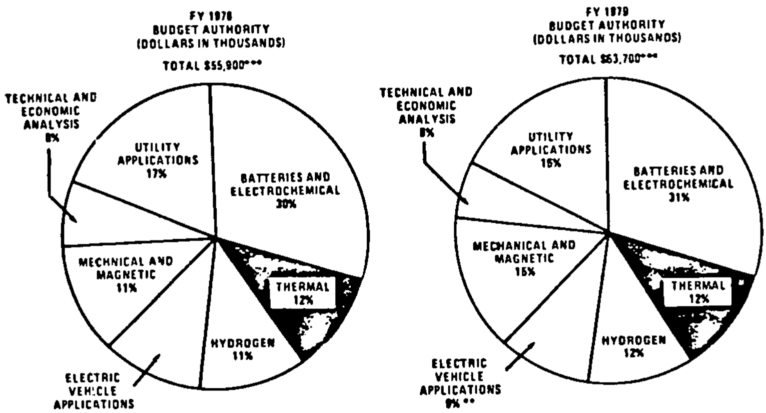



Figure 5. Field Organization of the DOE Thermal Energy Storage Program




*JOINTLY MANAGED WITH EES. FUNDS IN ENERGY STORAGE SYSTEMS DIVISION BUDGET.
**JOINTLY MANAGED WITH TRANSPORTATION ENERGY CONVERSION DIVISION (FUNDING FROM TEC).
***INCLUDING PASS THROUGH FUNDS

Figure 6. Division of Energy Storage Systems Funding by Program Area

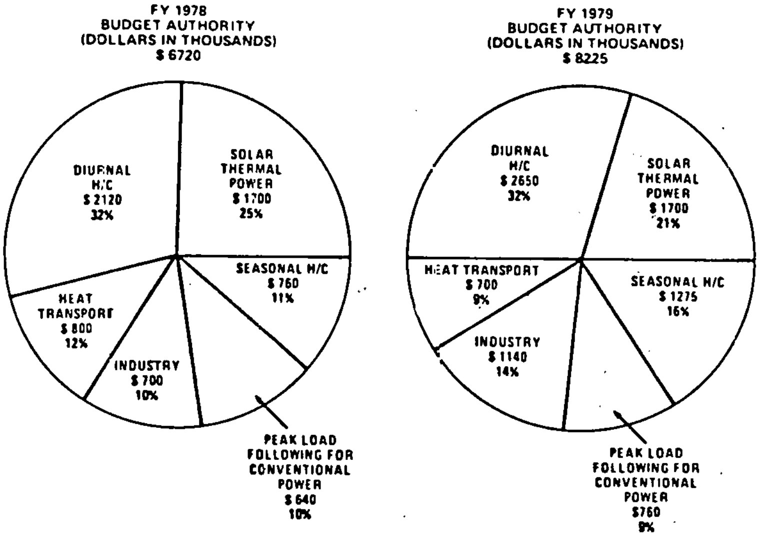



Figure 7. Thermal Energy Storage Program Funding by Application Area

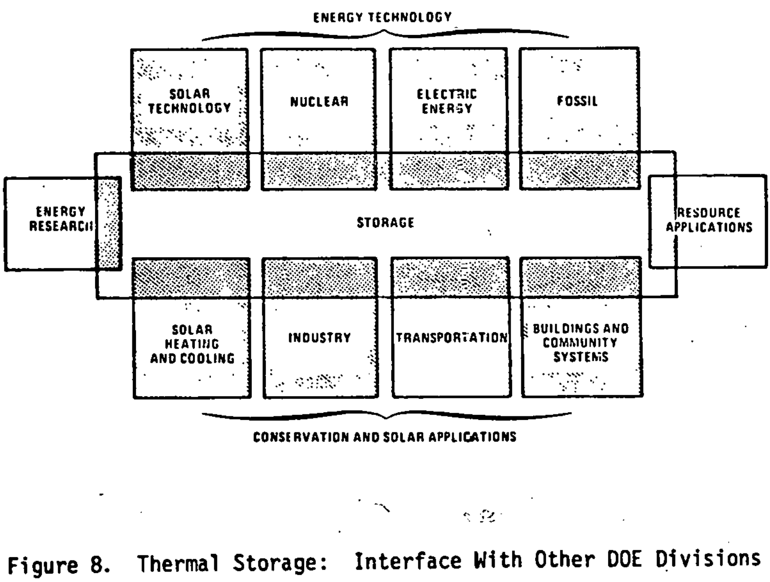



Figure 8. Thermal Storage: Interface With Other DOE Divisions

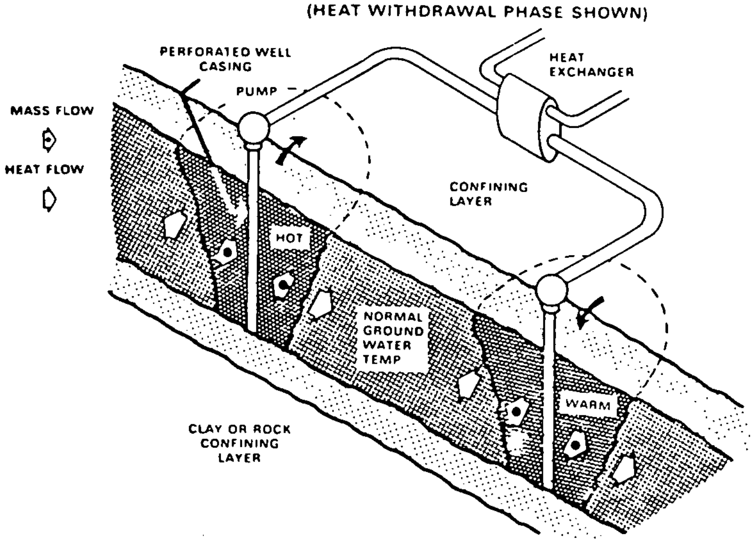



Figure 9. Thermal Storage in a Doublet Aquifer System

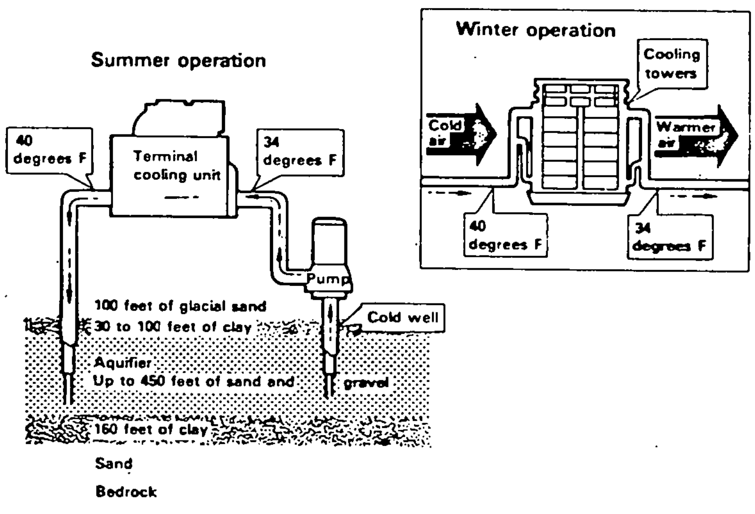



Figure 10. Proposed Natural Cooling System for JFK Airport

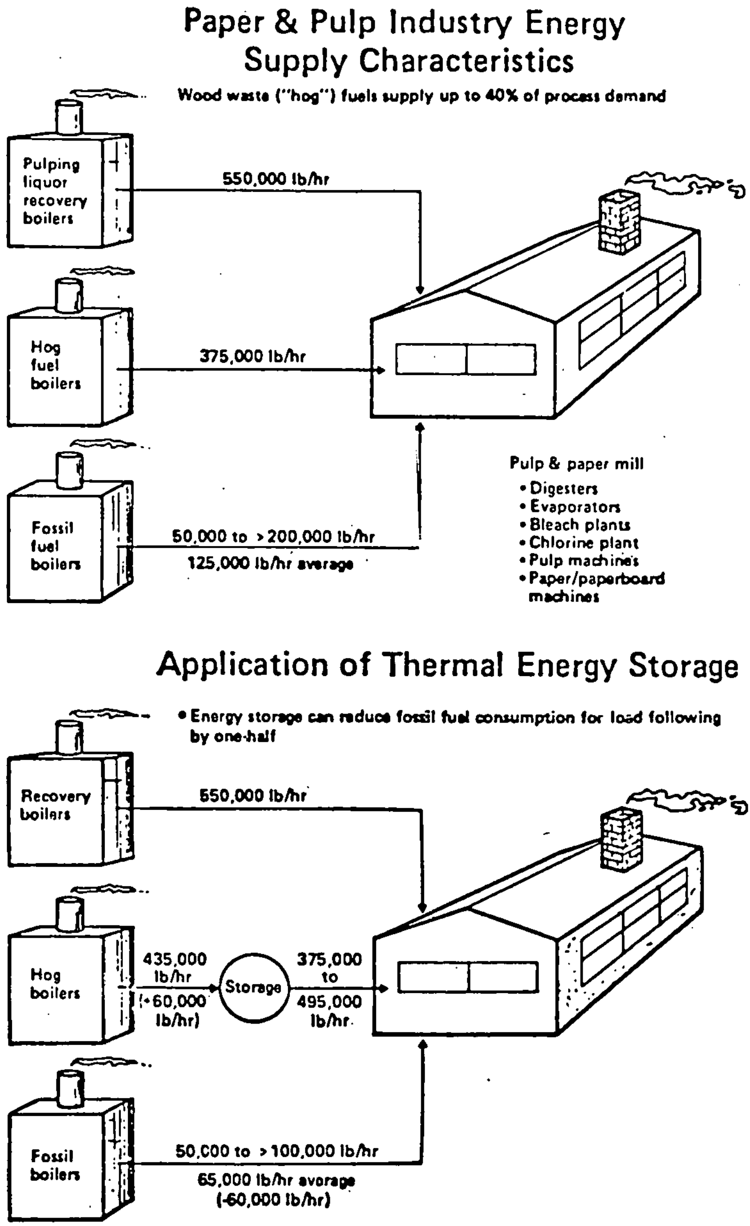
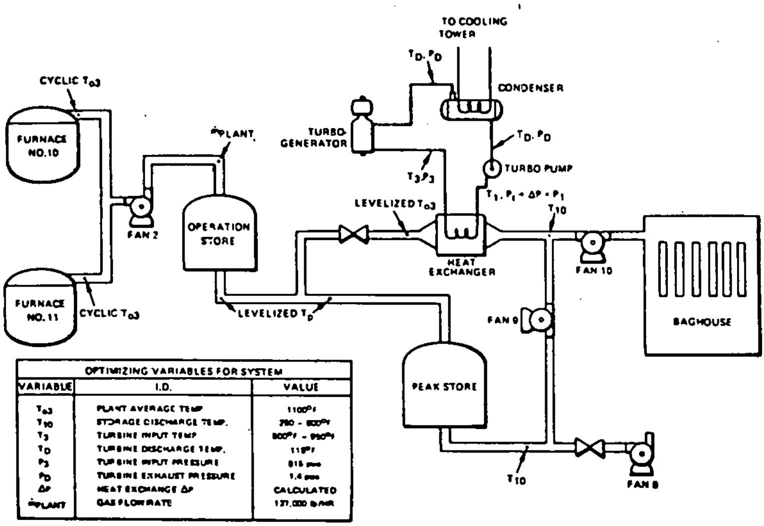



Figure 11. Thermal Storage Retrofit in the Pulp and Paper Industry




| OPTIMIZING VARIABLES FOR SYSTEM | | |
|---|---|---|
| VARIABLE | I.D. | VALUE |
| $T_{o3}$ | PLANT AVERAGE TEMP | 1100°F |
| $T_{10}$ | STORAGE DISCHARGE TEMP. | [illegible] |
| $T_3$ | TURBINE INPUT TEMP | 800°F - 950°F |
| $T_D$ | TURBINE DISCHARGE TEMP. | 119°F |
| $P_3$ | TURBINE INPUT PRESSURE | 815 psia |
| $P_D$ | TURBINE EXHAUST PRESSURE | 1.4 psia |
| $\Delta P$ | HEAT EXCHANGE $\Delta P$ | CALCULATED |
| $\dot{m}_{PLANT}$ | GAS FLOWRATE | 127,000 lb/HR |

Figure 12. Thermal Storage Retrofit in the Steel Industry

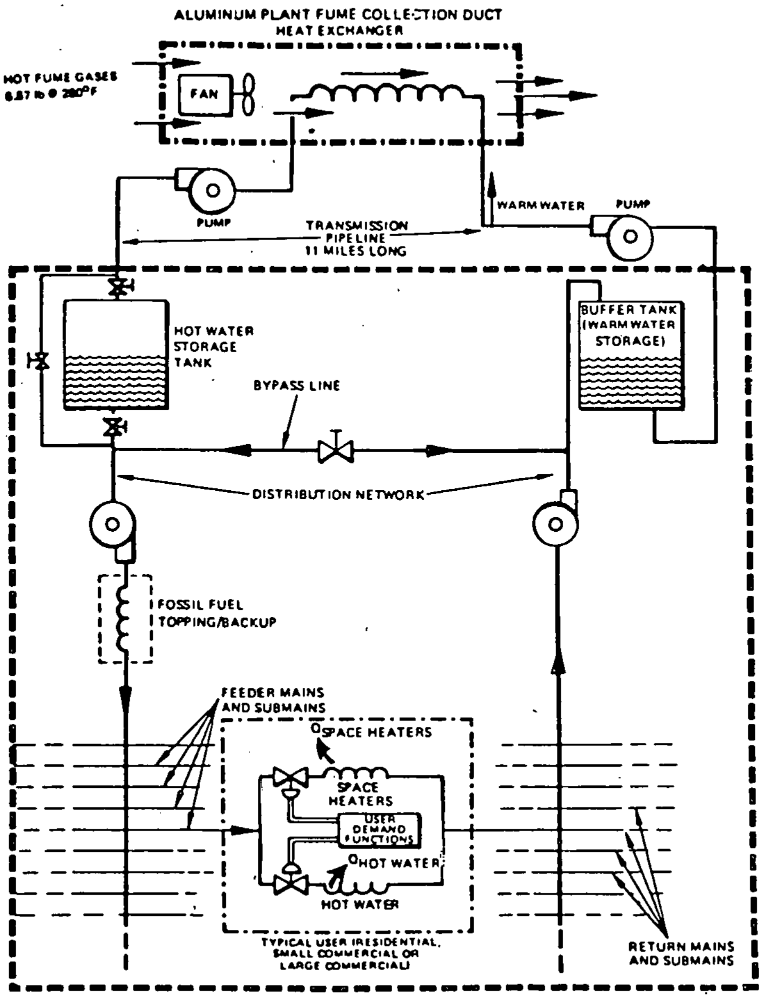



Figure 13. Thermal Storage Retrofit in the Aluminum Industry.

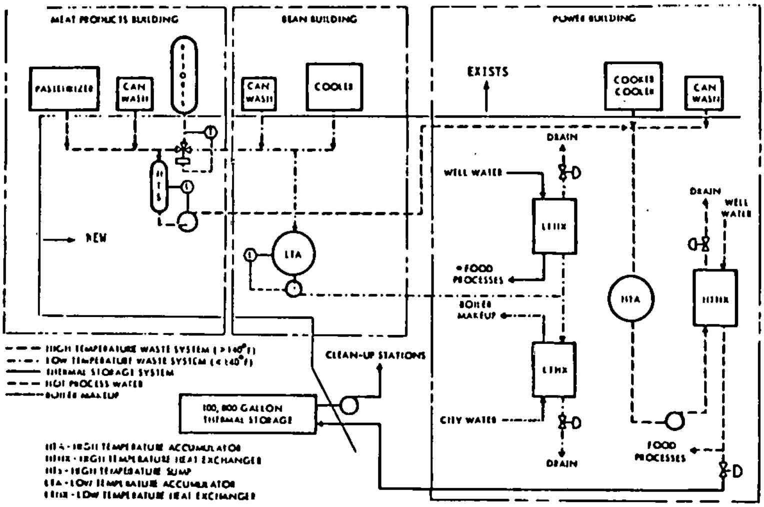



Figure 14. Thermal Storage Retrofit in the Food Processing Industry

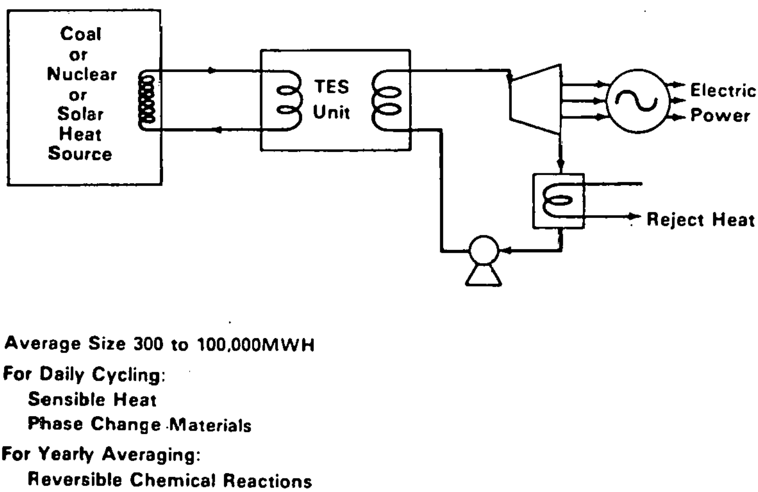



Figure 15. Thermal Energy Storage for Utility Peak-Load Following

BUFFERING STORAGE

- LARGE STEAM RANKINE POWER CYCLES
- SMALL DISH-MOUNTED HEAT ENGINES

DAILY STORAGE

- TPS BASELINE SUBSYSTEM SUPPORT
- LARGE STEAM RANKINE POWER CYCLES USING WATER/STEAM RECEIVERS
- LARGE STEAM RANKINE POWER CYCLES USING MOLTEN SALT/LIQUID METAL RECEIVERS
- LARGE BRAYTON POWER CYCLES
- SMALL RANKINE POWER CYCLES

ADVANCED TECHNOLOGIES

- TRANSPORT
- VERY HIGH TEMPERATURE STORAGE
- SR&T

Figure 16. Solar-Thermal Power Systems Applications of Thermal Storage

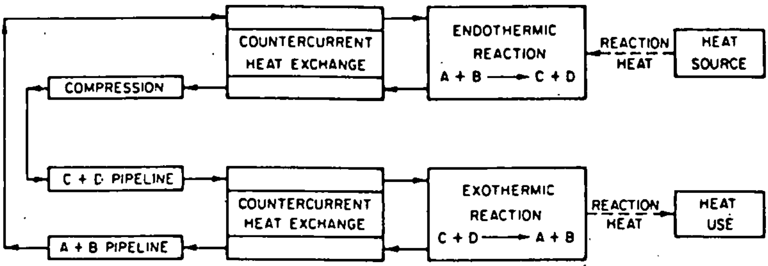
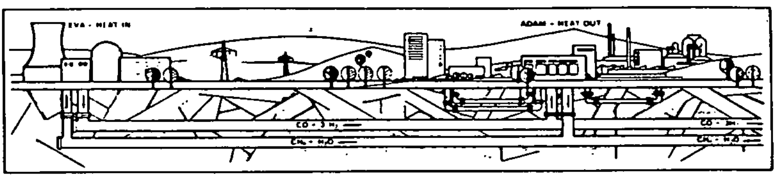



Figure 17. Closed-Loop Thermochemical Pipeline Concept



$CH_4 + H_2O + \text{HEAT} \rightarrow CO + 3\,H_2$ $\quad$ $CO + 3H_2 \rightarrow CH_4 + H_2O + \text{HEAT}$

Figure 18. The EVA-Adam Concept for a Thermochemical Pipeline Employing Reforming/Methanation

# III. Utility System Planning And Thermal Energy Storage

## INTRODUCTION

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Manager Office of Systems Evaluation
Argonne National Laboratory

The third session of the conference examines the role of thermal energy storage in context with utility system planning. As a technology option, TES offers the twin benefits of reduced utility fuel costs and reduced capacity expansion requirements. Against these benefits must be weighed the added capital cost to the customer of the storage equipement.

To examine these trade-offs, we are fortunate to have with us leaders and experts actively engaged in the evaluation, testing, and demonstration of thermal storage equipment. Dorman Miller (American Electric Power), who is directing the largest field test of storage heating systems to date in this country, will describe the status of that program. George Reeves (GPU Service Corporation) will discuss the benefits and costs of TES from a utility planning perspective. The Vermont Experience, including the first commercial introduction of TES in this country, will be discussed by Charles (Tony) Whitehair (Central Vermont Public Service Corporation). Quentin Looney (Electric Power Research Institute) will describe thermal storage as a conservation option and will review the EPRI thermal storage program. Finally, Michael Kuliasha (Oak Ridge National Laboratory) will describe the DOE-sponsored demonstration program which now includes some ten utility projects, involving both heat and cool storage systems.

Before introducing our speakers, I would like to take this opportunity to tell you about the results of some recent analyses at Argonne.[1] In these studies, which were sponsored by the Division of Energy Storage Systems, U.S. Department of Energy, we compared the *total cost* of supplying space heating and cooling services with different types of end-use technology. The important feature of these analyses that costs on both sides of the meter—those borne by the utility and by the customer—were calculated to obtain an overall value of the total cost of service.

Natural gas and fuel oil, as well as electric and electric-assisted heating technologies, were evaluated and compared. The SIMSTOR model, which uses synoptic hourly load and weather data, was used to simulate the performance and estimate the marginal costs of supplying electricity to the heating and cooling systems. A gas utility model was used to estimate the cost of supplying gas-fired furnaces.

Case studies of a number of utility service areas were performed. In each service area the individual heating and cooling systems were matched to load requirements of a 1500 ft , well-insulated, detached single family dwelling unit. The heating load amounted to four kilowatt-hours per degree-day.

Figures 1 and 2 show the results of the analyses for the different heating and cooling technologies for two service areas. One of the service areas is located in the Northeast and is supplied by a winter-peaking electric utility; the other, located in the Middle Atlantic Region, is served by a summer-peaking utility. The energy costs in the figures correspond to the combined costs of heating and cooling. The energy supply cost (vertical axis) includes utility (gas or electric) and/or fuel oil costs. Expressed in annualized values, the supply cost can be conceived as the utility's annual fuel bill plus its annual mortgage payment on the plant and equipment needed to meet the heating and cooling device load. The device cost (horizontal axis) represents the annualized capital cost of the onsite residential heating and cooling equipment plus the annual cost of a service contract covering repairs and maintenance. The dashed lines in the figures represent points of constant total cost, that is, the sum of costs incurred on both sides of the electric meter. As such, it is a comprehensive index for comparing the overall economic efficiencies of the different systems.

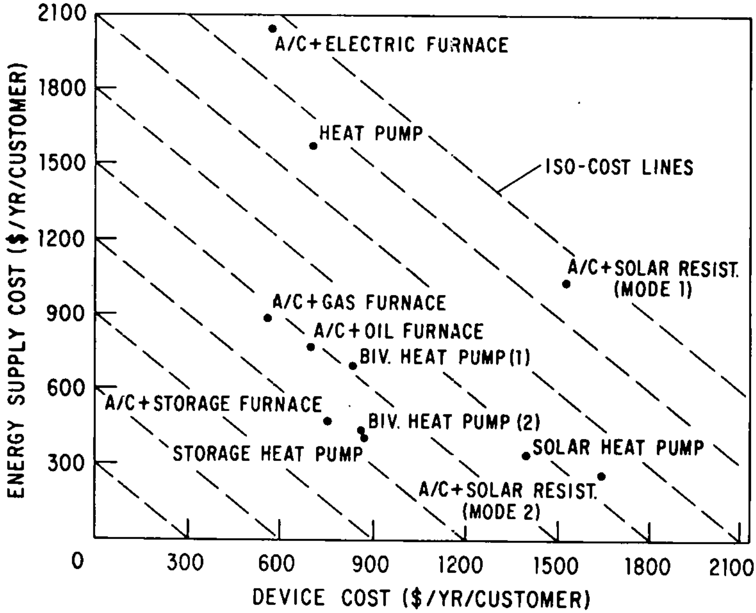


Fig. 1. Annualized Costs for Different Heating and Cooling Technologies, Winter-Peaking Service Area, Utility Cost of Money on Both Sides of Meter. "A/C" denotes a conventional central electric air conditioning system.

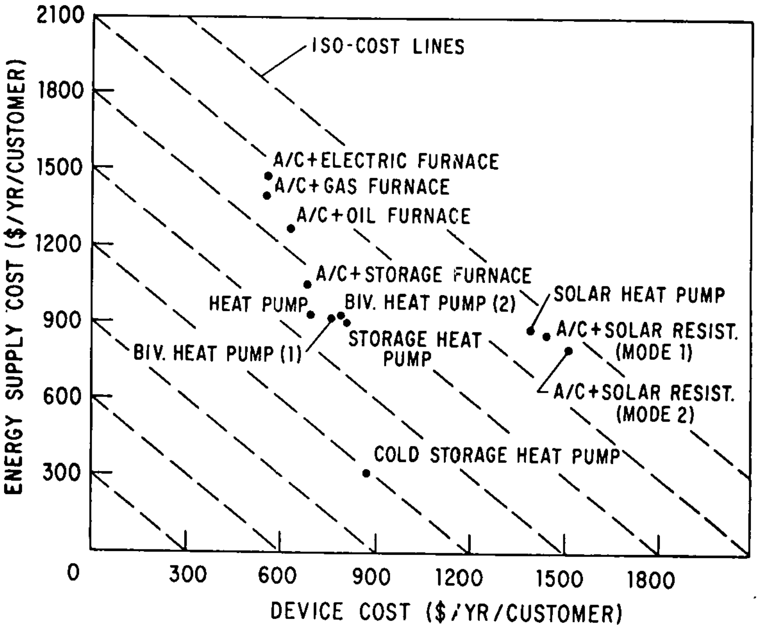


Fig. 2 Annualized Costs for Different Heating and Cooling Technologies, Summer-Peaking Service Area.

In the winter-peaking service area, the storage and bivalent systems are the most efficient heating systems in terms of overall cost. Presenting the utility with electric loads only during the off-peak hours, these systems do not contribute to the utility's coincident peak demand.

The ripple-controlled bivalent, or dual fuel, heat pump is especially attractive. Entailing a small customer capital cost penalty—approximately $500 over the cost of a heat pump with electric resistance backup, the heat pump with oil furnace backup achieves substantial savings through the virtual elimination of the on-peak electrical load.

As indicated in Fig. 1, the costs of energy supply to the solar resistance and the solar-assisted heat pump systems are lower than for direct resistance heating; however, the solar systems are not competitive in terms of overall cost with the storage and bivalent heating systems. In the winter-peaking service area, the total cost of the solar-resistance heating system becomes comparable to the cost of electric storage heating at a collector cost of about $5.00 per square foot.

For the service area supplied by a summer-peaking utility, the entire heating season is off-peak so that the benefits of storage and dual-fuel heating systems are greatly reduced. The conventional heat pump is the most economical heating technology. Storage and dual fuel technologies are 10-20% more expensive in terms of overall cost and suffer the disadvantage of being more complicated technologies.

An important finding, immediately evident in both figures, is that several electric-based heating technologies are cost-competitive with oil and natural gas heating. Among the electric-based technologies, the lowest cost systems in the winter-peaking service area are the storage resistance furnace combined with a conventional air conditioner and the heat pump augmented either by storage or by an oil furnace. In the summer-peaking service area, the heat pump with diurnal cool storage is the lowest cost system.

Although the foregoing results are strictly applicable only to the two service areas under study here, our analyses of other service areas indicate that load-managed electric heating is cost-competitive with oil and natural gas heating over most of the United States. For a nation wanting to reduce its dependence on foreign oil and attempting to conserve its domestic oil and gas reserves, the implications are obvious.

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1. Asbury, J.G., R.F. Giese, R.O. Mueller and S.H. Nelson, *Commercial Feasibility of Thermal Storage in Buildings for Utility Load Leveling*, Proc. American Power Conf., Chicago (April 1977). Asbury, J., J. Caruso, R. Giese, R. Mueller, L. Akridge, K. Heitner, A. Molander, and P. Moritz, *Assessment of Energy Storage Technologies and Systems Phase II: Heat Pump and Solar Energy Applications*, Argonne National Laboratory Report ANL/SPG-3 (March 1978).

# UTILITY SYSTEM PLANNING & THERMAL ENERGY STORAGE: THE AEP FIELD TEST PROGRAM

by

**Dorman M. Miller**
**Vice President, Customer Service**
**American Electric Power Service Corp.**

The 1973 oil embargo, rising fuel costs, and fuel shortages have awakened the American public to the stark realization that conservation, increased efficiency, and productivity must be accepted as a way of life in the years ahead. In the past, consumers had little or no interest in the operating efficiency of their electric utility—until the historic trend of declining electric costs was reversed and electric bills began to rise. Now, customers and others are developing a genuine concern for ways to improve electric industry operating efficiency. Previously, this was almost solely a concern of individual electrical utilities.

To many, efficiency connotes conservation of energy, but to a growing number, it also means conservation of capacity. There is an emerging national desire to smooth utility load curves by pulling down peaks and filling the load valleys. Many feel this can be accomplished by simply sending consumers new price signals through innovative rate forms. There are serious questions as to whether pricing alone can result in significant load shifts that will be permanent and predictable without a dramatic change in the American lifestyle. Rate levels already may have increased sufficiently for most customers to eliminate discretionary energy use. The remaining uses are considered essential and are almost directly linked to the consumer's working and waking hours.

These were introductory statements in a detailed technical paper prepared for the IEEE January 1978 Power Generation Committee Winter Meeting.

In 1978, the U.S. Congress enacted legislation that will shortly mandate consideration of energy management techniques. The Public Utilities Regulatory Policies Act (PURPA) will require many utilities to submit to state regulatory commissions, among many other provisions, rates based on time-of-day usage unless, not cost-effective and also practical, reliable and cost-effective load management techniques that will reduce utility KW demand. A second federal law known as the National Energy Conservation Policy Act of November 1978 also recognizes and encourages the use of "load management techniques" which includes the energy storage devices.

Whereas we began voluntarily considering time-of-day rates tied to thermal energy storage in 1975, shortly these time-of-day rates procedures must be considered by most utilities as a matter of federal law.

In 1975 we had an interest in time-of-day rate approaches tied to equipment or systems responsive to off-peak operation. Our interest in the AEP Test Program was triggered, however, by the concern expressed by our chief engineer in the cost of operating large 1300 MW generators during off-peak periods when these units were only partially loaded. The heat rate is most unfavorable and maintenance costs accelerate under these conditions.

As a partial answer to these problems, we proposed to our management that we investigate the value of Thermal Energy Storage equipment, specifically the European storage furnace and a 120 gallon American-built storage water heater. This study led to the purchase of 70 of each for installation in homes on our system during a three year period of testing.

The water heaters were manufactured by A.O. Smith Corp., Kankakee, Illinois and the storage furnace was a standard product of Creda International Ltd., a Division of Tube Investments, London, England.

We had another reason to believe that these TES systems had the potential of becoming another load management tool for the utility industry. The primary benefits were thought to be the following:

1) Smooth daily load profiles on a permanent, predictable basis. This could be an important benefit to utilities experiencing minimum load off-peak generating problems on either a seasonal or year-round basis.
2) Improved system daily and annual capacity factors.
3) Improved system daily and annual load factors.
4) Reduced rate of growth of peak loads.
5) Improved heat rates and perhaps reduced boiler maintenance expenses due to the load-leveling effects of TES equipment operation.
6) Conservation of present generation, transmission, and distribution capacity by absorbing growth in existing load valleys, thus delaying the need for future investment in these facilities.
7) Availability of TES for use as operating reserve with appropriate limitations. If real time, direct utility control systems are implemented, TES equipment could be interrupted for relatively long periods without user inconvenience and would become immediately available upon request.

Conventional electric home heating is a major contributor to AEP's winter peak, contributing almost 2,500,000 KW to the total peak day load of over 12,000,000 KW. This is a relatively new type of load for an electric utility system. We now have over 375,000 electrically heated homes on the system. Since 1973 an increasing number of AEP homeowners have installed electric heating; with almost 70% of all new single family and apartments installing electric heat, the trend persists.

Use of TES space conditioning and water heating devices have been demonstrated by our test program to be the means for efficient growth which will benefit the customer, the utility and the nation.

Let me share with you the nature of our experiment and the results, but first, a few words about program considerations.

The Residential Energy Storage (RES) program recognized that there may be important benefits to the utility from customer use of TES equipment. If the customers are to be encouraged to use such devices, they will expect general advantages: (1) a lower operating cost in the form of a time-of-day rate to offset the higher initial cost to purchase TES devices, (2) TES equipment designs which are capable of providing comfort or services equal to or surpassing conventional space conditioning and water heating systems, (3) the purchase of TES devices on a basis competitive with other equipment alternatives which are capable of producing equal operating costs, e.g., heat pumps, and (4) the recovery of the higher initial cost of TES equipment within a 3-5 year period. Payback is defined as the period required for the operating cost savings to equal initial cost premium without considering the time value of money. These payback criteria eliminated many technically feasible TES system alternatives.

Space conditioning and water heating were determined as having the greatest potential for TES equipment applications. Space heating, rather than cooling, was found to be more cost-effective for these reasons: (1) heating has a lower initial equipment cost, (2) it has a greater annual energy use which could be shifted to off-peak (a ratio of about 3.26 to 1 across the AEP service area), and (3) the impact of heating to cooling demands to system peak is about 1.97 to 1. Typically, electric space heating and water heating account for 60-70% of an all-electric home's annual kWH use. By combining space heating and water heating loads to off-peak TES operation, a significant shift in customer energy use is possible.

Installation records on our system indicate a strong customer trend toward the use of central, forced-air type space heating equipment on our system. Currently, about 65% of the electric heating systems installed by AEP customers are of this type. This represents a definite change in customer equipment preferences, due to their desire for present or future central air coniditioning. Because of this, the initial program emphasis was focused on locating and developing central, forced-air, furnace space heating devices. Creda International Ltd, a Division of Tube Investments, among others was found to mass produce TES central, forced-air furnace equipment. Other TES space heating alternatives were considered but the English TES furnace equipment was judged as having the greatest potential for near-term feasibility.

Water heaters are natural TES devices in that they convert electric energy to thermal energy and store it for future use. Within the AEP service area alone, approximately 800,000 conventional electric water heaters are in service. Only slight equipment design modifications are needed to produce desired TES operating features. These are seen to be as follows: (1) increased storage capacity to 120 gal., (2) improved insulation to reduce standby losses, (3) design features within the tank which enhance stratification, and (4) a load-leveling charge control to spread the daily charge requirements evenly over an eight hour off-peak period.

Charge control for TES equipment is an important part of this RES field test program. The ideal charge level is dependent on unconsumed charge from the previous day, length of off-peak charging cycle, and estimated following day's on-peak energy requirements. If the off-peak cycle is fixed, as it is in the AEP program at eight hours (11 PM to 7 AM), only two variables exist.

All of the AEP system TES furnace installations use automatic charge controls developed for this program. In the furnace, these variables are measured by a core thermocouple to sense core temperature and an outdoor thermistor to track temperature. It is not uncommon for outdoor temperatures to vary 20-30 degrees in a single day in this country. Therefore, these new charge controls were designed to maintain a furnace overcharge condition necessary to offset the outdoor temperature variations.

Climate is not a factor in TES water heater charge controls. Here it is desired to reach a full charge by the end of each off-peak cycle. Again, the length of the off-peak cycle is fixed at eight hours, so only one variable remains—the amount of unused charge from the previous day.

The remaining variable yet to be determined by the water heater and space heating TES charge control is rate of charge. Rate of charge is an all-important consideration to the utility. It is one goal to reshape system loads to off-peak, but another to accomplish this in a manner that benefits the utility, i.e., to the rate of charge.

An example is in order to illustrate this important point. With European clock-controlled systems, the off-peak cycle is signaled to begin. All TES space heating and water heating equipment is energized. These devices operate on a "full-on" mode and either the maximum on-peak demand is experienced for another several hours and then followed by the historic night load valley, or under certain conditions, the beginning portion of the off-peak cycle can experience a peak greater than the maximum on-peak demand. Both occurrences fail to provide the optimum benefit of TES to the utility. The ideal solution is to control the rate of charge and cause it to be spread over the full eight hour off-peak period. It is the minimum load night generation problem that is a concern to system operation and planning people.

Our program uses a "load-leveling" (LL) type charge control. Once the level of charge is determined by integrating time and temperature, the control determines what energy input is required over the eight hour charge cycle and energizes only the required number of heating elements to match the eight hour requirements. Present "LL control design" provides for switching loads in 25% increments. More refined "LL charge controls" are forthcoming.

The TES water heater charge control was designed and developed by A.O. Smith Corp., for this program. The control is of the LL type. It levels energy input over the eight hour off-peak cycle by switching elements in increments of 22%, 44%, 66%, or 100%.

Early investigations disclosed that European TES devices were technically acceptable, but in their present form were not economically feasible for use in the AEP Service Area. Primarily, this was due to the high cost of transportation and import duties. Also, the equipment, as designed, would not conform to various United States codes; however, the major drawback was the limitation of 100 KWH storage capacity. It became clear that if the concept was to have any chance of mass appeal in this country, there had to be an Americanized version manufactured in the United States with an increased storage capacity.

The decision was made to locate an American producer and a European manufacturer of proven performance who was interested in an American market. After extensive discussions, Creda International Ltd., London, England and TPI Corp., Johnson City, TN, entered into a licensing agreement to design and produce a line of Americanized TES equipment. Creda provided proven TES design experience and TPI, American mass production engineering expertise. It was agreed that the design of the Americanized unit would be concurrent with AEP's field test program which would proceed using existing modified Creda equipment supplemented by conventional direct electric heating furnace equipment produced by TPI. During this period, AEP arranged to test meter 70 installations to collect load research information to either prove or disprove the utility benefits of TES. If test results were favorable, TPI would be in a position to manufacture Americanized TES equpiment designs and all modified Creda/TPI furnace packages would be removed from the test homes and replaced with UL approved, Americanized equipment produced by TPI.

If test results were not favorable, the Creda/TPI furnaces would be removed and by prior agreement between AEP and the customer, the customer's space heating equipment would be converted to conventional equipment.

Another major goal of the RES program was to test the customer's willingness to pay a higher initial cost to earn a lower operating cost. This was an important factor, for regardless of the technical benefits of TES to the utility, the concept would have no value unless customers were willing to puchase and use such equipment. Purchase price of the Creda/TPI furnace and A.O. Smith water heater was established at $1050 or $650 greater than a conventional electric furnace and water heater. This was the estimated future user price of mass produced Americanized TES furnace designs of equal capacity. This additonal furnace and water heater cost would be refunded to the customer if the program proved unsuccessful.

The heat storage section stores heat during an eight hour off-peak period for use the following day and the companion TPI furnace provides all nighttime off-peak home heating requirements. The Creda section is rated 14.4 KW, single phase, 120/240 V, 60 Hz. The companion TPI unit is their standard Model F furnace rated at 10 MW, single phase, 120/240 V, 60 Hz.

The Creda and TPI furnaces are field coupled and controlled to function as a single TES furnace package.

A.O. Smith modified their standard 120-gal. "Conservationist" water heater to include a new heating element configuration and LL control package. It is a two element water heater. The bottom element is dual rated at 1000 W/2000W. The top element is a standard 4500 W unit.

Under normal conditions, the water heater will be energized only during the eight hour off-peak period. However, the Load-Leveling control package includes a manual override provision, or "guest cycle," which allows the homeowner to produce 30 gal. of additional hot water at on-peak energy costs, should the supply in storage be exhausted. There is also a pilot light which is labeled "reserve caution" to alert the homeowner when less than 30 gallons of hot water remain in the tank.

Proper sizing of the TES equipment storage capacity is vital if the benefits to the utility are to be realized. Unless proper safeguards are taken, there will be a natural tendency by the consumer to undersize the TES devices to reduce initial equipment cost—particularly space heating. If undersized, the TES furnace will have insufficient storage capacity to supply all on-peak home space heating requirements on the coldest design day, which is usually the system peak day for a winter-peaking utility. When insufficient storage is experienced, the homeowner would, of course, elect to exercise the option of manually overriding the automatic off-peak control system. This can be accomplished easily by pushing an override button located on the front panel of each TES furnace. When activated, the home is heated by the resistance heating elements located in the TPI section of the TES furnace package. A design feature of this override control circuit is that it will automatically reset itself at the start of the next off-peak cycle if for some reason the homeowner forgets to deactivate the override control. This minimizes the chance of inadvertent on-peak space heating energy consumption which would be billed on the basis of higher cost on-peak energy.

Conversely, the economies of TES to the utility and the customer can be greatly affected if oversizing is permitted—to the customer in the form of increased initial cost and to the utility by an increased cost to serve. Another important goal of this field test was to prove, or perfect, present equipment sizing formulas. The substantial amount of test metering data we have collected permits this.

The type of control system used by the utility for signaling off-peak charge cycles is an important consideration in electric rate deisgn. Electric tariffs for this program were developed on the premise of time clock control. Three of the reasons for this decision follow:

1) An analysis of past AEP system load patterns indicated a highly predictable 16 hour on-peak period between the hours of 7 AM-11 PM.
2) Historically, high system daily load factors provided little opportunity for further load management during on-peak periods.
3) We tested TES equipment in five of the seven states within the AEP service area. The economics of geography and the number of units to be tested did not favor use of any type central, direct utility control, load management system for this limited experiment. This could change with large numbers of TES installations.

Our RES (off-peak) tariff is available to serve only approved types of TES space heating and water heating loads. TES space heating is a condition of availability. The use of TES water heating, as previously stated, is optional. Electric vehicle battery recharging is also permitted under the provisions of this experimental tariff. This availability clause is consistent with the overall concept, i.e., that TES is intended to conserve electrical capacity by filling present load valleys.

AEP's present load valley alone could support a minimum of 100,000 TES homes.

The TES loads are metered by a two register (on-peak, off-peak) kWH meter. Meter registers are changed by a time switch 2 amp contact. The other 100 amp contact opens or closes one side of a 24 V control circuit originating from within the TPI furnace which serves both the TES furance and water heater. This circuit activates the automatic charge control devices internal to each TES device.

The RES tariff is designed to recover the increased utility cost to serve these type loads: (1) increased line transformer requirements, (2) larger service drops, (3) additional metering cost, and (4) increased operating expenses such as meter reading and other customer accounting expenses. The rate assumes a customer can be served with no normal on-peak capacity requirement and that off-peak capacity can be supplied by existing system capacity. Fuel, operating, and maintenance expenses are also included. These costs are divided between a fixed monthly service charge and off-peak kWH energy charge. The tariff was filed and approved as an experimental tariff in five states: Virginia, West Virginia, Ohio, Indiana and Michigan. Essentially, all RES tariffs are the same except for slight variations due to specific commission requirements, prevailing rate levels, and embedded fuel costs. On-peak energy costs are $0.05/KWH more than off-peak kWh costs plus the monthly service charge. Generally speaking, the incremental RES rate savings, compared with a customer using conventional electric space heating and water heating, were on the order of a $0.01/kWh reduction.

All other electric loads run the home (lighting, refrigeration, cooking, misc.) are not considered off-peak in nature; therefore, they are served under standard Residential

Service (RS) tariff schedules and metered by a conventional single register kWH meter.

All test homes were equipped with magnetic tape, load survey recorders. These instruments record all energy consumed by loads served by the two-register RES kWH meter (TES space heating and water heating).

Seven space heating and three water heating test homes were more fully instrumented to record TES equipment internal operating characteristics. The seven space heating test homes also have another recorder installed on the single-register RS meter circuit serving non-TES loads within each home (lighting, refrigeration, cooking, misc.)

A "Special Load Research" (SLR) computer program was written to summarize all test metering data. A family of reports was produced for loads recorded. These reports are available on an individual, divisional, state, company, or AEP system basis.

Individual test home data are available for either 15 minute or hourly integrated demands. Other jurisdictional reports are summarized only on an hourly integrated demand basis.

The SLR program combines all individual customer data and calculates jurisdictional diversified demands for each division, state, company, and the AEP system.

The family of SLR computer report forms are invaluable for evaluating these functions:

1) TES operating effects on the utility,
2) Detailed internal operation of equipment (which can be a basis for improved Americanized equipment designs),
3) Future rate considerations, and
4) Proving, or disproving, the design equation used to determine economic storage requirement.

Results from a data base of 70 test homes provide meaningful conclusions.

When we began this experiment there were a number of items which were required if the test was to be properly conducted and then evaluated. One of the important actions was training not only AEP personnel but selected dealers from each of the areas where a furnace and water heater were to be installed. The water heater is fairly conventional and requires no detailed training. But that was not the case with the TES furnace. Accordingly, training programs were conducted at the TPI Corp. headquarters utilizing TPI and Creda personnel as the trainers. Each selected dealer was required to have one or more representatives complete the training period before they were permitted to install the equipment. Similarly, AEP personnel participated in the same training program and in some cases were given extra training because we depend upon them to be directly involved in each installation to make certain that the equipment was properly sized, properly installed and properly serviced. The AEP personnel were not directly responsible for installation and servicing but were responsible to make certain that the dealers conducted the work in the proper manner. All sizing was determined by AEP personnel who have had long experience in HVAC applications.

It has been earlier noted that we require the homebuilder to make a payment in the amount of $650 more than the cost of the conventional electric furnace and water heater. We have a careful interest in determining whether the homebuilder would be willing to make such a payment in anticipation of receiving a payback of this amount in not more than 5 years. We can tell you that the homebuilder was quite willing to make such a payment, and this was an important finding because it indicates that should we find the experiment to be a success that homebuilders of the future would be willing to make these kind of payments and thus we have proven the market for this type of product. This acceptance took place even though the TES furnace was a new and strange device to every homebuilder who accepted them. One of the limitations which we had to overcome was the fact that the 14.4 KW Creda/TPI furnace limited the size home in which they could be placed but despite these two limitations we were successful in placing units in every area in our system according to a preplanned distribution.

The customer is receiving a satisfactory payback and all of them should expect to receive their $650 payback in not more than a 5 year period. In some cases the payback can occur in 2⅓ years. This occurs in the northern part of our system where the degree days are greater and more KWh are consumed than in the equivalent size house located in our Viriginia territory. As an example, a typical annual billing under our TES rate, which we call RES, shows that the customer actually paid $450 as compared with the cost of energy had this same customer installed a conventional furnace and water heater of $605. The range of payback was in the order of $150 to $300 per year over our system.

Aside from cost, the customer had other important concerns, and to determine how the customer reacted to the use of the TES equipment a survey was conducted in May of 1979 after the customers had been through at least one full winter, to solicit their responses to some 32 questions, 21 of which were related to the furnace and the remaining to the water heater.

Some of the key questions and answers are as follows:

91% of the customers ranked their TES space heating as "very satisfactory" to "good." When we asked them what answer best describes the type of heating provided by the TES furnace, 95% noted that comfort levels provided "cozy" to "average."

99% rated the TES system as "very clean" to "average."

54% of the customers did not find it necessary to manually override the TES automatic control system and of the 46% who did, almost all were caused by unusual outage problems associated with abnormal weather, bad thermostats and a few blown fuses due to overheating conditions caused by poor fuseholder connections.

92% made favorable comment regarding the furnace operation. Two of the most frequent comments were "operating cost savings" and ability to "set and forget the controls."

91% stated that it was not necessary to change any normal living habits or lifestyles due to the TES furnace operation.

95% rated the TES furnace as the same or better than their neighbor's heating system.

73% felt that the TES furnace was much better.

When we asked them what kind of system their neighbor was operating in which the comparison was made, 55% compared their system to electric, 22% to gas, 22% to oil, and interestingly, 1% to coal.

Then we asked them if they saved money or did it cost more to operate than their neighbor's system, 98% felt they saved on operating costs and 70% said they saved much more. One customer, who said it cost more was comparing it to free gas due to a gas well located on his neighbor's property.

53% said they used night set-back. The average amount of set-back temperature was 5.6 degrees from 11 PM to 7 AM and the average temperature maintained during the daytime was 69°.

71% of the customers in this program said they were more conscious of the amount of energy used to heat their homes.

94% said they were satisfied with the operating cost. And then we asked them, "Do you feel that a storage heating system is practical now?" 98% felt that TES was indeed practical. Finally, we asked them, "On the basis of your experience, would you recommend storage space heating to your friends?" 92% of the customers stated they would.

Then we turned to the water heater. 91% of the customers rated the supply of hot water as "acceptable." 9% said not so.

In one case the home had been built by a speculative builder, who did not want to sell it but rented it to a group of truck drivers. It became known as "the brothel" and as might be expected, hot water was not sufficient for their needs.

55% of the test homes indicated that they did not have to adjust their normal hot water patterns. The remaining 45% found it necessary to make some adjustments in their laundry, bathing and dishwashing habits.

But when we asked them if storage water systems were practical, 92% said yes.

Incidentally, Saturdays and Sundays were the days of the week when the greatest amount of hot water was consumed and Easter was the high use holiday.

These customers average 8 loads of laundry a week. Each person in the house averaged 6.8 baths per week.

And finally, 89% stated that they would recommend water heaters to their friends.

The average test home contains 3.3 persons with an average age of 36.4 years for adults and 8.6 years for children. Stated value of the homes averaged $58,000.

Another aspect of the test from the customer as well as the company's viewpoint, is the performance of the equipment. Was it satisfactory? And the answer to that question is, very satisfactory. But this requires some further comment.

When the equipment is properly sized, case emissions are quite modest and satisfactory to the customer. No small child was likely to be burned touching the housing of the furnace. We had some problems with loose connections which caused fuses to fail but this has been corrected by changing the type of terminals that are now in service. There were no failures of electric heating elements. We did lose some water heating elements due to sludge build-up particularly in the Canton, Ohio area where the water quality is not very satisfactory.

We had some problems with what we call "bleed-off." By this we mean that when the conventional furnace was operating at night to take care of the needs of the house, the damper that was interposed between the TES furnace and the supply going from the conventional furnace was not entirely effective and allowed heat to be drawn from the TES furnace during the time when it was being charged. This has been corrected in the American version. As part of this program, we installed four TPI Corp. TES furnaces, which operated during all of this past winter. We had no performance problems with this equipment.

This concludes our evaluation of the TES experiment from the customer's viewpoint and the equipment performance.

Now we turn our attention to the evaluation of this experiment from our company's experience. To reach these conclusions it seems important that we discuss some of the characteristics of the AEP system.

First, an examination of the AEP system hourly internal load shape, which occurs on a very cold day usually in January, shows that the system peak is something in excess of 12,200 MW which rises to that level beginning about 7 AM and remains above 11,000 MW until 11 PM. At that point there is a valley which occurs between 11 PM and 7 AM that average about 9700 MW. From our test data we were able to determine the effectiveness of RES devices on a daily heating load pattern. We found that the conventional electrically heated home will provide an annual daily system internal load of 6.6 KW. The properly sized TES furnace created no load during the on-peak period on our system from 7 AM to 11 PM. To satisfy the needs of that same house with TES equipment the average off-peak load increase is 19.59 KW or 12.99 KW greater than when the house is heated with a conventional furnace. Over the course of a 12 month period, the average test TES home consumed 17,360 KWH for space heating and water heating including the TES water heater which also operated during the warm months of the year.

It has been determined by our System Planning Department that we can easily accommodate more than 100,000 TES installations today. It would also appear that residential heating will continue to be added to our system in some form at a rate of about 30,000 units per year. If we are to project the number of TES installations that can be accommodated for the years 1979 through 1989 we find that by the latter year we could have in service about 180,000 units on our system. This corresponds to about 25% of all residential electric heating customers and 37% of all single family residential customers, which of course, is the most likely type of dwelling for TES applications. If we examine the monthly pattern of generating capacity peak loads and reserves on the AEP System, you will find that scheduled maintenance is much heavier in the spring, summer

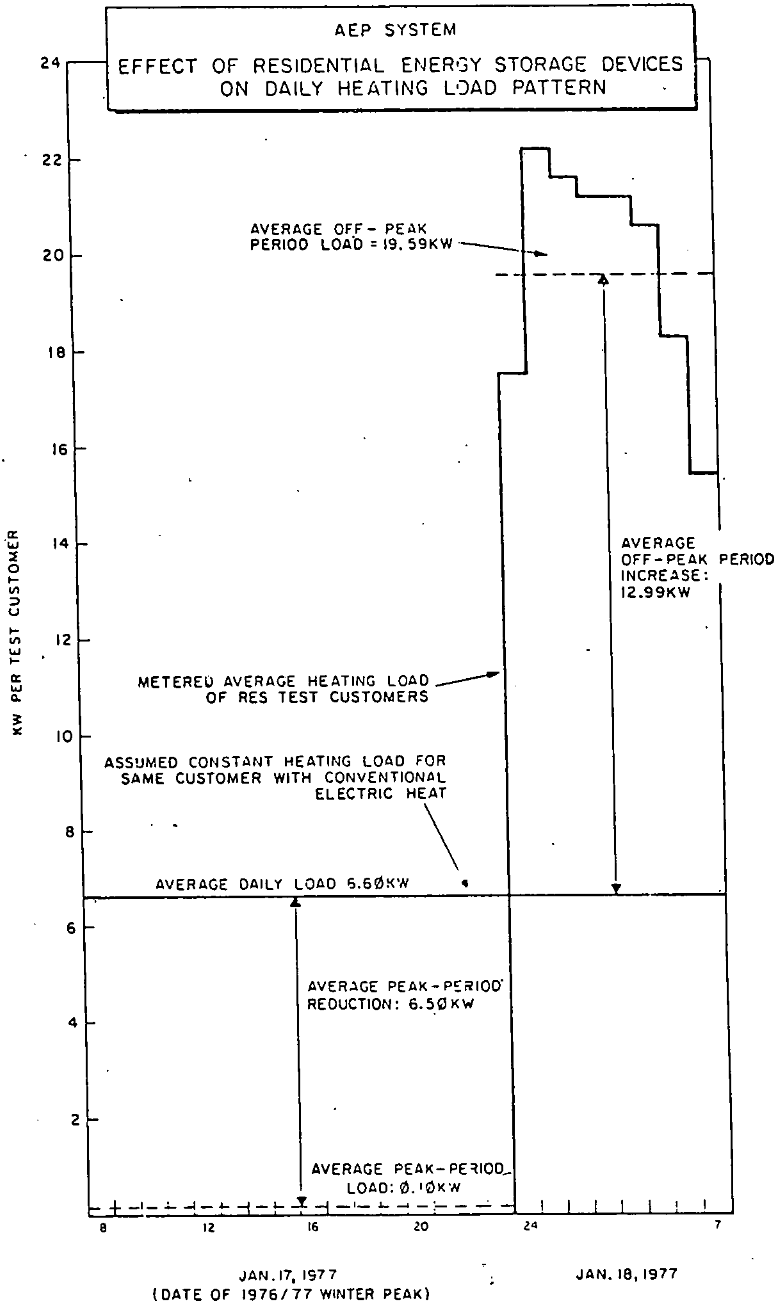
AEP SYSTEM
EFFECT OF RESIDENTIAL ENERGY STORAGE DEVICES ON DAILY HEATING LOAD PATTERN
KW PER TEST CUSTOMER
24
22
20
18
16
14
12
10
8
6
4
2
AVERAGE OFF-PEAK PERIOD LOAD = 19.59KW
AVERAGE OFF-PEAK PERIOD INCREASE: 12.99KW
METERED AVERAGE HEATING LOAD OF RES TEST CUSTOMERS
ASSUMED CONSTANT HEATING LOAD FOR SAME CUSTOMER WITH CONVENTIONAL ELECTRIC HEAT
AVERAGE DAILY LOAD 6.60KW
AVERAGE PEAK-PERIOD REDUCTION: 6.50KW
AVERAGE PEAK-PERIOD LOAD: 0.10KW
8
12
16
20
24
7
JAN. 17, 1977
(DATE OF 1976/77 WINTER PEAK)
JAN. 18, 1977

Exhibit I-1

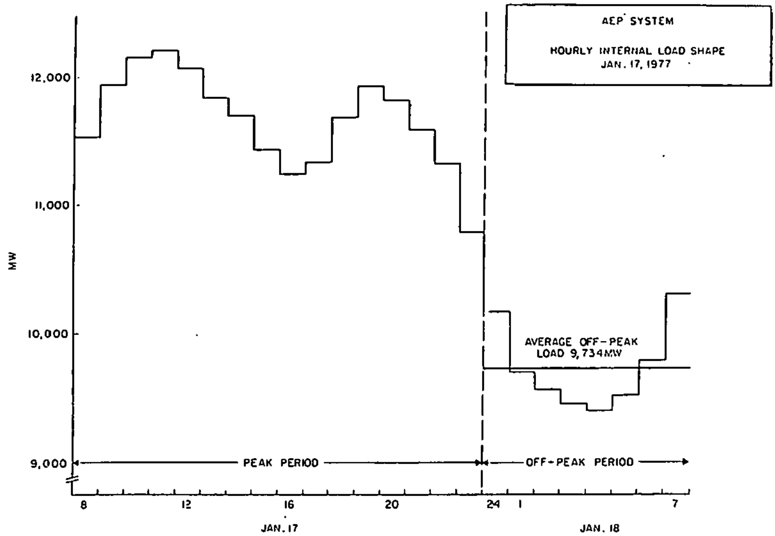


Exhibit II-1

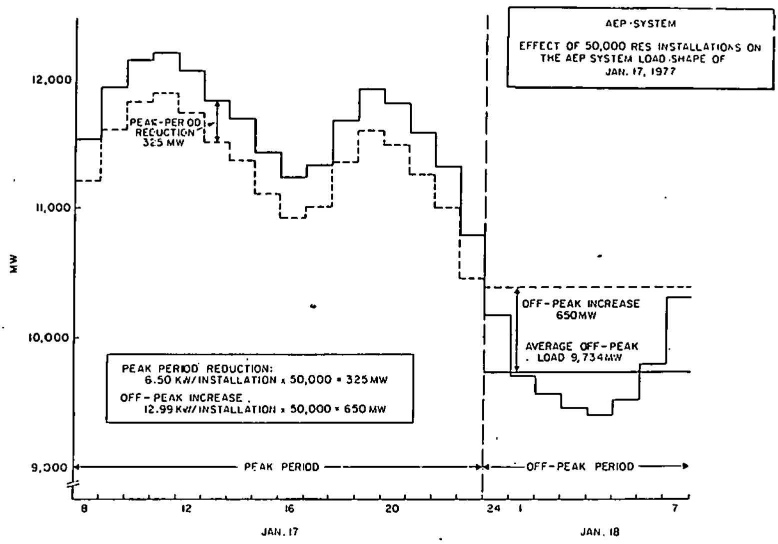


Exhibit II-2

and fall than that during the winter period when the internal load is much higher. If we now had available 100,000 RES units in service on our system, the monthly peak load during the winter would decline by an amount of 600 KW. This then would allow us to change our scheduled maintenance by conducting more of it in the winter and somewhat less in the spring, summer and fall.

On our system we do not plan capacity installations or generating installations based upon peak day consideration. With the mix of requirements to satisfy not only the monthly peak loads, while at the same time schedule maintenance outages it may sound trite but a properly planned system of the size of the AEP System is one in which every day is a peak day.

Likewise, when we plan capacity requirements, we look at it on a hour by hour annual basis. Thus with a TES installation you do have a winter peak load reduction of about 6 KW but on a 365 day average peak period the load reduction is 2 KW per installation.

With the very high cost of future generating plant additions the opportunity to avoid an annual average load of 2 KW for each additional electrically heated home is indeed attractive to our system in future capacity installation investment savings.

As we have stated, the experiment phase is finished. We have now learned all we can expect from this test and to continue with the extensive metering would be repetitious and non-productive from the standpoint of further understanding of the operation and of the value to both the customer as well as the company.

Meanwhile, we are conducting an examination of our data to determine whether our experimental rates are appropriate and what rates should be proposed to our regulatory commissions in nine different jurisdictions to satisfy the payback requirements of the customer, encouraging the installation of TES systems while at the same time, meeting the company's financial requirements. We expect to be making application to the various commissions within the next few weeks. When we broaden this program on a commercial basis to all of the territories served by our system it means that not only additional company personnel require training but there are a large number of dealers who must also receive instruction. This is a major undertaking when you are talking about an area scattered over seven states.

We will also be active in determining our promotional program because we are talking about a device that is relatively unknown in this country and certainly has not received acceptance. These plans must be carefully laid to convince the homeowner that his is advantageous for him. Promotion connotes advertising which requires the establishment of a budget and all of these things must be pulled together if we are to meet the suggested target date of about 1500 installations in the calendar year 1980 — our first year. A small number you may say, but 1500 is a big number when you must deal with a device and a system that are largely unknown in this country.

I am sure that you know that AEP has its answers well defined. Our company is going to move forward with the TES systems.

## SUMMARY OF AEP RESIDENTIAL ENERGY STORAGE CUSTOMER SURVEY

The following represents the major findings of a system-wide, Residential Energy Storage (RES), Customer Survey conducted by AP Co., I & ME Co., OP Co., and WE Co.

There are 71 test homes in our RES field test program; however, this summary applies only to 65 RES test homes as three owners could not be reached due to their being on vacations and these homes were unoccupied.

Questions 1 through 21 are applicable only to Electric Thermal Storage (TES) space heating. Questions 22 through 31 are specific to TES water heating. Questions 32 and 33 relate to initial equipment cost and demographic data. Question 32 (initial equipment cost) will not be included in this summary report as stated responses need further analysis and clarification.

Supplementary comments are given for each question where applicable and it should be noted that, generally, that which was applauded by one homeowner was common to many and that which proved unsatisfactory was unique to a few.

## TES SPACE HEATING (Questions 1-21)

| | |
|---|---|
| Question (1) | How would you rate the comfort level provided by your TES space heating equipment? |
| Answer | 91% of the customers ranked their TES space heating system as "very satisfactory" to "good." 3% rated it "average." |
| Question (2) | What answer best describes type of heating provided by the TES furnace? |
| Answer | 95% noted that comfort level provided was "cozy" to "average." It is interesting to note that 75% referred to the system as being cozy. |
| Question (3) | How would you rate the noise level associated with normal TES furnace operation? |
| Answer | 93% of the customers rated their equipment operation as "very quiet" to "slightly above average." Of the few people who checked "noisy", the major cause was damper noise which exists at 7:00 AM to 11:00 PM due to system changeover. Americanized TES equipment does not require these dampers, therefore, this objection is unique to our present Creda/TPI field test package. |
| Question (4) | Other than initial start-up procedures, has the TES furnace operated odor free? |
| Answer | 80% stated their furnace operated odor free. Of the 20% who detected some odor, approximately 50% gave no indication as to cause; however, post interview comments by our people indicate that many of the people misunderstood this question and really had no odor complaints. There were a few legitimate complaints that were traced to dust accumulation. |
| Question (5) | What statement can be made regarding cleanliness? |
| Answer | 99% rated the TES system as "very clean" to "average." It is of interest to note that 91% of the total rated the system as "above average" with 48% rating the system as "very clean." Only one customer rated the system as "dirty" and upon checking it was found that the installing contractor forgot to install a filter. |
| Question (6) | Were there any unusual operating characteristics? |
| Answer | Almost all were due to conditions resulting from an unusual number of power failures? |
| Question (7) | Were the TES furnace controls convenient to operate? |
| Answer | 97% felt the TES furnace controls were easy to operate. 3% indicated they would prefer to see override controls on the thermostat and perhaps a better thermostat. |
| Question (8) | Did you ever find it necessary to "override" your automatic control system to supply daytime heating during December, January or February? |
| Answer | 54% of the customers did not find it necessary to manually override the TES automatic control system. Of the 46% who found it necessary to override the automatic control system, almost all were caused by unusual outage problems associated with abnormal weather, bad thermostats, and a few blown fuses due to overheating conditions |

caused by poor fuseholder connections. Both the thermostat and fuseholder problems have been corrected in the Americanized TES equipment design.

| | |
|---|---|
| Question (9) | Can you tell us what you like most about your TES furnace? |
| Answer | 92% made favorable comments regarding TES furnace operation. Comments range from its "quiet operation" to its "cleanliness and efficiency in providing smooth, even heat." However, the *two most common responses were "increased operating cost savings" and the ability to "set and forget the controls."* |
| Question (10) | Can you tell what you dislike about your TES furnace? |
| Answer | 60% found nothing unfavorable. Of the 40% who said they disliked something about the TES furnace, almost all dislikes were related to operating difficulties which required some sort of maintenance, i.e., blown fuses, bad thermostats, etc. Other items were related to the size of the unit, slow recovery after night set-back, but perhaps the strongest objection was related to the service charge associated with the RES tariff. Of course, service charge is non-equipment related but the objection also surfaced in other areas of this survey. It was our people's opinion that only three RES test customers (approximately 5%) expressed any genuine dissatisfaction. |
| Question (11) | Can you recommend any equipment design improvements for your TES furnace? |
| Answer | 68% could not recommend any design improvements. The remaining -32% repeated previous recommended design improvements such as better thermostats, override controls located on thermostats, continuous fan operation, etc. |
| Question (12) | Was it necessary to change any normal living habits due to TES furnace operation? |
| Answer | 91% stated that it was not necessary to change any normal living habits or lifestyle due to the TES furnace operation. Of the 9% who indicated some change in lifestyle was required, most voluntarily maintained lower indoor temperatures to increase their operating cost savings. Some customers also used fireplaces for the same reason. |
| Question (13) | How would you rate the TES furnace performance in comparison with a neighbor's heating system? |
| Answer | 95% rated the TES furnace as the same or better. (73% felt the TES furnace was "much better"). It is interesting to note that the 5% who rated their TES furnace operation below that of their neighbor's compared it to an electric heat pump. |
| Question (13a) | It would help us to know what type of system(s) you are comparing TES with: |
| Answer | 55% compared their system to electric, 22% gas, 22% oil, and 1% coal. |
| Question (13b) | Do you think you saved money or that it cost you more to operate than your neighbor's system? |
| Answer | 98% felt that they saved on operating cost. (70% felt they saved much more.) The 2% who felt it cost more was really one customer who compared it to free gas which was available from a gas well located on |

his property.

Question (14-14a) Has your TES furnace system required any maintenance other than that required for initial adjustments and routine inspection(s) associated with this research project?

Answer 54% of the systems required no maintenance. 46% of the systems required some maintenance. Common problems reported were poor thermostats, several charge control failures, sticking relay in clock contact and loose connections in the fuseblock. It is felt these loose connections were caused by inferior fuseblocks of English design. This problem has been overcome in Americanized TES equipment design. It is also felt these loose connections were responsible for most, if not all, of the charge control failures. In general, required maintenance was extremely minor.

Question (14b) Was maintenance service satisfactory?

Answer 100% of the RES test homes reported equipment service to be satisfactory.

Question (15 a-d) Did you use a wood stove or fireplace to supplement TES furnace operation?

Answer 69% said they did not. The remaining 31% (20 homeowners) used their fireplace or a wood stove. Of these 20, nine used their fireplace or woodstove in their basement which was not designed to be heated by their TES furnace. Three customers stated they used their fireplace for atmosphere only and the remaining eight customers actually attempted to use their fireplace and woodstove to supplement their TES furnace. The average customer reported using 1.5 cords of wood during the heating season.

Question (16 a-c) Did you set your TES furnace thermostat back at night?

Answer 53% of the test homes indicated that they used night setback. The average set-back temperature was 5.6 degrees from 11:00 PM to 6:00 AM. Almost all of these customers reported using night set-back seven days a week.

Question (17) What daytime temperature was normally maintained?

Answer The average temperature maintained was 69°F. The indoor temperature settings ranged from 60°F to 75°F. Generally speaking, the customers in AP Co. maintained lower temperatures of 71/72°F. No particular pattern was evident for I & M and WE Co. test homes.

Question (18) Do you feel that participating in this research project caused you to be more conscious of the amount of energy used to heat your home?

Answer 71% of the customers reported they were more conscious. Most stated that they reviewed their bills more carefully and were more energy conscious.

Question (19) Are you satisfied with operating cost results of TES furnace?

Answer 94% of the customers reported they were satisfied. Those who were not, complained of the billing service charge and one customer questioned cost of maintaining storage in mild weather.

Question (20) Do you feel that a storage heating system is practical now?

Answer — 98% of the customers felt that TES storage heating is practical now. The 2% (1 customer) casting a negative opinion was due to the tariff service charge which, of course, is non-equipment related.

Question (21) — On the basis of your experience would you recommend storage space heating to your friends.

Answer — 92% of the customers surveyed stated they would recommend TES storage heating to their friends. The 8% remaining cited service charge costs, overstorage costs, and thermostat difficulties as the reasons for opposing it.

**SUMMARY CONCLUSION:**

It is felt that most, if not all, objections to the TES furnace test experience will be overcome and/or eliminated with newer Americanized TES equipment designs. Considering the lack of sophistication of the TES equipment used in this test, the survey results indicate a higher than expected customer satisfaction with this imported Creda furnace which was modified in England and coupled with a conventional electric furnace manufactured by TPI.

**TES WATER HEATING (QUESTIONS 22-31)**

Survey results of customer reactions to TES water heater operation were very similar to those given for TES furnaces. Again, positive reactions of the customer were shared by many; however, negative reactions appeared to be more closely related. As expected, TES water heating results are generally related to the number of people occupying a test home.

Question (22a) — How would you rate the supply of hot water available from your TES water heater?

Answer — 91% of the customers rated the supply of hot water as "acceptable". 9% judged supply as "unacceptable".

Question (22b) — How would you rate the supply of hot water available from your TES water heater?

Answer — It is interesting to note that 37% judged the supply as "adequate", 30% as "almost always adequate", 3% "average", 22% as "occasionally inadequate", 5% "almost always inadequate" and 3% "inadequate". Apparently, the 22% who rated their hot water supply as "occasionally adequate" judged this to be acceptable.

Question (23) — Was it necessary to adjust your normal hot water use patterns to stay within the available 120 gal. hot water supply?

Answer — 55% of the test homes indicated they did not have to adjust their normal hot water patterns. The remaining 45% found it necessary to make some adjustments in their laundry, bathing and dishwashing habits.

Question (24 and 25a) — Was it necessary to "override" the TES water heater control to provide an additional supply of hot water during the peak 7:00 AM-11:00 PM hours?

Answer — 52% did not have to override. Of the remaining 48%, 13% reported they found it necessary to override regularly, 29% occasionally and 58% infrequently. It is felt that unusual power outages necessitated customers to override automatic control systems.

Question (24 b-f) Was it necessary to override on any particular day of week, holiday or season and if so, how many override actions were necessary? Also, would additional storage or the option to override be preferred?

Answer Saturday and Sunday were the days of the week with the highest incidence of overrides and Easter was selected as the most frequently named holiday.

When asked if they preferred additional storage capacity or override capability, 81% of the customers indicated a preference.

Question (25) Other than normal equipment start-up maintenance, adjustments, or inspection has additional service or unusual maintenance been required?

Answer 62% of the water heaters required no maintenance. Most of the water heater maintenance problems were associated with the original shipment of 25 water heaters. These proved to have a design defect which required field modification. The remaining maintenance problems were minor including indicator light malfunctions and charge control relay failure.

Question (26) How would you describe the hot water storage temperature?

Answer 90% of the test homes judged water temperature to be "just right", 7% "too hot" and 3% "too cool". Suggested changes in tank temperatures were $-5°$ and $+10°F$.

Question (27) Can you suggest any TES water heater design improvements?

Answer 80% of the customers could not suggest any equipment design changes. Of the 20% who suggested design changes most were minor and pertained to some sort of an improved charge control system. It is felt that most of these suggestions have already been incorporated into a new, phase II electronic charge control already designed by A.O. Smith.

Question (28a) Typical hot water use data:

Answer 75% of the customers reported no variation in hot water use by season. No particular pattern was noted for the 25% who indicated varying use by season.

Question (28 b, c) Approximately how many loads of laundry per week and the normal laundry washing temperature setting:

Answer An average of 8 loads of laundry per week was reported.

Question (28 d-f) Approximately how many baths/showers would be considered normal. What is normal bathing water temperature and how would you describe the amount of water used per bath/shower?

Answer Each person in the house averaged 6.8 baths per week with the majority using warm water in normal quantities.

Question (29) Are you satisfied with operating cost results of TES water heater?

Answer 97% reported they were satisfied with operating cost. The 3% remaining (2 customers) cited tariff service charge and an over-sized water heater for the single person living in the test home.

Question (30) Do you feel that a storage water system is practical now?

Answer 92% said TES water heating is practical today. Of the 8% who said no, the primary reasons were tariff service charges, and perhaps, linking solar energy to the TES concept.

Question (31) On the basis of your experience would you recommend storage water heating to your friends?

Answer 89% stated they would recommend storage water heating to their friends. Of the 11% who said they could not recommend TES water heating, the predominant reasons given were tariff service charges, which offset operating cost savings and oversized heaters for a single occupant.

## DEMOGRAPHIC INFORMATION

**Question** (33 a-f) Misc. Data

Answer The average RES test home contains 3.3 persons with an average of 36.4 years for adults and 8.6 years for children. 100% of the homes used electric ranges of which 63% were self-cleaning. 92% used combination refrigerator/freezers. 70% of the homes were equipped with automatic dishwashers. 44% used garbage disposals. 100% were equipped with automatic washers and automatic dryers. Six homes used some form of supplemental electric heat in areas that are normally unheated such as basements and garages. Stated value of homes averaged about $58,000.

# PEAK-LOAD PRICING
# AND
# THERMAL ENERGY STORAGE

by

**George Reeves**
**Director**
**Technical Services Load Management**
**GPU Service Corporation**

For those of you who still don't know what a GPU is, General Public Utilities and its subsidiaries provide electric service to about half of New Jersey and Pennsylvania, with assets of over five billion dollars and annual sales of 1.5 billion dollars. We own Jersey Central Power and Light Company, and in Pennsylvania, Pennsylvania Electric Company, Metropolitan Edison Company and Three Mile Island. Incidentally, we have five hundred thousand gallons of warm water if any of you is really interested in thermal storage.

I have been asked to discuss utility planning and economics, to give you some understanding of why your friendly power company is interested in thermal storage and peak load pricing. To do that, I'm going to discuss a little history, show you what load curves look like and how utilities do system planning, throw some marginal costs at you, and tell you what we have done at GPU as a result of those factors. Then, because I can't resist a forum from which to expound, I'm going to list some common fallacies in this field in the hopes you'll avoid them, tell you what utilities need in thermal storage space - in hopes of redirecting some of your efforts, and present a relatively new concept - in hopes that reasoned argrument will test it.

First, the history. 1969 was an interesting year in the electric utility business. It was my first full year in the industry, and the first year that the average price per kilowatt-hour increased. I am assured there is no causal relationship. Why did the price go up? Well, the average price of a regulated product is not established that much differently from the price of any other product. We add up all the costs and divide by the expected sales. One significant cost difference is attributable to capital requirement. Most companies have a capital investment equal to one-fourth their annual sales. If they pay 8% in interest and earnings to their bondholders and stockholders, this amounts to 2% of sales. Electricity production requires the investment of about four years worth of revenue in capital. So if we need to pay interest and earnings of eight percent, this accounts for 32% of revenue. Wait, it gets higher.

Pre-1969, all costs were going down, or increasing very slowly. Interest rates hit a high of 6%, new power plants were cheaper and more efficient and few had heard of OPEC. We would add up all our capital costs - generators, transformers, wires and meters, and divide that by system peak demand to get a cost per kW. We'd add up the variable costs of fuel and maintenance to get a cost per kWh. We would then assume our customers could be grouped into relatively homogeneous groups called rate classes on the theory that, for example, all residences are fairly similar. Once every five years or so, we would notice things had gotten cheaper and ask the regulatory commission if we could please lower our rates. After careful deliberation, they would usually agree.

Since costs were going down, any new load cost us less to serve in those days than existing load. Many utilities successfully argued that selected customers should be charged lower than average costs (i.e., marginal costs) since increased load benefitted everyone by lowering average cost. We couldn't charge everyone these lower costs since that would not cover all our fixed charges, so we directed these prices at customer groups whose usage was thought to be most price sensitive. In those days that category included

.lectric heat and industrial load. Economists generally approve of that kind of pricing strategy as leading to an efficient allocation of resources, and they call it marginal cost pricing adjusted by the inverse elasticity rule. Before we leave those wonderful days of 1968, let me mention that the average residential price of electricity that year was 2.18 cents per kilowatt hour, which is less than the off-peak rate of most companies today.

In 1969, and the following years, inflation, and other factors, finally caught up with the industry. The cost of new power plants, helped by new concerns with environmental protection, began to skyrocket. Interest costs went from 5% to today's 15%. Remember that even in the low interest, low plant cost days, the utilities devoted 25-30% of their revenues to carrying costs and you can get a feel for the enormous upward pressure on rates. Of course we found out in 1973 what OPEC was, and that barrel of oil that cost $3 in 1968 now costs $23 or more. Another interesting new cost is risk. Utility stock used to be widow and orphan material - i.e., a safe, almost guaranteed income. Three Mile Island has shown that there are significant financial risks associated with owning a power company.

So we went back to the state commissions and told them our costs were now higher and asked if we could *raise* the rates. Much to our surprise, they didn't say yes as fast or as often as they did when we wanted to lower rates. And the phrase, "regulatory lag," gained a new meaning.

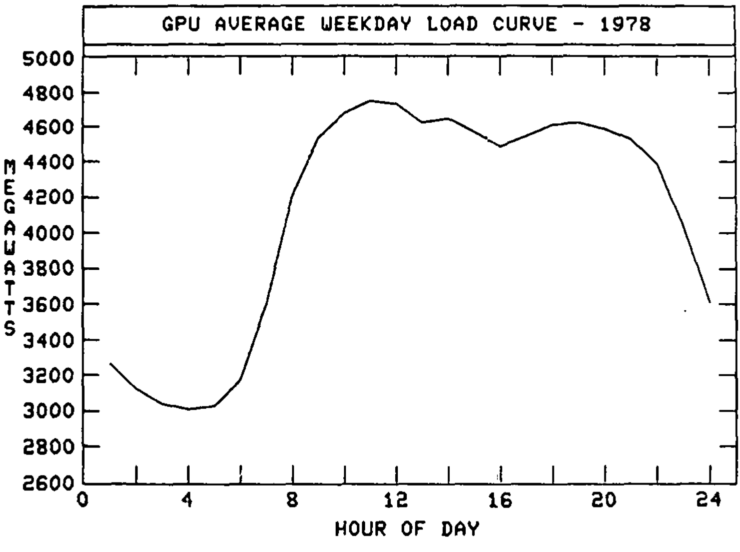


Figure 1

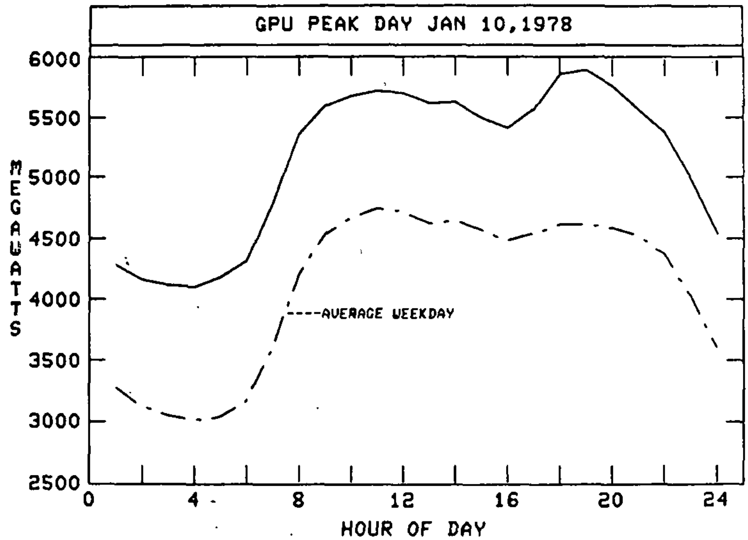


Figure 2

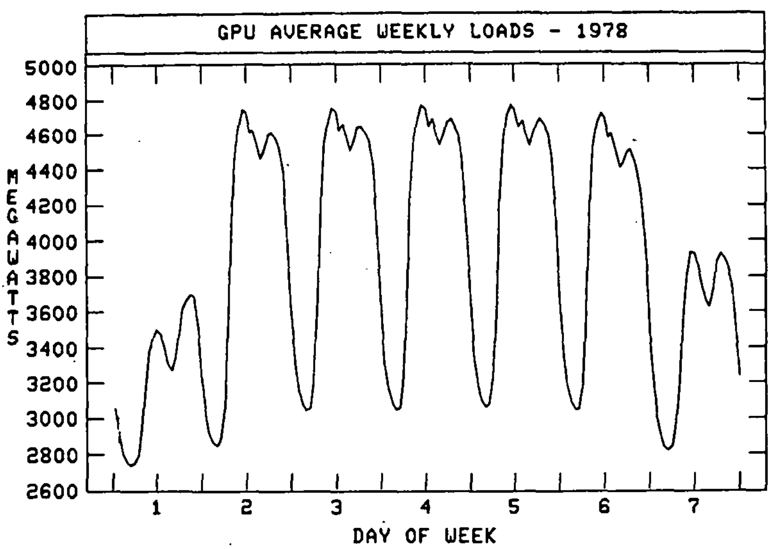


Figure 3

All this history of costs is to give you some appreciation for what causes rates to go up. Let's look at some load curves to illustrate. Figure 1 is the average load curve for GPU on weekdays in 1978. The first thing I want you to notice is that, while the peak occurs at 11 a.m., the curve is very flat on top, with an extended peak of about 12 hours. An individual customer on a demand charge rate may move some of his load from his 2 p.m. peak to 6 p.m. and not save us anything. Figure 2 is the GPU peak day, Jan. 10, 1978. Again notice that the high load period is extended, and notice that the peak day is not that

...ch higher than the average weekday. *Nobody builds nuclear power plants to serve just the peak hour of the year*. The advantage to thermal energy storage is that it can move load from *every* day's peak to the off-peak periods. Figure 3 is the GPU load curve for the average week of 1978. You can readily discern why our time-of-day rates consider Saturday and Sunday as off-peak.

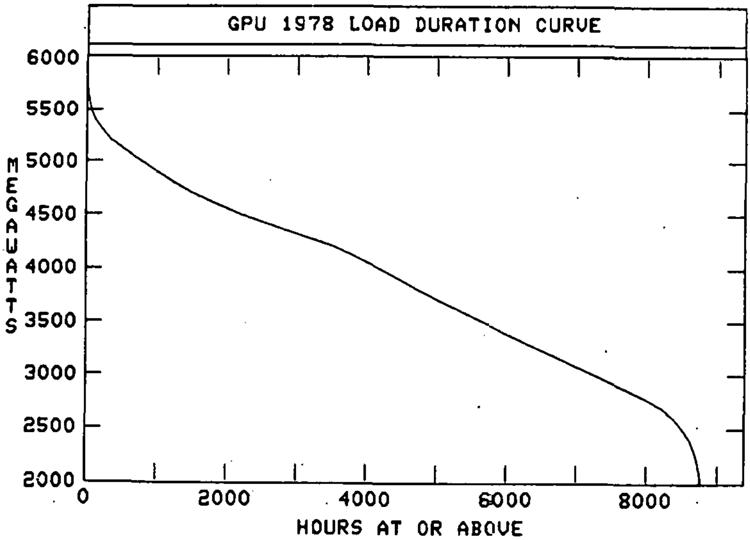


Figure 4

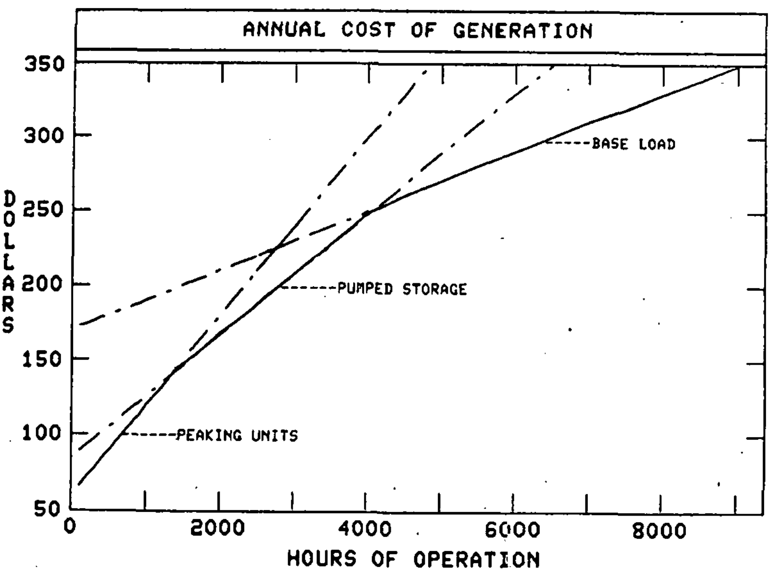


Figure 5

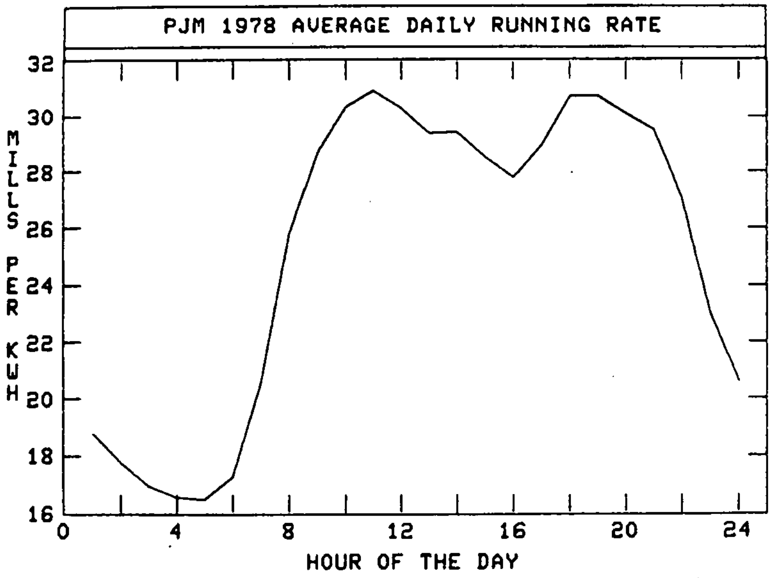


Figure 6

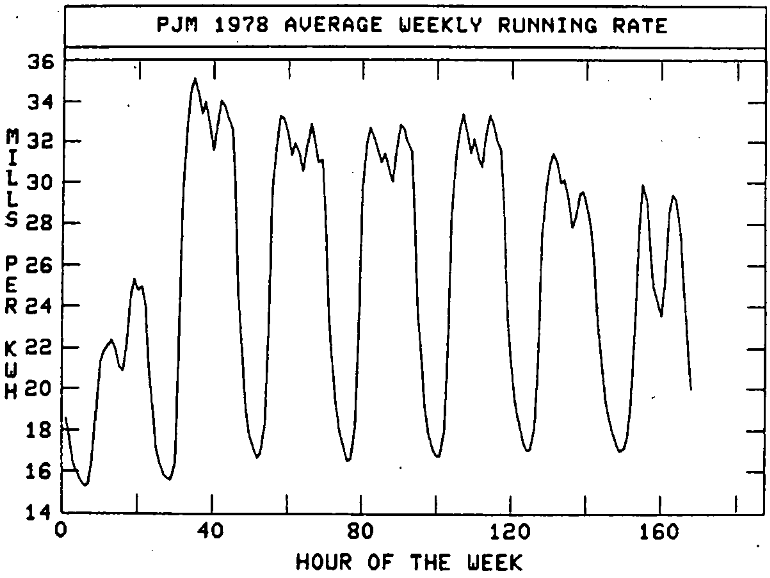


Figure 7

To plan our system, we take those hourly load curves and develop a load duration curve, such as Figure 4. This shows that, for example, GPU's load was above 3500 megawatts for 6000 hours of 1978, about 70% of the time. Determining the optimum mix of generation is a process of trading first cost for operating cost. Oil fired gas turbine peaking units cost about $350 per kW and about 50-60 mills per kWh. Pumped storage plants, with 70% up and down hill efficiency, cost about $500 per kW to build and about

50 mills per kWh to run. Base load coal or nuclear generation costs $800 to $1000 to build and 10 to 20 mills per kWh in operation. Figure 5 plots the total annual costs of each type generation (carrying charges and operating expenses) as a function of the annual operation. As you can see from this example, base load units would be sized to meet any load with more than about 4000 hours duration, peaking units would handle loads of less than 1500 hours duration and pumped storage the remainder. After this mix is determined and built, the lowest operating cost unit available is always run first, thus high load periods are also high cost periods. GPU is a member of the Pennsylvania-New Jersey-Maryland (PJM) interconnection which operates on complete economic dispatch. This means that the lowest cost unit is run, regardless of who owns it, resulting in economies to each company. Figure 6 is a curve of the operating cost per kWh of the last, or most expensive, unit running in PJM on the average 1978 day. You will note the similarity of this short run marginal cost curve to the load curve, especially in the length of the peak cost period of 3.0 cents per kWh for operating cost only. Figure 7 plots the average week, again showing lower costs on weekends, although Saturday is close to weekday levels due to maintenance in some units.

Having mentioned short marginal costs, I feel obligated to identify long run marginal costs. These would consider the first cost of any new generation required to serve load, as well as the operating costs, and any additional transmission or distribution needed. Again let me emphasize that an added kW on peak does not cost us the price of a base load plant unless there are over 4000 kWh associated with that peak kW.

Of course, all utilities are different. Any of the concepts I present can and will be disagreed with as not applicable to a given utility. But let me tell you that utilities are far more similar than they are different and though the lyrics may change where you operate, the melody is the same. Here are some order of magnitude numbers for GPU to illustrate the need for load management. In 1978 we had assets of about $3000 invested for each of the 1.5 million customers we serve. The average customer (and this includes commercial and industrial) used 20,000 kWh that year and paid us $840 on our $3000 investment or about 4.2 cents per kWh. That $840 is revenue, not profit. Our ''exhorbitant'' 25% profit was $210 per customer return on our $3000 investment. Of the 4.2 cents per kWh, about 1.4 cents was fuel, 2.1 cents was attributable to investment and 0.7 cents was miscellaneous operation and maintenance expense. In 1978 we spent $300 per customer on construction - over 30% of our revenues and almost 50% more than our profit. And that's our motivation for load management.

Since GPU began its load management program in 1973, we estimate we have moved about 500 MW off our peaks. Of that about 150 MW represents load shifts to nighttime and the remaining 350 MW is conservation. Almost all of that 500 MW has been achieved in the commercial and industrial sectors through such practices as high efficiency lighting and the night operation of foundry furnaces. We feel that we have pretty much exhausted the opportunities among existing customers and that our future efforts, to be significant, require a new tool. That tool is thermal storage.

We have been through the thermal storage R&D route - and feel we have demonstrated all we need to. While we will continue to test new concepts, our emphasis now is on selling thermal storage in significant quantities to move load off-peak, not on demonstrating programs. We have tested commercial and residential systems employing ice, hot water, chilled water, central ceramic, dispersed ceramic and sodium Thiosulphate Pentahydrate. We have time-of-day rates, off-peak demand rates, curtailable rates, controlled load rates and load factor rates. We have an unknown number of installations because people are putting in thermal storage systems as part of the normal operation of the market. If you've got a product, come to New Jersey and Pennsylvania to sell.

Let me review some of the fallacies I've heard about load management and give you my views on them:

Some companies have viewed load management as the function of one part of the utility. I'm indebted to my friends at AEP for pointing out to me when I first joined GPU, that I'd need a high degree of cooperation from rates, planning, operations, T&D, and financial sectors of the company. Fortunately we have that at GPU.

There are fallacies of analysis that look only at the company or only at the customer. One of the more common ignores energy cost differentials on the basis that they pass through the fuel clause. Besides providing a strong argument against a fuel clause, that position also ignores the Willie Sutton theory of ratemaking. *All* costs pass through to the customers, because that's where the money is. I feel the correct analysis looks at the total costs - regardless of where incurred - and then tries to set up rates to provide sufficient incentive for both the company and the customer.

Some people will argue that their existing load curve is perfect. This is usually first expressed as a worry about success - "What will happen when we move too much load"? I'd like to have that problem. I recall utilities in the 1950's proving they would have a winter peak if they ever got over 5% electric heat saturation. One I'm familiar with is at 15% and still peaking in the summer.

Some analyses concentrate on the control mechanisms whether economic (rates) or physical (ripple, radio, etc.). The value of storing off-peak energy is a separate issue from the control problem.

Some analyses assume the customer response can be described as simple payback. It can't. To illustrate, ask yourself if you would invest $600 to save $200 a year. Then decide if you would spend $60 to save $1.80 per month. Customer response is a function of net present value, and at a fairly high discount rate as evidenced by the success of 18% bank card loans.

Since we all live in homes and since people vote and factories don't, many analyses concentrate on the residential sector and ignore commercial and industrial loads. In GPU, we are concentrating our cooling storage effort in the commercial sector.

Don't assume that space heating and cooling is the whole market. GPU has 30 MW of storage on the lines for residential water heating and the potential for 300 MW more.

"My company is different." If you've got enough capacity, use storage to sell electric heat. If you aren't allowed to "promote", use storage to move load and minimize growth. I refuse to believe that Virginia is so different from Northern California that heat pumps, for example, were 80% of the market last year in one case and 5% in the other. I believe the major difference lies in the company's attitude as expressed in cost to the customer.

My last and favorite fallacy is the innovative, high technology, synergistic, gold-plated, bells and whistles syndrome. What we *don't* need is a storage off-peak heat pump with a solar-assisted windmill under power line carrier remote control. Each bell and whistle costs more to add, saves less and increases the probability of failure.

I promised you a new concept: If new capacity is so expensive that it raises all the rates, why don't utilities buy and own much cheaper thermal storage equipment instead? Of course there are practical problems of liability and regulatory policy, but if Carter is serious about saving oil and Schlesinger is serious about increasing nuclear energy, the concept would help.

And after all this buildup - to the subject of my talk, electric utility needs for thermal storage. For water heating, we need nothing but our own initiative to set rates. For residential heat, we need UL labeled competitors to Dick DeGrasse, who's getting rich in GPU territory. I'm sure these will be both ceramic and phase change systems. For the small commercial market, we need standards and experience with ice and phase change systems for partial storage for cooling. When that market develops, the heat storage will come with it. For large commercial buildings we have to work with architects and engineers on a one-to-one basis to design cost-effective systems, just as we did ten years ago for heat recovery. For the hard one, residential cooling I don't see much near term hope. Costs are way too high and savings way too low. Perhaps some combination of increased efficiency and storage will eventually work, but there's still a need for a lot of R&D. Please note that all the other applications I've mentioned are commercially viable today. Get to work.

# THE VERMONT EXPERIENCE

by
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Manager, Rates and Economic Research
Central Vermont Public Service Corporation

Central Vermont Public Service Corporation has been active in Load Management for over nine years now. This activity has led to the adoption of rate structures and policies which many feel are indications of steps all utilities should take. What I would like to do today is briefly take you through the development of our Load Management program, so that you may better understand some of the things we have done, in hopes that this may be of some assistance to you in evaluating your position.

Central Vermont is the largest electric utility in Vermont, serving about half of the state. The service area is rural in nature with the Company's 100,000 customers spread out at the rate of 17 per mile. 40% of our energy sold goes to the residential market. While the Company's industrial load comprised about 38% of its sales, it has no large, heavy industrial customers. This is why Central Vermont's Load Management Program has been directed at residential customers. Because of our northern climate, Central Vermont is a winter peaking utility with a peak of about 375 MW. The summer peak is about 65% of the winter peak. Our sources of power are as follows: nuclear 32.8%, coal 11.3%, oil 30.5%, and hydro 25.4%. Over the next ten years we expect coal and hydro to remain at the same absolute level, while nuclear will expand to 54.0% of our sources as oil shrinks to 15.5%.

In 1970, while preparing for a retail rate case, we prepared a graph showing the historic and projected trends in the price we pay for both capacity and energy. This was probably the single most influential factor in our decision to investigate Load Management. This graph clearly showed that our energy cost, which had been growing, would stabilize and perhaps even decline to some extent. At the same time, the capacity cost appeared ready to jump off the top of the graph. This graph told us we had better look into two areas. First, our rate structures were designed to produce revenues primarily through kilowatt-hour sales at a time when kilowatts and their cost were rising faster than kilowatt-hours and their cost. And second, was there anything we could do to reduce our kilowatt growth.

The first step taken was to more accurately reflect the capacity cost in our commercial and industrial rate structures. While perhaps a radical step for that time, it was an easy one. Next we began to look at other causes of peak growth, particularly in the residential area. Here electric heat stuck out like a sore thumb. Electric heat sales were booming, and the declining block rate structure would not produce the required revenue as capacity became more expensive. First we tried to control electric baseboard heat to reduce its impact on the system peak. We found that we could control the major part of the customer's load, but as soon as we exercised control that went beyond the natural diversity of the load the customer would get cold. Unlike space cooling, where humidity control and a temperature differential between indoors and outdoors produces comfort, space heating requires accurate maintenance of the indoor temperature. The next logical step was to investigate heat storage. After a few unsuccessful attempts at designing a heat storage device for residential applications, we discovered the Europeans had been doing this for many years. This led eventually to the importation of European equipment for use on our system. This equipment proved to operate as well in Vermont as it had in Europe.

So armed with equipment which could be substituted for baseboard resistance heat, we began a series of rate structure changes that would more appropriately reflect future costs. The first was to develop a price structure for the European storage heaters. Since this is a totally controllable load, we wanted to maintain maximum flexibility in serving the load. Keeping the heating load off-peak meant restricting it to night operation. This led to the design of a separately metered service available for a minimum of eight hours daily. Since this was a totally new type of service, we decided to price it on a marginal basis, and thus eliminate the possibility of the new service having an impact on existing customers. To keep the price level in competition with oil, we further restricted the service to locations where there was existing capacity in the generation, transmission, and distribution systems to serve the load. Thus the rate (special contract) for this equipment covers only the marginal cost of the local facilities, i.e., service and meter, and the cost of the energy used.

Now with an alternative for the new customer who wants to have a total electric home, we set out to discourage new electric heat on our basic residential rate. This proved to be relatively simple. We modified our basic residential rate to more accurately reflect cost by the inclusion of a seasonal differential. Since the winter price for four months was 2.5 times the summer price, the impact on electric heat can readily be seen. While stopping the growth of new uncontrolled heating installations, it also left us with several thousand irrate customers. Since they had operational heating systems, the storage heating equipment was not an acceptable alternative. We did find an acceptable alternative in time-of-use rates. Since these rates offer greater benefit to larger users with more load to control, they seemed useful for baseboard heating customers. Central Vermont, not being dominated by industrial loads, has both a morning peak and an evening peak, with a valley of about 10% between the peaks. Experiments showed that customers could reduce their loads significantly during both the morning and evening peak hours without a recovery load that would eliminate the midday valley. Consequently we introduced a time-of-day rate with three morning and four evening peak hours during the four winter months. The peak price is 6.25 times the off-peak price. This rate is based on energy consumption, since experiments with time related demand charges did not provide significant benefit. Most customers using this rate structure have installed automatic controls on their heating loads, turning off rooms not used during peak hours. Some have also installed wood stoves for heat during peak hours and turn off all heating loads.

Has all this action done Central Vermont any good? The growth rate during the 1960's, averaging about ten percent annually, has been dramatically reduced. The Company's annual load factor has gone from 52% in 1970 to 61% in 1978. More specifically, we now have about 200 storage heat customers with about 5MW of connected load. We have about 750 time-of-day customers with an average reduction of load during peak hours of 3.5 KW. This has been a big step forward, but we've got a long way to go. Current problems in the price and supply of home heating oil are putting new pressure on electric heat. Neither storage heat nor time-of-day rates can handle the impact of a major shift from oil to electricity for space heating. We are presently experimenting with an interruptible rate for residential space heating which could be combined with an oil furnace so that off-peak electricity is used for space heating when available, and oil when the electricity is interrupted. And we continue to review other ideas as they occur.

Perhaps I should close with some words of caution. We have discovered some pitfalls in achieving our successes. Initially we relied on the customer to perform the control of the storage heating load. While most customers are honest, the high capital cost of the equipment leads to undersizing in some cases. When the extreme cold does arrive, as it did last winter, the customer will get cold and the temptation to bypass the controls for heat is great. This did occur in several cases last winter on our system. Since we do not interrupt the service and only measure energy through a single register meter, the customer is able to receive peak energy without paying the proper price. We are now installing two-register meters on all storage heat customers. We will still not allow energy consumption during the peak hours, but should it occur we will be able to properly price the service. Should it occur more than once, the customer can lose their service. Incidentally, we do not allow storage heating equipment on our time-of-day rate for this same reason. The peak price on the time-of-day rate is not adequate to the low load factor consumption that could occur from undersized storage heat equipment. Recent studies have also indicated that the energy consumption of a structure with storage heat may be greater during the first twenty-four hours of a cold snap than a similar structure with uncontrolled heat. This appears to be related to the increase in the charge of the storage heaters during the initial charge period after the onset of cold weather. Looking at longer time periods shows the energy consumption to be equivalent, thus indicating no difference in efficiency between the two alternatives, only a question of timing.

In closing I would like to say what we have done has been very successful for us. This is not to say it is the answer for everyone. But I do think if we were all more open-minded in evaluating new and old ideas, we would have a much better chance of overcoming our energy problems.

Dup

# DOE/ORNL DEMONSTRATIONS OF LOAD MANAGEMENT BY CONTROLLED CUSTOMER-SIDE THERMAL ENERGY STORAGE*

by
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## ABSTRACT

The Division of Electric Energy Systems of the Department of Energy (DOE/EES) is funding a nationwide demonstration of electric load management through the use of utility-controlled, customer-wide thermal energy storage for residential space conditioning. These demonstration projects, which are being conducted by utilities under contract to Oak Ridge National Laboratory (ORNL), are designed to 1) collect reliable load research data for assessing the impact on the utility system, 2) delineate and solve installation problems, 3) establish maintainability, 4) illuminate customer and utility acceptance, and 5) generate cost data.

Ten demonstrations, 5 heat storage and 5 cool storage, are underway. The thermal energy storage systems being demonstrated include ceramic brick, pressurized water, and building structural heat storage systems, and ice cool storage systems. The demonstrations will cover two full conditioning seasons.

The results obtained from these demonstrations are expected to be useful to utilities in making local load management decisions, to assist DOE in establishing priorities for R&D efforts in load management, and to provide objective information related to electric system impact, energy conservation, and the cost effectiveness of this form of load management.

## INTRODUCTION

Load management has been proposed as a means whereby an electric utility can reduce its requirements for additional generation, transmission and distribution investments, make more efficient use of its existing facilities, and shift fuel dependency from limited oil and gas to more abundant resources such as coal or nuclear. In its broadest sense, load management refers to any method used to modify system load patterns to more closely match electric energy use with electric energy production. It is useful to distinguish between two different approaches to load management: *use management* and *supply management*. Use management refers to techniques which impact on the energy consumption patterns of individual consumers, (e.g. direct control or voluntary control either with or without customer energy storage), while supply management refers to the use of utility-owned facilities to improve the match between electric energy production and use by taking advantage of the natural diversity of power demand (e.g. expanded interconnection and operation of power systems) or by providing storage in the system (e.g. central of dispersed storage).

A careful analysis of any proposed load management program must be made because substantial costs can be incurred in initiating a load management program, and if the

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program is not carefully designed, the implementation costs can exceed the benefits that are realized. Assessing the desirability of various load management options can be a difficult task because of the significant differences in the shape and composition of load curves among utility systems, geographic variations in capacity types and fuel costs, and the unique set of benefits, costs, and social, technological, and environmental constraints associated with each load management option which must be considered in any analysis.

The DOE/ORNL demonstration program addresses one particular approach to load management; specificially the use of utility-controlled customer-side thermal energy storage (TES) for residential space conditioning. The demonstrations are part of a comprehensive load management program being conducted by the Division of Electric Energy Systems of the U.S. Department of Energy (DOE/EES)[1] which includes technical demonstrations of emerging technologies, the development and application of state-of-the-art analytic methods, and the development of advanced concepts and technologies for the future.

The objectives of the demonstration are to employ promising near-commercial, customer side TES devices in sufficient quantities to 1) collect reliable load research data for assessing the impact on the utility system, 2) delineate and solve installation problems, 3) establish maintainability, 4) illuminate customer and utility acceptance, and 5) generate cost data.

## DEMONSTRATION DESIGN

The concept of using customer-side TES for load management is not a new concept, having been practiced widely in Europe with varying degrees of success.[2] While customer-side TES has not been widely applied in the United States, a recently completed survey of utility load management and energy conservation projects has identified 71 utility-sponsored TES projects.[3] These projects generally consist of one or two TES units installed on a given region and, although valuable for determining the applicability of a particular TES concept to a given region, the information collected from these projects is inadequate for estimating what widespread implementation might mean to that utility because of the small sample size. Information such as the diversified demand characteristics of the TES units and of the conventional equipment they are replacing can only be derived if sufficient data is collected to cover the range of applications and use characteristics experienced in the region. Consequently, each project consists of from 30 to 50 of the same manufacturers' storage units installed in a given region. A number of projects, involving both heat and cool storage, are being conducted so as to cover a range of geographic, climatic, demographic, utility, and storage system characteristics.

The projects are limited to near-commercial heat or cool storage for residential space conditioning with the optional addition of water heating. The candidate storage systems were selected by the responding utilities on the basis of high potential for economic effectiveness and customer acceptance in their service area. The units are located in both new construction, or retrofit applications selected to be representative of the utility's service area.

Project plans include provisions to handle the service problems involved with the test including such steps as providing a service warranty, spare parts and trained dealer and utility personnel. Plans also provide for removing the storage system at the conclusion of the test if desired by the customer in order to minimize any ill feeling or inconvenience to the customer during and after the demonstration.

All of the storage homes, and a control group each containing a conventional space conditioning system, are to be instrumented to collect the necessary load research data. In addition, several of the storage homes in each project will be more fully instrumented to obtain detailed information on the storage unit characteristics. Data on utility operations and weather conditions will also be collected for correlation with device performance. The data from all the demonstrations will be collected in a consistent manner so that the results from the various projects can be compared.

Remote utility control of the storage device was required as part of the project. This is because one of the outputs desired from the demonstrations was a measure of the effectiveness of various controlled strategies from the standpoint of system reliability and costs. The utilities will be investigating a number of control options such as active utility control to minimize production costs, a fixed time-of-day control.

The demonstrations will cover two full conditioning seasons. At the conclusion of the demonstration, each of the utilities will prepare a final report which includes an analysis of the market potential of the TES system and the impact of this mode of load management on their system. Such factors as operational integration, transmission and distribution reinforcemnt, production costs, generation expansion, and customer acceptance will be included in the impact analysis.

## PROJECT DESCRIPTIONS

Ten storage demonstration projects, five heat and five cool, have been undertaken by the utility industry under contract to Oak Ridge National Laboratory (ORNL). Over 200 utilities received an outline of the demonstrations in a letter asking if they wished to receive a detailed Request for Proposal (RFP) to bid for participation. Sixty-four utilities asked for RFPs and seventeen proposals were received. Eight of these proposals resulted in contracts. (Two utilities are employing both heat and cool storage.) The work to be performed by each utility consists of (1) planning the demonstration; (2) selecting, purchasing, installing, and maintaining the storage space conditioning equipment and the instrumentation for load research and device-specific data; (3) providing a communication and control system and operating the storage system according to several control strategies; (4) collecting data; (5) performing data analysis and a preliminary assessment of the impact on the utility of TES load management; and (6) presenting results in a final report.

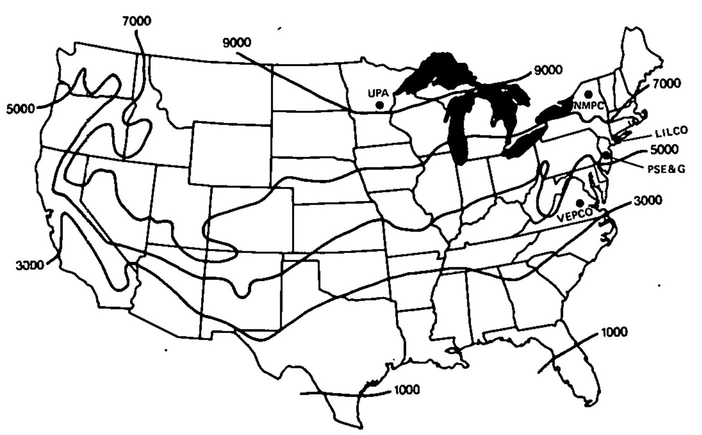


Figure 1

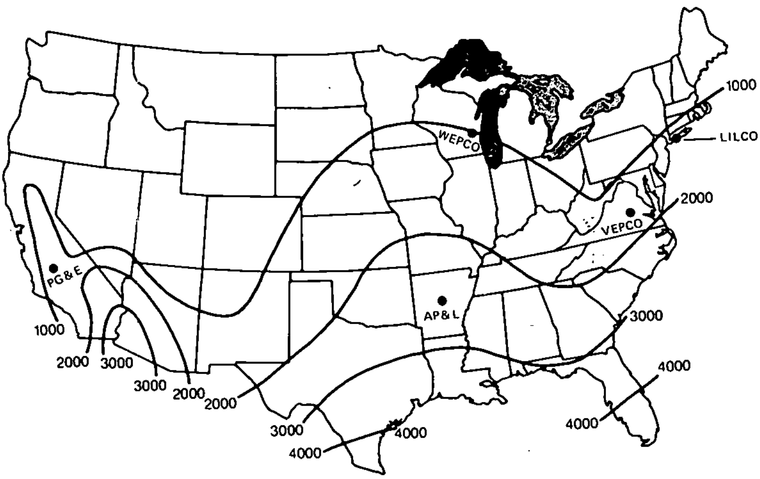


Figure 2

The location of the heat and cool demonstration projects are shown in Figures 1 and 2. As indicated in the figures, the storage projects cover quite a range of heating degree days and cooling degree days from some of the most severe in the country to more temperate regions. The projects also include quite a range of utility, geographic, and demographic characteristics.

All the demonstrations are to cover two space conditioning seasons and, except for the Niagara Mohawk project, are for single family residences only. The space conditioning systems in all cases respond to the local room thermostat, resulting in no life-style changes on the part of the occupants. The storage systems will be charged upon command from the utility. Several strategies will be employed, including simulation of the fixed periods of time clocks and time of day rates and the variable periods resulting from the most economic power production and anticipated weather conditioning.

The data, except as noted below, will be collected on four-track magnetic tape. All homes in both the test and control groups will produce load research data including at least the total house energy, the normal space conditioning energy, the storage unit energy, and indoor temperature. Additional device-specific data such as state of charge of the storage unit and temperatures and flows for efficiency determinations will be collected on a limited number of the units for each project. This device-specific data will be similar to, but not as extensive as, the data being collected by EPRI projects RP1089-1 and RP1089-2 for cool and heat storage instrumentation and data verification. In these projects one or two installations in a number of utilities (15 to 25) are heavily instrumented to provide extensive data (approximately 20 points) on device operation, weather conditions, and comfort levels in the installation. The EPRI projects and this DOE project were planned together in order to promote effective utilization of the results of both programs.

Each utility will use the data for planning studies to determine the impact of several levels of saturation of thermal energy storage in their system. These studies will include an assessment of both costs and benefits.

| UTILITY | EQUIPMENT | NUMBER TEST/CONTROL | CONTROL |
|---|---|---|---|
| UPA | TPI | 35/35 | RADIO |
| PSE&G | TPI | 30/30 | TELEPHONE |
| LILCO | MEGATHERM | 50/35 | RADIO |
| VEPCO | MEGATHERM (CARRIER HP) | 40/40 | TELEPHONE |
| NMPC | AEG | 8 | TELEPHONE |
| | MEGATHERM | 8 | |
| | CARRIER HP | 4 | |
| | PSC (SLAB) | 4 | |

**Table I. Heat Storage**

| UTILITY | EQUIPMENT | NUMBER TEST/CONTROL | CONTROL |
|---|---|---|---|
| WEPCO | A. O. SMITH | 35/35/25 | PLC |
| LILCO | CALMAC | 50/35 | RADIO |
| VEPCO | CARRIER | 40/40 | TELEPHONE |
| AP&L | A. O. SMITH | 35/35 | RADIO |
| PG&E | CARRIER | 30/30 | RADIO |

**Table II. Cool Storage**

The projects chosen for contract award are listed in Tables I and II. The participating utilities with their project descriptions are:

**Wisconsin Electric Power Company (WEPCO)**—Cool storage, 70 retrofit installations in two sizes. Full storage using two A.O. Smith ice tanks and a full-size compressor for off-peak operation only and half storage using one tank with a half-size compressor for nearly continuous operation. The control group of 25 residences will have conventional air conditioning. All residences will be fitted for load research instrumentation while five full-storage and five half-storage residences will have additional instrumentation for device-specific data. Storage control and data acquisition will be through a two-way power line carrier communications system from a central control office.

**Long Island Lighting Company (LILCO)**—Heat and cool storage, 50 homes each. Heat storage using Megatherm pressurized water units retrofitted in existing oil-fired hydronic heating systems. Cool storage using Calmac ice tanks retrofitted in existing air conditioning systems. Control groups of 35 homes each will be established with conventional heating and air conditioning. All residences will be instrumented for load research data with ten each from each group instrumented for additional device-specific data. Storage control will be by Scientific Atlanta radio from the central load management project office.

**Virginia Electric Power Company (VEPCO)**—Heat and cool storage in 40 new construction homes using a heat pump for space conditioning. Electric storage water heaters will also be installed. Megatherm pressurized water units will provide heat storage for supplemental heat, and Carrier (Girton) ice tanks will supply cool storage for air conditioning. Heat for domestic hot water will be reclaimed during the air conditioning season. Forty control homes will be new construction with conventional heat pumps only. All homes will be instrumented to collect load research data, and six test homes will be instrumented for additional device-specific data. Storage control will be through leased telephone lines to groups of five homes.

**Arkansas Power and Light Company (AP&L)**—Cool storage in 35 homes using A.O. Smith ice tanks retrofitted into existing 2½ and 3½ ton central air conditioning systems. A control group of 35 homes will have conventional air conditioning. A.O. Smith storage water heaters will be installed in 15 homes in place of existing electric water heaters. All homes will be instrumented for research data while six homes will have additional instrumentation for device-specific data. Storage control will be by existing Motorola radio control from the system dispatch center.

**Pacific Gas and Electric Company (PG&E)**—Cool storage in 30 homes using Carrier (Girton) ice tanks retrofitted into existing air conditioning systems. A control group of 30 homes will have conventional air conditioning. All homes will be instrumented for load research data with five homes instrumented for additional device-specific data. Storage control will be scientific Atlanta radio from UPA's Elk River Energy Control Center.

**Public Service Electric and Gas Company (PSE&G)**—Heat storage in 30 homes using TPI ceramic brick storage furnaces retrofitted in existing central forced air systems. Each home will also have an electric storage domestic water heater. Thirty control homes will have conventional electric furnace central heat. All homes will be instrumented for load research data while five homes will be insrumented for additional device-specific data. Storage control will be by DARCOM telephone communication from the load management program office.

**Niagara Mohawk Power Corporation (NMPC)**—Heat storage in a dormitory complex for the 1980 Winter Olympics. Four of five dormitories will have multiple heat storage units of the same type, each unit being approximately the size for a single family residence. Each dormitory is a modified circular two-floor building with eight sleeping wings. The environmental aspect of all buildings is nearly uniform. The heat storage systems are: eight AEG ceramic brick units, eight Megatherm pressurized hot water units, four Carrier heat pumps with hot water supplemental heat storage, and four Peak Supervision Control (PSC) trellis (in-slab) heating systems. The fifth dormitory in the complex will have electric resistance forced air heat and will be the control sample. Storage control and data acquisition will be by leased telephone line from a central office.

## STATUS OF PROJECTS

Some heat storage equipment was installed and tested under local control during the 1978-79 heating season, but the demonstrations will really commence with the 1979 cooling season. The installation of the cool storage units is underway and the first season's operational results are expected in the fall of 1979. Equipment installation is also underway for the heat storage projects and first season results will be available in the summer of 1980.

The impact assessments will be performed at the conclusion of the second conditioning season after which final reports will be prepared and available.

## CONCLUSIONS

The results of these demonstrations will include data on the use characteristics of residential customer-side TES space conditioning and water heating systems, and on the use characteristics of their conventional counterparts. These results will include the performance of the storage systems as a function of regional and weather characteristics suitable for forecasting what the widespread implementation of these systems might mean to the utility system.

These results can be used in a number of assessment areas such as forecasting, expansion planning, production costing, and reliability analyses. Work is also underway as part of the load management program to develop new tools for assessing the impacts of load management alternatives on such things as generation expansion plans, short-term operating procedures, distribution system operation and reinforcement, and consumer reliability.

In addition, much valuable information will have been gained from the demonstrations on the installation of customer-side TES systems, their maintainability, and consumer acceptance of this technology.

These results should be useful to utilities in determining the system savings that might be realized through the widespread implementation of customer-side TES in residences. This information is needed to design appropriate rates and, together with the cost data generated, will help utilities make decisions on the desirability of this load management alternative.

## REFERENCES

1. U.S. Department of Energy—Division of Electric Energy Systems, *Program Plan for Research, Development and Demonstration of Load Management on the Electric Power System*, DOE/ET-004, January 1978.

2. Systems Control, Inc., *Critical Analysis of European Load Management Practices*, CONS/1168-1, January 1977.

3. EUS, Inc., *Survey of Utility Load Management and Energy Conservation Projects*, ORNL/Sub-77/13509/4, December 1978.

# IV. The Role Of Peak-Load Pricing In TES Commercialization

# PEAK LOAD PRICING AND THERMAL ENERGY STORAGE: THE EXPERIENCE AT VEPCO

by

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In relating our experience with peak-load pricing and the role it will play in the commercialization of thermal energy storage (TES), a number of technical, regulatory and legal issues must be addressed. As there is very little actual data on TES, I would like to comment on our experience in developing and implementing time-differentiated rates, and discuss some of the issues which will ultimately effect the cost of TES systems. However, before covering these experiences, and in order to give a perspective from which to view my comments, I believe it may be worthwhile to briefly describe VEPCO's recent experience with TES systems and with time-of-usage, or peak-load pricing rates.

Our experience with thermal storage has been very limited except with water heating. Several years ago, we had approximately 150,000 water heaters that were used to store water for home heating use with time clocks controlling the heating periods. In the 1960's, the family use of hot water rose significantly and as a result the customers were not satisfied with the charging hours since they did not receive an adequate supply of hot water.

Also, from the company standpoint, the time clocks were on in an "incorrect" time period and as a result contributed to the system peak load in many instances. The end result was that by the early 1970's, there were no customers supplied on the time-controlled water heating rate.

The main reasons for the elimination of this service were that the customers' storage capacity was too small and the time clocks used for controlling the charging hours did not have a carry-over feature which would have allowed the clocks to stay on.

We are now conducting studies on storage water heating using a modern time clock with a carry-over feature, and also using radio control and ripple control as the control mode.

At the present time, we are preparing to start installation of TES systems in 40 newly constructed homes under a demonstration project funded by the Department of Energy (DOE). A delay caused by contract negotiations means we will not be able to get any data on this current cooling season. Heat pumps will be used to provide heat to Megatherm pressurized water storage tanks, and to extract energy from water stored in Carrier (Girton) water tanks. An off-peak electric storage heater is also used, and waste heat will be reclaimed during summer air conditioning for the water heating unit.

We have had an annual cycle energy storage (ACES) home in operation since 1977, although very little can be said about its operation because of difficulties in data collection.

Because of our interest in load management using customer-side energy storage, when we needed a new district office complex, we decided to install a storage heating and cooling system supplemented by solar energy. This building complex, which has just been completed, has 11,300 square feet in the office area and 7,200 square feet in the storeroom. The system consists of three 10,000 gallon storage tanks which can be used for either hot or chilled water storage. The solar panels are of the air type, rather than water, and total 740 square feet.

We have been planning from a rate standpoint to provide a rate that would fairly price electricity for TES systems. Basically, TES systems can provide a vehicle for reducing the cost of electricity to the consumer if it is designed properly to take into account the cost of the electricity. For example, if the TES system needs electricity supplied only during off-peak hours of the utility system, then the cost of electricity will be less for a given number of kilowatt hours. This electrical energy cost will then have to be weighed against the other costs of the system to determine the type and design of the TES system that is best for the customer.

Now, I will discuss the basic consideration of rate design and the plan VEPCO has for implementing time-of-use (TOU) pricing which will open up a rate we think will fairly price electricity to TES systems.

We are presently a summer-peaking Company, although, with an increasing saturation of heat pumps, our winter heating load is growing and we expect the summer and winter peaks to be almost equal by the mid-1980's. In fact, for practical ratemaking purposes, they are equal. Heat pumps are very compatible with the climate of the area we serve, and this, combined with high oil prices and occasional natural gas shortages, has resulted in increased heat pump usage, leading to our latest forecast showing the winter load growth of 4.5% exceeding the summer growth of 4%.

At present, our summer peak period extends from 10 a.m. to 10 p.m. during July, August and September, although June does contribute significantly. We decided the billing months of July, August and September would encompass this summer period. The winter months of December, January and February have a double peak in the 7 a.m. to 10 p.m. period, with the secondary peak occurring in the morning followed by an afternoon valley and the primary peak in the evening hours.

With a new load forecast being used in our production costing model, we determined that July through September and December through February are months of equal cost and should, therefore, be priced the same, with the remaining months being classified as lower-cost shoulder months.

In all previous filings, we received comments from some that the year-round 10 a.m. to 10 p.m. period was too long. We recognized then that the winter hours could extend from 7 a.m. to 10 p.m., and this was also indicated in the work done for our most recent filing. Therefore, in trying to reconcile metering difficulties with current costing hours, and keeping the rate schedule reasonably simple from the standpoint of consumer comprehension, we have retained 10 a.m. to 10 p.m. hours, Monday through Friday, during the winter for simplicity. With the summer peak still greater than the winter peak, we felt it was best to allow the summer hours to control the peak period throughout the year. We plan to use the load management techniques that are currently being developed to control the expected winter peak that falls outside of the peak period.

This outlines our current and near-run projection of seasonal and daily loads, and is the basis for our decision on time-of-use (TOU) pricing.

We have asked the Virginia Commission to approve the TOU rate implementation plans that I will now discuss.

The TOU residential rate, Schedule 1P, has a demand charge which varies according to season,with the new peak period months of December through February and July through August being charged more than base period months. The off-peak energy charges are the same in all months.

We currently plan two programs to implement residential Schedule 1P. The first plan would be mandatory for all customers who exceeded 3500 kWh in any one of the four summer months of 1976, 1977 and 1978. We have installed meters on 8500 customers based on the summer of 1976 usage. We have identified and started meter installations on 7500 additional customers that qualify based on 1977 summer usage and have also identified an additional 4500 customers from the summer of 1978. All of these customers receive a personal visit and the subsequent meter installation, the customers continue to pay the traditional billing, but they also receive a comparable statement showing the TOU billing for the same usage. The customers are invited to use this comparative billing period to experiment and familiarize themselves with the rate structure.

We have proposed to the Virginia Commission an extension of this procedure to the class of customer whose usage is between 3000 and 3500 kWh per month. We will also propose in the near future that all customers above 3500 kWh be mandatorily billed on the TOU rate. We have received many comments from the customers receiving comparative bills that they would like to be billed on the TOU rate. Therefore, we have decided to allow any of these customers to volunteer for the TOU rate if they desire.

The second plan is strictly volunteer. Because of metering cost considerations, we limited the customers volunteering to usages of greater than 720 kWh per month during a summer month. We originally decided on a maximum of 1000 customers for this program but after receiving over 17,000 requests, we expanded the program to 2000 customers. We have also proposed to embark on new volunteer programs of 2000 customers per year after considering the interest generated from our original proposal. Preliminary results show an approximate 50/50 split of billing increases and decreases but we expect a greater percentage of people receiving decreases after more customers adjust to TOU pricing.

We have also received approval for TOU rates for customers with storage space conditioning systems and for solar systems involving extensive storage. We have proposed the TOU rate to be mandatory for customers with solar heating and other supplemental sources of energy.

With recent advent of TOU rates, we are now offering an off-peak storage water heating rate to all volunteer residential customers. This rate, which is offered in conjunction with the regular residential rate, is separately metered at an additional cost of $3.14 per month and contains an off-peak energy charge based on marginal cost. The meter is clock-operated and does not allow operation between 10 a.m. and 10 p.m., Monday through Friday, which is the on-peak period. The battery operated carry-over on the meters helps to maintain proper on- and off-period cycles.

We also have Rider I, Standby or Parallel Operation Service, which will be offered under Schedule 1P to customers desiring to use alternate energy sources such as windmills. We offered this Rider in order to be responsive to some customers who wanted supplemental or auxiliary sources of energy. We feel that Schedule 1P will give these customers the incentive to operate these systems in the most efficient manner for both the Customer and the Company.

We are currently offering Rider J, an interruptible water heating credit of $1.85 per month, in two geographic areas. One area is using a ripple control system and the other is using radio control. The response in both areas was encouraging and we obtained an excellent acceptance rate after explaining our intent to these customers. The two areas combined have resulted in 700 customers allowing us to interrupt their water heaters and this number is increasing each day.

We are in the process of installing Automatic Meter Reading, or AMR, systems in three geographic areas with an expected completion date of October, 1979. We plan to interrupt water heaters in these areas and study other aspects of the AMR system.

We have recently filed implementation plans for large general service customers. We have proposed that any customer who has established a demand of 750 kW or more be mandatorily billed on the TOU rate. This would represent approximately 620 customers. In addition, we proposed a volunteer program for general service customers and limited participation to 100 customers.

These issues will be decided in a rate case this fall. We expect some of the largest customers to oppose our TOU rate based on marginal costs. These customers are concerned about the marginal energy costs because these costs are considerably higher than the energy prices contained in the traditional rate structure.

Having given you a brief outline of our current and planned experiments, I would like to discuss our position on time-of-use pricing. Since one of the purposes of TES systems is to take advantage of generation during low-cost periods, it is obvious that rate structures must properly reflect costs which are time-variant. In addition to the energy cost savings, this managed load should, if properly designed, also reduce the need for adding new generating capaicty.

Although time-varying rates can be based on different costing methodologies such as embedded, we have chosen marginal cost-based TOU rates as being the most efficient pricing system. It is felt that this approach will lead to advantages for both the utiltiy and the customers because of its greater efficiency in resource allocation. Not only should prices reflect costs, but they should also act as signals to the customer, guiding him in his consumption of electricity today and indicating what future costs will be.

We believe that TOU rates do not impose restrictions on customer use, but do let the customer make his decisions based on price as long as prices accurately reflect costs. This does not mean that we are indifferent to load management, as our proposed implementation plans have shown.

Generally speaking, we are involved with indirect and direct load control. Indirect control is characterized as the customer responding to the Company's price signals, by having the option of changing his usage patterns or using devices such as load limiters or time clocks to control his usage and consequently costs. Direct load control is the utility actually controlling the operation of certain power consuming devices owned by the customer. We are offering a rate to customers which has elements of supply- and demand-side management in that the customer is offered a billing credit if he allows the utility to interrupt his water heating service during certain hours of the day. We are studying the feasibility of offering credits for the interruption of heat pumps, since this would provide advantages in both summer and winter months in reducing peak loads.

Initially, in deciding on the type of rate form to use, we concluded that we would use a three-part rate consisting of customer, kilowatt demand, and energy charges. Without the kilowatt demand charge, customers might reduce their energy consumption until the hottest hour of a summer afternoon and turn their air conditioning on, possibly creating a ''needle-peaking'' condition worse than what would have normally occurred.

At the time we were selecting for our residential implementation plan, metering technology, although improved over the last several years, did not offer much of a choice. Since metering cost is one of the main determinants in deciding whether TOU rates will be cost effective, we do not feel that smaller use customers can be metered at reasonable cost with equipment available today. The costs probably outweigh any benefits which could be gained for the small customer.

While it is very difficult to predict with any certainty what the rate structure will be in 10 years, we can analyze what the rate structure should be today. While reasonable people may differ about the exact form of these rates, it appears that at least one point of agreement is that rates should vary by time-of-use in order to better track costs.

In summary, we are proposing a plan to the Virginia Commission which we believe will be a reasonable approach to pricing for TES systems. We believe that our rate design takes into account the three main cost factors in the supply of electricity: namely, the customer, demand and energy costs. It appears that these rates should provide a vehicle for the manufacturer and the customer to make an economic decision that is correct.

One of my major concerns as a rate man is to make sure that as far as humanly possible we do not provide rates that will cause the customer to make a significant investment and then have rate cost factors change so that it renders his equipment unsatisfactory. This is a most serious matter for the manufacturer, the customer, and the company. One of the main areas of activity over which the utility has very little control is what the government policy is going to be with regard to energy. For example, if the national policy turns out to be that the Federal government will relax the tremendous restrictions on the construction of coal and nuclear power plans, and relax to some appropriate degree the requirements for environmental protection, this could mean one thing to the utility industry. On the other hand, if the restrictions that now prevail continue in their present status and get more restrictive in the future, then the cost picture could change very rapidly.

This is especially true since a very large portion of the cost of providing electric service today is tied up in the ten-year construction period for a nuclear plant and approximately the same for a coal-fired plant, and the extemely burdensome environmental protection requirements.

Also, the electric energy picture would be significantly different if the national energy policy develops so that we can reprocess nuclear fuel and allows us to go to the breeder reactor.

Another concern is that we are proceeding on many fronts to provide for rate experimentation. There are many factors that we do not know a great deal about. For example, we do not know, to my satisfaction, what the impact of prices will have on the customer shifting load. Can the customer shift load? If so, how much load will he shift? If the customer does shift load, will this reduce the peak demand or will it just shift the peak demand to another hour? For instance, an off-peak hour.

On the other hand, there are many experiments going on in thermal energy storage and these have many significant possibilities. Some of these will turn out to be not acceptable to the customer, and others will turn out to be beneficial. At the present time, we do not know, for example, whether the ACES system will prove to be of significant value. It has a great deal of potential and may prove to be a great help to the customers.

I do not think there is any doubt that we should proceed on all of these fronts, but we should proceed with caution, always with the customer in mind. It is extremely important that we explain our systems and our rates to our customer so that they will understand them. Not only so that the customer will be happier, but so that the customer can get the total benefits that such a system and such a rate structure offers to him or her.

I wish to thank you again for the opportunity of discussing these matters with you.

# RATEMAKING AND ALTERNATIVE TECHNOLOGIES

By
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## Introduction

The basic principles of ratemaking are well known[1] and will not be expounded upon in this paper. What is needed in the area of alternative technologies, including thermal energy storage (TES), is for all the advocates to stop generalizing about how good their particular technology can be and instead come up with a set of hard, site- and utility-specific facts based on principles of rational economic analysis. How one might go about obtaining this data and perform the necessary analyses is one of the subjects of this paper.

It seems that one of the basic assumptions underlying the political pressure to commercialize thermal energy storage systems is the notion that the use of such systems will result in cost and energy savings. It must be remembered that no single strategy will prove to be a panacea for the energy problem—TES, cogeneration, solar—all are pieces of the puzzle. The best ultimate answer will be one that relies on concepts of economic efficiency rather than on concepts of motherhood. To quote a NERA colleague:

> The objective is to give the consumer the economically correct price signal upon which to base his or her decisions. If people don't want to consume off-peak and are willing to pay what it costs to provide electricity on-peak, then this is fine. On the other hand, if they are willing to suffer the inconvenience of consuming off-peak in order to save money, then that is also fine. Of course, you can command, cajole or shame people into changing their consumption patterns to buy at a time they would rather not, but why do so if it reduces people's quality of life more than it reduces the cost of the service they are consuming? In other words, if the cost of the inconvenience of shifting consumption to the off-peak periods is greater than the cost of providing for that consumption on-peak, it is counterproductive and uneconomic to shift load just because the shift will lower average unit production costs.

The consumer is the ultimate judge and jury and reigns supreme.

## Saving Energy

Will we save energy through the use of TES, and, as a corollary, will we necessarily save scarce or imported resources? It is a simple engineering fact that electrical losses are going to increase due to the increase in loads during off-peak hours. It also seems to be a simple engineering fact that most energy storage systems will not have an input/output efficiency equal to unity. With regard to saving scarce or imported resources, one must have specific knowledge regarding system dispatch in order to answer the question. The displacements most likely will be coal in the Midwest and oil in the Northeast.

## Economic Evaluation

The basis for an economic evaluation of thermal storage projects is rooted in marginal costs. Potential purchasers will make their decisions on the basis of a comparison between the marginal costs of alternative energy delivery systems and the marginal costs of the storage systems.

The first step in the analysis should be to measure both the private and social costs and benefits resulting from the delivery of energy to consumers from a storage system. In order to accomplish this, one must compare the marginal costs of providing the same service by conventional means with the marginal costs of providing service by means of storage. We begin our analysis with the following assumptions:

1) The load characteristics of the potential thermal load to be served are known.
2) The cost of providing service through conventional energy delivery systems is known.
3) The incremental costs of generating, transmitting and distributing electrical energy at various times of the day, month and year by the local electric utility are known (or can be reasonably estimated).

The first step in our analysis would be to design a storage system capable of meeting the thermal load characteristics of the project to be served and to measure the total cost of such a system. Compare this cost with the cost of providing services to the project through conventional energy delivery systems. At this point, it should be remembered that the upper bound of the marginal cost of providing this service is logically the cost of providing service through conventional energy delivery systems. If the cost of providing the thermal requirements through storage is below the cost of providing such service through conventional energy delivery systems, then we will see such systems come into general use and vice versa.

**Opportunities for Load Management**

It is in the quantification of benefits that the interrelationship between marginal costs and load management becomes apparent. Let us look at a hypothetical scenario and examine the various trade-offs. Imagine a device that enabled the utility to control a portion of the customer's demand whenever climatic conditions indicated a high probability of a peak occurrence. Posit an annual carrying cost for this device of $500 per location. Now for each kilowatt shaved from the expected system peak, the utility would be able to defer or cancel a kilowatt of generating capacity. Next examine the effect of the deferral or cancellation on total system costs. If the system was planning to add a mix of peaking and baseload units, the most likely reaction would be the deferral of some portion of the peaking unit additions. If the utility is adding only baseload plant, it will probably defer some of the baseload plant addition; however, this will cause an increase in the expected fuel bill. The net cost difference to the utility will be the savings of the annual charges on deferred capacity less the annual fuel cost increase resulting from the deferral.

Likewise, the utility may also save on transmission and distribution facilities investment. Of course, the savings here will also be net of additional fuel costs, as cutting back on transmission and distribution capacity may lead to increased losses. The system planner could estimate the net per-kilowatt annual savings from the three functions. Let us assume that this amounted to $50 per kilowatt.[2] Optimal behavior would be for the utility to offer load management to consumers, charging the customer $500 per year to cover the cost of load management facilities and crediting the consumer with $50 per year for each kilowatt subject to load control.

Now assume that the utility has based its load management credit only on the deferral of the annual carrying cost of the baseload plant and transmission and distribution facilities, but has ignored the added fuel cost and additional cost of losses resulting from the deferral. The credit would be increased to $97.50 per kilowatt a year. The optimal decision for the industrial customer would be to subscribe for curtailment of all loads where the added labor cost would be less than $97.50 per year.

But, since the marginal cost savings to the utility is only $50 per kilowatt per year, such a plan will lead to inefficient allocation of resources as the customer will not choose to curtail loads up to the most efficient point because the credit that he received is less than the cost savings generated.

In sum, when a firm seeks to optimize its scheduling of energy consumption and other factors through anticipation in a load management program, it will choose the course that will lower its total private costs. The solution will be coincidental with the least total costs of production (defined, of course, on the basis of the sum of the customer's and utility's costs) only when the load management incentive is based upon marginal costs. Furthermore, the greater the departure of the load management incentive from marginal costs, the greater the quantity departure from the most efficient allocation of the various factors of production.

**PURPA Considerations**

The passing by Congress of PURPA appears to me and my colleagues at NERA to have brought the great utility rate debate to an end. It is our contention that the language of the Act itself compels one to conclude that marginal cost data must be gathered and given consideration in the ratemaking process. The Act inaugurates, among other things, "a program providing for . . . increased efficiency in the use of facilities and *resources* by electric utilities."[3] Further, at Section 115 we find:

> In prescribing such methods, such State regulatory authority or nonregulated electricity utility shall take into account the extent to which total costs to an electric utility are likely to change if:
> (A) additional capacity is added to meet peak demand relative to base demand; and
> (B) additional kilowatt-hours of electric energy are delivered to electric consumers.

Indeed, the foregoing passages, in language uncluttered by academic jargon, require a movement toward economic efficiency in terms of resource use and also set forth a simple definition of marginal costs. Section 133 of PURPA sets forth rather precisely what data are to be gathered in order to determine the cost causative factors of serving different types of consumers so that rates may more closely track costs and give the proper price signals to consumers.

**Summary**

Alternative energy technologies will each have their place in the overall energy picture. No one technology is going to work in each section of the U.S., or for each class of customers. Where each technology is going to work best still remains to be defined. PURPA has given both utilities and industry the opportunity to formulate the necessary definitions.

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1 See James C. Bonbright, *Principles of Public Utility Rates* (New York: Columbia University Press and Alfred E. Kahn, *The Economics of Regulation* (New York: John Wiley & Sons).

2 Baseload plant cost of \$450/kW × 15% carrying charge less additional annual fuel cost of \$40/kW plus transmission and distribution investment of \$200/kW × 15% carrying charge less cost of additional losses of \$7.50/kW.

3 Senate Report No. 95-1291, October 6, 1978, page 3, emphasis added.

4 Ibid, page 10.

# THERMAL ENERGY STORAGE AND THE REGULATORY ENVIRONMENT

by

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**Public Service Commission of Wisconsin**

The advent of peak load pricing in the United States over the last five years has greatly increased the potential for the commercialization of thermal energy storage systems. To be sure, "valley hour rates" and "scheduled power rates" as well as controlled water heating programs have existed for some time in this country. Many controlled water heating rates were phased out of service. As the marginal costs of added service have started to go up bringing with them substantial rate increases, regulators have sought ways of refining the tariff structure for electricity. A closer tracking of marginal costs by time-of-day provides a price signal that not only lets the customer know how expensive electricity is during peak hours but also gives him an opportunity to save by shifting load to off-peak periods where the costs and therefore the price are lower. Thermal electric storage systems provide one way of shifting loads providing that the rate differential between peak and off-peak use is sufficiently large to make them economic.

Not everyone is enthusiastic about thermal energy storage (TES). Since most TES applications at the present provide only low grade electric heat for residential space conditioning and water heating, some opposition is encountered from environmentalists. Their opposition stems from a dislike of electric space conditioning as being inappropriate from a source of high grade heat which is possible from electricity use. They are further piqued with low off-peak storage rates which they feel will be competitive with natural gas and oil heating and a hindrance to an accelerated development of solar space conditioning and water heating.

Natural gas prices for residential and commercial use will however be kept artificially low by incremental pricing provisions of the Natural Gas Policy Act. Further, since our dependence on foreign oil is almost 50%, if any oil heating is backed out by TES so be it as long as the TES customer is paying the full marginal cost for his use. Solar development is less constrained by competing with the life cycle costs of alternate energy systems as it is with the fact that its costs are largely front end loaded. When energy alternatives and the economy are perceived as risky, requiring low payback periods of five years or less, solar development will be enhanced by financing and tax credit schemes that reduce up front costs. Nevertheless, I expect some environmentalist groups in this regard to be active on the regulatory scene over the next few years. Rulemaking arising from the Public Utility Regulatory Policies Act of 1978 (PURPA) has by contrast provided a valuable basis for intervenors interested in TES applications. Rulemaking on Section 133 of the Act now requires that not only data but also the calculation of marginal costs is to be made for about 150 major utilities in the country.

If individuals or organizations wish to be heard regarding TES applications, it may be wise to band together in a national organization for TES that will provide a member with pooled information and an expert witness for intervention in local rate cases.

In all instances where such information results in a diurnal variation of rates as in time-of-day rates for large commercial and industrial customers, TES may become advantageous along with other load shedding and shifting systems. Nevertheless, the bulk of TES applications will probably continue to take place in the residential market. Here my expectation is that time-of-day (TOD) rates will not be adopted for some years yet even though TOD meter attachments are now less expensive than the price of a second meter and a time clock required to retrofit controlled water heating. The reason for hesitance belies a cautious attitude by regulators toward an across the board change in tariff structures affecting the bulk of the electorate.

What is taking place, is the development of special rates that may or may not be limited to TES. Such rates will by their nature tend to diminish the potential for TES commercialization. The rate may be as low as the marginal off-peak running costs of generation. Rulemakers and regulators that use embedded cost bases will often load other costs on this "off-peak scheduled power" rate. In the past a "split the difference" in the savings attitude was reflected in some scheduled power rates splitting the difference between the off-peak running costs and the fully-distributed-cost regular rate. By charging the customer more than the costs[1] that the customer imposed on the thermal-electric system, the viability of TES was reduced. In other cases incremental customer metering costs for storage cooling have been added to the off-peak kWh rate rather than being collected separately. This results in overcollections of large TES applications.

Even when charges above marginal running costs are eliminated in the rate, a strong bias against TES will remain. Since the TES customer's alternative to the special rate is the currently subsidized non-time-differentiated flat, or even worse, declining block rate, the rate differential between the TES rate and the standard rate will be less than the peak-hour marginal costs:

Mandatory TOD Rates

| Peak Hours | Off-Peak | Differential |
|---|---|---|
| 6.25¢/kWh | 2.00¢/kWh | 4.25¢/kWh |

Voluntary TES Rates

| Standard Rate | TES Rate | Differential |
|---|---|---|
| 4.10¢/kWh | 2.0¢/kWh | 2.10¢/kWh |

The lower differential without mandatory TOD rates can therefore significantly diminish the TES potential. About all that can be said for the voluntary rate is that an intervenor does not have to convince the regulator to adopt TOD rates for all or a large number of residential customers. There may be one other advantage to having a storage rate that is separate from a TOD rate. In the example above, we may assume that the TOD rate has twelve on-peak hours and twelve off-peak hours. The off-peak hour rate represents an averaging of the marginal energy costs which vary hour by hour during that period. Some TES equipment is compatible with a six hour rate. By choosing the six lowest cost hours of the diurnal period, we may have derived a cost of say 1.5¢/kWh for TES. While this will help[2] to increase the TES potential with voluntary (and mandatory) rates, having mandatory rates in place would be better.

The question arises if anything can be done to structure the standard residential tariff so as to induce the customer to accept a voluntary TOD tariff. Obviously if most of his usage is currently on peak (and shifts or reductions in use incur costs or a loss in consumer surplus) he is not likely to seek out a rate that requires him to pay 2.15¢/kWh more as in our example.

One way around this problem is to design an inverted rate as the standard rate. The end block would be at 6.25¢/kWh in our example, the middle block say 4.3¢ (more than the flat rate of 4.1¢) and the first block of relatively inelastic lighting load at 3.5¢ in order to avoid excess revenues. A tariff similar to this design is presently being filed by my staff in Wisconsin for Docket #6690-UR-10. We also have preliminary empirical evidence that shows that large residential customers consume proportionately more on-peak electricity than smaller customers.

I believe that inverted rate structures (with voluntary TOD rates) will be more readily accepted by cautious regulators than mandatory TOD rates for the bulk of residential customers who would benefit from TES.

Let us now examine the regulatory climate for TES for customers that face a demand charge. With few exceptions, I see gloomy prospects for several years even if mandatory TOD rates were accepted. The reasons go beyond the issues debated in discussions over peak load and marginal cost pricing. Since the appropriateness of the demand charge itself is in question, few regulators will accept such an innovation without lengthy reprieves.

The exceptions to this prospect are customers that have only a small lighting load that lends itself to a conventional existing rate schedule and a potential TES load that will require no backup or standby power. Such customers will benefit from standard rates with relatively high demand charges since this will increase the peak to off-peak rate differential and hence the expected savings with TES.

Other customers, who would retain a significant motor or process load or who require standby power, will find that current demand billing practices penalize the TES load shift. Arbirtrary grouping of customers, the fifteen or thirty minute time intervals of demand, noncoincidental demand billing and demand ratchets, are a few of many reasons why the demand charge is similar in impact to a declining block rate.

A customer considering TES would, in his benefit/cost calculation, have to consider the peak to off-peak rate differential, plus the added cost per KWh for his remaining load on-peak. For a long time I wondered why large concerns with significant opportunities for load shifting were reluctant to intervene on behalf of TOD pricing. The answer of course is that unless reform is also brought to the present manner of demand billing, the customer is penalized in his cost per KWH for remaining on-peak consumption.

The KWH charge is intended as a rationing device to limit the demand for KWh's to the available supply. Several of the billing practices such as use of non-coincident demand do not ensure that even this rationing function is carried out well. The scope of this paper does not allow me to go into detail on the problems with the demand charge. Suffice it to say that in most instances the time interval of demand should be expanded to equal the peak rating period in order to provide only a kWh charge during peak periods. The peak to off-peak rate differentials would be similar in magnitude to those for residential customers. Any remaining need to ration KWh's is relegated to other instrument variables. Those interested in a full exposition of this concept will find it in the above referenced docket. It is safe to say that I do not expect these reforms which would favor TES to take place overnight.

Research by the Department of Energy shows that many standby rates penalize potential cogenerators and solar users even more with unduly high demand charges. Any TES facility requiring backup will face a similar situation. Here some hope is in sight. DOE staff proposals for rules for Section 210 of PURPA would require utilities to remove many of the obvious demand charge penalties. President Carter, during the unveiling of his solar program in June of 1979, also directed that utility reform be carried out in order to remove standby charge penalties from solar customers. Nevertheless, we may not expect with current directions to see these reforms from placing standby power customers on a footing close to that of firm customers. This would still leave . place the disincentives to load shifting that remain with firm demand billing. While cost based standby rates for cogenerators are rare, one exception is a recent rate introduced by Pacific Gas and Electric; there is no demand charge penalty. This in and of itself is not proof that California favors TES; it does indicate a generally progressive approach.

Several utility controlled direct load managenent projects are underway in Wisconsin. The 11-hour controlled water heating rate Rw-3 at Wisconsin Power and Light charges 2.05¢/kWh (the standard rate is 5.08¢/kWh). Of the 4,600 customers in this rate several use hot water space heating. The utility believes that possible increased distribution costs (if rapid charging of TES is involved) should be reflected in the TES rate. By comparison, their TOD tariff for renewable resource electrical backup has an off-peak rate of 1.5¢/kWh. If controlled water heating customers were increased to 40,000,the utility would have practically flat load curve.

At the latest count,[3] there are over 58 utilities with TES suitable controlled water heater rates. Only 13 appear to have a controlled space heating rate. Pratically all peak load pricing TES applications are therefore in the residential market. This market will likely grow by several orders of magnitude but for reasons indicated earlier be limited by low rate differentials to low cost TES technology. Its growth is also assured by the preference of many state regulators for direct utility controlled or contracted load management over a broad scale application of TOD rates. This failing will probably hinder the application of the more desirable residential-commercial applications of TES. Larger rate differentials with mandatory TOD pricing, or inverted standard rates with optional TOD rates would, with the higher potential savings, stimulate higher technology TES. The market referred to is the development of residential-commercial storage cooling. A recent study[4] using ice as a storage medium indicates a 15 year payback with a storage rate and a standard flat rate alternative. Such long paybacks are unacceptable to residential customers. If regulators respond to the remedies suggested, the payback for storage cooling may be brought into an acceptable range.

In conclusion, marginal cost based pricing and peak load pricing will, along with direct load management rates, greatly enhance the market for TES. The prognosis for widespread applications is poor for the present due to needed regulatory reform that will take time to accomplish. The adoption of mandatory TOD rates or optional TOD rates with inverted standard rates could greatly increase the potential especially for space cooling and higher technology efficient space heating. All applications could benefit from a national TES association able to provide expert witnesses for rate case interventions.

1 Assuming that in most instances use of relative Loss of Load Probability estimates (Loss of Energy Probabilty is preferable) have identified marginal capacity costs as being incurred by peak and shoulder peak rating periods only. Where this is not the case, notably with systems where hydraulic capacity is at the margin, very low peak to off-peak cost differentials will eliminate the potential for electric TES.

2 TES rate stability is improved as well since other utility load management efforts will probably over the years fill in shoulder periods necessitating some expansion of the number of hours in the peak period.

3 Derived from Table V-A, "Technical Institutional and Economic Analysis of Alternative Electric Rate Designs and Related Regulatory Issues in Support of DOE Utility Conservation Programs and Policy," D.O.E. Economic Regulatory Administration, May 1979.

4 "Residential Off-Peak Storge Cooling and the Summer Peaking Utility," Joseph C. Schuh, *Public Utilities Fortnightly*, April 26, 1979.

# COMMERCIALIZATION OF ELECTRIC STORAGE HEATING

by

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## I Introduction

Time-of-Use (TOU) and time-of-day (TOD) rates of several different types are now being offered to residential and commercial customers by a rapidly growing number of electric utilities across the country. According to the results of an Edison Electric Institute survey, utilities in 32 states have TOU rates in effect or filed with their respective utility commissions. TOU rates represent a significant change in electricity pricing and will have an important effect on how future utility customers use electricity. This paper presents the views and experience of a manufacturer of electric storage heating and load control systems who has been designing, manufacturing, and marketing storage heating equipment for use under TOU rates since these rates were first offered by a major utility in 1974.

Most of the recent Federally-funded experiments on customer responses to TOU rates look more at thermal storage hardware than at all the possible uses of the rates. Future experiments should allow a residential customer, for example, the full range of options for using electricity on a time-of-use basis including washing off-peak, storage heating, off-peak hot water, cycled air conditioning, and other deferrable loads. For successful commercialization, the entire range of uses of TOU rates must be considered, not just thermal energy storage. Our experience has been that both residential and commercial customers can respond positively to TOU rates. What is needed is education of the public and utilities as to what can be done with various rates. At this time, public awareness of TOU rates is nearly zero.

## II Manufacturer's View

A company marketing electric storage heating and load control devices such as demand limiters and devices made to control a whole host of residential and commercial customer loads sees TOU rates in a different light than both government and the electric utility. We see a number of different rates in different climates with a number of different metering and use provisions, and virtually no customer awareness of the rates and TES hardware. For example, a manufacturer looking at the potential market for electric storage heating and controls sees:

1) Off-peak periods as short as six hours per day and as long as 17 hours per day.
2) Off-peak rates offered on weekends by some utilities. Other utilities offer off-peak rates seven days a week.
3) A few utilities are load specific, requiring hot water and space heating on separate meters with off-peak contract rates. Most utilities do not make their TOU rates load specific and allow all types of off-peak use during off-peak hours.
4) Several Eastern utilities have mandatory TOU rates. Most TOU rates are optional.
5) Off-peak, on-peak rate differentials vary from utility to utility by as much as 5¢ per kWH to as little as 1¢ per kWH.
6) Public awareness of the availability of the TOU rate is nearly zero in most utility service areas. Public awareness of storage hardware is almost nonexistent except in markets where we have been active for several years.
7) Electric utility knowledge and support of customer-side-of-the-meter TES systems varies widely. Some utilities have no in-depth technical knowledge of

TES systems and discourage the use of their own TOU rates and TES systems. Others are highly enthusiastic and support TES systems and TOU rates.

8) The electric industry (electrical contractors, engineers, and HVAC) has had no reason to pay much attention to electric rate structures until now and, therefore, they have little appreciation for TOU rates and the TES systems that go with them.

Control Electric Corporation has a marketing program underway to deal with some of these problems. Until now there have been only three or four companies actively marketing TES equipment, none of whom have the resources to promote and market TES systems on the scale necessary to make an impact on America's use of electric energy during the next decade. Certain local markets have a measurable amount of storage heating installed now, but they are very small compared with the country as a whole.

## III Market Entry Criteria

In evaluating a market for TES equipment, we believe it is essential that the additional capital cost of the storage and control equipment be paid back in electricity cost savings in five years or less. This usually means a minimum rate differential of 2:1 between the optional TOU rate (including fuel adjustment and extra metering charges) and the regular rate. A mandatory TOU rate with a differential of 1.5:1 would probably be sufficient. The off-peak rate should also be approximately equal to or less than the prevailing price of oil or gas. Even a payback of less than five years and all other market entry criteria being met is no guarantee that off-peak electricity and TES systems sell.

Since we are marketing a new concept in electricity usage, there is no accurate means for determining marketable storage and control equipment selling prices except comparing TES systems against conventional heating systems. Storage and control equipment prices vary between $90 per KW to $150 per KW, but suffice it to say that a rate differential of 2:1 with off-peak electricity competitive with competing fuels, will create a market, providing the peak charge or meter charge is not so high it negates any savings. For example, 10% on-peak consumption should not cost so much as to cancel out any savings with 90% off-peak consumption. Fortunately we have several system design options, particularly when we set aside the notion of 100% off-peak storage system as our only way of going to market and look at all the loads on the customer side of the meter, which means we can adjust the initial cost of the TES system and electricity cost savings to fit the rate. For example, control of *all* significant electrical loads in the home or business on a TOU basis means greater savings than if we just deal with the heating load.

Utility economists talk about elasticity of demand, but our market analysis boils down to five things:

1) What percentage of annual electric usage can we shift using the off-peak rate as it is offered?
2) At what hardware cost?
3) What is the annual savings to the customer?
4) What are prevailing market conditions?
5) What is our expected return on investment in the market?

We know how technologically to build a residential all-electric system that would use 100% off-peak electricity with almost any presently available off-peak rate. The hardware cost for such a system is now prohibitive. We now, for example, are achieving annual usage of 90% off-peak and 10% on-peak using the 12 hour daily off-peak period at competitive TES equipment prices offered by the Metropolitan Electric Company in Pennsylvania and with no significant change in consumer lifestyle. Once a consumer has accepted the TOU rate concept for his total energy usage, he needs and buys hardware. As a start for TES commercialization, the rate savings must be there, the utility must be supportive, and the prevailing market conditions must be acceptable for the manufacturer to make an investment in the market.

## IV Where are TES Systems Now?

Control Electric Corporation has the TES system and control hardware which can adapt to all known electric utility TOU rate forms. Control Electric Corporation has room storage heaters and central storage heaters in mixed and 100% storage applications operating now on time-of-day rates, demand rates, off peak demand rates, and local management contract rates. These TES systems are time, outside temperature, and demand controlled in a variety of applications such as: apartments, nursing homes, schools, office buildings, commercial establishments, condominiums, and homes, including passive solar homes. The systems operating now prove that TES systems work well in the United States under a wide variety of rates and applications. Recent tests by Massachusetts Electric Company of 80 TES heated aparments operating side by side with 50 identical conventionally electric heated apartments showed that TES used 15% less electric energy than conventional electric heat. We attribute this to the fact that TES systems provide more comfortable heating at lower room temperatures. Suffice it to say, we have finished the initial testing phase of TES systems, and are moving into the growth phase of the industry. even through our annual sales volume of TES systems is small, when compared with other similar American companies, the trend is clear. Until now we have intentionally focused our attention on markets on the Eastern seaboard because the TOU rates are better there, the utilities for the most part are supportive, and we have growing markets.

My company sees an exciting future for TES systems during the next 20 years. We see the business becoming as large, if not larger, here than TES business is in Europe. If home heating fuel prices continue to increase as they are now, the rebirth ofelectric heating is on the horizon and any rebirth of electric heating must now include TES systems because the TOU rates are available. In the East, electric energy is gaining favor as oil and gas prices rise. In some states, Maine for example, oil is being priced out of the new heating market and gas is not widely available. Electric heat is the only real alternative except for supplemental wood heat. Solar heating is not now commercially competitive on a wide scale. The choice now for new construction is on-peak or off-peak electric heating. Since Central Maine Power has a TOU rate for residential customers in effect and a similar TOU rate for commercial customers on the drawing board, we see TES systems having a sizable future share of the new heating system market. Control Electric Corporation has spent considerable time and money in Maine working with the utility, Maine customers, and Argonne National Laboratory helping the market get started. No matter how much time and money is spent, it takes several years to get the market started even with favorable TOU rates. In some of our market areas electric heat of any sort has had a bad name in spite of available domestic sources of electricity: nuclear, hydro, or coal. Overcoming these obstacles is one marketing problem Control Electric Corporation must deal with every day.

## V What Is Needed For Commercialization?

The frustrating problem for a TES heating system manufacturer these days is to hear and read all the promises made by government that our future heating problems can be solved using solar energy. A businessman selling in today's market, where regulated natural gas is not widely available, is facing a confused situation. He sees oil at 90¢ per gallon and going up, electric heat with a bad name, knows that solar systems are not being purchased on a competitive basis on a wide scale, and that wood heat is more attractive than ever imagined. What is happening in these areas is that the electricity is rapidly becoming the only available long-term home heating system. In my opinion, it is time we faced up to the fact that electricity is our most important, universal long-term means for converting available domestic energy and delivering it to homes and businesses in America. Our experience marketing TES systems has shown very clearly that electric utilities, particularly their customer service representatives who deal with the public every day, need help in understanding TES system applications using their own TOU rates now in effect.

All the notions about electric utility rate structures and their use by both residential and commerical customers, given the spectrum of TES systems available, should be made better known. We have demonstrated that TES systems and control technology can adapt to any electric utility rate structure with a positive effect on both the end user and the utility. Rates supposedly reflect electric utility marginal costs. By the time rates are approved, however, utility costs have changed. TES technology can effectively adapt to changing utility costs. If demand rates more nearly reflect utility costs than conventional residential rates, then demand rates should be offered. We are now marketing inexpensive demand controllers coupled with TES systems that can handle residential demand rates.

The single most important initiative that can be taken to further the commercialization of the TES systems in all their configurations is for government to give the same attention to thermal energy storage that it has given to solar, wind, and other alternative energy systems. A more widespread public commitment accompanied by various electric industry education and demonstration programs is required if TES systems commercialization is to be accelerated. The adoption of TES systems will take place without government help because TES market economics exist where most TOU rates exist, but it will take years longer. The Argonne National Laboratory program in Maine has shown conclusively that demonstration and education programs do speed commercialization. I'm certain Argonne's program shortened TES system adoption in Maine by at least two years.

It is my opinion that United States dependency on foreign oil can be reduced faster with widespread adoption of the TES systems and TOU rates than with solar systems, particularly in view of the current oil heating situation and the effort utilities are making to reduce use of oil-fired peaking facilities.