LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES

3 4456 0510978 0

ORNL-5796

ornl

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

Utility-Controlled Customer-Side Thermal Energy Storage Tests: Heat Storage

D. T. Rizy

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.
UCN-7969 (3 9-77)

POWER SYSTEMS TECHNOLOGY PROGRAM

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05 Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL-5796
Dist. Category UC-97b

Contract No. W-7405-eng-26

ENERGY DIVISION

UTILITY-CONTROLLED CUSTOMER-SIDE THERMAL ENERGY STORAGE TESTS: HEAT STORAGE

D. T. Rizy

Date Published: February 1982

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES
3 4456 0510978 0

ACKNOWLEDGMENTS

The utility-controlled customer-side thermal energy storage tests discussed in this report are part of the U.S. Department of Energy (DOE) nationwide program for the research, development, and demonstration of electric utility load management. The tests, which used residential heat storage, were conducted by five electric utilities under contract to Oak Ridge National Laboratory (ORNL). This subcontract arrangement was made possible by the support, assistance, and direction provided by David L. Mohre, Phillip N. Overholt, and J. Charles Smith of DOE's Division of Electric Energy Systems and Joseph R. Gracia of DOE's Oak Ridge Operations Office.

The electric utility program managers who were responsible for conducting the tests for the five participating utilities are: Jack Kinirons of Long Island Lighting Company; Mike Cahill, Ruth Bebko, and Bob Maraio of Niagara Mohawk Power Corporation; Clark Gellings of Public Service Electric & Gas; Vance Zehringer of United Power Association; and John Lobdell of Virginia Electric and Power Company.

The technical managers who were responsible for managing the utility tests for ORNL included: P. Randy Barnes, John W. Klein, Hugh M. Long, D. Tom Rizy, and John P. Stovall. The guidance provided by Hugh Long, former group leader of the ORNL Electric Energy Systems, and Thomas W. Reddoch, manager of the Power Systems Technology Program, is also acknowledged.

The support and guidance of the utility industry working group in planning and reviewing the utility demonstrations are acknowledged. Organizations and individuals who have represented these organizations are:

American Public Power Association (APPA) — Eric Leber and Alex Radin;

Association of Edison Illuminating Companies (AEIC) — Robert E. Ashburn;

DOE, Economic Regulatory Administration (ERA) — Howard Perry;

DOE, Division of Energy Storage Systems (ESS) — George Pezdirtz;

Edison Electric Institute (EEI) — Paul Greiner, Mike McGrath, and Dorman Miller;

Electric Power Research Institute (EPRI) — Eldon Ehlers, Quentin Looney, Robert Malko, Robert Mauro, and Orin Zimmerman;

Midwest Utilities Group Seminar (MUGS) — John H. McLean;

National Association of Regulatory Utility Commissioners (NARUC) — Parker D. Mathusa, David Stricos, and Andrew Tokmakoff;

National Rural Electric Cooperative Association (NRECA) — Lowell Endahl;

Pacific Coast Electrical Association (PCEA) — J. T. DeYoung and Earle Knowles;

Rural Electrification Administration (REA) — Thomas McDonald and Robert Stukey.

Finally, thanks are due Suzie Newberry for typing the draft manuscript and the individuals in the Technical Publications Department responsible for editing the draft report and getting the report ready for publication.

CONTENTS

	Page
ACKNOWLEDGMENTS	iii
LIST OF FIGURES	vi
LIST OF TABLES	vii
ABSTRACT	1
1. INTRODUCTION	2
1.1 Load Management by Customer-Side Storage	2
1.2 DOE/ORNL Test Program	4
1.3 Summaries of Utility Tests	6
2. TEST DESCRIPTIONS	13
2.1 Utility Participants System Characteristics	13
2.2 Heat Storage Systems	16
2.3 Utility Control of Storage Systems	27
2.4 Data Collection	29
3. CUSTOMER SELECTION	33
3.1 Selection Procedure	33
3.2 Customer Incentives	36
3.3 Problems with Customer Selection and Incentives	38
4. EQUIPMENT INSTALLATION	40
4.1 Equipment Delivery	40
4.2 Installation Experience	42
4.3 Test Costs	47
5. EQUIPMENT CHECKOUT AND OPERATION	51
5.1 Heat Storage Equipment Performance	51
5.2 Storage Equipment Modifications	56
5.3 Communication and Control Experience	59
5.4 Instrumentation Equipment Experience	63
6. CUSTOMER ACCEPTANCE	66
7. COMMERCIALIZATION OF HEAT STORAGE SYSTEMS FOR USE IN LOAD MANAGEMENT	69
7.1 Reliability of Storage Equipment	69
7.2 Economics of Storage Equipment	70
7.3 Controllability of Storage Systems for Load Management	71
7.4 Commercialization Potential	71
8. CONCLUSIONS	73
BIBLIOGRAPHY	75

LIST OF FIGURES

Figure		Page
1	Location of utilities conducting tests showing number of Fahrenheit heating degree-days	8
2	NMPC test site	11
3	Central ceramic brick storage (TPI)	18
4	TPI load-leveling control	19
5	Concrete slab storage	21
6	Model 50 SQ heat pump with storage	23
7	Pressurized hot water storage	24
8	VEPCO storage system	26

LIST OF TABLES

Table		Page
1	Summary of heat storage tests	9
2	Geographic, climatic, and utility load information on participating utilities	14
3	Participating utility system characteristics	15
4	Test data parameters	31
5	Customer selection information	34
6	Cost of test installations in residential homes	48
7	Cost of NMPC test installations	49

UTILITY-CONTROLLED CUSTOMER-SIDE THERMAL ENERGY STORAGE TESTS: HEAT STORAGE*

D. T. Rizy

ABSTRACT

Customer-side thermal energy storage has been identified as a load-management option available to the electric utility industry. However, the uncertainty of costs and benefits to the utility and the customer has prolonged its implementation. The tests described in this report are part of the U.S. Department of Energy (DOE) national program for the research, development, and demonstration of electric load management using utility-controlled customer-side thermal energy storage for residential load management. The demonstrations were sponsored by DOE's Division of Electric Energy Systems and conducted by utilities under contract to Oak Ridge National Laboratory.

The five heat storage tests described in this report and the five cool storage tests described in a companion report were conducted to (1) collect reliable load-research data, (2) delineate and solve installation problems, (3) establish maintainability, (4) determine customer and utility acceptance, and (5) generate cost data to determine the potential of utility-controlled customer-side storage as a load-management option. The results are expected to assist the utility industry in making local load-management decisions and to assist DOE in establishing research and development priorities in load management.

This report discusses (1) the five heat storage tests conducted by five utilities and (2) the utilities' experiences in the tests from contract start through equipment installation, checkout, and operation. Experiences of the utilities conducting the cool storage tests are discussed in a companion report. Subsequent reports will discuss results of data collection during the 1980-1981 heating season for four of the utilities, data collection for the fifth utility during the 1981-1982 heating season, and potential utility system impacts of using a significant penetration of utility-controlled customer-side storage systems for load management.

The five utilities involved in the tests are Long Island Lighting Company, Niagara Mohawk Power Corporation, Public

*Research sponsored by the Division of Electric Energy Systems, U.S. Department of Energy under Contract No. W-7405-eng-26, with the Union Carbide Corporation.

Service Electric & Gas, United Power Association, and Virginia Electric and Power Company. All the utilities tested the storage systems in the 1980-1981 heating season except Niagara Mohawk Power Corporation. Because of continued equipment problems, they will not test equipment until the 1981-1982 heating season. The utilities tested four types of heat storage systems: (1) central ceramic brick, (2) concrete slab, (3) heat pump with storage, and (4) pressurized hot water storage.

Results of installing and operating the storage systems indicate that (1) these residential heat storage systems are not fully commercial in their present state for use as a load-management option and (2) the technology requires further development. Also, the numerous operational problems experienced by the utilities and high costs of installing and maintaining the storage equipment resulted in poor acceptance of the technology by the utilities and customers.

1. INTRODUCTION

1.1 Load Management by Customer-Side Storage

Historically, electric utilities have supplied electric energy on demand from the customer. This demand varies with the time of day and is greatest during daytime periods, or peak demand periods, and lowest during nighttime periods, or off-peak periods. This pattern of electric energy demand is principally caused by the greater daytime activities in commerce and industry and the greater requirement for space conditioning by residential, commercial, industrial, and municipal customers during the day. This fluctuating pattern of energy use places a heavy burden on the electric utility's energy delivery system because, at the present time, electricity cannot be stored conveniently and must be produced directly in response to demand. To meet this demand during peak periods, most electric utilities supply electric energy known as peak generation using hydroelectric plants and inefficient gas- or oil-fired units. During off-peak demand periods, utilities supply electric energy known as base generation with more efficient oil-fired, coal-fired, and nuclear generating plants. In the past, utilities have easily financed and built new generating plants

to meet the growing peak demand for electric energy; however, less abundant and more expensive fuels such as oil and gas, stricter utility industry regulations, less favorable financial conditions, and legislative requirements such as the Public Utility Regulatory Policies Act (PURPA) have changed the electric utility industry's philosophy about meeting customer's electric demand. As a result of all these factors, utilities are now motivated to look at means to tailor their electric energy demand to match energy supply in order to delay financing and building new base generating facilities and to reduce the need for peak generation.

Load management is a method to alter or reshape the electric utility load vs time, either directly or indirectly by the utility. The purpose of load management is to reduce peak demands to level the daily or annual electric demand. This leveling of electric demand can reduce the need for peak generation and delay a utility's requirements for additional generation, transmission, and distribution investments. In addition, load management can improve the efficiency, load factor, and production costs of a utility; shift electric power production from scarce fuels such as oil and natural gas to more abundant domestic fuels such as coal and uranium; and lower the utility's reserve requirements.

Load management can be separated into two categories: supply management and use management. Supply management refers to the management of the bulk energy supply on the utility side of the customer's electric meter. It involves using utility-owned facilities, such as interconnections and pumped hydro, to modify the apparent load as seen by the utility's central generation without affecting customers' loads. Use management refers to the management of the electric customer's energy usage patterns. Alternatives for use management include direct control of customer loads, voluntary or indirect control of customer loads, interruptible rates, and customer-side thermal energy storage. Direct control of customer loads has been implemented by utilities in cycling air conditioners, water heaters, and other appliances. Indirect control of loads has been experimented with and implemented by various forms of electricity pricing and rate structures designed to encourage

customers to change usage patterns. Customer-side thermal energy storage has not been widely applied in the United States because substantial costs are incurred in initiating such a program and it is unclear that the benefits outweigh the cost.

Customer-side thermal energy storage offers a means for the utilities to tailor the electric demand of customers to electric delivery systems while allowing the customer to utilize electric energy without changing life-style. Also, savings can occur for the customer with the storage systems because it provides a means of storing the electric energy in the end-use energy form, such as heat, which can be charged with off-peak electric energy from the utility's most efficient base generation plants. However, the utility's rate structure must be designed to reflect the cheaper cost of providing electric energy during off-peak period for the customers to benefit. By charging the storage systems with off-peak energy, the utility also benefits because the peak electric demand is reduced and thus the fuel mix for electric energy generation is shifted away from less abundant fuels such as gas and oil toward more abundant domestic fuels such as coal and uranium.

1.2 DOE/ORNL Test Program

In an effort to answer the technological and economic questions surrounding the use of customer-side thermal energy storage for load management, the U.S. Department of Energy (DOE), Division of Electric Energy Systems (EES), embarked on a national test program. The objective of the program was to test the feasibility of promising near-commercial customer-side thermal energy storage in sufficient quantity to (1) collect reliable research data for assessing the impact on the utility systems, (2) delineate and solve storage equipment installation problems, (3) establish maintainability of storage equipment, (4) determine customer and utility acceptance of residential load management, and (5) generate installation and operating cost data. Results of the test are expected to assist utilities in making local load-management decisions, assist DOE in establishing priorities for research and

development efforts in load management, and provide objective information related to the electric system impact, energy conservation, and cost effectiveness of this form of load management.

The test program was planned to involve several utilities because of significant differences in the shape and composition of load curves among utilities, as well as geographical variations such as capacity requirements, fuel mix, and electric rates. Oak Ridge National Laboratory (ORNL) planned to carry out the tests by contracting with each utility; each utility would then be responsible (with ORNL approval) for (1) planning its test; (2) selecting, purchasing, installing, checking out, and maintaining all test equipment; (3) providing a communication and control system to operate the storage systems for various control strategies; (4) collecting data; (5) analyzing the data; and (6) presenting the results in a final report.

The utility tests were limited to near-commercial, residential-sized heating or cooling or mixed (heat and cool) storage devices for space conditioning with optional addition of domestic water heating. Hybrid storage systems involving nonelectric supply (such as solar energy with supplemental heating) were specified as being outside the scope of the test to avoid increased complexities with these proposed systems. Each test was to consist of from 30 to 50 storage units of the same design and manufacturer. This range of test size was a compromise between the limited funding and the acceptable sample size for obtaining reliable load-research information. The candidate storage systems were selected by the utilities on the basis of greatest potential for economic effectiveness and customer acceptance and of suitability for the new or retrofit home market.

Instrumentation was required to collect the load-research data and storage device performance data. Both the test homes containing the storage devices and a comparison group of control homes with conventional space conditioning systems were instrumented. The research data included at least the total house energy use, conventional space conditioning system energy use, storage device energy use, and indoor temperature. These data are to be used to determine the system impact of this

type of load-management technology on each utility system. Also, a limited number of test installations were heavily instrumented to collect device-specific data for evaluating the storage device performance.

A communication and control system was required for each of the utility tests to control the operation of the storage devices. This type of active control was necessary because one of the desired outputs from the tests was a measure of the effectiveness of various control strategies on system reliability and cost. This method allowed the implementation of several control strategies, such as fixed-time-of-day control, direct control based on the cost of energy production, and control based on weather conditions.

All the tests were originally planned for two space conditioning seasons to cover a wide range of weather conditions. However, delays in equipment installations, operational problems with the storage equipment, and problems with the performance of the communication systems reduced some tests to one season or less of operation.

1.3 Summaries of Utility Tests

In September 1977, letters requesting expression of interest and outlining the test program were mailed to the Electric Power Research Institute (EPRI) and 77 utilities identified in a survey as having completed, ongoing, or planned projects in customer-side thermal energy storage or having indicated interest in starting such a program. The survey was conducted by Energy Utilization Systems, Inc. (EUS), a consultant for the EES group at ORNL. In November 1977, a request for proposal, RFP No. ELM-01 titled "Demonstration of Electric Load Management by Controlled Customer-Side Energy Storage," was mailed to the 64 utilities that responded to the September letter. By January 1978, 12 utilities had submitted proposals for a total of 16 heat and cool storage projects. The evaluation committee for the RFP recommended 10 of these 16 projects for cofunding by DOE. Seven utilities were selected to participate on a cost-shared basis. The utilities included Arkansas Power and Light Company, Long Island Lighting Company, Pacific Gas and

Electric Company, Public Service Electric & Gas Company, United Power Association, Virginia Electric and Power Company, and Wisconsin Electric Power Company. They conducted four heat storage and five cool storage tests (two utilities are employing both heat and cool storage). A fifth heat storage test to be conducted by Niagara Mohawk Power Corporation involving multioccupant buildings was selected separate from this RFP to be cofunded by DOE, EPRI, New York State Energy Research and Development Authority (NYSERDA), and New York State Department of Public Service (Public Service Commission).

This report describes the five heat storage tests, and a companion report discusses the five cool storage tests. The tests are summarized from contract start (May 1978 at the earliest and December 1978 at the latest) through installation, checkout, and operation of the test equipment. A subsequent report will discuss the data that were collected by the five utilities during the winter of 1980-1981 and the potential utility system impacts of this type of load management.

The five utilities that conducted the five heat storage tests (Fig. 1) are Long Island Lighting Company (LILCO), Niagara Mohawk Power Corporation (NMPC), Public Service Electric & Gas Company (PSE&G), United Power Association(UPA), and Virginia Electric and Power Company (VEPCO). Table 1 gives a summary of the five tests as originally planned and shows the actual number of test homes used in each test. The number of test and control homes in each test was reduced because of installation and operation problems with the test equipment. These problems are discussed later in the text. A more detailed description of each test as originally planned follows.

1.3.1 Long Island Lighting Company (LILCO)

Heat storage was tested in 50 test homes using Megatherm pressurized hot water tanks retrofitted to existing oil-fired hydronic heating systems. The control group consisted of 35 homes with conventional electric-resistance baseboard heating systems. Data were collected on magnetic tape recorders, while the storage systems were controlled by a Scientific Atlanta radio communication system from the LILCO central load-management project office.

ORNL-DWG 79-11279R

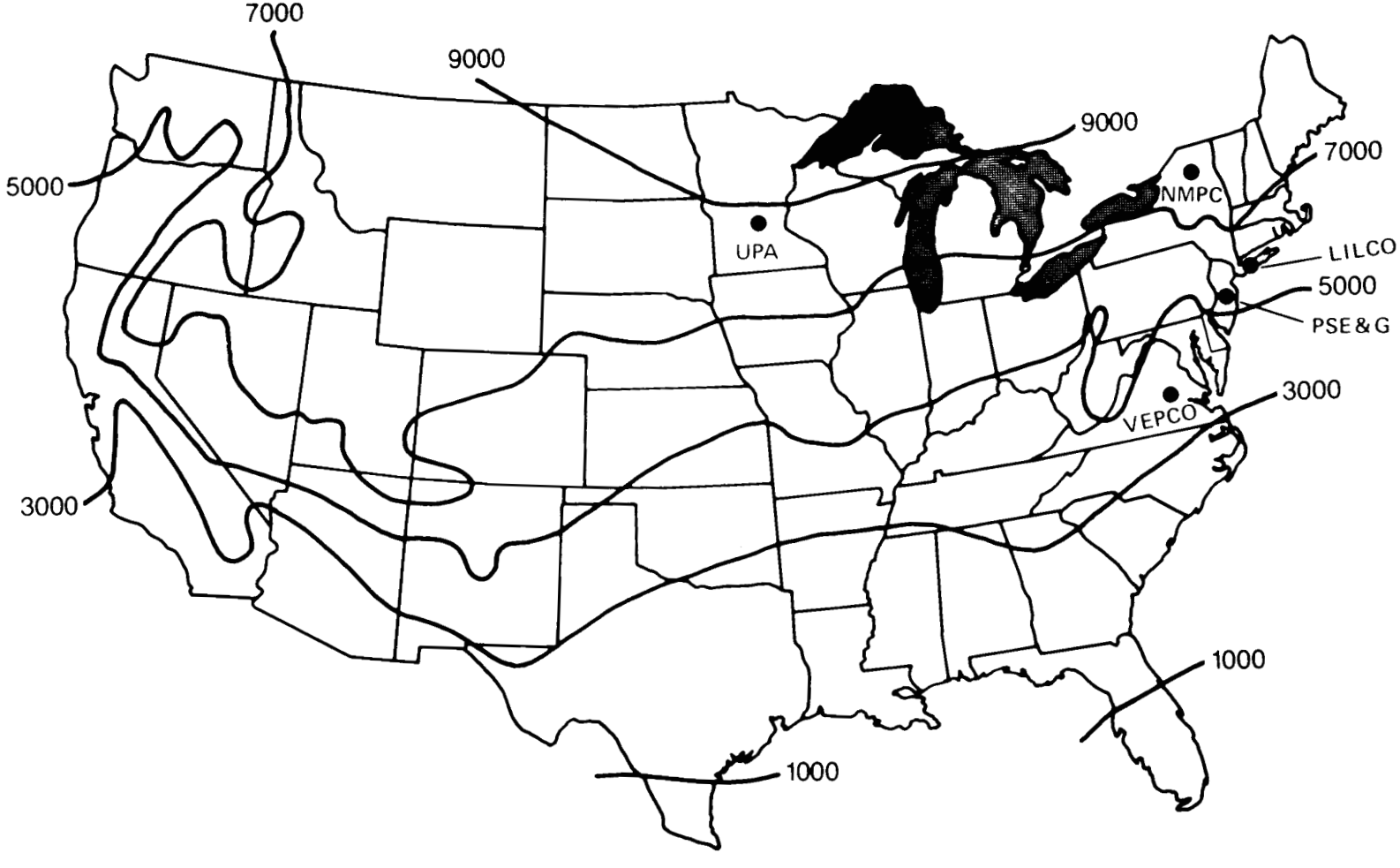


Fig. 1. Location of utilities conducting tests showing number of heating Fahrenheit degree-days.

Table 1. Summary of heat storage tests

Utility	Storage system (manufacturer)	Number of tests (planned/actual)	Number of controls (planned/actual)	Communication and control (manufacturer)
LILCO	Pressurized hot water (Megatherm)	50/30[a]	35/30	Radio (Motorola and Scientific Atlanta)
NMPC	Ceramic brick (AEG)	1[b]	1	Leased telephone
	Pressurized hot water (Megatherm)	1[b]	[c]	Leased telephone
	Heat pump with storage (Carrier)	1[b]	[c]	Leased telephone
	Concrete slab (Peak Supervision)	1[b]	[c]	Leased telephone
PSE&G	Ceramic brick (TPI)[d]	30[a]	30	Telephone (Darcom)
UPA	Ceramic brick (TPI)[d]	35/22[e] + 13[a]	35/32	Radio (Scientific-Atlanta)
VEPCO	Pressurized hot water (Megatherm)[d]	40/34[e]	40/31	Leased telephone

[a]Retrofit installations in existing homes.

[b]Retrofit installations after construction on building had started.

[c]One building with conventional central electric space heating used as control for all four NMPC test installations.

[d]Domestic hot water storage also used in test.

[e]Installations in new homes.

1.3.2 Niagara Mohawk Power Corporation (NMPC)

Heat storage was tested in four dormitory-style buildings (Fig. 2). Each building had multiple storage units of the same generic type and manufacturer, with each unit approximately the size for a single-family residence. The heat storage systems were eight AEG ceramic brick units (building F), eight Megatherm pressurized hot water units (building G), four Carrier heat pumps with hot water storage (building H), and four concrete slab storage heating systems (building E). A fifth dormitory, building J, with electric resistance forced-air heat was the control building. Data acquisition and control of the storage systems were through a leased telephone line.

This test did not involve single-family residential homes like the other tests but involved multioccupant buildings located at the Raybrook Correctional Facility, formerly the dormitories for the athletes at the 1980 Winter Olympic Games. Also, the conventional electric space heating systems in the buildings were left in place for use after the test.

1.3.3 Public Service Electric & Gas Company (PSE&G)

Heat storage was tested in 30 test homes using Tennessee Plastics, Inc. (TPI), ceramic brick storage furnaces retrofitted in existing central forced-air systems. Storage domestic water heaters were installed in all test homes in place of existing electric water heaters. The control group consisted of 30 homes having conventional electric central furnace heating. All data were collected using magnetic tape recorders. Storage systems were controlled by a Darcom telephone communication system from PSE&G's load-management program office.

1.3.4 United Power Association (UPA)

Heat storage was tested in 35 test homes using TPI ceramic brick storage furnaces. The storage systems were installed in a mix of existing homes and new homes in the Anoka Electric Cooperative of Anoka, Minnesota, and the Wright-Hennepin Cooperative Electric Association of Maple Lake, Minnesota. A. O. Smith storage domestic water heaters were installed in all test homes. The control group consisted of 35 homes

ORNL-Photo 0747-80

ORNL-DWG 81-17516

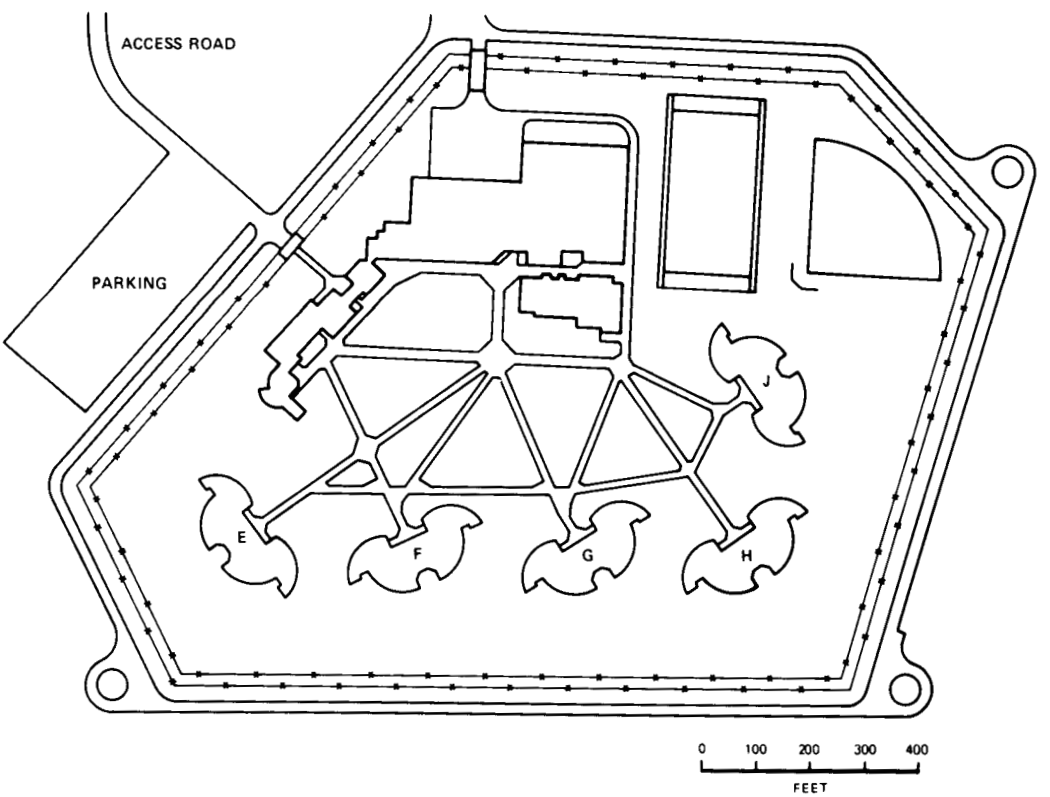


Fig. 2. NMPC test site.

having conventional electric forced-air central heat. Data were collected using magnetic tape recorders. Control of the storage systems was by Scientific Atlanta Radio from UPA's Elk River Energy Control Center.

1.3.5 Virginia Electric and Power Company (VEPCO)

Heat and cool storage were tested in 40 new homes using oversized heat pumps for space conditioning. The heat storage portion of this test used 40 Megatherm pressurized hot water tanks for storage. Storage domestic water heaters were installed in all the test homes, and heat for domestic hot water was reclaimed from the heat pump compressor. The control group consisted of 40 homes having conventional heat pumps. Data were collected using magnetic tape recorders. Storage control and limited data acquisition were through leased telephone lines to groups of five test homes.

2. TEST DESCRIPTIONS

2.1 Utility Participants System Characteristics

The five utilities selected to participate in the heat storage tests cover a range of geographic, demographic, climatic, and system characteristics. All these factors are important in determining the feasibility of using customer-side heat storage for load management. Also, these characteristics determine the benefits and acceptance of this type load management by the utility and customers. Table 2 gives the geographic, climatic, and load characteristics of the participating utilities. The generation, load factor, and peak load demands for each utility are summarized in Table 3.

Four utilities — LILCO, NMPC, PSE&G, and VEPCO — are investor-owned combination gas and electric utilities. UPA is a generation and transmission cooperative which provides wholesale power to 15 rural electric cooperatives that distribute power to consumers.

LILCO provides electric service to residential and commercial-industrial customers in a 3185-km^2 (1230-sq mile) area of Long Island, New York. Gas turbines, diesels, and some older oil-fired steam plants provide intermediate and peak generation requirements for LILCO at a high operating cost. Its residential class customers comprise the major portion of the winter peak.

NMPC has a service area that covers 62,159 km^2 (24,000 sq miles), or nearly 50% of the area of New York State. The service area includes a broad range of urban, suburban, and rural areas. NMPC has experienced a swing away from higher load factor industrial customers to a preponderance of residential and commercial loads.

PSE&G serves 77% of New Jersey's population located in a 3626-km^2 (1400-sq mile) highly industrialized and densely populated corridor between Philadelphia and New York City. As a result, PSE&G suffers from an annual load factor significantly below the utility industry average. In 1976, the residential class customers comprised 28% of PSE&G's electric energy sales.

Table 2. Geographic, climatic, and load information on participating utilities

Utility	Test site	Heating degree-days	Number of electric customers[a]		Average residential electricity[a]	
			Total	Residential	Use (kWh/year)	Rate (¢/kWh)
LILCO	Mineola, NY	4,700 to 5,400	909,848	822,819	6,964	6.2
NMPC	Raybrook, NY	6,500 to 8,500	1,321,733	1,189,013	6,777	3.95
PSE&G	Marlton, Edison, and Fanwood, NJ	5,000 to 6,000	1,666,742	1,468,924	5,378	6.6
UPA	Anoka and Maple Lake, MN	8,300 to 8,500	40,123 16,610	37,948 16,215	9,648 11,742	4.26 4.1
VEPCO	Richmond, VA	3,000 to 4,000	1,269,957	1,138,470	10,944	4.42

[a]1978 data.

Table 3. Participating utility system characteristics

Utility	Generation mix[a] (%)	Generation capability[a] (MW)	Annual load factor[b] (%)	Peak load[b] (MW)		Peak coincident residential electric heat load (MW)
				Summer	Winter	
LILCO	71 — oil 29 — gas turbines and diesels	3842	53	2997	2456	1206[c]
NMPC	30 — coal[b] 39 — oil 13 — hydro 13 — nuclear 5 — gas turbines	4762	71	5130	5485	*d*
PSE&G	57 — fossil fuel[e] 31 — gas turbines 10 — nuclear 2 — pumped hydro	9993	47	6615	4925	*d*
UPA	70 — coal 30 — oil	515[f]	57[f]	411[f]	451[f]	80[g]
VEPCO	75 — fossil fuel[e] 22 — nuclear 2 — hydro 1 — gas turbine	9912	58	7805	7401	*d*

[a]1979 data.

[b]1978 data.

[c]1975 data.

[d]Data not available.

[e]1976 data.

[f]1980 data.

[g]1977 data.

VEPCO serves residential and nonresidential customers in about an 83,000-km^2 (32,000-sq mile) area consisting of northeastern North Carolina, east-central West Virginia, and the urban corridor of Virginia from Fairfax County through Richmond and south to Hampton Roads. VEPCO is a summer-peaking utility; however, it expects that within a few years its winter peak will be higher than the previous summer peak and lower than the following summer peak. It estimates that about 25,000 to 30,000 residential electric heating customers are added to its system each year.

UPA, with headquarters in Elk River, Minnesota, provides power to 15 cooperatives that distribute power to consumers in Minnesota and Wisconsin. Its service area is characterized by long winters and short summers. As a result, UPA is experiencing increasing winter demand, much of which is caused by electric heating.

2.2 Heat Storage Systems

The purpose of these tests was to collect information on a variety of near-commercial generic storage systems under a range of geographic, climatic, demographic, and utility system conditions. The tests were not set up to develop the storage technology but to apply it to residential load management.

In accordance with the RFP, the utilities selected candidate near-commercial storage devices on the basis of high potential for economic effectiveness and of customer acceptance. Thus, the storage equipment manufacturers had to have obtained some experience with the candidate systems and had to be able to produce a sufficient number to meet the needs and time schedule of the utility tests. Also, the utilities were required by the RFP to provide for service warranties, trained equipment dealers, and trained utility personnel.

The storage systems selected by the utilities for residential space heating were of four types: ceramic brick, concrete slab, heat pump with storage, and pressurized hot water. Storage systems using phase-change materials involving salts were determined not to be

near commercial. In the tests, PSE&G and UPA used the ceramic brick systems, VEPCO and LILCO used the pressurized hot water systems, and NMPC used all four systems. All four types of storage systems were designed for diurnal storage — that is, to provide space heating during on-peak periods and use off-peak electric energy to store heat.

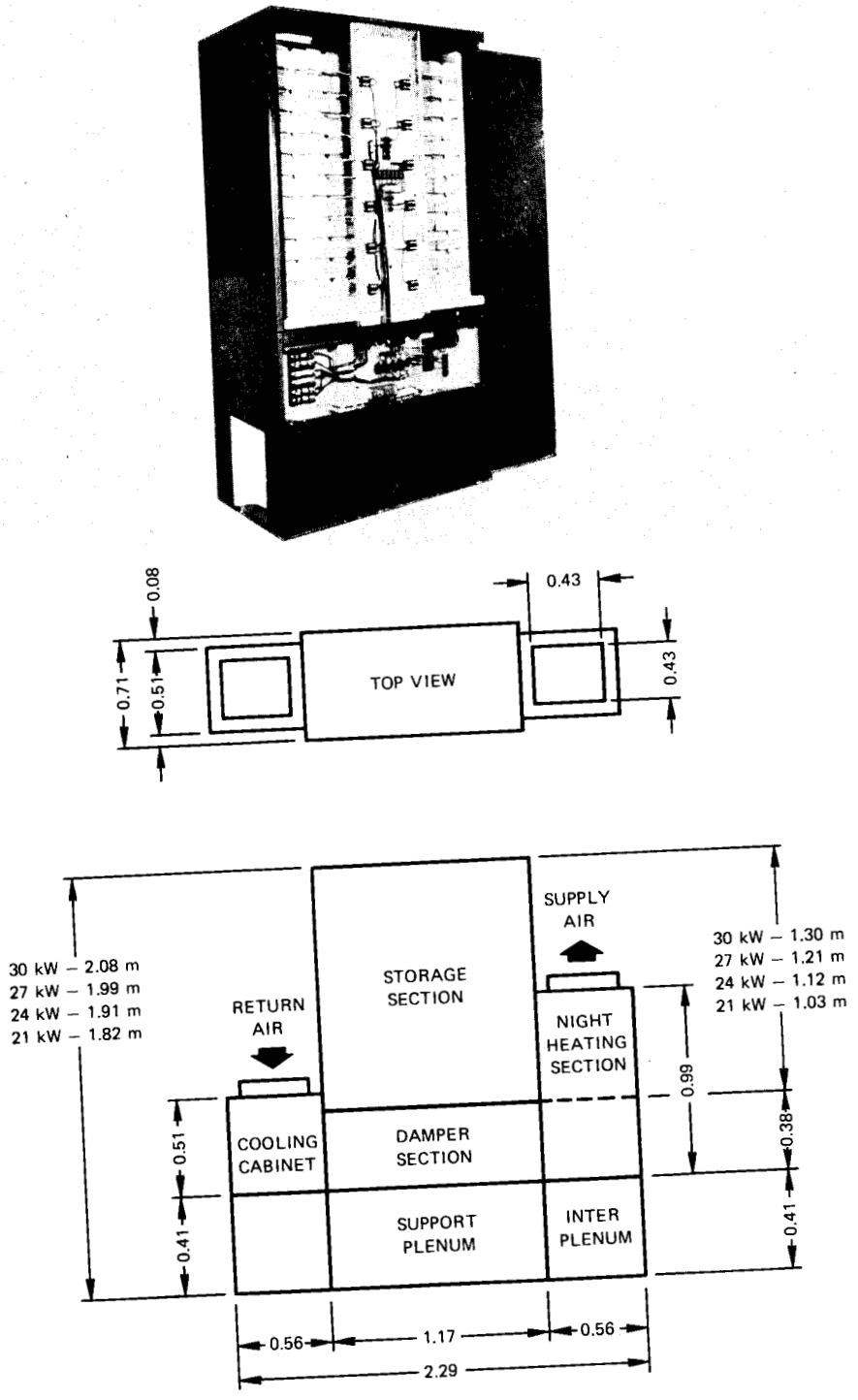
The ceramic brick systems were developed in Europe after World War II for room use and as central installations to provide residential electric heating. Direct imports or modified systems have been used in residences in the United States since the early 1970s. The concrete slab and hot water systems were developed in the United States over the past ten years to capitalize on reducing electric demand charges and to take advantage of off-peak rates.

2.2.1 Central ceramic brick storage

Central ceramic brick storage systems are designed to heat an entire residential home or multiple-living area from one unit. To date, the systems are of the forced-warm-air variety, making them very compatible with central heating. The ceramic bricks, which are housed in a heavily insulated metal cabinet, are heated to temperatures of 649 to 760°C (1200 to 1400°F) by electric heating elements distributed throughout the bricks. Air is circulated as in a conventional forced-air furnace, with dampers to divert a portion of the air over the heated bricks. This heated air is mixed with unheated air to provide a discharge temperature between 52 and 60°C (125 and 140°F). The two manufacturers of the ceramic brick systems used in these tests were TPI, Johnson City, Tennessee, and AEG, Federal Republic of Germany. PSE&G and UPA used the TPI system, and NMPC used the AEG system.

Tennessee Plastics produces a central brick furnace under license with Creda, Ltd., of Great Britain. The unit operates in series with a backup electric furnace and is approved by Underwriters Laboratory (UL). The 30-kW TPI storage unit used in the tests is capable of storing approximately 200 kWh and is designed to operate for a 12- to 16-h off-period each day by charging for an 8- to 10-h period. The unit (Fig. 3) consists of four major sections: a night heater or auxiliary furnace, a

ORNL–DWG 81-17513R



DIMENSIONS ARE IN METERS

Fig. 3. Central ceramic brick storage (TPI).

storage core, dampers, and controls. The night heater, a 15-kW electric furnace, is sized to provide heat to the entire residential home while the storage section is charging. In the storage section, the ceramic bricks are fitted together in layers, with electric heating elements in each layer. The fitted-together bricks form air passages for directly heating air. The storage section is surrounded with several layers of insulation to maintain storage temperatures and reduce heat loss from the surface or skin of the unit. A hydraulic limiter in the storage section is connected in series with the storage unit's safety contactor and the solid state charge control to prevent overheating of the units. The damper section controls (1) air movement through the heat storage section and (2) the volume of bypass air. The control section, or logic panel, which is not shown in the schematic, contains all the sensing and control devices for the unit.

During charging of the unit, the charge level of the storage section varies with outdoor temperature (Fig. 4). The control section senses outdoor temperature and storage section temperature; thus, only those electric heating elements necessary to bring the storage section to a predetermined temperature and to level the storage charging over the on-period are energized. When the house thermostat calls for heat,

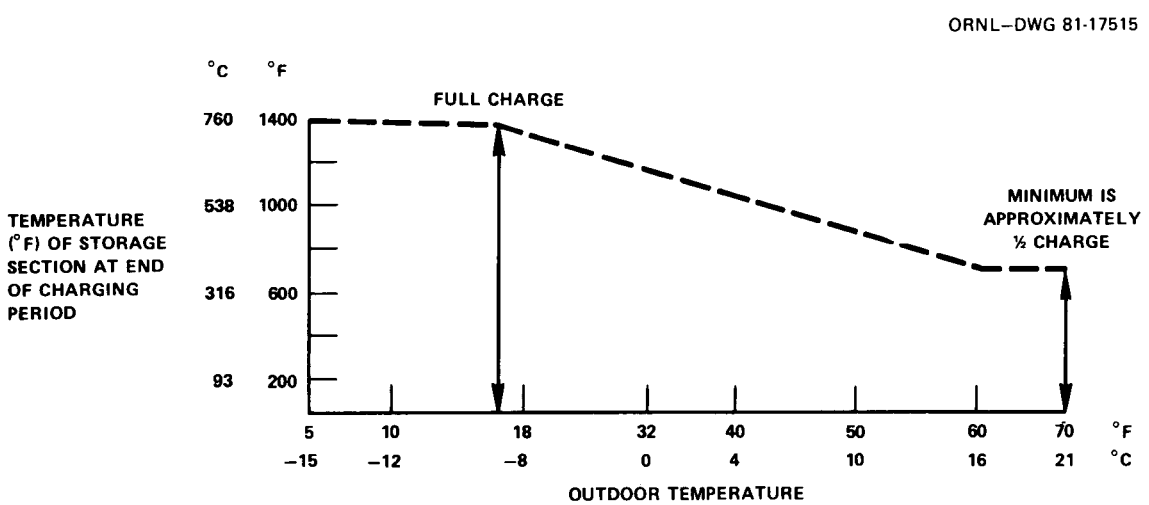


Fig. 4. TPI load-leveling control.

the dampers are set so that circulated house air only flows through the night heater. During on-peak periods, the storage section heating elements and night heater are deenergized; then, when the house thermostat calls for heat, the dampers route a portion of return house air through the storage section.

At present, TPI units are available in four sizes ranging from 21 to 30 kW. The 21-kW unit has a storage capacity of 140 kWh, the 24-kW unit has a capacity of 160, the 27-kW unit has a capacity of 180, and the 30-kW unit (as stated previously) has a capacity of 200 kWh.

Ceramic brick units manufactured by AEG were assembled and supplied by Control Electric Corporation, Burlington, Vermont. NMPC used eight 48-kW units in building F of the Raybrook Correctional Facility. This unit, like the TPI, consists of a storage section layered with ceramic bricks and having electric heating elements between layers. As with the TPI unit, the dampers are controlled by the indoor building thermostat, and the charge level of the unit is set by the storage temperature and outdoor temperature sensors. Each of the units is capable of reaching full storage capacity in less than 8 h with a maximum temperature of 787°C (1450°F).

2.2.2 Concrete slab storage

The slab or trellis storage system (Fig. 5) consists of electrified structural reinforcing mesh embedded 0.10 m (4 in.) below the top of a concrete floor energized at 24 V. Power is supplied to the structural reinforcing mesh by copper bus bars from a stepdown transformer, which converts line voltage to 24 V. When operated as designed, local control of the system is provided by a load demand controller that keeps the system's electric demand below a preset value for an entire month. For this test, however, local control was by the space thermostat; the controller was not operated. A high-temperature thermostat in the slab limits the design maximum temperature to 29°C (85°F). The size of the system allows large storage capability with only small temperature rises; heat is discharged from the system by radiation and natural convection.

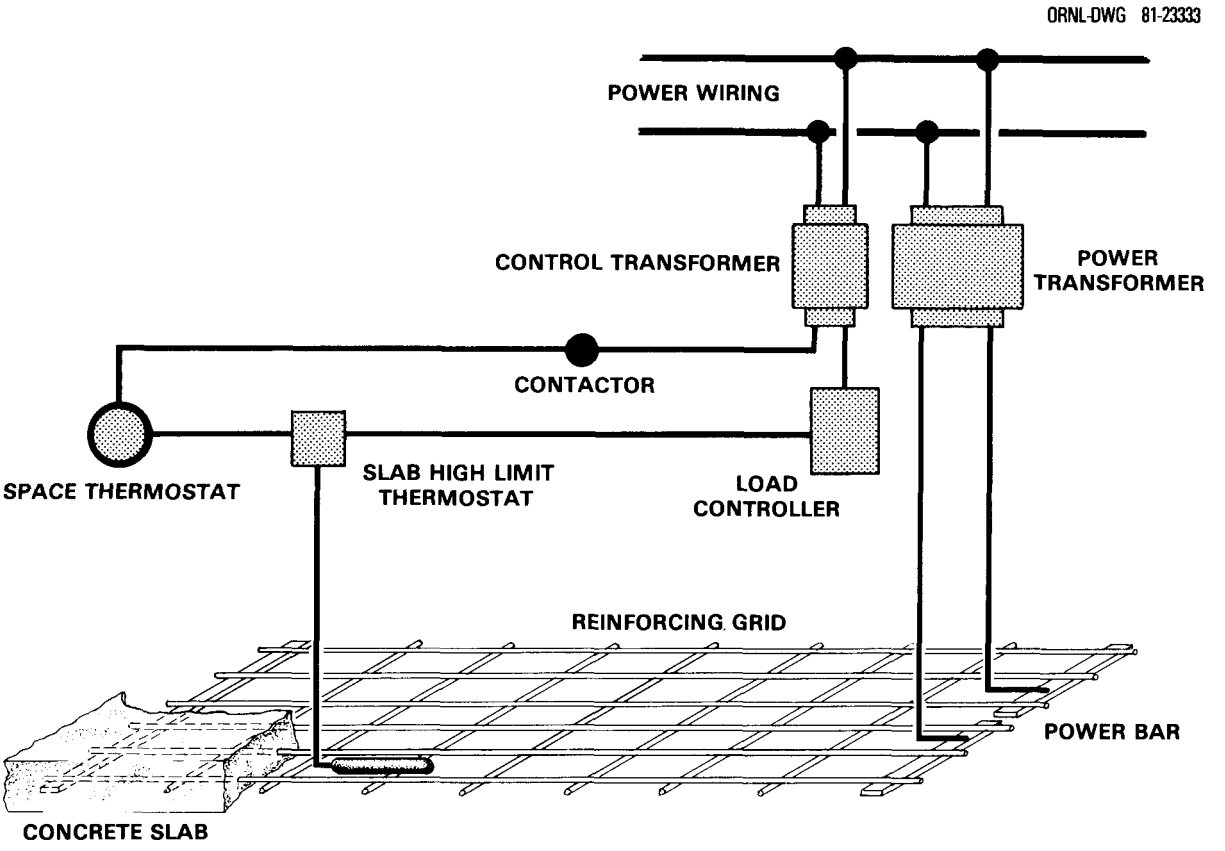


Fig. 5. Concrete slab storage.

The slab heat storage system manufactured by Peak Supervision Controls, Ltd., is an electric-slab heating system on-grade design marketed throughout Canada. Its components and support services are readily available through U.S. suppliers. NMPC, the only utility that used this system, purchased the slab system components from Modular Comfort Systems, Inc., in Camillus, New York, in the summer of 1978.

The system, installed only on the first floor of building E of the NMPC Raybrook project, is divided into ten areas, with each area having its own separate electrical and temperature-limit system (mesh, transformer, control relay, space thermostat, and slab high-temperature-limit thermostat) with heating capacities of 22 to 33 kW. One load controller serves all ten systems and is capable of sequencing the storage systems.

2.2.3 Heat pump with storage

The heat pump heat storage system (Fig. 6) can operate in air-to-air, air-to-water, and water-to-air modes. The system consists of a Carrier Model 50 SQ conventional air-to-air heat pump with 15-kW maximum load, 51.7-kW electric resistance heating coils, 19-m^3 (5000-gal) nonpressurized water storage tank, and a backup 64-kW electric boiler. The 19-m^3 (5000-gal) storage tank was designed to be heated by either heat from the heat pump or the auxiliary 64-kW electric boiler. The hydronic system was designed to operate in the range of 32 to 54°C (90 to 130°F) by the auxiliary boiler. The heat pump was limited to heating the storage tank water to 49°C (120°F). Local control for the storage system is provided by a microprocessor that controls the operation of the storage system in response to utility on and off commands. During the charging period, the local control first operates the heat pump in the air-to-air mode to provide space heating to the building in response to the space thermostat and then operates the heat pump in the air-to-water mode to charge the water in the storage tank. The electric boiler is only energized by the local control to supplement the heat pump in charging the storage tank if the heat pump capacity is not sufficient to charge the storage tank for a predetermined charging period. During the non-charging period, the local control deenergizes the heat pump and operates the storage tank in a water-to-air mode to provide space heat to the building. When the water temperature in the storage tank drops to 43.3°C (110°F), which should be the beginning of the charging period, the heat pump operates air-to-air to provide space heating. NMPC installed four heat pump systems in building H of the Raybrook Correctional Facility — one to serve each wing of the building.

2.2.4 Pressurized hot water storage

The pressurized hot water storage unit (Fig. 7) consisted of a 1.1-m^3 (300-gal) pressurized steel storage tank insulated to heat chemically treated water by electric emersion elements. The unit was designed to hold 0.9 m^3 (240 gal) of water at 344 kPa (50 psia) pressure; the water in the tank is electrically heated to temperatures of

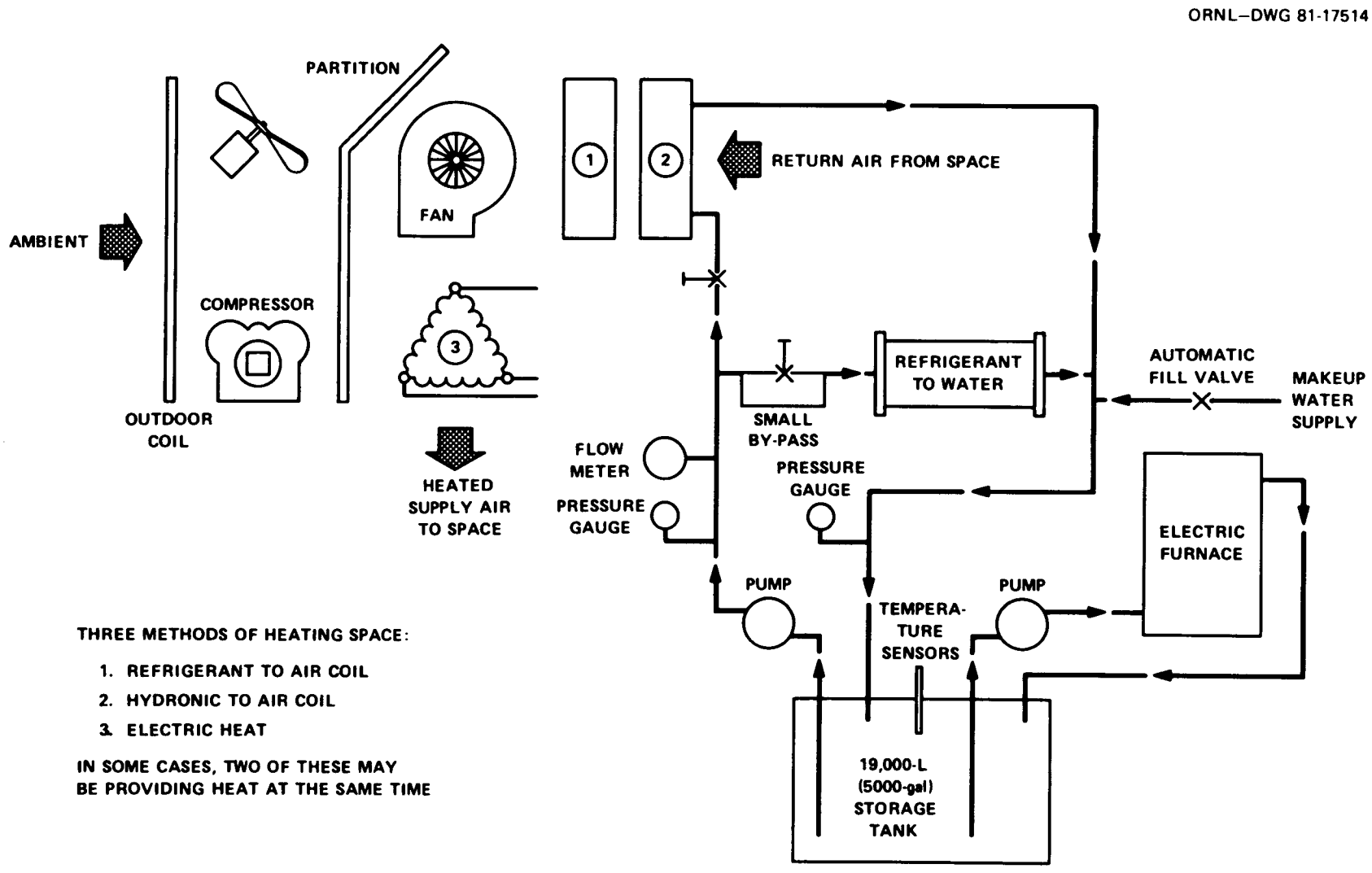
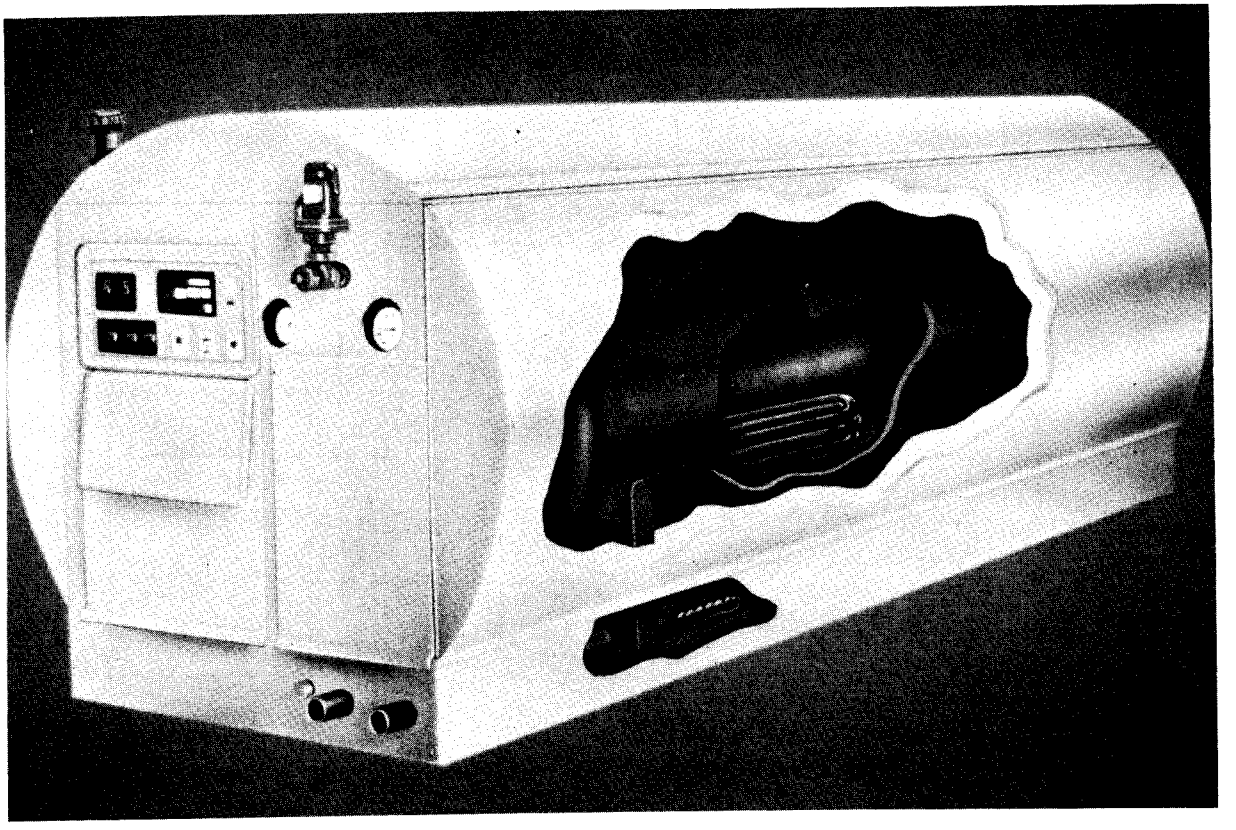


Fig. 6. Model 50 SQ heat pump with storage.

ORNL-Photo 5157-81



ORNL–DWG 81-23334

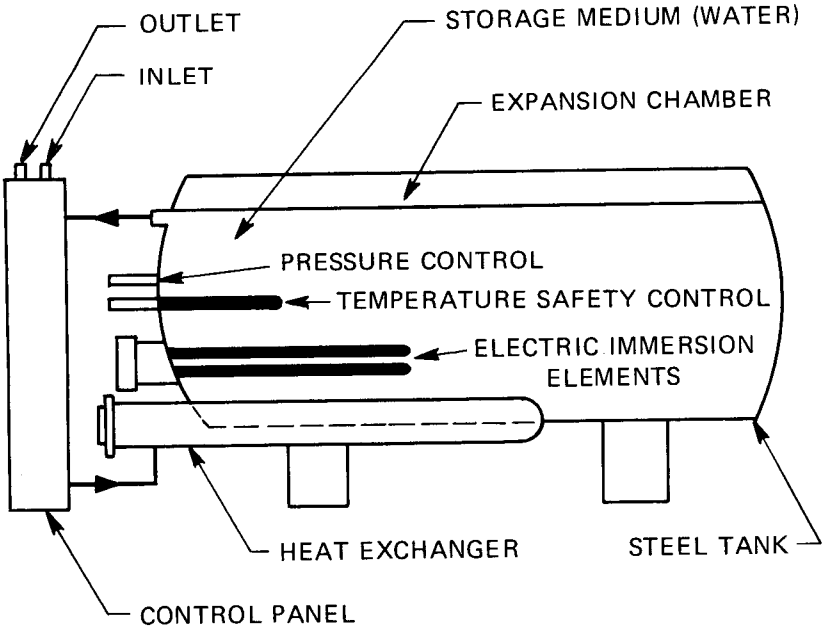


Fig. 7. Pressurized hot water storage.

129 to 143°C (265 to 290°F). Dimensions of the unit are 1.02 m (40 in.) tall, 0.96 m (38 in.) wide, and 2.29 m (104 in.) long. The tank weighs 499 kg (1100 lb) without water and 1288 kg (2840 lb) with water. The unit was rated at 30 kW and can be reduced in rating by steps of 6 kW by disconnecting lead wiring. On start-up, the heating elements are staged in 6-kW increments. The control of the electrical elements of the storage unit is achieved by pressure control because pressure changes of the water inside the tank are directly related to temperature changes and because the pressure control is more sensitive to pressure changes than the temperature control is to temperature changes. A high-limit reset temperature safety controller is used to shut off all power to the unit if the maximum temperature of 143°C (290°F) is exceeded.

The storage system provides space heating by circulating heated water through a closed loop from the storage unit heat exchanger through a hydronic coil located in the air duct or baseboard heating system. Water used in the hydronic space heating system enters through the water inlet ports of the storage device. Mixing valves in the unit control water flow through the heat exchanger to maintain about 55°C (130°F) water temperature in the hydronic heating system, while the balance of the water entering the unit bypasses the heat exchanger. The heated water, now at the required temperature, enters the home hydronic heating system through the outlet ports.

The pressurized hot water storage units used by three of the utilities — LILCO, NMPC, and VEPCO — were manufactured by Megatherm Division of Vapor Corporation, East Providence, Rhode Island, and are built to American Society of Mechanical Engineers standards. In the NMPC test, eight Megatherm units supplied heat for building G. In the VEPCO test (Fig. 8), a conventional heat pump provided supplemental space heating while the storage device charged. The heat pump was deenergized when the storage device provided space heating from storage.

ORNL-DWG 79-20393

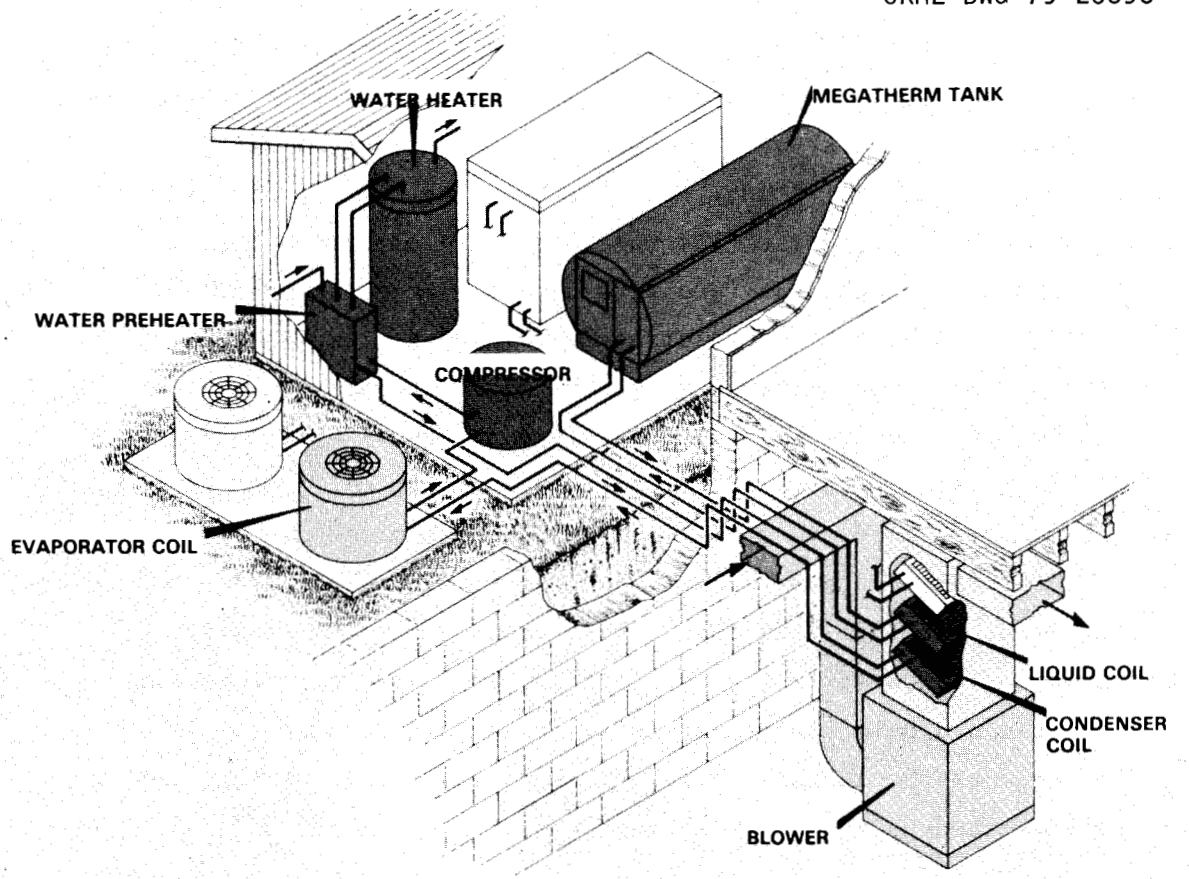


Fig. 8. VEPCO storage system.

2.2.5 Domestic hot water storage

Three utilities — PSE&G, UPA, and VEPCO — used oversized storage tanks for domestic hot water. During charging, the storage hot water heater operates like a conventional hot water device; the electric elements are energized to heat the incoming replacement cold water and the cold water in the tank to operating temperature. The remainder of the time, the electric elements in the storage unit are deenergized. In the VEPCO test, the domestic water entering the storage tank was preheated by reclaimed heat from the heat pump compressor.

The storage domestic water heaters used were the A. O. Smith Conservationist and Jackson-Executive types. The storage tanks are 0.45-m^3 (120-gal) units as compared with 0.21- to 0.3-m^3 (55- to 80-gal) conventional water heaters and are 1.78 m (70 in.) tall and

0.71 m (28 in.) in diameter, weigh 181 kg (400 lb) empty and 635 kg (1400 lb) with water, and have better insulation than conventional tanks to reduce standby losses.

2.3 Utility Control of Storage Systems

In each utility test, storage systems for both space heating and domestic hot water were controlled by a central communications and control system that transmitted command signals from the simulated utility control station to the remote terminal units (RTUs) at the test homes or buildings. The communication media used were radio and telephone (Table 1). Test home customers were provided with the ability to override utility control to protect against communication system failures and lack of space heating or domestic hot water.

The utilities controlled the charging periods of the storage devices, but they did not control when the customer thermostat could call for heat nor did they control the temperatures of the storage units. Use of a central control system rather than a local control such as a time clock was selected to provide the utilities the flexibility of controlling the on/off charging times for the storage devices for load-management and load-leveling purposes. This type of control allowed the utilities to test various control strategies such as fixed time-of-day and direct control to determine performance characteristics and load-leveling characteristics of the storage systems.

2.3.1 Radio

Two utilities, LILCO and UPA, used radio as a communication media. LILCO used an existing radio control system that sent coded signals to receivers installed at the test homes. The signal was then transmitted over the ac house wiring to a high-current load controller for activating or deactivating charging of the storage device. The radio receivers had a fail-safe feature: if a "return-to-charging" signal was not received in 1 h after turn-off, the radio receiver would automatically return the test home load to local control. Local

control was provided by a General Electric type IR-70 programmable watt-hour meter that was linked to the time control of the storage devices. The radio system permitted extending the operating strategy programmed into the IR-70 meter.

UPA controlled the on and off charging operations of the storage space heating and water heating devices from its Energy Control Center by radio through a series of four 100-W transmitters. A special switch with a latching relay was provided to UPA from Scientific Atlanta for use on its 153-mHz mobile communication frequency. The switch was modified with positive-on or positive-off capabilities to eliminate need for constant signaling. Thus, control signals were sent only when a change in the status of the device was needed.

2.3.2 Telephone

Three utilities — NMPC, PSE&G, and VEPCO — used leased telephone line for their communication media for transmitting command signals from the central control station to individual RTUs at the test homes. They controlled the storage charging times of the storage system and monitored the on/off charging status of the systems.

In the NMPC test, RTUs for controlling the operation of the storage system were located in four buildings at the Raybrook Correction Facility. The RTUs were linked to a central control center computer in Palo Alto, California (headquarters of Systems Control, Inc.), via an unconditioned voice-grade communication channel. All control and monitoring information was converted to a one-digit bit stream for transmission at the rate of 1200 baud.

PSE&G used a two-way system manufactured by Darcom to control and monitor the status of the storage devices. This system used normal voice-grade telephone circuits with no special dedication or conditioning, thus reducing communications costs. The system is similar to that used in the DOE/EPRI-sponsored communications trial with Omaha Public Power District; PSE&G used a microprocessor-based master station (Model D2200) linked by telephone circuits to the remote units (Model 404 transponders) located at the test homes. The master station con-

sisted of the microprocessor-based D2200 communications controller operating into dual modems. New Jersey Bell Telephone supplied data couplers with the outgoing control signal being issued via an outgoing Wide Area Telephone Service (WATS) line or a local line during emergencies. A standard General Electric (GE) Terminet replaced the controller during emergency conditions. The manner in which relays were used for control enabled the remotes to detect when either the heat storage device for space heating or the storage domestic water heater had been placed in the override mode.

In the VEPCO test, leased telephone lines linked the supervisory control and data acquisition system (SCADA) with RTUs located in selected master test homes to create a two-way system. The remaining test homes were linked to the master homes by direct-burial dc control cable. The SCADA computer controlled an on/off latch relay in each home to control charging the storage devices and energizing the heat pump; these systems could be controlled either individually or in groups of 20. In addition to controlling the operation of the storage systems, the VEPCO communication and control system was capable of displaying on demand the status of the storage devices and analog values from selected sensors in six master homes.

2.4 Data Collection

Because the objective of the utility test was to evaluate the technical and economic feasibility of using utility-controlled customer-side thermal energy storage for load management, the utilities had to collect both load-research data and data on the performance of the storage devices. To meet this objective, the participating utilities instrumented all the test homes to collect load data associated with the storage systems and instrumented all the control homes to collect comparison load data on conventional electric heating systems. These data included at least the total energy use of the home or building, storage system energy use, and conventional space conditioning system energy use, all synchronized with the time of day. Also, indoor temperature and local weather data were collected to allow correlation

of energy use with environmental and internal home or building conditions. All these parameters were important for determining the load-leveling characteristics of customer-side storage and for correlating these characteristics to weather conditions and customer comfort. Also, in each utility test, a small number of test and control homes were heavily instrumented to collect device-specific data. These data were needed to evaluate the energy efficiency, capacity, and heating capability of the storage systems and to determine how these systems compared with conventional systems. Data parameters included various temperatures and flows associated with the storage systems and conventional systems. The data parameters collected by each utility are shown in Table 4.

The data were collected by a variety of sensors and converted to current output by signal conditioners and then to pulses by analog-to-frequency converters. These data pulses were then recorded on four-track magnetic tapes with time recorded on one track. Three different time periods for data collection were used by the utilities: NMPC used 7.5-min intervals; LILCO, PSE&G, and UPA used 15-min intervals; and VEPCO used 30-min intervals. All the utilities (except NMPC) recorded data on magnetic tape recorders directly at the site of the storage systems. In the NMPC test, the data were collected by the computer at the central control center and then later put on magnetic tape.

In the tests, weather information such as outside ambient temperature, wind speed and direction, and solar radiation were measured with instrumentation at the site of the storage systems or obtained from local weather stations. Electric energy uses of the heat storage system, auxiliary heating system, conventional space heating system, and domestic hot water unit and the total energy use for the home or building were measured and recorded on magnetic tape recorders by kilowatt-hour meters equipped with integral pulse initiator units. In the NMPC project, these energies were measured using standard utility 1000:5 or 200:5 current transformers (CTs) for each phase of the circuits. The currents were then converted to pulses via current/

Table 4. Test data parameters[a]

	LILCO	NMPC	PSE&G	UPA	VEPCO
Total house or building kilowatt-hours	T, Ca	T, C		T, C	T, C
Baseload kilowatt-hours		T, C	T, C		
Furnace kilowatt-hours	C	T, C	T, C	T, C	
Heat pump kilowatt-hours					C
Thermal energy storage (TES) unit kilowatt-hours	T		T	T	T
Circulating pump kilowatt-hours					T
Indoor fan kilowatt-hours					T
Compressor and outdoor fans kilowatt-hours					T
Water heater kilowatt-hours		T	T, C	T, C	T, C
Indoor air temperature	Ta, Ca	T, C	T, C	T	T
Indoor relative humidity			Ca		Ta
Outdoor air temperature	Ta, Ca	T, C		Ta	Ta
Outdoor relative humidity					Ta
TES skin temperature				Ta	
TES medium temperature	Ta	T	Ta	Ta	Ta
Heating coil temperature delta					Ta
Heating coil flow rate					Ta
Air handler temperature delta			Ta	Ta	Ta
Air handler flow rate		T, C	Ta	Ta	Ta
Water heater temperature delta			Ca	Ta	Ta
Water heater flow rate			T, C	T, C	Ta
Water preheater temperature delta					Ta
Water preheater flow rate					Ta
Solar intensity		T		Ta	
Wind velocity		T		Ta	

[a]T = data collected at all test homes or buildings; Ta = additional data collected at heavily instrumented test homes; C = data collected at all control homes or buildings; Ca = additional data collected at heavily instrumented control homes.

pulse transducers for each three-phase circuit, and the pulses were counted by the pulse accumulator circuitry of an RTU in each building. Air flow in the homes and buildings was measured by air turbine units mounted in the ducts. Ambient and device temperatures were measured with thermocouples whose outputs were converted to currents with transducers and converted to pulses by analog-to-frequency converters for recording. In the NMPC project, underground temperatures for the concrete slab and central ceramic brick heated buildings were measured along with the other temperature data shown in Table 4.

3. CUSTOMER SELECTION

The utilities were directed to select customers who were as representative as possible of the potential market for residential heat storage in their service area for participation in these tests. This step was necessary to ensure that the data collected in the tests would be valid in assessing the acceptance of the storage technology by that portion of the public who would purchase the storage equipment and thus provide a significant penetration for load-management capability. However, because the candidate near-commercial storage equipment was only available in limited physical sizes and storage capacities and because the variety of storage systems considered in these tests were all central units, only those customers having homes with (1) adequate space for the storage unit, (2) a given range of heating requirements, and (3) central heating systems could be considered for selection. In addition, the test required volunteers because the reliability of the equipment was uncertain and the customer would be subjected to a number of inconveniences and intrusions during the test.

3.1 Selection Procedure

Each of the utilities, with the exception of NMPC, developed its own procedures and criteria for selecting a sample of residential electric customers to participate in the test (Table 5). NMPC did not require a customer selection procedure because its test involved a federal correctional facility.

The test customers were selected to be somewhat representative of electric residential customers whose homes could be converted to storage space heating and storage domestic water heating in a significant number to provide a load-management capability. The test home groups had to be selected this way so the collected data could be used to perform a system impact study and cost/benefit analysis.

Four utilities — LILCO, PSE&G, UPA, and VEPCO — limited their samples to single-family detached homes, except PSE&G, which also

Table 5. Customer selection information

Parameter	LILCO	NMPC	PSE&G	UPA	VEPCO
Home construction	Existing	New	Existing	New and existing	New
Home or building size, m^2	139-167	2694	120-219	190[a]	139-167
Heat loss, kW	*b*	165	11.3-25.1	11.7-16.1	*b*
Sample size surveyed	1900[c]	*d*	382	307[e]	18 builders

[a]Average size of the test homes; sizes of control homes averaged 167 m^2.

[b]Data not available.

[c]1500 surveyed for test participants and 400 for control participants.

[d]No survey conducted.

[e]70 customers in new homes and 152 in existing homes surveyed for test group; 85 surveyed for control group.

included residents of townhouses, apartments, and condominiums. The control group for PSE&G consisted of 15 residents of a condominium building.

To stimulate volunteer participation in the tests, the utilities held press conferences with local newspapers and used local radio to announce the tests to the public and, in the case of LILCO, to stimulate phone calls from volunteers for the test. LILCO also displayed its thermal energy storage unit with diagrams and charts at its press conference.

Two utilities, UPA and VEPCO, identified residential electric customers of new homes for participation as test home participants. In the UPA test, utility personnel reviewed new electric service applications and contacted local homebuilders. In the VEPCO test, Richmond homebuilders were contacted directly or through the local homebuilders association. VEPCO signed agreements with 18 builders who were willing to build test and matching control homes for the test. When the home was complete, VEPCO signed an agreement with the customer buying the test or control home before the home was bought.

LILCO, PSE&G, and UPA identified potential test home participants in existing homes for retrofit installations. LILCO surveyed residential electric customers with central hydronic oil-fired space heating systems as the customers called in to inquire about the project after reading about it in the newspaper or hearing about it over the radio. PSE&G reviewed utility records and identified customers with central electric furnace heating systems. UPA reviewed billing records to identify high electric users.

Questionnaires were also mailed to customers to identify potential test and control home participants. Once the potential participants for the test were identified, the utilities used information acquired by the mailed questionnaires and field surveys (interviews with potential participants) to make the final selection.

During field surveys, information was gathered on each house and on the customers; this information included such items as customer location, insulation level, existing heating system, supplemental heating

systems, size of house, access to the existing heating system, and level of difficulty to install the heat storage system and instrumentation. Information on the numbers of household members and their life-style was also gathered. The utilities used the field surveys as an opportunity to survey the potential customers on their knowledge of thermal energy storage, electric costs, and utility peaking and to assess the customers' acceptance of utility control of their heating systems and their satisfaction with conventional heating systems. The homes were also checked to determine if the installation of the storage equipment would meet local safety and electrical codes and if the equipment could be installed without excessive damage to the customer's property.

Once data were collected on candidate homes, the utilities performed heat loss analysis and identified house orientation to the sun to determine the heating requirement of the house. Prior to final selection of the test and control home customers, the utilities signed agreements with the selected customers outlining the conditions of participation and providing for installation and subsequent removal or sale of the storage system, instrumentation, and communication equipment in the homes.

3.2 Customer Incentives

To stimulate customer participation in the tests, a number of incentives were offered by the utilities. The utilities also had to ensure that they would not change the customer's life-style. All the utilities offered the test home participants free installation and maintenance of the heat storage systems and other test equipment. This allowed the utilities access to the equipment to gather data on maintainability and reliability and to collect the data tapes each month at the equipment site. Because there were no guarantees on the performance and acceptance of the test equipment, all test home participants were also offered the option to terminate participation at any time, have the test equipment removed, and have their space heating system restored to normal operation. The option to purchase the storage system at the end of the test was offered by each utility along with other incentives.

LILCO guaranteed the test home customers that the cost of electricity for operating the heat storage system would not be more than their cost would have been had they not installed the system. At the end of the test, its customers had the option to purchase the storage equipment for $500 or receive free restoration of their original heating system. Forecasts of dramatic increases in the prices of heating oil and possible supply shortages served as an additional incentive for some customers to convert from their existing hydronic systems heated by oil to a storage system charged by electricity. Some of the customers were even willing to incur high renovating costs to have the storage systems installed. These costs would have included breaking through concrete basement walls and installing a door and stairs. The control home occupants were offered $100 for participation in the test.

PSE&G offered its test home participants a residential load-management rate. A summary of this rate is as follows:

Period	June-October (¢/kWh)	November-May (¢/kWh)
On-peak (7 A.M.-9 A.M. Mon.-Fri. and Sun.)	11.5	6.0
Intermediate (7 A.M.-9 A.M. Sat.)	9.5	5.0
Off-peak (all other times)	2.8	2.8

Control home participants received $10 per month. At the end of the test, PSE&G offered the test home customers the option of negotiate a purchase price for the storage equipment or receive free restoration of their original heating system.

In the UPA test, test home participants were offered a special off-peak electric rate of 2.5 ¢/kWh. In addition, each test home participant received $37.50 per quarter for allowing UPA to maintain and operate the thermal energy storage equipment in the customer's basement. Control home participants were offered $37.50 per quarter. At the end of the test, UPA offered the test home customers the option

to purchase the storage equipment for $700 or receive free restoration of their original heating system.

VEPCO initially billed the test home customers on a load-management rate that was estimated to result in a $30 average monthly energy cost savings. However, this did not cover the high energy costs associated with the storage system, so VEPCO replaced this offer with their standard electric rate, with adjustments made for excess energy use. In addition, a credit of $30 per month was given to the participants. No incentive was offered to the control group. At the end of the test, VEPCO offered the test home customers the option to purchase the storage equipment for $100 or receive free restoration with a conventional electric heat pump.

3.3 Problems with Customer Selection and Incentives

The utilities experienced a number of problems selecting test home customers and offering incentives for participation. These problems included lack of interest in participation by customers, poor new home market, difficulty in finding homes with adequate space for the storage unit, and insufficient incentives to cover the higher energy use of the storage systems. The utilities also experienced problems acquiring enough control home customers because of lack of customer interest, insufficient incentives to cover the inconvenience of equipment installations and meter readings, poor responses to mailed questionnaires, problems with location of circuit breaker panels in the finished areas of homes, incompatibility of heating systems with other selected control home systems, and the presence of supplemental heating systems such as wood stoves.

Two utilities, LILCO and VEPCO, experienced the most difficulty acquiring a sufficient number of test home participants. Because of the poor new home market in Richmond, Virginia, early in the test, VEPCO had difficulty getting the selected homebuilders to complete construction of enough new homes for the test. LILCO experienced difficulty locating enough existing homes with an adequate access route for delivery of the storage unit from outside the home into the furnace

area. For this reason, LILCO had to make close inspections of the homes to check the size of door openings, hallways, stairways, and the existing furnace rooms.

To improve customer participation in the tests, LILCO and PSE&G raised their incentives. LILCO increased its cash incentive for the control group from $50 to $100 to improve customer response to the questionnaires. PSE&G raised its cash incentive from a $50 lump sum for participation during the complete test to $10 per month for the 24-month test to increase control group participation.

Another problem with customer incentives that was experienced by the utilities during test operation involved the high electric energy use by the storage systems. This problem was not expected at the time of customer selection. Because of the higher energy use of the storage systems, PSE&G and VEPCO experienced problems with the incentives they were offering customers being inadequate. The higher energy use was believed to be caused by heat losses from the storage unit, poor operation of the storage systems, extra ductwork and piping required by the storage units, and high thermostat settings by the customers. Also, PSE&G's test home customers experienced higher energy charges during the summer; inadequate air flow in the ducts caused by the storage unit installation resulted in increased operation of the central air conditioning system. Additional adjustments were made to compensate these customers for excessive energy charges.

4. EQUIPMENT INSTALLATION

As required, all the utilities installed storage systems for space heating (three utilities also installed storage domestic water heating equipment), instrumentation for data collection, and communication and control systems for monitoring and controlling the storage systems. The installation of the equipment did not start prior to the 1978-1979 heating season as originally planned because of delays in the utilities' subcontracting the installation work, late equipment deliveries, and the utilities having difficulty in acquiring test homes.

Delays in subcontracting installation work were caused by the experimental nature of the tests. As a result, mechanical and electrical contractors were uncertain about how to bid the installation work because they lacked any experience with installing residential- or commercial-sized heat storage systems (except for VEPCO's installation contractor). The contractor for the VEPCO test was selected because of his experience installing storage equipment for the Richmond, Virginia, ACES house. The other utilities selected contractors who were experienced in installing conventional space heating and domestic water heating systems in residential homes and commercial buildings and who could provide dependable service. Most of the utilities used one to two installation contractors; UPA, however, elected to involve several (18) local electrical contractors rather than subcontract the work to only one or two.

The poor market for new homes was the major reason for the difficulty in acquiring test homes for the VEPCO test. Because of this problem, VEPCO was the last to start equipment installations. In the LILCO and PSE&G tests, the extreme physical size and weight of the storage equipment limited the selection of test home customers. Only existing homes with the physical space to accommodate the equipment could be used.

4.1 Equipment Delivery

The utilities received reasonable and timely deliveries of heat storage equipment, with some exceptions. Most problems were experienced

with the delays in the delivery of communication and control equipment and instrumentation for data collection. All the utilities ordered storage equipment too late to start equipment installations prior to the 1978-1979 heating season except NMPC; they had to rush order the equipment at high shipping costs to install the storage equipment prior to the 1979-1980 Winter Olympic Games in Lake Placid, New York.

LILCO received 11 storage units that had cracked pipe fittings. These were not found until the units were installed and in operation. LILCO also experienced delays in receiving temperature-monitoring equipment, which was ordered in early spring 1979 but was not delivered until December 1979.

PSE&G experienced some quality control problems in the delivery of ceramic brick storage units. Some deliveries were missing parts bags and insulation for the units. Also, some storage units had mislabeled electric supply element wires, thus preventing correct installation and operation. Limited availability of storage domestic water heaters caused by manufacturers' delays also affected the schedule. Delays with the communications and control equipment were also experienced. Communication equipment to PSE&G was scheduled to be delivered 24 weeks after the issue of its purchase order in December 1978. The equipment was delayed by software development and not received until August 1979. Signal-processing equipment and water meter equipment were also received behind schedule.

UPA experienced some problems in the delivery of storage equipment and instrumentation. The first two ceramic brick storage units received were of the original design with the thermocouple and hydraulic limit (device to prevent overheating) installed in brick-level eight. The redesigned units have the hydraulic limit and thermocouple in brick-level two. The units were ordered in July 1978 and final shipments received in December 1978. This late delivery delayed the equipment installation until after the 1978-1979 heating season. In addition to the delay, about half the units arrived with bent support plenums; this problem was remedied later when the manufacturer began shipping units in wooden frames. Problems were also experienced with the delivery of storage domestic

water heaters. The heaters were ordered in August 1978, and final shipments were not completed until November 1978. Eighteen of the water heaters were incorrectly shipped with 480-V elements rather than 240-V elements.

In addition to these problems, UPA experienced delays in receiving magnetic tape recorders, kilowatt-hour meters with pulse initiators, and other instrumentation. Recorders and meters were ordered in June 1978, but the order was not completed until December 1978. Signal conditioners, analog-to-frequency converters, and sensors for temperature, wind, and insolation were ordered in August 1978 and not received until two to three months later. As a result, UPA was unable to begin assembly of instrumentation panels until January 1979.

VEPCO received storage units with faulty equipment and experienced delays in the delivery of RTUs, control software, and instrumentation equipment. Two storage units were received with cracked pipe fittings, and two were found later to have leaks in the pipe coupling to the heat exchanger. The RTUs to be used in the master test homes were ordered in April 1979, and the last was received in March 1980. Late receipt of the RTUs and software delayed control of the first test system until March 1980. Because of the one- to two-month delay in receipt of temperature and humidity sensors and Btu meters, many installations made in occupied homes required coordination with homeowners.

4.2 Installation Experience

Storage units were installed in various locations in the utility tests, depending on whether the installation was in new or existing construction and on the type of storage unit. In the LILCO, PSE&G, and UPA tests, the storage units were installed in basements, garages, and lower levels of the test homes. In the NMPC test, the storage equipment was retrofitted in equipment rooms in the multioccupant buildings. The storage units in the VEPCO test were installed in equipment rooms built on as part of the new home.

Problems encountered in the installation of the storage units included the extreme size and weight of the storage equipment, inexperience of the contractor installing the equipment, poor quality control and design of the storage equipment, and equipment delivery delays. The weight and size of the ceramic brick and pressurized hot water units presented problems in transporting the units to the installation site and placing them in the home or building, especially for those utilities such as LILCO and PSE&G with retrofit installations in basements. Most of the installation contractors lacked direct experience with the storage systems. Only the VEPCO contractor had previous experience in installing storage equipment for the Richmond, Virginia, ACES house.

Some installation modifications were necessary to accommodate the storage units; modifications included upgrading the electric service to the home and using larger blower motors in the heating ducts. In the NMPC test, existing wiring was replaced to accommodate the larger load of the storage equipment. In the PSE&G test, a 5-kW duct heater was added to supplement the night heating section in 29 of the 30 test homes because all these homes had an existing 22-kW furnace and the lower heating capacity of the 15-kW ceramic brick auxiliary furnace might be noticeable and, therefore, objectionable to the test home customers. The increase in static pressure in the heating ducts caused by the added hydronic coils in the VEPCO test or the ceramic brick unit in the PSE&G and NMPC installations required a larger blower motor than normally found in conventional space heating systems. However, static pressure was not a problem in the UPA installations.

Installation of heat storage systems was new to most utility areas, thus requiring the utilities to give orientation sessions to local inspectors and to hold on-site inspections with the local building and electrical inspectors. Waivers of installation code requirements were obtained for the storage equipment that did not have laboratory approval (such as UL) or where local codes were not clear or did not address a particular item.

4.2.1 Long Island Lighting Company (LILCO)

Storage unit installations were started in November 1979, and the final installation was completed in October 1980. In each installation, the existing oil furnace was removed; the storage unit was then installed nearby to utilize the existing heating system circulating lines. The physical size and extreme weight of the units made them difficult and costly to install in basements. The installation subcontractor performed all work in accordance with local codes.

No installation problems were experienced with the instrumentation and communication equipment. This equipment is in standard use at LILCO in other ongoing programs.

4.2.2 Niagara Mohawk Power Company (NMPC)

Installations of the storage equipment in this test were started in September 1978 and essentially completed in January 1979. During 1979, the installation of the remainder of system components, including necessary modifications to and interfaces with the existing conventional space heating systems, was completed.

The ceramic brick and pressurized hot water units were installed in equipment rooms serving the separate cell block wings (first and second floors) of the buildings. By necessity, the pressurized hot water units had to be installed in tight quarters because the buildings were originally designed for conventional heating systems. The slab system was installed on the first floor of one building, and the heat pump units were installed on the roof.

Installation of the storage units required changing the underground conduit system to accommodate the increased wire size needed for the units. Circuit breakers were also replaced with larger sizes.

For the ceramic brick units, duct modifications had to be made in the vicinity of the furnace to install damper controls and larger blower motors. The motors had to be increased from 373 to 560 W (1/2 to 3/4 hp) to accommodate increased static pressure. Each storage unit required a separate distribution panel to provide fuse protection for the electrical elements.

For the slab system, circuits had to be reconfigured while distribution panels and switches were added. Reinforcing mesh with copper supply and shorting bars had to be installed prior to the final concrete pour. This system could not be installed on the second floor because of the limited space in the concrete sandwich created by the existing reinforcing bars and conduits.

Installation of pressurized hot water units required that the original heating system be relocated in the equipment room to make space for the storage unit. Hydronic coils were installed in the ducts.

In the heat pump with storage installations, the air handler/heating units were completely replaced by the roof-top air handler/heat pumps. Electrical controls were installed in place of the original pneumatic system. The duct system was increased in size to accommodate the requirements of the heat pumps. The 19-m^3 (5000-gal) storage tanks were buried outside the building.

Communication RTUs and pulse transducers were installed in the power supply room in each building because the current transformers were installed on circuit conductors in these rooms. No problems were experienced in installing this equipment.

4.2.3 Public Service Electric & Gas (PSE&G)

The installation of the storage units began in August 1979 and was completed in April 1980. Eight of the storage units were retrofitted in basements in the same approximate location as the existing electric furnace. The remaining units were located in existing utility closets that were constructed in unheated garages. These installations required 21 to 24 m (70 to 80 ft) of additional ductwork, repairs to the utility room after the existing furnace was removed, and a 300-A service.

One storage unit installation was complicated by problems in upgrading the electric service to the home because of limited access to the service location; it required complete teardown and reconstruction of the storage unit for delivery to the basement. All the installations were performed by a subcontractor who had attended a three-day training session conducted by the storage equipment manufacturer.

The storage equipment that lacked UL approval required PSE&G to obtain a waiver to local building codes from the State Department of Community Affairs. Also, PSE&G installed Honeywell battery-operated day/night thermostats to meet a State Department of Energy requirement for energy conservation devices. Some of the storage water heater installations required an extra shutoff valve to comply with local codes.

As part of the installation procedure, PSE&G charged the storage units prior to connecting the unit to the ductwork. This eliminated the objectionable odor associated with burning in the insulation. This suggestion was made to PSE&G by UPA.

Wiring and checking the instrumentation board assemblies prior to installation confined most problems to wiring errors. No installation problems were experienced with the communication equipment.

4.2.4 United Power Association (UPA)

The first storage unit was installed in September 1978, and installations were completed in November 1979. All the storage equipment was installed in basements or lower levels of the homes on the existing concrete slab. The extreme weight [1360 kg (3000 lb)] and physical size [2.1 m (82 in.) high, 2.3 m (90 in.) wide, and 0.7 m (28 in.) deep] of the ceramic brick storage units presented some difficulty in transporting the units to the homes and handling them at the site. The weight [136 kg (300 lb)] and size [1.6 m (62 in.) high and 0.7 m (29 in.) in diameter] of the water heater also presented some handling problems. The water heaters were a tight fit through 0.7-m (30-in.) doorways and almost impossible to handle without denting.

All material and equipment were required to meet the National Electrical Code. No problems were encountered in meeting these requirements because orientation sessions and on-site inspections were conducted with local building and electrical inspectors prior to installations.

The instrumentation and communication equipment was installed by UPA personnel and did not present any problems, except for the control homes. Instrumentation in these homes was performed by electrical contractors. Problems were experienced in isolating the electric furnace circuits for metering purposes.

4.2.5 Virginia Electric and Power Company (VEPCO)

Storage equipment installations were started in October 1979 and completed in October 1980. The storage equipment was located in a 3- by 3.7-m (10- by 12-ft) mechanical equipment room that the homebuilder attached to each new test home. Because the homes were new, VEPCO did not experience the problems associated with retrofit installations. A 400-A service was installed at each home in place of the standard 200-A service to supply electric power for the heat pump, storage unit, and balance of house loads.

Local building code authorities permitted deviations where practical and cleared the installation as an experimental test project where local codes were not clear or did not address a particular matter.

Because all communication equipment for the test is used in normal utility operations, its installation could be considered normal. However, the coordination of the homebuilder's construction schedule of the test homes with leasing and installing telephone data circuits presented some problems. The requirement to obtain right-of-way agreements from property owners delayed the installation of buried control cable between the master and slave homes. Completion of paired master and slave homes could not be coordinated with homebuilders, thus delaying remote control operation.

Installation of the instrumentation equipment proceeded normally except for temperature and air flow sensors, which were incorrectly installed at several test homes and required relocation. Installation of indoor sensors in occupied test homes was difficult because of absence of homeowners.

4.3 Test Costs

Costs of purchasing and installing the storage units, communications and control equipment, and instrumentation reflect the experimental nature of the tests and different circumstances associated with each utility test installation. The test installation costs were very much a function of the type of installation (new or retrofit), type of storage equipment used, communication and control system employed, local code requirements

of the utility service area, and experience of the installation contractor in installing heat storage units. Costs associated with the installations in the residential homes for the LILCO, PSE&G, UPA, and VEPCO tests are summarized in Table 6. Costs for the NMPC test are given in Table 7.

Table 6. Cost ($)[a] of test installations in residential homes

	LILCO	PSE&G	UPA	VEPCO
Storage equipment	2,360	1,859	1,473	8,095[b]
Labor and materials[c]	4,404	11,500[d]	1,300[e] 1,600[f]	4,547
Total	6,400	13,359	2,733[e] 3,073[f]	12,642
Communications and control	535	3,323	1,159	2,831
Instrumentation	2,981	7,606	5,081	7,162

[a]Average cost per test home installation.

[b]Costs include heat pump, water heater and preheater, and mechancial equipment room. These costs are common to both heat and cool storage.

[c]Mechanical and electrical material and labor required for storage equipment installations.

[d]Includes relocating central air conditioner; relocating humidifier; installing duct heaters, freezestats, and control wiring; burning in storage unit insulation; and other miscellaneous duct and piping work.

[e]Installation in new construction.

[f]Retrofit installation.

Costs of the storage systems shown in Tables 6 and 7 reflect the high costs associated with purchasing and installing near-commercial systems for experimental testing. These units were not produced in mass quantity and did not have a wide distribution service. The VEPCO costs also reflect the additional equipment used in its test and the construction of an equipment room.

Installation costs of the storage systems reflect the higher number of manhours required to install nonconventional space heating systems.

Table 7. Cost ($)[a] of NMPC test installations

	Ceramic brick[b]	Concrete slab	Heat pump with storage[c]	Pressurized hot water
Equipment cost	59,000	71,950	77,755	36,771
Labor and materials[d]	114,022	139,092	262,137	102,947
Total	173,822	211,042	328,892	139,718

[a]Total equipment and installation costs.

[b]Costs for eight storage units.

[c]Costs for four storage units.

[d]Mechanical and electrical material and labor and structural modifications required for storage equipment installations.

In general, the contractors were not experienced in installing the heat storage systems. In the UPA test, installation costs were significantly lower than in the other tests because rural electrical contractors were used and because UPA monitored the first two complete installations to establish cost limits for the installations. PSE&G experienced high installation costs because of the high cost of labor in its service area and because of all the extra modifications PSE&G made to the test homes to reduce heat loss and meet customer acceptance. These modifications included repairing utility rooms, insulating ductwork, adding day/night thermostats, and relocating air conditioner evaporator coils.

Costs of the instrumentation indicate all the metering, magnetic tape recorders, sensors, wiring, and labor needed to allow collection of load-research and device-specific data at the test homes. The low cost of the LILCO equipment indicates the lesser quantity of data it planned to collect as compared with the other utilities.

Costs of the communication and control systems indicate the difference between the use of new vs an existing communication system and the use of radio vs telephone. The lesser cost reported by LILCO was because of its use of an existing radio system, which only required the purchase of radio switches for the test homes. PSE&G and VEPCO costs reflect the use of new systems using telephone circuits, thus requiring the purchase of expensive master control units and RTUs and rental of leased telephone circuits. UPA costs reflect the addition of three 100-W transmitters and a message generator unit to its radio system. Originally, UPA planned to use only one transmitter and a modified portable test unit to control the storage units; however, poor reception and/or receiver sensitivity problems required the purchase and installation of extra communication and control equipment.

5. EQUIPMENT CHECKOUT AND OPERATION

In all tests except the NMPC test, the storage equipment was fully operated and data collected during the 1980-1981 heating season. NMPC was delayed in getting the storage equipment and communication and control systems ready for testing. As a result, NMPC will not test the equipment and collect data until the 1981-1982 heating season. Because of the poor equipment performance in the LILCO, PSE&G, and VEPCO tests, the storage equipment is being removed. In the UPA test, experience with the storage units was generally good, and UPA expects most test home customers to retain the storage equipment. A detailed analysis of the results of the 1980-1981 heating season is presently under way by LILCO, PSE&G, UPA, and VEPCO and will be presented in a subsequent report.

5.1 Heat Storage Equipment Performance

In general, the utilities encountered numerous hardware and operational problems with the storage units. The problems included high equipment failure rate, insufficient heating capability, excessive electric energy consumption, air conditioning problems caused by the reduction of air flow in the central duct system, and poor temperature regulation. Some minor problems with the storage domestic hot water heaters were experienced because of the reverse connection of electric elements and low settings on thermostats. Most of these problems appeared to be the result of poor quality control by the manufacturers and lack of experience of the contractor personnel working with the storage equipment. Some problems were also caused by the design of the equipment.

To date, only the ceramic brick units in the PSE&G and UPA tests and the pressurized hot water units in the LILCO and VEPCO tests have been fully operated.

5.1.1 Central ceramic brick

On initial start-up and testing of these units in the PSE&G and UPA tests, problems were experienced with defective control relays, frozen dampers, frozen blower motors, and defective hydraulic limiters, low-voltage transformers, and local logic control boards. Also, an odor problem was experienced on initial heating of the insulation in the units and was encountered again whenever adhesives were used in the home and their fumes circulated through the storage unit via the duct circulation system. Problems encountered during operation of the units in the heating season included failure of logic control boards, insufficient heating, and high energy use. Also, the installation of the storage units in test homes having central air conditioning caused problems with air conditioning during the 1980 cooling season.

During initial testing, the major problem experienced by PSE&G and UPA involved the failure and incorrect operation of hydraulic limiters. Limiters for several ceramic brick units had to be recalibrated or replaced because the limiters were set to deenergize at about 677°C (1250°F) instead of 746°C (1375°F) as indicated in the manufacturer's service manual. The original setting would not allow the storage section to go to full charge under control of the storage section thermocouple. Several units also suffered from excessive hydraulic limit tripping, which prevented the storage unit from charging. Causes were found to be a factory wiring problem and incorrect location of the temperature-sensing probe. During initial testing, defective relays and problems with mechanical operation of dampers also prevented correct operation of the storage units. In the PSE&G test, a damper stuck in the open position. If it had stayed open, 760°C (1400°F) hot air from the storage section would have entered the house. However, the temperature safety override switch for the device operated to turn the blower motor off, not allowing this to happen.

Several problems were experienced with the failure of low-voltage control transformers and their protective fuses. Some transformers failed with open secondary circuits, and one failed because the contractor wired it incorrectly. During initial charging of storage units

and when only the night heating sections were allowed to operate, the 24-V control transformer's protective fuse failed in several storage units because an inrush 5-A current exceeded the 3.1-A steady-state rating of the transformers. Repair required removal of the transformer from the storage unit and disassembling the transformers to gain access to the cartridge-type fuse that was integral to the transformer and soldered in place. No additional transformer failures have been experienced since the steady-state demand on the transformer during on/off operation of the unit was estimated to be within the 3.1-A rating.

Initial charging and operation of the storage units were found to be a source of noxious odors. Initial heating of the units resulted in annoying odors associated with burning-in the insulation. When the storage units were first energized, rock wool insulation in the unit bonded together with a substance that vaporized when exposed to the heat, thus causing the annoying odor that generally lingered for 2 to 4 d, depending on ventilation. The odor recurred in some cases when the device did not heat to the maximum operating temperature during initial charging. UPA forewarned PSE&G of the problem. As a result, PSE&G charged the units to maximum operating temperature before connnecting the furnace into the customer's ductwork.

One unit in UPA's test produced blue haze and odor. This unit was disassembled and checked for irregularities. It was then reassembled with new brick and element components and a new thermocouple and hydraulic limiter. The problem did not recur. Also, UPA found in its test that extremely noxious odors can occur if vapors from certain adhesives, such as floor and paneling adhesives, or highly aromatic substances are allowed to circulate through the storage unit. These odors are believed to result from a chemical change occurring in the fumes of the adhesives at the high temperatures.

During summer 1980, PSE&G found that test homes with central air conditioning systems retrofitted with central ceramic brick storage units experienced poor cooling performance. The primary reasons were (1) insufficient air flow in the ductwork because of the installation of the storage unit and (2) air aspirations through the seams, joints, and

convection cooling louvres of the storage unit. Warmer-than-normal weather also exacerbated the air conditioning problems in several test homes. A 373-W (1/2-hp) multispeed motor was substituted for the 249-W (1/3-hp) motor to increase the air flow in the ductwork, and the storage units were sealed with duct tape and caulking to reduce the amount of outside air aspirated through the unit.

In the PSE&G test, insufficient storage capacity problems were experienced partly because the heat losses of the storage units were underestimated and thickness of insulation in the test homes was overestimated. Infrared scanning combined with a house pressurization/depressurization device revealed that poor home construction techniques and craftmanship were responsible for a high level of infiltration in some test homes. Another problem was that the original ductwork had some separations, which were attributed to the higher operating pressure of the storage unit fan. In addition, the infrared scan revealed that significant heat losses occurred through the surface of the new ductwork. PSE&G took several actions to correct the problems. They inspected, repaired, and reinforced both the new and existing ductwork in the homes, increased insulation in the homes, and took measures to reduce infiltration.

PSE&G experienced problems with high electric energy use in some test homes having the storage units located in garages because of the heat loss from the units and the aspiration of ambient garage air. These problems caused the excess energy use and contributed to the depletion of stored heat.

Problems were experienced with the logic boards in the storage units. In initial testing by PSE&G during the 1979-1980 winter, nearly half of 30 logic boards in the ceramic brick devices failed.

5.1.2 Pressurized hot water

The initial testing problems experienced with these units included heating element failures and failure of several internal control relays. However, some of these problems appear to have resulted from improper operation by personnel not adequately familiar with the system. Generally,

the units performed satisfactorily, although maintenance for leaks and control malfunctions was a continuing problem. Operational problems experienced by LILCO and VEPCO included defective hardware, a failed heat exchanger, leaks, malfunctioning mixing valves, and other hardware malfunctions.

During testing of the first device in the VEPCO test, leaks were found in the pipe coupling to the heat exchanger. The manufacturer of the storage unit repaired these leaks and checked all other test home installations for potential leaking problems.

Also, VEPCO experienced problems with the mixing valve in the Megatherm tanks not maintaining the correct temperature set point in several test homes and failing in four storage devices. The mixing valve controls the temperature at which water from the space heating hydronic system is heated by the storage device unit exchanger.

Storage unit flow switches, which were designed to indicate to the storage unit heat exchanger circulator pump when a flow is occurring in the space heating hydronic system, did not operate properly because of low-velocity water flow in the hydronic system. The low-velocity flow was caused by the long length of piping and extra valving required for test home installations.

In the LILCO test, an unusually high number of circuit breaker trips were experienced. These were caused by the poor air circulation around the storage unit circuit breakers.

The pressurized storage unit used in the test had four means of protection to prevent overpressurizing the storage tank, but LILCO had one case in which three of the four means failed. If the fourth protection — the pressure relief valve — had failed, the storage tank would have been endangered of rupturing with steam in excess of 517 kPa (75 psi) and 143°C (290°F).

5.1.3 Concrete slab

No systematic, scheduled operation of this system has yet been performed or monitored; however, the systems have been used to a limited degree, and no problems have been experienced.

5.1.4 Heat pump with storage

Early testing of the four installed heat pump devices revealed several operational problems. Improper valve assembly at the factory resulted in excessive frosting. This problem was solved by factory technicians and corrected. In spring 1980, NMPC discovered that the system charged with water could not withstand the severe cold temperatures of a Lake Placid, New York, winter. One or more water coils suffered freezing damage and had to be replaced. The devices were charged with glycol to solve the problem. The microprocessor control system for heat pumps has not operated successfully, indicating it is not a commercial or near-commercial control mechanism.

5.2 Storage Equipment Modifications

Several modifications were made to the central ceramic brick and pressurized hot water storage systems in the LILCO, PSE&G, UPA, and VEPCO tests in an attempt to correct operational problems experienced with these systems. NMPC has not reported any operational modifications because it is still preparing the systems for operational readiness for the 1981–1982 heating season.

Modifications to the central ceramic brick systems included making changes needed for UL approval, disconnecting electric charging elements to reduce electric demand during storage charging, recalibrating hydraulic limits, and changing the residences to decrease infiltration and home heating requirements. Modifications to the pressurized hot water storage systems included disconnecting electric charging elements to reduce electric load demand and eliminating storage unit flow switch operation. Modifications made for each type of storage unit are summarized below.

5.2.1 Central ceramic brick

PSE&G and UPA made minor modifications to central ceramic brick storage units to try to correct operational problems. PSE&G also made changes to the test homes to meet local codes and improve customer satisfaction with the storage heating system.

All storage units required modifications to meet UL specifications. At the time PSE&G and UPA began their review of the possible ceramic storage systems that could be employed in their tests, the storage unit did not yet have UL labeling. In the UPA test, modifications needed to bring the storage units up to UL requirements included replacing the safety contactor and logic panel in the damper section, replacing the high-temperature limits and hydraulic limit in the storage section, rewiring the supply panel in the storage section, adding a safety contactor to the auxiliary furnace section, and replacing relays in the auxiliary furnace section.

One of the utilities — PSE&G — did not connect two electric heating elements in the storage section of the storage unit because its residential load-management rate schedule allowed for a 10-h charging period vs the 8-h period preprogrammed into the charge controller. With the manufacturer's recommendation, PSE&G replaced the internal storage unit fuses serving these elements with ones of a smaller size.

Both PSE&G and UPA recalibrated the storage unit hydraulic limits to alleviate excessive tripping on and off of the unit's storage section. Also, in the UPA test, all storage unit thermostats were replaced with Honeywell round thermostats for better reliability.

In the PSE&G test, freeze protection devices were installed in the control circuit to turn on the storage unit auxiliary furnace if interior house temperature could not be maintained. Initially, these devices were installed by mounting to the return air ducts. However, in the garage locations this caused excessive trips, and those sensors were relocated to the laundry rooms in each home.

PSE&G added a 5-kW duct heater to the auxiliary furnace section in 29 of the 30 test homes. This addition was made because all homes had an existing 22-kW Lennox furnace. PSE&G believed that the lower heating capacity of the 15-kW TPI night heating section might be noticeable and, therefore, objectionable to the customers.

Early in winter 1979-1980, PSE&G noted that the storage furnace aspirated ambient air through the center-panel convection-cooling louvres during storage unit fan operation when the device was either charging or

in the off mode. This phenomenon presented no problem when the furnace was located in a heated space; however, with the PSE&G devices in the garages, outside cold air was being pulled through the storage section. An analysis of the energy use of the garage-located devices indicated excess energy consumption. In an attempt to reduce the heat loss, PSE&G taped the storage units along all seams as well as the louvres, added insulation to the plenums and ductwork, and built enclosures for the storage units.

5.2.2 Pressurized hot water

Modifications made by LILCO and VEPCO to the pressurized hot water storage devices included disconnecting electric heating elements, eliminating flow switch operation, and modifying control logic.

In the VEPCO test, two of the five 6-kW electric resistance heating elements in each Megatherm tank were disconnected and the associated power wiring removed, thus reducing the total connected electric load of the test home and spreading storage charging of the device over more hours. In the LILCO test, three heating elements were allowed to energize instead of only one element during the period that space heating was provided by heat storage because the storage device could not maintain the required minimum temperature in the test home.

The storage unit flow switches, which were designed to indicate to the storage tank heat exchanger circulating pump when flow occurs in the hydronic heating system, were made inoperative in the LILCO and VEPCO tests because of operational problems. In the LILCO test, to eliminate the flow switches from the operation, the Megatherm heat exchanger circulating pump was wired parallel with the home thermostat. In the VEPCO test, the Megatherm circulating pump was connected in parallel with the hydronic system circulating pump.

In the VEPCO test, control wiring of the Megatherm device was modified from an electric demand control system that would reduce the number of electric heating elements energized at one time to an electric energy control system that would reduce the storage temperature of the tank as a function of outside ambient temperature. The charging control

was made to operate in three temperature regions in a step function to provide three separate storage capacities for outdoor ambient temperature.

LILCO placed washers behind the bolts holding the front control panel to the Megatherm tank to improve air circulation in the area of the circuit breakers, thus reducing circuit breaker trips. Megatherm storage devices have since been redesigned with air vents in the front control panel.

5.3 Communication and Control Experience

The only utility that reported having significant operational problems with the radio communication and control system was UPA. LILCO reported none, and PSE&G, NMPC, and VEPCO reported only minor problems with the telephone communication and control systems. Major problems experienced by UPA included erratic operation of receiver switches, poor signal strength, and a malfunctioning master control unit.

The communication system at UPA was originally designed with one transmitter. According to vendor-supplied specifications, one transmitter should have given adequate coverage within a 40-km (25-mile) radius. Initial testing in early 1979 indicated poor reception beyond 19 to 25 km (12 to 15 miles), so three more 100-W transmitters were installed during late summer 1979. In addition, four monitors were installed to indicate transmitter operations. The radio system with the three transmitters provided a good strong signal; however, the frequency of 153 MHz was a poor choice because of interference from voice communications traffic, especially during high use times.

The original intent of UPA was to control the customer-side energy storage systems with a modified portable radio test unit; however, this unit was found to be incapable of communicating to more than one transmitter when the three additional transmitters were installed. The portable test unit was replaced with Scientific Atlanta's microprocessor-based message generator unit. The message generator crashed frequently because of minor voltage fluctuations until it was transferred to an inverter power supply and grounded through an isolation transformer. The unit

required a software change to increase transmission time, and major component failures occurred during 1980.

Some other operational problems experienced by UPA included problems with the erratic operation of receiver units. Severe weather conditions such as heavy lightning and thunderstorm activity caused sporadic operations of the transmitter monitors and switch operations. Also, computer printouts and switch event counters indicated erratic operation of the receiver switches even after the three transmitters were added and the message generator was operating as intended. A check of radio switch operations indicated that some switch responses were as low as 3% and others exceeded 100%. A faulty capacitor in the wave shaper circuit of the receiver units caused an excessive bandwidth, which enabled the switches to receive both water heater and storage unit signals. All switches were sent back to the manufacturer for repair and then returned to service.

NMPC, PSE&G, and VEPCO experienced only minor operational problems with the telephone communication and control systems. In the NMPC test, operational problems were experienced with the master control computer, RTUs, and the telephone link. The master station computer and peripherals failed on several occasions. However, each downtime was only for a few hours because maintenance personnel were nearby. During the post-Olympic remodeling phase of the dormitory buildings at Raybrook, some problems developed that were caused by cut signal wire, blown fuses on analog cards, and pulse accumulator failures in the RTUs.

The long line telephone service delayed operational checkout of NMPC's communication and control system. The telephone service from Systems Control, Inc., in Palo Alto, California, to Raybrook, New York, was discontinued in April 1980. Although the service was rescheduled for September 1980, it was not available until December 1980. Satisfactory service was available from December through January 1981, but problems arose during February, making the complete checkout of the control system impossible at that time.

In the PSE&G test, problems were experienced with the tone dialer cards of the DARCOM master controller. The cards were found to have

design problems that were also temperature sensitive and would, at times, not allow PSE&G to contact test homes. Testing indicated that the device sometimes would be slow in recognizing a dial tone or would not recognize it at all, resulting in a failure to contact a test home. Problems with the cards were caused by an overdriving of the phase-lock-loop circuits and a failure to consistently initialize the dialer chip. DARCOM redesigned and hand-reworked, tested, and shipped new dial tone cards to PSE&G.

PSE&G also experienced problems with the DARCOM remote devices. These problems included uncommanded operations of relays during storms and long weekends, a remote having both identification and access code errors, and interface card failure in the remote devices.

The DARCOM system was placed in operation in August 1979, and a number of cases appeared to be telephone system trouble. One problem was the large number of "trunk busy" signals that occurred at times. The "trunk busy" signals were usually severe enough that some locations could not be contacted, even after multiple attempts were made. These "busy" signals appeared in March, April, and December 1980. In each case, the problem cleared, and the telephone company reported no trouble found.

The majority of the software problems with the DARCOM system were found and corrected prior to the master controller leaving the manufacturer. The only software problem to appear after testing and during operational use of the DARCOM system involved the control strategy time table. Unless a nonstandard technique was used when revising the time table, certain entries would be buried in the software and reappear as unscheduled operations. Rather than revise the computer programming, a nonstandard technique was developed by PSE&G and used successfully during the test.

During April 1980, PSE&G experienced control problems involving the summer/winter switches at the test homes. Because of weather conditions in the PSE&G area, several storage customers elected to disable the storage section of the TPI storage units using the summer/winter switch. However, storage units were still being controlled by the DARCOM system.

On days when no heat was required, no problem occurred as far as the homeowner was concerned. However, on days when heat was required during the hours when the storage unit was deenergized, only cool air was supplied, resulting in the customer hitting the override to energize the auxiliary furnace section of the storage unit for heat. This procedure was required daily. Examination of the DARCOM control system logic revealed a constraint that prevented eliminating commands to only the disabled storage units and even eliminating commands to control all storage units. The system required the command to be sent to all three pieces of controlled equipment — storage unit, water heater, and electric meter — at the test home locations. To solve the problem, PSE&G requested all customers to disable the storage section of the storage unit. The storage units were then given the command to always store heat and activate the auxiliary furnace section. This solution made the auxiliary furnace section available on a 24-h basis under the control of the customer's thermostat without the necessity of a customer override.

VEPCO experienced minor difficulties with the leased telelphone line communication and control system. Minor defects in the hardware of two RTUs were corrected, and the computer software was modified to accommodate changes in instrument analog ranges on six test homes as well as the addresses on a number of other test homes.

Intermittent operation of the first installed telephone data line was traced to telephone company switching and was corrected. One installed telephone line and two slave home control cables were cut by others during excavations.

The communication system at VEPCO operated very satisfactorily, and experience was that an estimated 98% of commands transmitted were received and executed. The 2% of commands not executed were probably caused by equipment failure, equipment testing, battery failure from disconnected charging system, and other minor equipment problems.

5.4 Instrumentation Equipment Experience

Multitudes of instrumentation failures and problems were reported by all utilities except LILCO and NMPC. These problems included incorrect wiring, incorrect calibration, instrumentation design problems, and magnetic tape recorder failure. PSE&G, UPA, and VEPCO made changes to the instrumentation equipment to correct these problems. Changes included wiring, equipment design, and additional temperature-sensing equipment.

Instrumentation problems identified in the PSE&G test included measurement problems, incorrect wiring, incorrect pulse rates, and calibration problems. One instrumentation problem involved measuring the change in air temperature variable across the storage unit. Because of the electronic design of the temperature probe, the determination was made that pulses were generated at a certain rate dependent on the air temperature in the duct. Conversion to actual temperature was dependent on the same pulse rate being maintained for the entire metering interval. Therefore, if the storage unit cycled on and off during a metering interval, the temperature of the air being monitored varied as the duct air cooled during the off period. This temperature change resulted in a variation in the rate of pulses recorded on magnetic tape, leading to inaccurate data.

All the ambient air temperature probes were miswired because wiring colors on the probes differed from expected color coding. This problem was subsequently resolved. Also, the Btu and water meters did not perform properly because of a wiring problem within the meters.

Signal processors for the Btu meters were supplied by the manufacturer to measure the net energy used by the water heaters; these processors produced incorrect pulse rates. This problem was modified by PSE&G personnel in accordance with the manufacturer's instructions. Also, indoor temperature sensors were not well calibrated. Validity of these data is being reviewed for possible modification.

UPA experienced problems with signal conditioners, analog-to-frequency converters, temperature sensors, magnetic tape recorders, data-time sequence of data tapes, and other instrumentation. The utility also

experienced a much higher failure rate of instrumentation equipment than anticipated, requiring addition of more spare signal conditioners and analog-to-frequency converters.

Fifteen Scientific Columbus signal conditioners required repair because of operational amplifier failures. The problem was caused by transient spikes from the 120-V water meter relay and was solved by adding varisters to the signal conditioners.

Integrated circuit chips in 20 of the Scientific Columbus analog-to-frequency converters failed. Transient spikes were suspected to be the cause because the problem disappeared after the varisters were added to the input of signal conditioners.

Sensors used to measure the temperature of the storage unit continued to malfunction in several homes during the 1979-80 heating season. Special dual thermocouples were installed to alleviate this problem.

Duncan magnetic tape recorders failed at an unacceptable rate almost immediately after implementation. Communications with the factory personnel revealed the problem to be defective drive motors. These recorders were recalled and repaired by Duncan.

Two to five tapes collected each month indicated a data-time relationship of as much as 8 h out of synchronization. The reason for this problem was not identified; however, UPA believes it could have been eliminated. Data editing could have been made easier by coupling magnetic tape recorders in each home in a master-slave configuration and recording time on only one tape.

All instrumentation to measure delta storage unit air temperature was modified to measure actual inlet and outlet air temperatures. Also, the instrumentation to measure the delta domestic water heater temperature was modified to measure actual inlet and outlet water temperatures.

Instrumentation problems encountered in the VEPCO test included pulse generator failures and instrumentation design, calibration, and measurement problems. Several printed circuit boards for instrumentation pulse generators failed and were replaced. These failures were not discovered until erroneous data were found on tapes. Pulse generators for recording temperature data were incorrectly designed to

produce twice the required pulses per hour, resulting in data saturation on several tapes and in lost data. All temperature and humidity instrumentation was modified to deliver the correct pulse rate output, and a correction factor will be applied to all previous temperature and humidity data, if feasible.

Field recalibration of temperature and humidity instrumentation (sensors and amplifiers) was required when matched components failed and were replaced. The duct system air flow instrumentation performed unsatisfactorily because of difficulty in locating the air flow sensor in an area of the duct with minimum air turbulence. Outdoor air temperature sensors were relocated because of higher ambient temperatures in close proximity to the house.

6. CUSTOMER ACCEPTANCE

The philosophy of utility-controlled customer-side thermal energy storage is to allow the utility to control customer loads so the utility will be able to level electric load demand and, at the same time, provide the customer with uninterrupted space heating and domestic hot water. Ideally, thermal energy storage will provide the customer with the same space heating comfort as with conventional heating systems (oil, gas, and electricity) and with no change in the life-style acquired with conventional heating systems.

For the storage systems to perform as an electric demand-leveling tool and for the utility to provide the customer an incentive rate, the storage systems must have sufficient storage capacity to meet the heating requirement of the home and not cause the customer to override the utility control. If the storage system has insufficient storage capacity, then the customer will experience a lack of space heating or water heating and override the utility control of the storage system, thus defeating the demand-leveling principle of the storage system and eliminating benefit to the utility. Also, the storage system must respond accurately to the customer's thermostat to retain indoor temperature comfort in the house or building and must not be too noisy to disturb the customer at night, for example.

After the tests, all utilities circulated questionnaires or conducted face-to-face interviews using personnel from their marketing services, load-research, and load-management departments to collect data on the customers' attitudes towards the use of thermal energy storage to provide space heating and domestic hot water. Results of the tests generally indicated poor acceptance of the storage systems for space heating. Areas causing this poor acceptance included lack of sufficient heating, poor temperature regulation, poor equipment reliability, and high electric cost. Only VEPCO experienced negative acceptance of the storage domestic hot water heaters.

Three of the utilities — LILCO, PSE&G, and VEPCO — received complaints from their test home customers concerning the poor heating capability and the cost of heating with the storage systems probably

because of (1) insufficient storage capacity involving space heating and (2) operational performance. Some of the causes were the high heat losses of the storage units and the high level of home infiltration in the test homes caused by poor home construction techniques and craftsmanship. The high heat losses, as well as increased ductwork and piping and inadequate air flow in the duct systems for the storage installations, were determined to be responsible for the higher-than-normal electric energy used by test home customers.

Customer complaints about noise have been few. In the VEPCO test, most have been associated with the heat pump compressor or indoor air handler. Some noise problems with the storage domestic water heaters in the PSE&G test were caused by chattering of the load-leveling relay controlling the lower element assembly.

The only customer complaints on temperature regulation involved pressurized hot water units in the LILCO and VEPCO tests. These were related to the malfunctioning heat exchanger mixing valves in these storage units.

The number of times customers override the utility control of the storage systems is an indication that the customers are out of storage or that the units are not providing sufficient heat to retain temperature regulation. All the utilities except UPA reported an excessive amount of customer overrides, indicating that the units were neither operating properly nor sized properly for the test homes. During the heating season, VEPCO accumulated 1831 house days of experience. Customer overrides of the utility control were performed 230 times, or 12.6% of the total house days.

Three of the utilities removed one to two storage systems during the test because of insufficient storage capacity, inadequate heating, too many operating problems with the storage heating system, or customer skepticism about the economics of the system without utility subsidies. Some of the removals, however, were caused by customers who were not participating in the test purchasing homes from customers who were participating in the test. At the advice of these test home owners, the future customers requested removal of the storage systems. In the LILCO

test, one storage unit was removed because the customer felt that he had experienced too many operating problems with the heating system and that the system would not be economical in the future. In the PSE&G test, two storage units were removed, and some other customers requested removal to avoid summer cooling problems caused by the storage equipment. In the UPA test, the removal of a storage system prior to the 1980-1981 heating season because of insufficient capacity was a special case. The particular test home required 43,000 kWh for space heating during the 1979-1980 heating season. VEPCO reported no removals, despite frequent complaints of inadequate heating from the customers.

A final area of customer dissatisfaction was the high operating costs of the storage systems caused by the poor performance of the equipment and high kilowatt-hour use. In the VEPCO test, most test home participants were disappointed with the storage system because of the high number of operating problems and high operating costs. Billing adjustments are being made by PSE&G and VEPCO to all test home participants to compensate them for these problems and high energy uses.

UPA appeared to have the best customer acceptance of customer-side storage technology for space heating. Most of its test home participants indicated they will purchase the storage equipment after the test is completed.

Only one utility test, VEPCO, resulted in complete negative response to the domestic hot water storage. In this test, all the storage domestic water heaters were removed from utility control because of frequent customer complaints about insufficient amounts of domestic hot water.

7. COMMERCIALIZATION OF HEAT STORAGE SYSTEMS FOR USE IN LOAD MANAGEMENT

7.1 Reliability of Storage Equipment

Reliability of heat storage equipment for space heating and domestic water heating has a direct bearing on its commercialization. In these utility tests, reliability of equipment has been a major problem. During the tests, numerous utility service calls to customers' homes were made to correct operational problems with the storage equipment. Therefore, before the equipment can reach wide-scale commercialization and use and be reliable as a space heating system and a load-management tool, these equipment problems must be corrected by equipment manufacturers.

To be fully accepted by the utilities and their customers, customer-side energy storage systems will have to be as reliable as conventional space heating systems. This reliability includes system life, system performance, and types and frequency of equipment failures. Because of the extra controls, motors, and equipment components required to store heat in the storage device and discharge heat into the home, storage equipment apparently will have higher component failure potential than conventional space heating systems. Thus, better quality control standards need to be developed and applied by the equipment manufacturers to limit these potential problems. Qualified dealers with trained technicians, adequate spare equipment parts, and manufacturers' support are also needed so that the customer-owned storage equipment will receive fast repair service. Repair service and part replacement costs must be comparable to those of proven commercial heating systems as well.

Another item related to equipment reliability is the incorporation of some type of indicator of component failure in the storage equipment. A customer with storage equipment could be without heat for an entire day if a component in the storage equipment failed without warning and failed to store heat.

7.2 Economics of Storage Equipment

Economics of the heat storage systems for the customer will depend on the initial costs (capital and installation) and the operating costs of the systems. These costs will be dependent on reliability of the equipment, electric rate offered by the utility, and expected life of the system. In these tests, high capital equipment costs, high installation costs, and high maintenance costs were incurred, indicating poor economic feasibility. This indication is probably caused by the prototypic nature of the storage equipment. Therefore, costs incurred in these tests cannot be used to project the future costs of the storage systems or draw any conclusions about the economic feasibility of future heat storage systems. However, the initial cost of future storage systems will probably be higher than that of conventional heating systems because of the additional controls and materials required for storage equipment. This higher initial cost will tend to dampen sales of the storage equipment directly to homeowners and homebuilders.

As experienced during the tests, use of storage heating systems in the residential sector will affect utility distribution costs because of (1) increased peak demand requirements of a residential home with storage equipment and (2) lack of energy use diversity. Added demand from the storage system for space heating will cause increased expenses for distribution circuits and transformers.

Another utility-related cost is marketing the storage systems. For a utility to increase the penetration of heat storage systems on its electric system for load management, the utility must incur marketing costs that will cover training utility personnel and disseminating information on storage equipment to the customers.

To achieve load management with the customer-owned storage systems, the utility will need to have some type of control. In the early stage of implementing customer-side energy storage, the utility may choose to use time clocks or meter-activated devices such as a smart kilowatt-hour meter to control storage devices at customers' homes. Once substantial increases in penetration of storage systems are reached,

active remote utility control will be needed to achieve load management so the utility will not experience new load peaks with storage systems. Thus, a central control system with RTUs will be needed to give the required flexibility of utility control. Considerable uncertainties still exist in the cost, operation, and reliability of this type of communication and control system.

7.3 Controllability of Storage Systems for Load Management

Problem areas related to controlling the storage device for load management include central utility control vs device logic control, utility control between conditioning seasons, and communication and control system reliability. The control logic of the central ceramic brick storage devices, for example, determined the initial charge for the storage-charging mode based on outside temperature and a predetermined charging period. This built-in load-leveling capability of the storage device limited the utility's ability to remotely control charging the device.

The utility's central control of the storage devices in the tests was dependent on reliability of the communication and control system. Most utilities experienced reliability problems with the systems.

Utility control of the storage devices during intermediate seasons was another problem area. In some tests, test home participants experienced overheating during the fall and spring.

7.4 Commercialization Potential

Several factors have been identified in the tests that may tend to inhibit rapid acceptance and commercialization of the customer-side storage concept in the market place. These factors include high capital and operating costs, poor manufacturers' quality control of presently available storage equipment, and structural limitations that restrict installation of storage equipment in residential homes and buildings. Also, lack of accurate installation, checkout, and performance data on

the storage equipment and continuing availability of conventional heating fuels such as gas and oil will inhibit commercialization and customer acceptance.

8. CONCLUSIONS

The storage equipment that was used in the utility tests and is discussed in this report was advertised to be near commercial or fully commercial by the equipment manufacturers. However, the poor performance of the equipment in most of the tests indicated that the equipment was not near commercial and that this technology required further development before implementation by the utilities as a load-management tool.

In most field tests, the utilities experienced high capital, installation, and maintenance costs associated with the customer-side heat storage systems. These costs could lead to the conclusion that the systems are not economical for electric residential customers or economical as a load-management tool for electric utilities. However, the costs have been inflated because of the high capital cost of the test equipment that is not in mass production, the inexperience of the utilities and installation contractors implementing the storage equipment in these tests, and the poor operational performance of the storage systems. Therefore, these costs cannot be used to project costs of implementing commercial-type customer-side storage systems developed in the future.

In future tests of this nature, acceptance tests involving one to two test systems should be conducted to identify capital and installation costs for the systems. The study will shed light on any cost uncertainties associated with the new technology and will ensure that equipment is operational and can be maintained at a minimal cost. Only when acceptance testing is completed and the equipment shown to be operating successfully should full-scale tests be performed.

Customer acceptance of the utility-controlled customer-side storage technology in all but one of the utility tests has been extremely poor because of numerous operational problems with the storage systems, high electric energy use of the storage systems, and unproven commercial aspects of the technology.

Complete acceptance of utility-controlled customer-side heat storage technology by the public and by electric utilities for load

management will be inhibited by the continued availability of conventional space and water heating fuels, high costs of the available storage equipment, unproven commercial aspects of storage equipment, high costs and numerous operational problems associated with existing central communication and control systems, and lack of experience of heating, ventilating, and air conditioning contractors in installing and maintaining the storage equipment.

BIBLIOGRAPHY

Demonstration of Electric Load Management by Controlled Customer-Side Energy Storage, unpublished interim report by Public Service Electric & Gas, Newark, New Jersey, February 1981.

Directory of Electric Utilities, 1979–1980, 88th ed., Electrical World, McGraw-Hill, New York, New York.

Electric Power Research Institute, *Evaluation of Load-Management Systems and Devices,* EPRI EM-1423, Palo Alto, California, June 1980.

Interim Report for Thermal Energy Storage (TES) Demonstration Project — Heat Storage, unpublished interim report by Long Island Lighting Company, Mineola, New York, February 1981.

Interim Report — Thermal Energy Storage Demonstration Project, unpublished interim report by United Power Association, Elk River, Minnesota, February 1981.

Kuliasha, M. A., *Utility-Controlled Customer-Side Thermal Energy Storage Tests: Cool Storage,* ORNL-5795 (to be published).

Long, H. M., and D. L. Mohre, "Status of Load Management Storage Demonstrations," presented at IEEE Transmission and Distribution Conference, Atlanta, Georgia, April 1–6, 1979.

Long, H. M., and P. N. Overholt, "Load Management from a Department of Energy Perspective," presented at IEEE Power Engineering Society Winter Meeting, New York, New York, February 3–8, 1980.

Olympic Village Load-Management Demonstration Project, unpublished interim report by Niagara Mohawk Power Company Corporation, Syracuse, New York, March 1981.

Virginia Electric and Power Company TES Interim Report — Heat Storage, unpublished interim report by Virginia Electric and Power Company, Richmond, Virginia, January 1981.

ORNL-5796
Dist. Category UC-97b

Internal Distribution

1. S. I. Auerbach
2. P. R. Barnes
3. R. S. Carlsmith
4. G. E. Courville
5. P. D. Fairchild
6. W. Fulkerson
7. H. W. Hoffman
8. W. T. Jewell
9. M. A. Kuliasha
10. W. P. Levins
11-14. A. S. Loebl
15. J. F. Martin
16. B. W. McConnell
17. J. M. McIntyre
18. J. W. Michel
19. R. E. Minturn
20. W. R. Mixon
21-70. M. S. Newberry
71. S. L. Purucker
72. T. W. Reddoch
73-77. D. T. Rizy
78. G. Samuels
79. D. J. Slaughter
80. I. Spiewak
81. J. P. Stovall
82. R. C. Tepel
83. T. J. Wilbanks
84-85. Central Research Library
86. Document Reference Section
87-88. Energy Information Library
89. Laboratory Records - RC
90-92. Laboratory Records Department
93. ORNL Patent Section

External Distribution

94. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee 37830

95. R. D. Dunlop, Department of Energy, Division of Electric Energy Systems, 12th & Pennsylvania Avenue, Washington, DC 20461

96. J. R. Gracia, Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee 37830

97. H. F. Perry, Economic Regulatory Administration, Office of Utility Systems, Department of Energy, 2000 M Street, Washington, DC 20461

98. G. F. Pezdirtz, Department of Energy, Division of Energy Storage Systems, 20 Massachusetts Avenue, NW, Washington, DC 20585

99. D. J. Roesler, Department of Energy, Division of Electric Energy Systems, 12th & Pennsylvania Avenue, Washington, DC 20461

100. J. C. Skroski, Department of Energy, Division of Electric Energy Systems, 12th & Pennsylvania Avenue, Washington, DC 20461

101. T. C. Smith, Department of Energy, Division of Electric Energy Systems, 12th & Pennsylvania Avenue, Washington, DC 20461

102. J. H. Swisher, Department of Energy, Division of Energy Storage Systems, 600 E Street, NW, Washington, DC 20545

103. Robert Ashburn, Long Island Lighting Company, 250 Old Country Road, Mineola, New York 11501

104. Lowell Endahl, National Rural Electric Cooperative Association, 1800 Massachusetts Avenue, NW, Washington, DC 20036

105. C. W. Gellings, Public Service Electric & Gas Company, 80 Park Place, Room 2168A, Newark, New Jersey 07101

106. Jack Kinirons, Long Island Lighting Company, 250 Old Country Road, Mineola, New York 11501

107. Earle Knowles, Arizona Public Service Company, P.O. Box 21666, Phoenix, Arizona 85036

108. R. E. Leber, American Public Power Association, 2600 Virginia Avenue, NW, Washington, DC 20037

109. John Lobdell, Virginia Electric & Power Company, Richmond, Virginia 23261

110. J. M. Loorya, Pacific Gas & Electric Company, 77 Beale Street, Room 2700, San Francisco, California 94106

111. Robert Malko, Electric Utility Rate Design Study, Electric Power Research Institute, 3412 Hillview Avenue, Box 10412, Palo Alto, California 94303

112. R. A. Maraio, Niagara Mohawk Power Corporation, 300 Erie Boulevard, W, Syracuse, New York 13202

113. Mike McGrath, Edison Electric Institute, 1111 9th Street, Washington, DC 20036

114. John McLean, Wisconsin Electric Power Company, 231 West Michigan Street, Milwaukee, Wisconsin 53201

115. Dorman Miller, American Electric Power Service Corporation, Two Broadway, New York, New York 10004

116. D. L. Mohre, Allegheny Electric Cooperative, Inc., 212 Locust Street, P.O. Box 1266, Harrisburg, Pennsylvania 17108

117. P. N. Overholt, Honeywell, Inc., 7900 Westpark Drive, McLean, Virginia 22102

118. Ken Pollack, Inform, 25 Broad Street, New York, New York 10004

119. Veronica Rable, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, California 94303

120. Don Reck, Wisconsin Electric Power Company, 231 West Michigan Street, Milwaukee, Wisconsin 53201

121. David Stricos, New York Public Service Commission, Empire State Plaza, Agency Building No. 3, Albany, New York 12223

122. Robert Stukey, Rural Electrification Administration, U.S. Department of Agriculture, Washington, DC 20250

123. Andrew Tokmakoff, California Public Utility Commission, 107 South Broadway, Los Angeles, California 90012

124. Fred Whitmore, Arkansas Power & Light Company, P.O. Box 551, Little Rock, Arkansas 72203

125. Vance Zehringer, United Power Association, Elk River, Minnesota 55330

126. Orin Zimmerman, Electric Power Research Institute, 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, California 94303

127-203. Mailing List for the IEEE Load Management Working Group

204-459. Given for distribution as shown in DOE/TIC-4500 under Category UC-97b (Electric Energy Systems Power Distribution)

* U.S. GOVERNMENT PRINTING OFFICE: 1981-546-067/375