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TENNESSEE VALLEY AUTHORITY

Division of Energy Conservation and Rates

WATER-HEATING/SPACE-CONDITIONING

CONTROL TEST

1979 - 1981

Final Report

Prepared by

Load Management Branch

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EMB

EXECUTIVE SUMMARY

In fall 1977, the Tennessee Valley Authority (TVA) Board of Directors (Board) authorized a $1.5 million test project to assess the potential TVA/distributor system benefits from specific residential electrical load management techniques. The test became operational on July 2, 1979, and was completed March 31, 1981. The purpose of the test, which utilized a study sample of 457 single-family homes, was to quantify the benefits to be gained from managing residential water heating and space conditioning (both heating and cooling), to measure consumer acceptance of load management technology, and to gather information about the various components of the residential demand for electricity. An interim report summarizing information gathered during the summer of 1979 and winter of 1979-1980 was published in the summer of 1980.

The purpose of this final report is to describe the test design, data collection procedures, analytical methods, analysis results, and study conclusions concerning load management for TVA. The analysis and final conclusions are based on the data from the second year of the test, since experimental adjustments made after the first year provided better quality data in the second test year.

The study indicates that management of standard and storage water heaters can achieve a 1.36-kW peak demand reduction per unit during winter months and a 0.39-kW peak demand reduction per unit during summer months. Management of residential central air-conditioning can produce a 1.0-kW peak demand reduction per unit on very hot summer days when the maximum daily temperature reaches at least 100°F. A 0.65-kW peak demand reduction per air-conditioning unit could be achieved on a day with a maximum temperature of 96°F. These air-conditioning demand reductions result from a 25-percent (7.5 minutes off during a 30-minute period) management strategy.

Additional data and analysis are necessary to draw conclusions about the load reductions which can be obtained through load management of central electric furnace space heating. Analysis of the space heating test data, which was based on the 25-percent cycling strategy, showed negligible peak demand reductions and suggests that longer off times would be required to produce significant load reductions from cycling central electric resistance furnaces.

Less than 2 percent of the test participants stated that they would not take part in a load management program on a permanent basis which is evidence of wide acceptance by those taking part in the test of load management.

This test was based on a large sample size and yielded comprehensive appliance and total load data from the homes that participated in the test. The test results and data will have many planning and operational applications. Future residential energy use and/or residential load management studies will be able to build on this substantial data base.

Currently, TVA is cycling water heaters and central air-conditioning of residential and under 50-kW commercial consumers through the volunteer Cycle & Save Program.

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1. INTRODUCTION

1.1 Overview

In October 1977, the Board authorized a $1.5 million test project to determine the potential system benefits from specific residential load management techniques. Preliminary studies indicated that water heater management was a potentially viable and economically attractive activity within the TVA system. Further, the large amount of space conditioning (heating and cooling) load in the TVA service area emphasized the need to perform a comprehensive investigation to determine the feasibility of managing such loads.

This project, the Water Heating/Space Conditioning Control Test, was TVA's first large-scale attempt to evaluate end-use load management methods. It was designed to gather and analyze data pertaining to a number of related topics. These topics included the advantages and disadvantages derived from managing residential water heating, the ramifications of extending management to residential space conditioning, consumer acceptance of load management techniques, and further information about the various components of residential demand for electricity.

The test officially became operational on July 2, 1979, with a planned life of 2 years. The test was terminated on March 31, 1981, since adequate summer data had been collected during the summer of 1980 and continuing the test until July 1981 would interrupt data collection during the 1981 cooling season. In March 1981, TVA initiated a larger follow-up program (Cycle & Save) to introduce the load management concept to the TVA service area.

1.2 Test Objectives

The Water Heating/Space Conditioning Control Test had the following objectives.

1. To assess the potential of residential water heaters and space conditioning systems for load management with attention to economic justifications, TVA system effects, and consumer acceptance considerations. Appliances monitored and managed included:

   - Standard electric water heaters.[1]
   - Superinsulated 120-gallon storage water heaters.

1. Standard water heaters, as opposed to 120-gallon storage water heaters, are defined as those electric water heaters initially found in the test homes.

- Central air-conditioning systems.
- Heat pumps in the cooling mode.[2]
- Electric resistance heating systems.

2. To collect baseline load data from selected large electrical home appliances. These data were added to an existing TVA data set for use in future program evaluations and studies.

1.3 Project Responsibility

The Electrical Systems Group in the Division of Energy Demonstrations and Technology and the Load Management Branch in the Division of Energy Conservation and Rates had joint responsibility for load management during the first 9 months of the project. The test equipment and load management responsibilities for the project were totally transferred to the Load Management Branch in March 1980.

1.4 Report Organization

Chapter 2 describes the test design and the general experimental approach. Chapter 3 addresses the sampling process for the selection of distributor and consumer participants. The test equipment is referenced and described in chapter 4 and cycling strategies and schedules are discussed in chapter 5. Chapter 6 reports the consumer participants' responses to the load management of various appliances.

The experimental methods and empirical results of cycling standard water heaters, storage water heaters, central air-conditioners, and forced-air central electric furnaces are discussed in chapters 7, 8, 9, and 10, respectively.

The final chapter presents a summary of the study results and an overview of TVA's load management program plans.

Appendix A, the referenced appendix, contains most of the tables referred to in the discussions of the data and analyses in chapters 6 through 10. Appendix B contains tables presenting the results of the data analyses not explicitly mentioned in the test report. These tables present additional data on the test results for the reader who requires more extensive information.

All times referenced in this report refer to central standard time or central daylight time depending on the season of interest.

2. Initial plans provided for the management of heat pumps on a year-round basis; however, potential problems in interrupting the defrost cycle made management during the heating season infeasible.

2. TEST DESIGN

The Water Heating/Space Conditioning Control Test involved 457 residential consumers from four distributor areas representative of the broad range of climatic and geographic variations and time zone differences in the TVA service area.[1] The test sample is described in detail in section 3.2.

The test sample was divided into the following subgroups based on the appliances being cycled and monitored.

1. Standard water heater cycled, other appliances monitored. Other electrical appliances monitored included electric ranges, electric clothes dryers, window air-conditioners, and electric diswashers.

2. Standard water heater cycled, central air-conditioner or heat pump cycled.

3. Standard water heater cycled, central electric heater cycled.

4. Managed 120-gallon storage water heater, central air-conditioner or heat pump cycled.[2]

5. Managed 120-gallon storage water heater, central electric heater cycled.[2]

The test was purposely designed without a separate control group. Instead, each home served as its own control for statistical comparison. Load management of the participants' appliances was implemented on alternate weeks and baseline information was collected during the intervening weeks.[3]

The load control system consisted of an FM radio central controller, four base station transmitters (one located in each participating distributorship), and radio-controlled switches installed on the residential appliances. Most of the appliance load management was executed by sending an

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1. TVA wholesales power to 160 power distributors located in seven states. These distributors in turn sell power to all residential and most commercial and industrial end-use consumers.

2. Test participants in these subgroups were furnished the storage water heaters at no charge. The term "storage water heater" as used in this report denotes a large-capacity (120-gallon), superinsulated water heater.

3. During the 1980-1981 winter season, additional electric furnace consumers were monitored to provide more unmanaged space heating data. This was deemed necessary because data collection difficulties and weekly weather variations prevented the collection of adequate space heating control data.

FM radio signal from a base station receiver to the radio receivers on residential appliances.[4] These base stations were keyed by the Chattanooga-based central controller. During certain hours of the day standard water heaters, storage water heaters, central air-conditioners, and central electric furnaces were cycled, i.e., turned off, for varying amounts of time. The cycling schedule implemented depended on the type of appliance being cycled. Detailed descriptions of the load management equipment used and of the cycling schedules employed are presented in chapters 4 and 5.

A 4-channel magnetic tape load survey recorder logged various types of load data from each of the 457 test homes. By recording electrical pulses, this equipment stored three quantities of electrical consumption. For each home, total home load and total electric water heater load data were recorded. The third data channel was utilized to collect data from those space conditioning systems being cycled or to gather baseline data from another large electrical appliance.[5]

The reduction in electrical demand achieved through load management of a particular appliance was quantified by comparing properly adjusted baseline and managed loads.[6] The raw baseline loads were adjusted to reflect the differences in parameters that affected the data. These parameters included climatic conditions, appliance usage habits, etc., which changed from week to week.

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4. Refer to section 4.4 for a description of the auxiliary method.

5. Other electrical appliances monitored included electric ranges, electric clothes dryers, window air-conditioners, and electric dishwashers.

6. Refer to sections 9.2.2, 9.3, 10.2, and 10.3 for descriptions of adjusted loads.

3. SAMPLING PROCESS

3.1 Distributor Selection

Immediately following the Board's approval of the project authorization for this test, all TVA district managers were asked to poll their respective area power distributors to determine their interest in participating in a test of this nature. General guidelines were supplied to the districts for evaluating potential distributor participants. These guidelines were only advisory since the field offices were considered best equipped to evaluate the interested respondents. The guidelines suggested that the participating distributors should have sufficient staff and technical expertise to accomplish the installation, testing, and maintenance of the radio and metering equipment within a stated time schedule. Equally important, the distributor's management should have a strong commitment to carry out an experiment of this scope. Each distributor was to designate one person whose full-time responsibility would be to see that the various project requirements were accomplished on schedule. This "project contact" would act as the intermediary between TVA and the power distributor.

Other criteria used to evaluate and select individual distributors included geographic location, climatic characteristics, time zone, radio coverage, and saturation of electric water heating and space conditioning considerations.

To represent as much of TVA's large service area as possible, geographic location was taken into consideration when distributor selection was made. The TVA service area encompasses a wide range of weather conditions; therefore, it was necessary to collect data from several representative climatic regions. Further, TVA operates in both the eastern and central time zones; therefore, both time zones were represented in the test.

The availability of adequate radio coverage was of utmost importance in the distributor selection process. In some cases it was not feasible to cover the service area of a distributor interested in the test due to the limitations of FM transmission. The selected test equipment provided a coverage of approximately a 20-mile radius from each base radio station. The distance from the Chattanooga-based central controller made it necessary to utilize the existing TVA microwave network to communicate the signal frequency used for load management to each remote radio location. Therefore, it was important for the selected distributors to be accessible by microwave or relatively close to the termination of a microwave circuit.

The TVA districts identified approximately 20 power distributors which expressed an interest in participating in TVA's Water Heating/Space Conditioning Control Test. From this list, the TVA district management and load management officials evaluated distributor characteristics and made final recommendations. Finally, four power distributors were invited to participate. These distributors, whose geographic locations are indicated in figure 3-1, were:

- Cleveland Utilities	Cleveland, Tennessee
- City of Huntsville Utilities	Huntsville, Alabama
- Jackson Utility Division	Jackson, Tennessee
- Tri-County Electric Membership Corporation	Lafayette, Tennessee

3.2 Consumer Selection

In addition to requiring geographic dispersion among selected participants, it was also important to obtain a test sample as representative of Valley homes as possible given the financial constraints of the study. A sample size of about 500 participants (or 125 consumers per distributor) was considered adequate to achieve a representative sample of single-family homes.

3.2.1 Original Sample Design

Consumers were selected from each distributorship by a method of stratified random sampling. The stratification variable used was average monthly energy consumption during the July 1977 through June 1978 period. For two distributorships, a primary sample and 10 backup samples were selected. For the other two distributorships, the upper strata were exhausted after seven samples were drawn.

Following screening to eliminate apartments, street lights, electric fences, etc., consumers in the primary and first two backup samples were mailed a letter explaining the test and inviting them to participate.[1] TVA sought the participation of 300 consumers who would allow their existing electric water heaters to be cycled off for specific periods of the day. An additional 200 consumers who would allow not only their water heaters but also their central heating or air-conditioning systems to be cycled during management periods were also solicited. (It was hoped that these 200 consumers would be evenly divided between the heating and air-conditioning cycling groups.) Of these 200 participants, 100 were randomly selected to receive superinsulated, energy-efficient, 120-gallon storage water heaters to test the feasibility of offpeak water heating.

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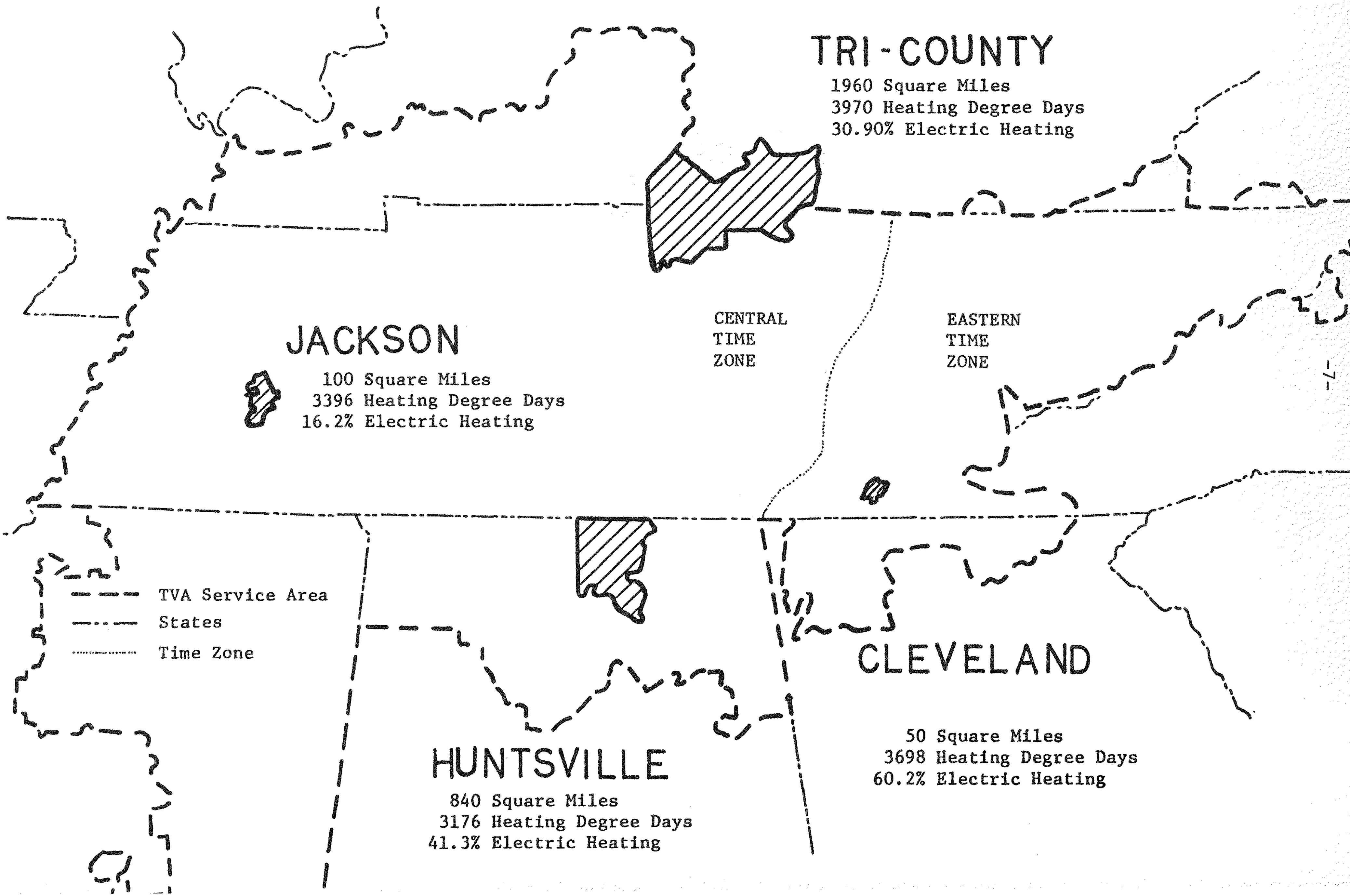
1. Single-family dwellings were favored to apartment or multifamily housing units to simplify the administration of the test and to enhance the probability that the occupant would reside in the test home for the duration of the test.

Figure 3-1

DISTRIBUTOR LOCATIONS



3.2.2 Random Sample Selection Attempts

The process of participant recruitment began in October 1978 and by March 1979, 1,500 letters had been mailed out. Approximately 15 percent of these consumers responded by agreeing to participate in the test. However, these respondents were not evenly distributed by consumption strata or type of heating systems. Almost all the response was from the medium to high consumption strata with virtually no response from the low and very high consumption groups or from consumers with central electric furnaces. The letter of invitation requested interested consumers to respond only if they had an electric water heater. Unfortunately, an unquantifiable number of consumers had gas water heaters and for that reason did not reply. (There was no method to identify and eliminate these consumers beforehand.) Although saturations of electric heat may have been high in some areas, many of the heating systems were heat pumps, ceil heat, or wall heaters, all of which were unsuited for management by a single radio switch.

3.2.3 Volunteer Approach

As the summer of 1979 approached, it became important to obtain as much data as possible to determine the potential TVA system benefits from managing loads during the cooling season. In an effort to increase the number of participants, the decision was made to abandon the original sampling process and adopt a volunteer approach to obtain the sample. All residential consumers in the four distributor areas were invited to volunteer for participation in the test. The stratification boundaries, the requirement for equal allocation among strata, and the 50/50 quotas for heating and air-conditioning were still to be maintained in the sample designation. While overall response increased slightly, still few responses from low consumption and central electric furnace consumers were received. By mid-May 1979 all stratification boundaries and quotas for heating systems were eliminated. Table 3-1 presents a summary of the demographic characteristics by geographic subset of the final test sample.

3.2.4 Participant Incentive Payments

Participating consumers received incentive payments according to the following schedule:

- Consumers with only standard water heaters managed received $50.

Table 3-1

PARTICIPANT CHARACTERISTICS

MEDIAN VALUES

	Cleveland	Huntsville	Jackson	Tri-County	Overall
Number of household inhabitants	3(103)	3(100)	3(87)	3(125)	3(415)
Age of head of household (years)	35-44(103)	45-54(100)	35-44(87)	35-44(125)	35-44(415)
Number of bathrooms	2(102)	2(100)	2(85)	2(125)	2(412)
Age of house (years)	6-10(103)	11-15(100)	1-5(86)	6-10(125)	6-10(414)
Inches of floor insulation	0(95)	0(96)	0(82)	0(122)	0(395)
Inches of wall insulation	3(89)	3(99)	3(81)	3(122)	3(391)
Inches of attic insulation	6(95)	6(90)	6(84)	6(118)	6(387)
Percent with storm windows**	47(101)	73(96)	73(81)	99(124)	74(402)
Number of water heaters	1(103)	1(100)	1(87)	1(125)	1(415)
Size of water heaters (gallons)	30-50(102)	51-75(97)	30-50(87)	30-50(125)	30-50(411)
Percent with dishwashers**	67(103)	81(99)	67(86)	49(125)	65(413)
Percent with washers**	95(103)	97(93)	93(85)	97(125)	96(406)
Electric furnace capacity (kW)*	13.6(72)	14.7(54)	16.4(36)	16.5(105)	15.4(267)
Air-conditioning capacity (Btuh)*	31,900(72)	44,800(67)	34,200(28)	28,800(113)	34,000(280)
Home square feet*	1,807(102)	1,904(97)	1,796(77)	1,484(123)	1,729(399)

*Mean value
**Percentages, not mean or median value
Subsample or sample sizes are indicated by parentheses

- Consumers with standard water heaters and central heating or cooling systems managed received $90.[2]

- Consumers with TVA-supplied, 120-gallon storage water heaters and central heating or cooling systems managed received the water heater as their incentive for participating.[2]

Cash incentive payments were divided into an initial $25 payment at the beginning of the test and a $25 or $65 payment at the conclusion of the test. Consumers were usually unaware of the incentive until after they had agreed to participate.

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2. Heat pumps were considered central air-conditioners for the purposes of the test.

4. TEST EQUIPMENT

The Water Heating/Space Conditioning Control Test equipment for communicating load management directions to home appliances consisted of an FM radio central controller, four base station transmitters, approximately 615 home FM radio receivers, a distribution line control system, and associated load survey equipment.[1] These system components are briefly described in the sections which follow.

An FM radio frequency was dedicated to TVA for use during the test. Since TVA is a government agency, it has the advantage of being able to obtain dedicated radio frequencies. Often non-government users of FM radio frequencies have to share their FM band with other users which can cause unacceptable interference.

4.1 FM Radio Central Controller

The central controller was manufactured by Motorola Communications and Electronics, Incorporated, and is designated a Model DIV-4 TLC. It was configured to generate four audio tones. Each tone remotely initiated management of the standard water heaters (tone 1), the 120-gallon storage water heaters (tone 2), the central resistance electric heating systems (tone 3), or the central air-conditioners (tone 4). The controller contained four tone-generator boards and the logic circuits necessary for gating the tones through a console to the base radio stations in the four participating distributorships. The transmissions from the console to the stations were accomplished through the existing TVA microwave network.[2] The controller also contained the logic and formatting circuitry required to drive a printer. The printer routinely recorded the time, the initial tone transmission patterns, and the acknowledgments from the four base radio stations. The central controller was located with the Load Management Branch in Chattanooga, Tennessee.

4.2 Base Station Transmitters

The four base station transmitters were 250-watt stations located at Cleveland, Tennessee; Jackson, Tennessee; Monte Sano (Huntsville), Alabama; and Russell Hill (Tri-County Electric Membership Corporation service area), Tennessee. The base stations, after receiving an audible tone from the central controller, transmitted a series of tones

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1. Many test homes had more than one radio receiver to accommodate the management of both water heaters and space conditioners.

2. In Jackson, Tennessee, the microwave link terminated at the Jackson substation. However, the base station transmitter was located at Norton Hill. Two voice-grade circuits were the communication link between the microwave termination point and the base station.

to the individual load management receiver units located at the consumers' homes. Each base station also monitored the transmitted control tones and reported back to the central controller in Chattanooga that the tones were, in fact, transmitted. The four base stations reported back in sequence to avoid simultaneous transmissions.

4.3 Home FM Radio Receivers

The radio receiver units were Motorola 800-W remote radio switch receivers. Each unit contained an FM radio receiver, antenna, control relay, and a power supply. The switch was designed for interior or exterior mounting. Since the unit contained an FM radio receiver operating in the VHF frequency range and had a built-in antenna, there were specific location requirements. It was recommended that the remote switch be mounted as high as possible when installed in a home basement. The decision was made to install the radio switch on the weatherproof submetering equipment enclosure whenever feasible. However, this was not always an optimal location for FM reception.

4.4 Distribution Line Control Device

After FM transmission proved to be unsatisfactory in the remote parts of Tri-County Electric Membership Corporation's large, mountainous region, TVA and Tri-County agreed to accept the English Electric Corporation's proposal to install and test their Cyclocontrol system. This device relayed the load management commands to the test residences through the distribution line via a coded distortion in the normal electrical voltage waveform. A 69/13-kV substation was chosen at Westmoreland, Tennessee, for the installation because of its location with respect to test homes without FM coverage and the existence of desirable facilities.

The Cyclocontrol transmitter was installed and in service by March 1979. During March and April of 1979, 20 remote, 2-channel receivers were installed in test participants' homes. The consumers linked by the Cyclocontrol system were subjected to the same basic management schemes as the participants linked by the Motorola system, i.e., their water heaters were turned off for several hours per day and their air-conditioners were cycled off for short periods every half hour.

Unlike conventional ripple systems which require considerable power, Cyclocontrol extracted power in such a way as to modify the 60-Hz waveform. This distortion was applied as far as possible from the voltage peaks to avoid adversely affecting normal voltages. Because the signal had no significant high frequency component, attenuation along the distribution network was negligible.

4.5 Load Survey Equipment

A General Electric PDM-76 4-channel magnetic tape recorder was installed at each test residence to collect detailed information about electrical usage patterns. The 4-channel recorders were used for collecting load data from three sources. The fourth channel recorded a time pulse every 15 minutes or one pulse for each revolution of the recorder capstan.

Each source of data was metered by a GE IW70-S watthour meter which was equipped with a D-53 pulse initiator. This device generated a pulse by opening or closing a relay each time the meter disk made a specific number of revolutions. A 1:1 ratio of pulses to disk revolutions was used in this test. Therefore, each revolution of the meter disk caused a pulse to be recorded on the appropriate track of the tape cartridge. Each pulse recorded on a data track represented a specific number of kilowatthours. Since the data tracks were recorded parallel to the time track, the number of energy pulses between each time pulse could be summed to derive the integrated demand over any 15-minute multiple time period. In addition to demand data, processed magnetic tape data provided hourly diversified demand profiles which were used for most of the time-of-day analyses of this test.

4.6 Unique Tape Translation Equipment

A multipurpose analog to digital translation system was used for magnetic tape analysis. The translation system was built by Vitro Services, Incorporated, of Fort Walton Beach, Florida, for TVA and designated a DCS-50. The analysis consisted of partitioning 15-minute tape segments into 1-minute divisions. Translation of each 1-minute division provided an estimate of the electrical demand for each appliance monitored during each minute of interest.

5. CYCLING SCHEDULES AND STRATEGIES

The management of water heaters is defined as cycling or turning the water heater elements off for several hours each day. The management of space conditioning is defined as cycling or turning the space conditioning appliance off for 7.5 minutes during each 30 minutes of the management period.[1]

In the early months of the test, load management was implemented 7 days a week during each load management week. Management schedules for standard water heaters varied from day to day while space conditioning and storage water heater schedules remained fixed. After several months of operation, weekend management of storage water heaters was eliminated to allow participants more flexibility for activities such as washing clothes which are not normally accomplished during management times of week days.

As stated previously, the original standard water heater schedules varied from day to day. However, these variable schedules were replaced with fixed daily schedules. This modification was made to provide more useful data for analysis and planning of future programs. Beginning in March 1980, attempts were made to limit load management of standard water heaters to periods that were coincident with the TVA monthly system peaks. Storage water heaters were originally managed for periods as long as 16 hours per day; however, some consumer inconvenience resulted and shorter management schedules were implemented to allow afternoon recharge periods (which also corresponded to the normal winter TVA load profile) during the winter months of the test. For both types of water heaters, the fixed schedule was repeated for 1 week then followed by an unmanaged week.

Space conditioning cycling schedules were fixed daily but varied weekly in duration. One week of scheduled management was followed by an unmanaged week, the same as for water heaters. Also, attempts were made to manage space conditioning appliances during periods that were coincident with the TVA monthly system peaks. This was easier than with water heaters since space conditioning appliances are utilized only during the summer and winter months when TVA system monthly peaks usually occur in the late afternoon and morning hours, respectively.[2]

Management periods were planned for the 2-year test. The majority of unique management baseline sequences were repeated once. To facilitate analysis, the data from two or more management periods were often combined and averaged to purge random disparities and to effectively increase the number of observations used to determine load management effects.

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1. The compressor was managed for air-conditioners while the resistance heating elements and circulation fans were managed for electric furnaces. The air-conditioning circulation fans were not managed in order to allow uninterrupted air movement during the summer months.

2. Water heaters are utilized during the entire year. Monthly system peaks are often difficult to predict during the spring and fall.

6. CONSUMER RESPONSE TO LOAD MANAGEMENT TECHNIQUES

6.1 Introduction

A major objective of the Water Heating/Space Conditioning Control Test was to determine consumer response to various end-use load management techniques, specifically, load management of both standard and storage electric water heaters and cycling of central electric heating and cooling systems. This chapter describes the methods used to examine consumer response and the results of analyses of the collected data.

6.2 Method of Assessment

Consumer acceptance of load management was assessed using several measures during the test. Each time a consumer experienced discomfort or inconvenience great enough to prompt a call to the power distributor, a standardized "trouble report" form was completed and forwarded to the Load Management Branch. In May 1980, a midtest survey was mailed to all test participants. About 70 percent of the surveys were returned. Summary results of the "trouble reports" and the survey are contained in chapter 6 of the interim report.

Following completion of the test, a posttest questionnaire was distributed in the summer of 1981. Responses were received through January 1982. Response to this survey was considerably lower, with only 165 consumers out of 456 (about 36 percent) responding.[1]

The posttest questionnaire was designed to address the following points of interest:

- Consumer awareness of load management as measured by the extent to which consumers knew which of their appliances were under load management and knew the cycling schedules for those appliances.

- Consumer acceptance of load management as measured by consumer reports of hot water availability and home comfort levels.

6.3 Consumer Awareness of Load Management

The posttest survey sought to investigate how knowledgeable consumers were about the application of load management in their home. Specifically, two questions were designed to measure this. One asked if the consumers knew which of their appliances were load managed. The other

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1. Of the original 457 test participants, 1 dropped out of the test before the end of the 2-year test period.

asked if they knew the load management schedules which were applied to their appliances. Table A-1 summarizes the respondent's answers to these questions.[2]

Of the 128 respondents to the question concerning which appliances in the home were "load managed," 75 of the respondents answered correctly. The remaining consumers most commonly thought that appliances in addition to the water heater were cycled, when in fact they were not.

Of the 127 respondents to the question of when load management was conducted, only 5 answered correctly--5 days a week, alternating weeks. Some 50 consumers indicated they did not know or were not sure and 69 consumers thought load management was conducted 7 days a week, year round.

An analysis of the relationship between correct or incorrect knowledge of cycling category and of which appliance(s) were cycled indicated a significant correlation between these two factors.[3] In other words, those participants with only water heaters cycled had a poorer knowledge of which appliance was cycled than expected, while those participants with both water heaters and space conditioning systems cycled had a better knowledge of which appliances were cycled than expected.

6.4 Consumer Acceptance of Load Management

The posttest survey responses were analyzed to assess consumer acceptance of water heater cycling and air-conditioner cycling.[4] Consumer acceptance was operationally defined in terms of consumer reports regarding hot water availability (for standard and storage water heater cycling) and comfort levels (for air-conditioner cycling).

6.4.1 Water Heating

Of the 165 respondents to the posttest survey, 125 answered the question concerning hot water availability. Table A-3 summarizes the answers to this question. The analysis of

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2. Tables A-1 through A-6 are found in appendix A.

3. A Chi-square analysis was used to test the correlation between the variables of interest. The chi-square statistical technique is used to find significant correlations between two factors that are of a categorical nature. See table A-2 which summarizes the results of this analysis.

4. Space heating comfort levels were not assessed. Refer to chapter 10 for detailed discussion of test results related to the management of central forced-air electric furnaces.

this data indicates that 91 (73 percent) of these consumers discerned no difference in availability of hot water during the test as compared to before the test. In addition, seven consumers (6 percent of the respondents) indicated that service was better during the test. Only two of these seven consumers, however, were using their original standard water heaters; the other five had 120-gallon storage water heaters installed for the test.

On the other hand, 24 (19 percent) of the respondents indicated that hot water availability was worse during the test. Only 1 of these consumers had a storage water heater installed; the other 23 consumers reported inferior service from their original water heaters as a result of cycling.

Several statistical analyses were used to determine significant factors that may help explain participant response to the "no difference" and "worse" categories in relationship to hot water availability before and during the test.[5]

The first analysis correlated the type of water heater, i.e., standard versus storage, with response to hot water availability. A significant correlation was found and observation of the response data indicated that fewer responses occurred in the "worse" category for the storage water heater participants than was expected. Therefore, the major portion of hot water unavailability during the test can be attributed to standard water heaters.

From the test data and record of consumer complaints during the first year of the test, standard water heater sizing guidelines were developed. These guidelines were used to classify the standard water heater participants of the posttest questionnaire into the sizing categories of "properly sized" and "undersized" according to available home demographics, such as number of inhabitants, number of bathrooms, presence or absence of a dishwasher, and presence or absence of a clothes washer. The results from a second analysis indicated that a significant correlation between the sizing factor and reported availability of hot water does exist and that more observations were found in the "worse" hot water category for undersized participants than expected. Therefore, both analyses indicate that sizing of the water heater is an important factor if water heaters are to provide sufficient hot water during cycling.

Overall, 98 of the 125 responding participants indicated unchanged or better hot water availability during the test.

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5. Chi-square analyses were used to examine several plausible explanatory factors. See tables A-4 and A-5 which summarize the results of these analyses.

6.4.2 Space Conditioning

Of the 165 survey respondents, 93 responded to the question concerning the relative comfort of their homes during the test period as compared to before the test. Table A-6 summarizes the answers to this question. Only 46 of the responses received were valid.[6] Of the 46, 41 consumers had their cooling systems cycled and 5 consumers had their heating systems cycled.

All five heat cycled consumers reported that there was no difference in the comfort level of their homes between the two periods.

Of the 41 air-conditioner cycled participants, 34 indicated no difference in comfort, 6 indicated the comfort level was worse during the test, and 1 chose the "don't know or not sure" response.

Overall, 46 of the surveyed participants had some form of space conditioning cycled. Consumer acceptance of cycling was favorable with 39 (85 percent) of the valid respondents indicating no difference in the comfort level of their homes during the test.

The valid responses were compared to determine if the ratio of home size to air-conditioning system capacity explained at least some of the division of responses between the "no difference" category and the "worse during test" category. Statistical analysis (based on the 46 valid responses) indicated no significant relationship between the change in comfort levels and the average home square footage per ton of air-conditioning.[7] This finding implies unit sizing was not responsible for reported consumer discomfort during the test. Factors, such as the general condition of the air-conditioning unit, thermostat settings, and other participant characteristics, may be the primary influencers of perceived comfort levels.

6.4.3 General Participant Acceptance of Load Management

During the middle of the test, a participant survey was administered which contained five general attitude questions to be

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6. Of the remaining 47 consumers, 26 mistakenly thought their space conditioning system was cycled when in fact it was not, and 21 responded to the question even though they apparently knew their space conditioning was not cycled.

7. The Student t-test, a statistical technique for comparing the means of two populations, was used to make the analysis.

answered by the participants. Table 6-1 summarizes the answers to the five attitude questions. The composite results show a favorable acceptance of load management by the responding test participants. Perhaps the most significant question for long-term consideration is the second question which asks "Based upon your experience with the load management test, would you care to participate on a permanent basis if a credit were offered?" Of the 253 participants answering the question, only 4 (less than 2 percent) indicated that they did not want to participate in a load management program on a permanent basis.

6.5 Review of Consumer Complaints

During the second year of the test, which included the period of summer 1980 through spring 1981, the power distributors received no complaints from test participants. This absence of complaints during the second year is probably attributable to two factors: (1) the detailed followup of complaints received during the first year served as input to developing sizing guidelines for participants with conventionally sized water heaters and (2) the durations of cycling periods during the second test year were reduced by limiting cycling operations to time blocks which were coincident with the predicted TVA monthly system peak.

These two steps were taken as a part of an effort to reduce consumer inconvenience from load management. The second year test results suggest that this effort was successful.

6.6 Conclusions

Ninety-eight of the 125 responding water heater test participants (78 percent) indicated hot water availability during the test. Sizing considerations are the most important factors for reducing participant complaints during times of management. The water heater must be properly sized to meet the participant's hot water needs during management periods.

Most participants, whose responses to space conditioning cycling discomfort were considered valid (85 percent), did not report discomfort from space conditioning cycling. Of the ones who did, no predominant explanatory factor such as unit size could be found.

Less than 2 percent of the test participants expressed that they would not be interested in participating in a load management program on a permanent basis.

Finally, most test participants were not aware of which appliances were cycled and when cycling was actually implemented.

Table 6-1

SUMMARY OF ANSWERS TO SURVEY'S PARTICIPANT ATTITUDE QUESTIONS

Question	Answer	Cleveland	Huntsville	Jackson	Tri-County	Total
Based upon your experience in this test, do you think consumers would allow control of their appliances if a credit were offered on their bill?	Yes	51	62	53	63	229
	No	4	1	2	3	10
Based upon your experience with the load management test, would you care to participate on a permanent basis if a credit were offered?	Definite yes	29	48	32	32	141
	Probably yes	25	15	20	32	92
	Definite no	1	0	0	1	2
	Probably no	0	1	1	0	2
	Undecided	5	0	7	4	16
Would you have volunteered for this test had there been no incentive payments for participation?	Yes	41	51	38	60	190
	No	14	9	1	9	33
	Don't know	0	1	2	0	3
In your opinion, do load management devices affect energy conservation?	Promote	40	40	33	41	154
	Discourage	1	0	0	0	1
	No effect	2	6	1	4	13
	Not sure	14	18	19	24	75
Based upon your experiences, do you believe that being in this load management test has affected your electric bill?	Saved	33	35	20	31	119
	Cost more	1	3	2	5	11
	No difference	18	19	26	28	91
	Don't know	4	6	5	4	19

7. STANDARD WATER HEATER MANAGEMENT

7.1 Introduction

During the first year of the test, water heater management periods were exploratory and provided inadequate data for analysis since management schedules were changed from day to day. However, water heater management schedules used during the second year of the test provided sufficient data for conclusive analysis. The load reduction and recovery effects of load managing standard water heaters were studied by estimating demand reductions per water heater and the resultant demand.

7.2 Experimental Design

Of the 457 households included in the test, 358 were equipped with standard water heaters.[1] Because of data recovery difficulties and equipment failures, all of these households were not included in all of the analyses.[2]

Standard water heaters were cycled on alternate weeks, Monday through Friday, excluding weekends and holidays. When cycled, all water heaters were denied energy during the cycling period and were simultaneously returned to service after the cycling period.[3]

The hourly diversified demands of individual water heaters were recorded by magnetic tape recorders. The data consisted of hourly demand profiles recorded 7 days a week, 24 hours a day. Because cycling occurred on alternate weeks (Monday through Friday), baseline or control data was derived from the weekdays of the unmanaged weeks.

The average demand reduction per water heater was estimated by observing average unmanaged demand profiles. The demand reduction estimate for each hour of interest is the hourly demand that would have been present had the water heater not been managed. However, some cycling periods did not start and end exactly on the hour during the test; therefore, limited water heater demand was present during the first and last hours of these cycling periods.

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1. Table A-7 lists the number of households by geographic area. Tables A-7 through A-9 are found in appendix A.

2. For example, data from 207 households was used to analyze standard water heater cycling for February 1981. The data used in other monthly analyses came from different subsets of the total 358 homes equipped with standard water heaters depending on data availability during the month of interest.

3. Table A-7 lists the management schedules used during the second year of the test.

7.3 Empirical Results

Water heater electrical demand appears to be determined by inlet and outlet water temperature and consumer hot water usage. These factors are affected, to varying degrees, by seasonal changes. To analyze the effects of water heater management, the months of February 1981 and July 1980 were selected for analysis since these months are likely months for TVA's winter and summer seasonal peaks. Figures 7-1 and 7-2 show average managed and average unmanaged electric water heater demand curves for the two analysis months.[4] Tables A-8 and A-9 present the hourly load data on which these figures are based.

During the winter, the TVA system demand peak normally occurs around 8 a.m. or 9 a.m. The results of the data analysis revealed that the average potential demand reduction at this time is 1.4 kW per managed standard water heater during the month of February. This reduction is possible during the hour ending at 8 a.m.

The TVA summer system demand peak usually takes place between 4 p.m. and 6 p.m. The summer managed water heater data showed a potential reduction of 0.39 kW per water heater. This reduction occurred during the hour ending at 5 p.m.

The option to remove the water heater demand during times when available generating capacity is not sufficient to match impending system demand should be most beneficial to load dispatching personnel. Unfortunately, there is a cost associated with this capability. The cost is a period of extra demand immediately following the period of water heater management. Stated differently, most of the energy denied during the management period is made up relatively quickly when the water heaters are allowed to draw electrical energy after being cycled

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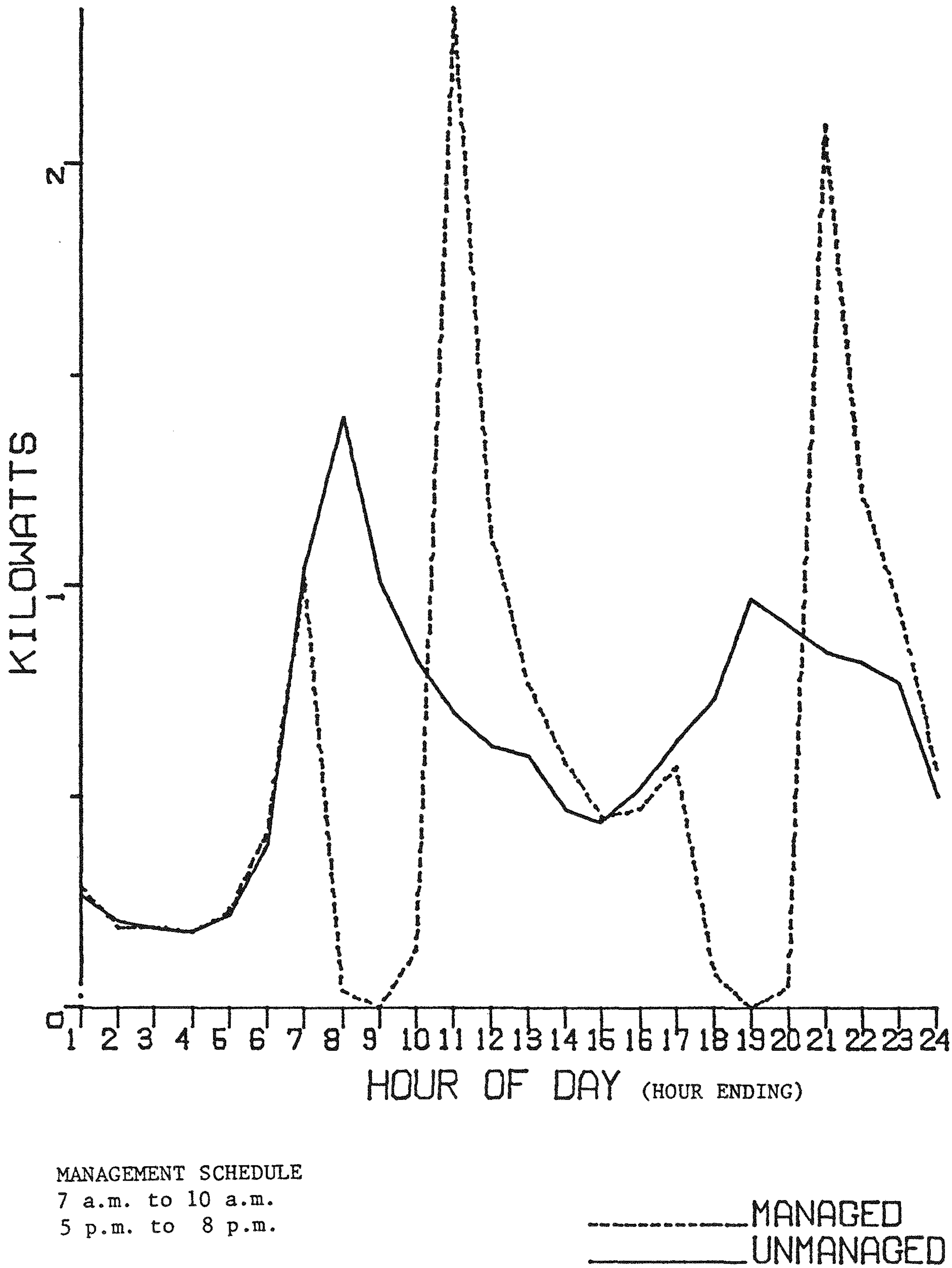
4. Several points should be considered when viewing figures 7-1 and 7-2. (1) The lines were drawn by connecting data points that reflect history which occurred during the hour prior to the stated hour. For example, the point at 8 a.m. actually represents the average electrical demand experienced from 7 a.m. to 8 a.m. (2) Theoretically, all observations during the management period should have been zero; however, the raw data did not always show this. Two possible reasons for this phenomenon are: (1) all remote receiver switches may not have responded to each load management radio transmission signal and (2) the editing of raw data may have inadvertently caused a small number of the observations to be misaligned with respect to time.

Figure 7-1

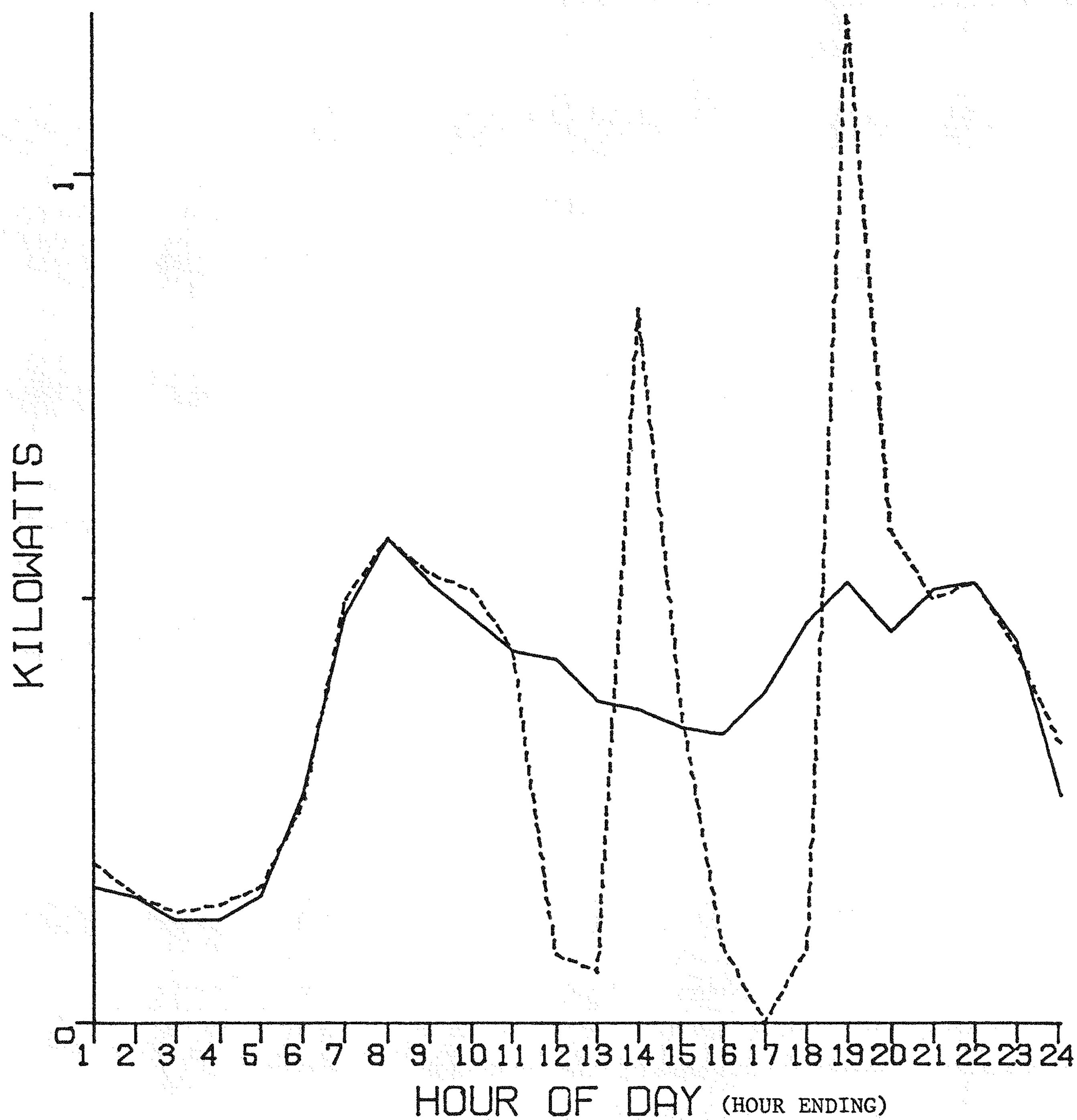
STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
FEBRUARY 1981



MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

Figure 7-2

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
JULY 1980



MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
3 p.m. to 6 p.m.

off.[5] This makeup period is commonly referred to as the payback period. This phenomenon is illustrated in figures 7-1 and 7-2. A comparison between managed and unmanaged demand profiles was made to estimate the payback effects. Since normal random variation is responsible for some of the difference between the hourly load profiles, a statistical procedure was used to determine if the difference between the two profiles was due to management effects instead of normal random variation.[6]

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5. This phenomenon can be minimized by subdividing a large number of controlled water heaters into separate management groups and using control schedules which feature staggered (by management group) return-to-service strategies. In actual practice, the energy payback should be somewhat less than 100 percent for two reasons: (1) the standby losses should be lower during and immediately after the management period because the average water temperature in the water heater should be lower than normal during this period and (2) total energy used by the water heater should be reduced if the user consumes water cooler than if there had been no management. The deviation from 100-percent payback should be a function of many variables, such as the hour and duration of the management period, consumer habits and tolerances, and physical characteristics of the hot water system.

6. A paired difference Student's t-test was applied to the data to determine hour statistically significant differences between managed and unmanaged profiles. Each consumer's daily managed hourly demand profiles and unmanaged hourly demand profiles were averaged to produce two averaged profiles (one managed and one unmanaged) for each consumer. The hourly differences between the consumer's average profiles was calculated. The differences for all the consumers were then averaged by hour and the t-test applied to determine if each hourly average difference was significantly different from zero. If the difference for a particular home was found to be significant, this average difference was used as an estimate of the payback demand.

8. STORAGE WATER HEATER MANAGEMENT

8.1 Introduction

As part of the Water Heating/Space Conditioning Control Test, 99 consumers received, at no charge, superinsulated (heat loss of less than 4 watts/square foot/hour), 120-gallon water heaters to replace their existing water heaters.[1]

Most conventionally sized residential water heaters, termed standard water heaters in this report, are storage water heaters in the sense that they are generally sized to use tank storage, primarily to satisfy normal hot water requirements. However, the term "storage water heater," as used in this report denotes a large-capacity (120-gallon), superinsulated water heater. Prolonged load management of water heaters precludes allowing the water heater to recover during TVA's high load demand periods and requires the use of storage water heaters. Since only a few hours are necessary for water heater recovery, storage water heater recovery can be postponed until a period during the day when the TVA system has excess generating capacity. Therefore, load management of storage water heaters can improve the system load factor and, consequently, power system operating efficiency.

8.2 Experimental Design

During initial phases of the test, storage water heaters were denied energy for periods as long as 16 hours per day (7 a.m. to 11 p.m.), 7 days a week.[2] Some consumer inconvenience, i.e., inadequate hot water supply, resulted from these longer control periods. Therefore, 15-hour control periods (8 a.m. to 11 p.m.) soon replaced the 16-hour control scheme and load management was eliminated on the weekends. During the second year of the test, the winter load management schedule was modified to allow an afternoon recharge period and to better interface with the TVA system load. Under this schedule, water heaters were cycled off from 7 a.m. to 11 a.m. and again from 5 p.m. to 10 p.m. The use of shorter single control periods with an afternoon recharge period resulted in no apparent degradation of hot water service to the consumer.

8.3 Energy Payback and Conservation of Storage Water Heaters

The payback phenomena associated with storage water heaters and standard water heaters are dissimilar. While deferring payback with storage water heaters actually improves the system load factor, all natural diversity of storage water heater loads ceases with the end

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1. Refer to chapter 2 of this report.

2. Refer to chapter 5 of this report.

of the management period. Consequently, the restored load may be several times greater than it was at the time of interruption. As a result, staggered restoration of service may be needed to prevent a demand surge and to levelize the diversified system load.

The magnitude of the anticipated diversity loss appears to be a function of the time of interruption, the duration of the interruption, hot water usage during interruption, and the elapsed time since service was restored. Given these influencing factors, it is possible that the payback of storage water heaters may be greater than those water heaters with conventionally sized tanks.

A second issue considered is the possible conservation effects resulting from the replacement of possibly inefficient standard water heaters with energy efficient storage water heaters. The following discussion will address both of these issues.

8.4 Empirical Results

Table A-10, which is found in appendix A, describes the sample characteristics of storage water heater participants and the management schedules used during this test. Because of data recovery difficulties, the usable sample was often less than 99.

Figures 8-1 and 8-2 depict the managed and unmanaged storage water heater load curves based on data collected during the months of July 1980 and February 1981.[3] Tables A-11 and A-12 present the load data for these months.[4]

Since storage water heaters would be used to replace standard water heaters, managed storage water heater performance should be compared to managed and unmanaged standard water heater performance. However, different management schedules were used for storage and standard water heaters during this test; therefore, direct comparison of managed standard and storage water heater performance was considered inappropriate.

Analysis of covariance (ANACOVA) was used to determine if significant differences exist between energy usage by storage water heaters and energy usage by standard water heaters.[5] This technique was chosen

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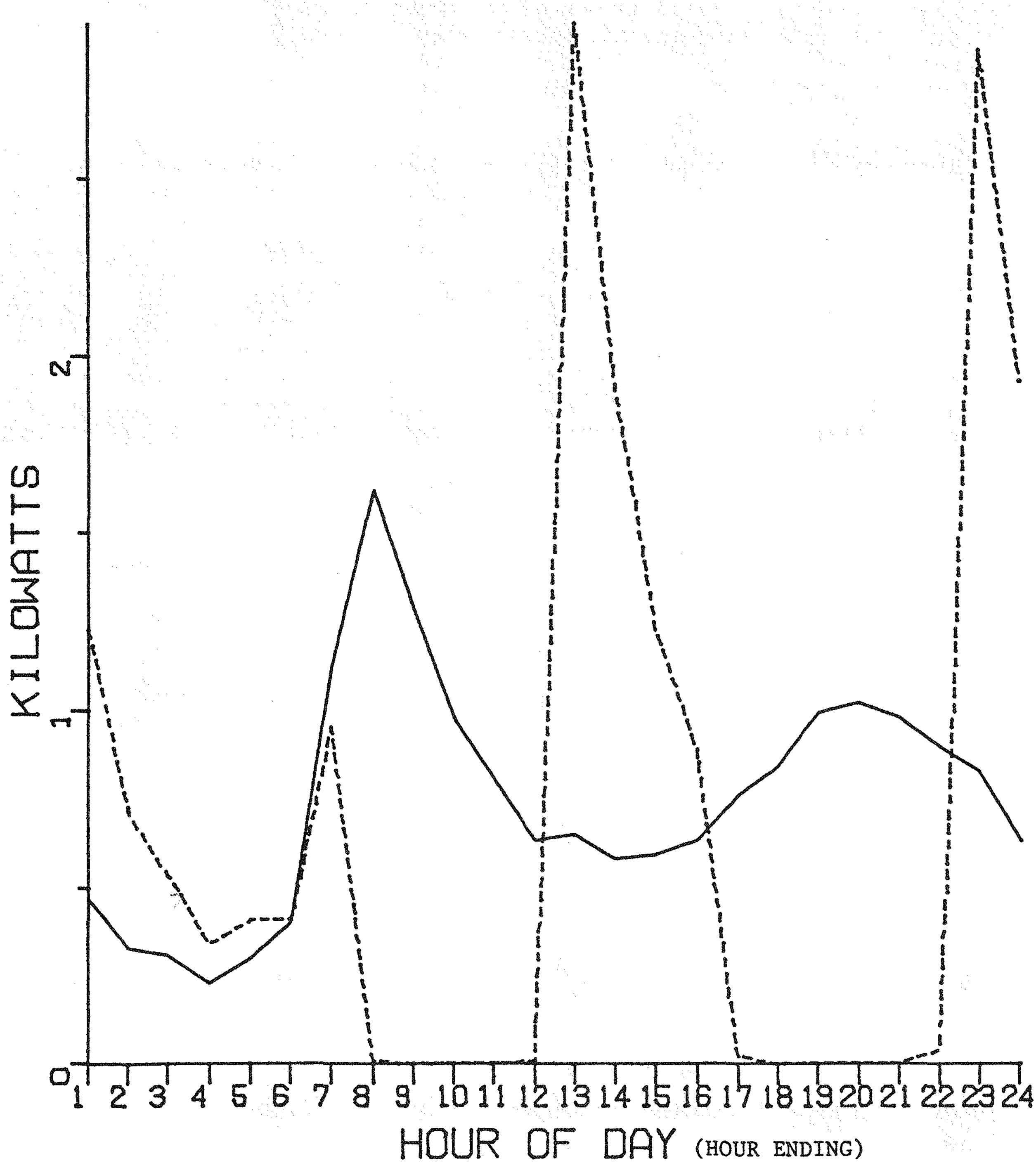
3. See footnote 4 of chapter 7 for the summary of points to consider when viewing figures 8-1 and 8-2.

4. Significant differences were determined by use of the paired difference Student's t-test as described in footnote 5 of section 7.3.

5. ANACOVA is a statistical technique which determines remaining (if any) differences between the observations on a particular parameter from two or more samples after the effects due to other observable and quantifiable variables have been removed.

Figure 8-1

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
FEBRUARY 1981

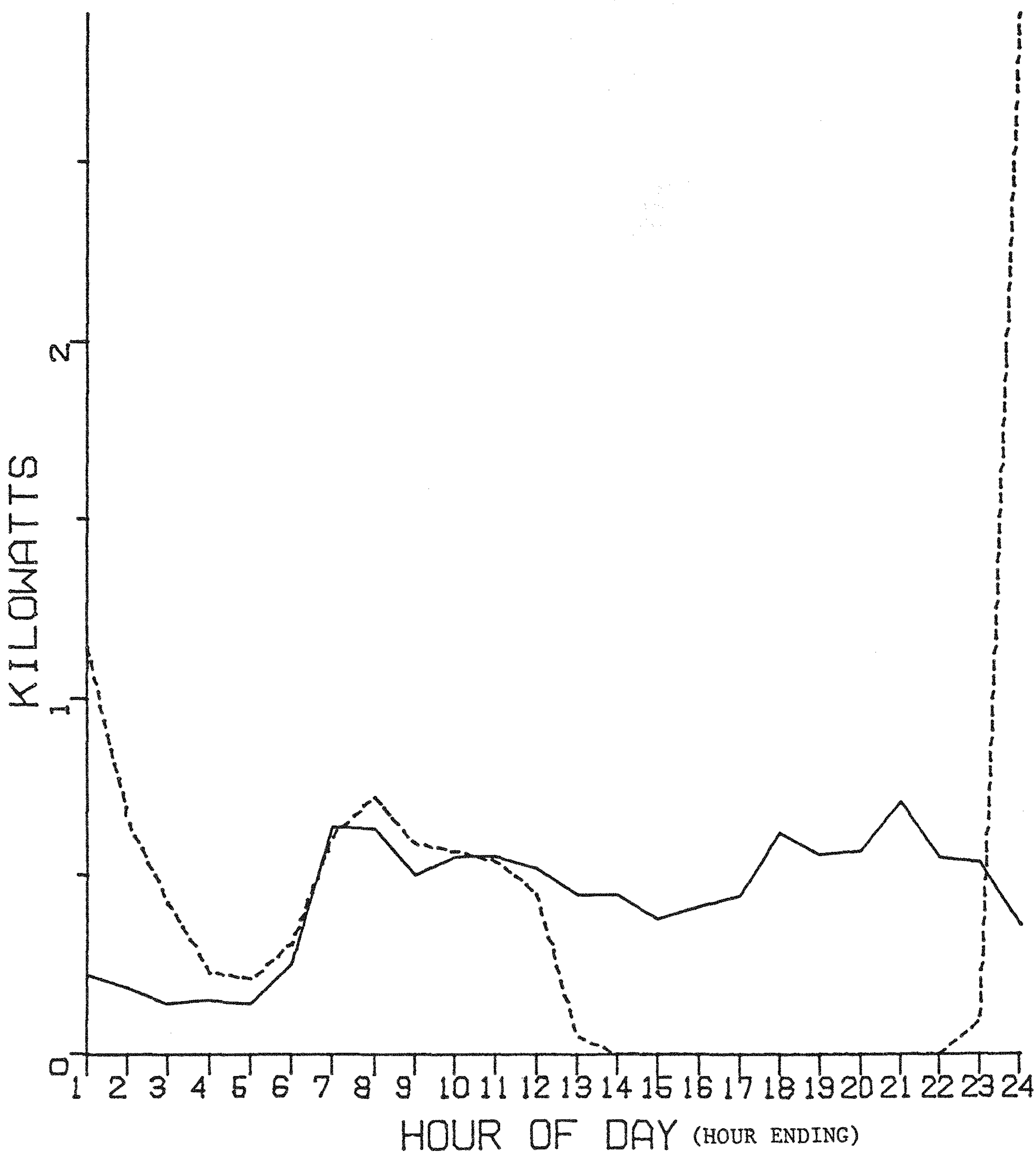


MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

-------------MANAGED
_____________UNMANAGED

Figure 8-2

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
JULY 1980



MANAGEMENT SCHEDULE
12 noon to 11 p.m.

to remove the hot water usage effects due to the presence or absence of a clothes washer, presence or absence of a dishwasher, number of household inhabitants, and number of bathrooms.[6] The subset of data selected for the analysis consisted of unmanaged storage water heater and unmanaged standard water heater average daily energy consumption data from the month of February 1981.

The results of this analysis indicate that the number of household inhabitants and the number of bathrooms in the house significantly influenced water heater electric consumption. The presence or absence of a dishwasher did not significantly influence water heater energy consumption. Because all participants had a clothes washer, the effects due to this appliance could not be studied. After the demographic effects were removed, the analysis revealed no significant difference in average daily electrical consumption between standard and storage water heaters.[7]

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6. Previous experience has suggested that these demographic features are the primary determinants of residential hot water usage.

7. Refer to table A-13 of appendix A for a summary of this analysis.

9. AIR-CONDITIONING MANAGEMENT

9.1 Introduction

The estimated demand reductions per air-conditioning unit, operating characteristics of unmanaged air-conditioning, and potential energy shift as a result of cycling air-conditioning were studied to assess the effects of cycling central air-conditioning in the Tennessee Valley and to develop optimal cycling strategies. The air-conditioning data from the summer of 1980 was used for this analysis. Preliminary results from the summer of 1979 were presented in the "Water Heating/Space Conditioning Control Test Interim Report."

9.2 Control Strategy

9.2.1 Experimental Design

The compressors of test participant central air-conditioning units were monitored during this test. Each compressor was cycled from 12 noon to 10 p.m., Monday through Friday, excluding holidays. Cycling began June 2, 1980, and continued every other week through September 1980. When cycling did occur, the compressor was turned off for 7.5 minutes out of every 30 minutes allowing the compressor to run only 75 percent of the time during management. Indoor fans were allowed to run continuously during management to allow air circulation to continue in the house. Raw data was recorded 24 hours a day, 7 days a week.

Hourly air-conditioning diversified demands (kilowatts) were recorded by magnetic tape recorders. Hourly outside air temperature and dew points were obtained from regional weather sources. Relative humidity was computed from an algorithm relating relative humidity to outside air temperature and dew point. Of the 91 homes in the air-conditioning cycling test, 30 had central air-conditioning while the remaining 61 had heat pumps that were used in the cooling mode. Table A-14 provides a geographic breakdown of the sample while table A-15 summarizes demographic characteristics of the 91 test participants with central air-conditioning systems.[1] The number of observations per hour was often less than 91 because of equipment, instrument, and/or data recovery failures.

Days were divided into two categories: load managed and unmanaged. Even though load management took place for only a few hours a day, all observations from load managed days, regardless of hour, were considered managed observations. This

1. Tables A-14 through A-17 are found in appendix A.

was necessary to assess the carryover effects of load management. Days in which no load management efforts were made provided the raw control data. Of the 122-day data collection period, 83 days were of the unmanaged category while 39 days were considered managed days.

One-minute interval measurements of the electrical demand of individual air-conditioning compressors were constructed (refer to section 4.6). This information was used to estimate the run time percentages (duty cycle) for the compressors during the hours of interest.

9.2.2 Methodology

9.2.2.1 Demand Reductions

Since managed and unmanaged days did not have identical weather profiles, adjustments to compensate for weather differences were necessary before comparisons could be made between the two sets of demand profiles. Two approaches were considered to estimate hourly demand reductions during managed hours.

One approach was to model average hourly diversified unmanaged air-conditioning demands such that weather variables were incorporated into the resulting unmanaged prediction model.[2] Then the unmanaged prediction model was used to predict unmanaged air-conditioning demands using the appropriate weather data of managed days. The observed managed air-conditioning demand profiles were compared to the related predicted unmanaged air-conditioning demand profiles.

The second approach to estimating hourly demand reductions was to simulate managed demand on unmanaged days. Since the percent hourly run time of the air-conditioning unit's compressor was known and the hourly demand for that time was also known, the following algorithm was used to estimate hourly demand reductions:

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2. Regression analysis, a statistical technique, was used to develop this model. Regression techniques attempt to relate a dependent variable, in this case average hourly diversified demands, to several independent variables such as relative humidity. Because a high level of significance was required for independent variable acceptance by the model, the model was considered conservative; therefore, the normal regression statistical assumptions were considered irrelevant. The goodness of fit was judged by the R-square statistic.

$$\text{DEMAND REDUCTION}_t = \left[\text{DEMAND}_t - \text{DEMAND}_t \div \text{DC}_t\right] \times 75$$

where t - hour of day.

DEMAND_t - hourly diversified demand at hour t, i.e., the actual observed unmanaged demand for an individual compressor.

DC_t - duty cycle of the compressor or percent hourly run time at hour t.

75 - multiplication by 75 percent since cycling for 7.5 minutes out of every 30 minutes allowed the compressor to run only 75 percent of the time during managed hours.

This second method seemed more appropriate since it allowed variations between individual homes to be considered. Measures of central tendency (median or mean) were used to estimate the effects of the demand reductions created by the above algorithm. One-minute compressor readings (described in section 9.2.1) were available for determination of compresssor run times. Hourly demand data was correlated with hourly compressor run times. After the algorithm was used to determine the demand reductions, regression analysis was used to smooth irregularities in this generated data so that tabular data could be constructed.

9.2.2.2 Operating Characteristics of Unmanaged Air-Conditioning

Knowledge of the factors which influence air-conditioning demand can be beneficial to determining proper cycling strategies. The answer to the question, "How long during a 30-minute period should air-conditioning compressors be denied electrical energy to produce the desired effects of management?" is essential to successful strategy formulation. For example, if the typical air-conditioner, under specific conditions, normally runs 75 percent of the time, a management strategy which calls for 7.5 minutes off during each 30-minute period only serves to control which 7.5 minutes the unit will be off. The previously discussed 1-minute compressor data for unmanaged days was used to determine compressor duty cycle percentages by hour. This information, coupled with the related weather data, greatly facilitates the understanding of residential air-conditioning demand.

9.2.2.3 Energy Shift

Several aspects of the energy shift associated with air-conditioning management were examined by analyzing the data made available by the test. The following three related topics were defined with respect to energy shift.

a. Precooling effects - Do managed homes use significantly more air-conditioning energy during the hours of 7 a.m. to 11 a.m. (before cycling is initiated) than do unmanaged homes?

b. Postcycling effects - Is most of the air-conditioning energy saved during the cycling period shifted to the hours of 11 p.m. to 6 a.m.?

c. Total energy use - Do managed air-conditioning systems use less, more, or the same amount of energy as unmanaged air-conditioning systems?

Regression analysis was the technique used to test the following general hypothesis: the difference between managed and unmanaged air-conditioning energy use is significant.[3] Various tests of the general hypothesis were used to formulate answers to all three of the above questions. All that was required was to properly define the time-of-day boundaries.

9.3 Empirical Results

9.3.1 Estimates of Demand Reductions

The Valley-wide model used to estimate the unmanaged air-conditioning demand had an R-square = 0.83. This result was accepted as evidence that the model was adequate to estimate

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3. In an attempt to eliminate the many difficulties associated with the individual air-conditioning unit sizes and operating conditions, total compressor run time or duty cycle was selected as a proxy for kWh measurements. Total compressor run time during the hours of interest were regressed against a categorical variable to represent managed versus unmanaged observations, maximum daily temperature, and an interaction variable measuring the effects between the categorical variable and maximum daily temperature. The interaction variable was included since it was anticipated that at some temperatures no differences between managed and unmanaged observations would be found while at other temperatures significant differences would be found. Testing the significance of the categorical and the interaction variables determined whether the relationship between air-conditioning energy use and maximum daily temperature was the same for managed and unmanaged observations during the time period of interest.

the unmanaged air-conditioning demand which would have occurred during managed periods had there actually been no management. Similar models were developed for the four geographic areas with similar R-square values.[4]

Figure 9-1 is a graphical Valley-wide comparison of per unit modeled hourly unmanaged demand and per unit observed hourly managed air-conditioning demand. July 16, 1980, was the TVA system peak day for the summer of 1980. The daily temperature reached a Valley-wide average maximum of 100°F at 3 p.m. The TVA system demand peaked at 5 p.m. Cycling of air-conditioning systems began at 12 noon and ended at 10 p.m.

The graph shows that payback from the previous day's cycling continued until 5 a.m. while a possible precooling period occurred from 7 a.m. to 11 a.m. Cycling demand reductions appeared over the entire management period while energy payback may have begun immediately after the management period. At the time (5 p.m.) of the TVA system peak, the estimated demand reduction per unit was 1.04 kW. Although this estimate is consistent with other published reports, verification of the demand reduction estimates at other times proved to be more difficult. The periodic variation evidenced in the managed data could have been the result of air-conditioning switches failing to respond to transmitted signals. It was estimated that 19 percent of the switches failed to respond to at least some transmitted signals. Figures 9-2 and 9-3 represent per unit graphical comparisons of modeled Valley-wide hourly unmanaged air-conditioning demand and observed Valley-wide hourly managed air-conditioning demand on other dates during the summer of 1980. The irregularity of the observed managed, payback, and possible precooling demand is again shown.

Since the reliability of the observed managed data was questionable, simulation of managed hourly air-conditioning demand using known compressor duty cycles and observed unmanaged data seemed to be an acceptable alternative. The algorithm outlined in subsection 9.2.2.1 was used for this purpose. Table 9-1 summarizes the median Valley-wide demand reduction per air-conditioning unit as a function of maximum daily temperature

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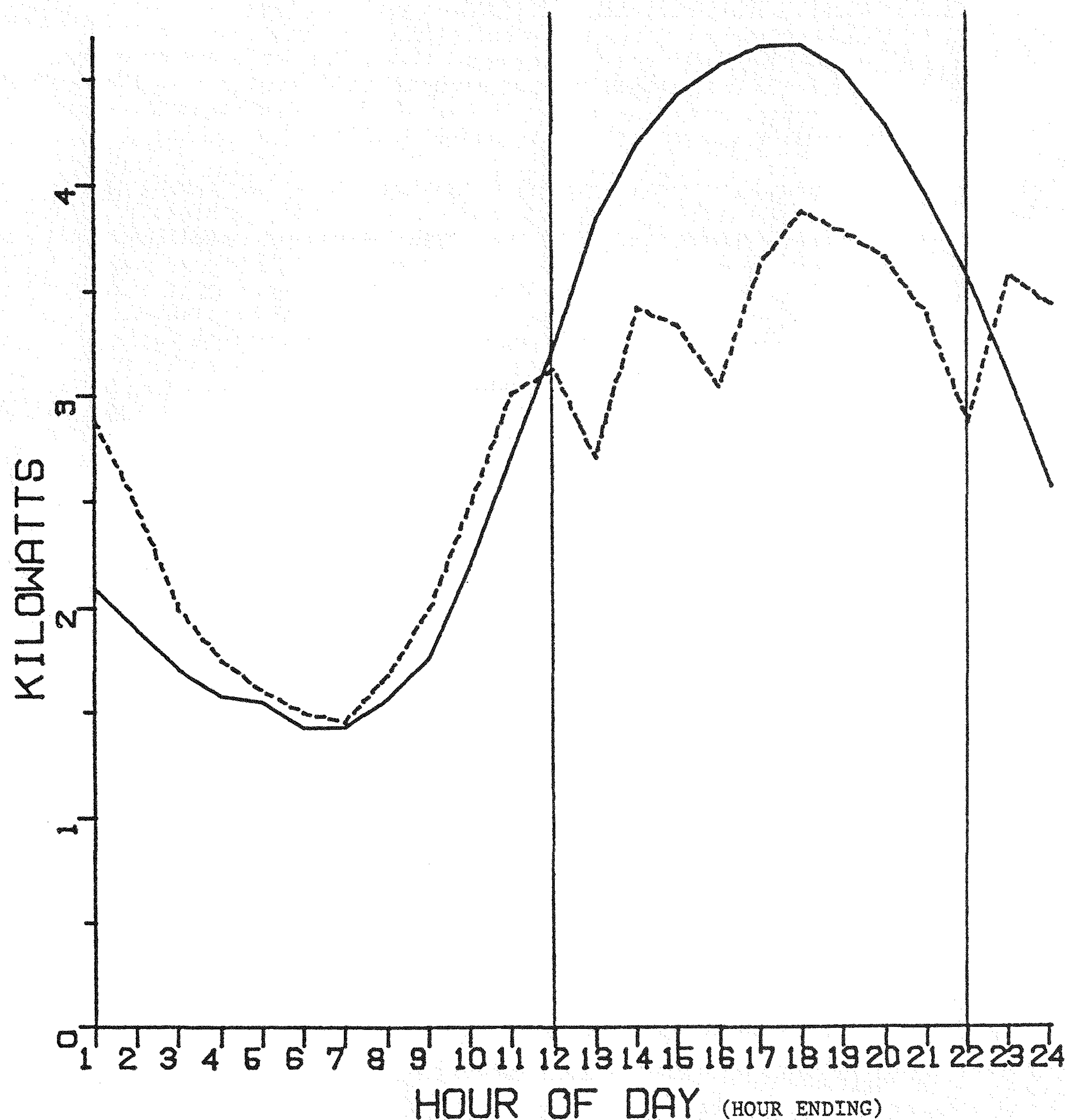
4. Refer to table A-16 for a summary of R-square values and significant independent variables. The subset of possible significant explanatory independent variables was different for the data from each geographic region. There is no apparent reason for this except for the idiosyncrasies of the data.

Figure 9-1

MANAGED AND UNMANAGED
AIR-CONDITIONING LOAD PROFILES*

TVA VALLEY-WIDE
July 16, 1980



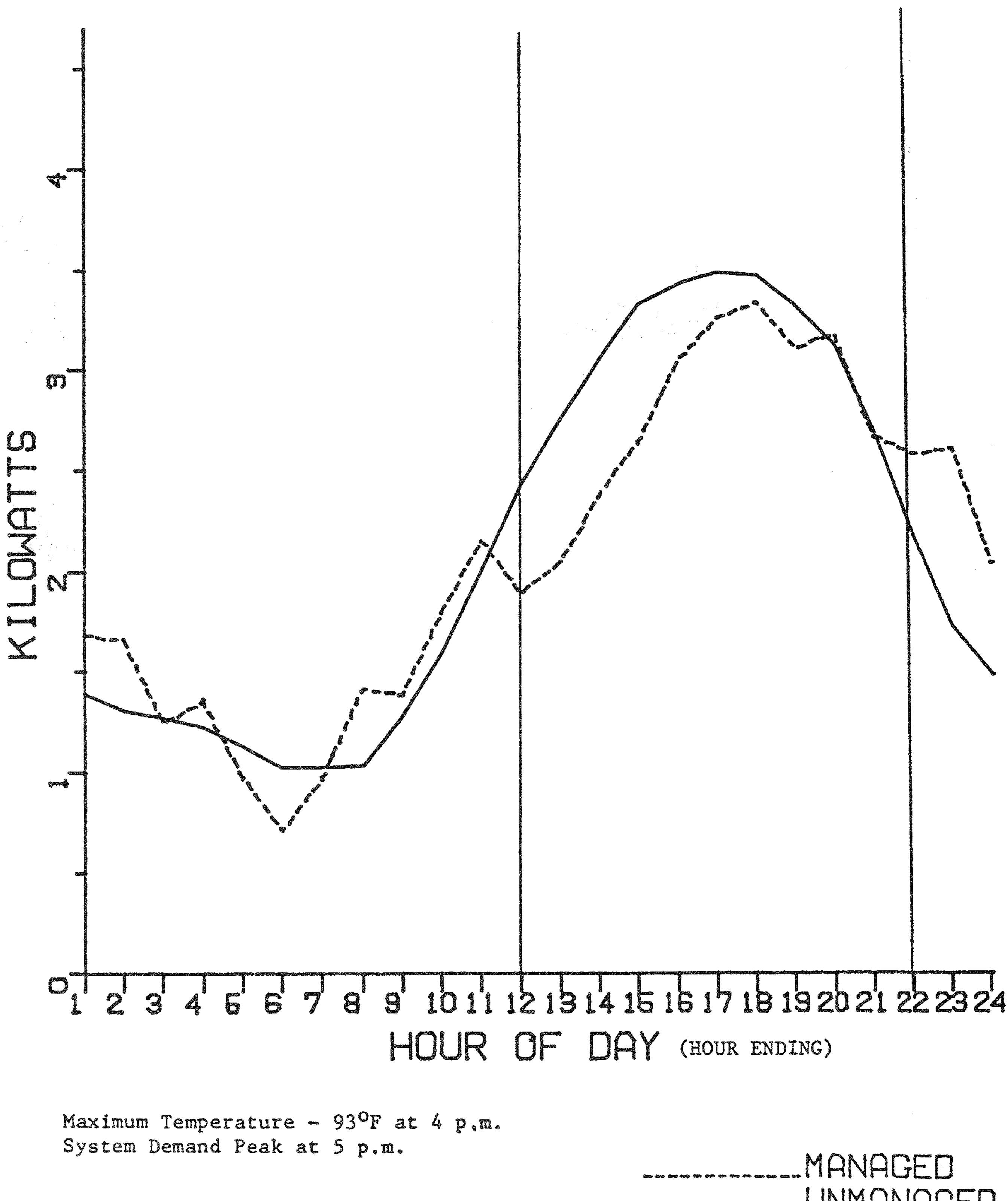
Maximum Temperature - 100°F at 3 p.m.
System Demand Peak at 5 p.m.

------------ MANAGED
———————— UNMANAGED

Figure 9-2

MANAGED AND UNMANAGED
AIR-CONDITIONING LOAD PROFILES*

TVA VALLEY-WIDE
July 2, 1980

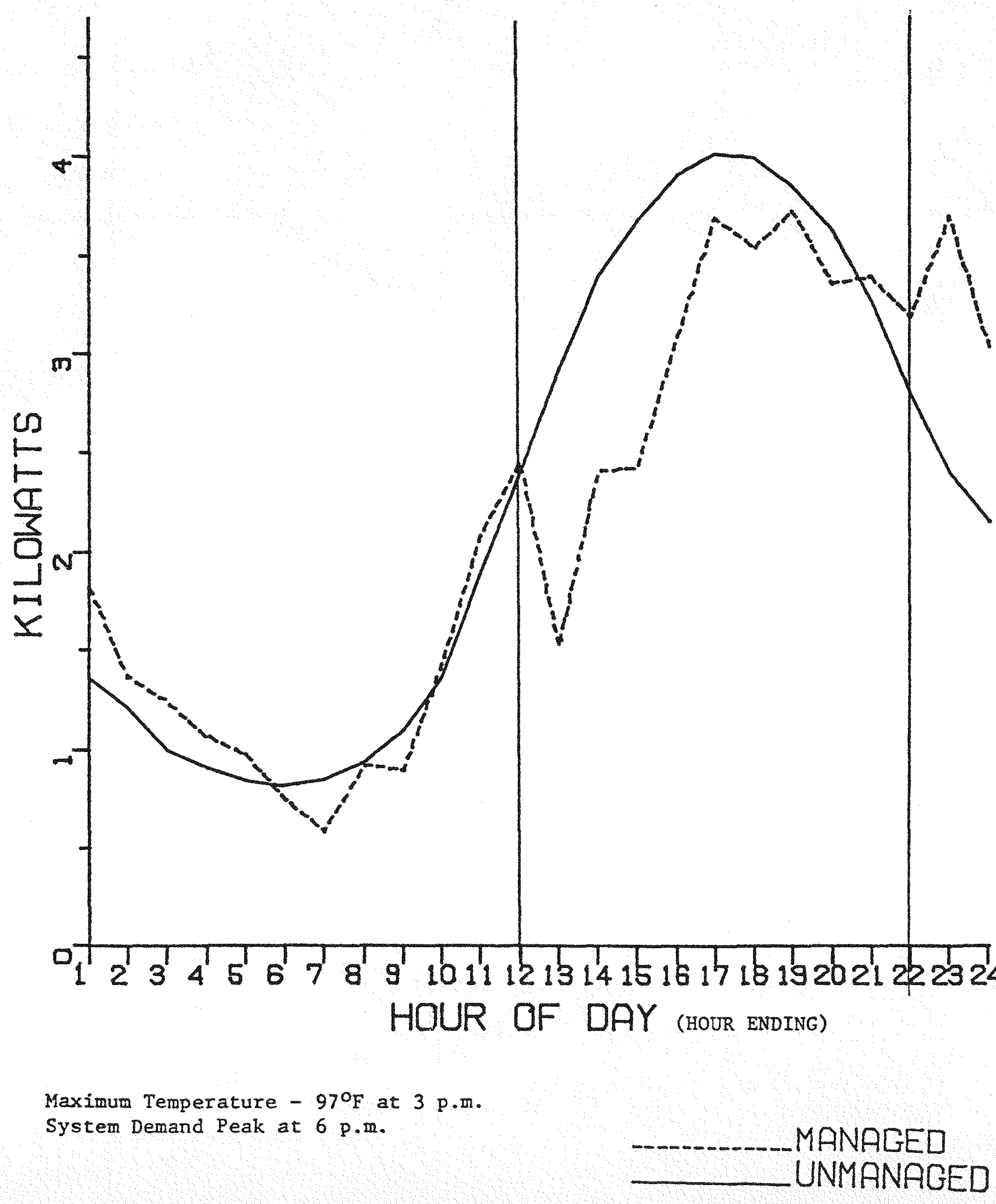


Maximum Temperature - 93°F at 4 p.m.
System Demand Peak at 5 p.m.

Figure 9-3

MANAGED AND UNMANAGED
AIR-CONDITIONING LOAD PROFILES*

TVA VALLEY-WIDE
July 31, 1980



Maximum Temperature - 97°F at 3 p.m.
System Demand Peak at 6 p.m.

Table 9-1

ESTIMATED MEDIAN kW DEMAND REDUCTION PER AIR-CONDITIONING UNIT (1980)

Hour of Day (Hour Ending)	Valley-Wide Average Maximum Daily Temperature (^{o}F)												
	88	89	90	91	92	93	94	95	96	97	98	99	100
1300	0	0	0	0	0	0	0	0	0	0	0	0	.09
1400	0	0	0	0	0	0	0	0	.07	.16	.25	.34	.43
1500	0	0	0	0	0	.08	.17	.26	.35	.44	.52	.61	.70
1600	0	0	.01	.10	.19	.27	.36	.45	.54	.63	.72	.81	.90
1700	0	.03	.12	.20	.29	.38	.47	.56	.65	.74	.83	.92	1.01
1800	0	.03	.12	.21	.30	.39	.48	.57	.66	.75	.84	.93	1.02
1900	0	0	.02	.11	.20	.28	.37	.46	.55	.64	.73	.82	.91
2000	0	0	0	0	0	.05	.14	.23	.32	.41	.50	.59	.68
2100	0	0	0	0	0	0	0	0	0	.04	.13	.22	.31
2200	0	0	0	0	0	0	0	0	0	0	0	0	0

Example: Given a day when the maximum temperature reaches 98^{o}F, the expected savings per managed air-conditioning unit will be 0.52 kW during the hour ending at 3 p.m., regardless of the actual temperature at that time and hour of day.[5] The results shown in this table are consistent with expected demand reductions and patterns and are in agreement with the results shown in figures 9-1, 9-2, and 9-3.

9.3.2 Operating Characteristics of Unmanaged Air-Conditioning

Table 9-2 summarizes observed data relating air-conditioning compressor run times (i.e., duty cycle) and hour of day to maximum daily temperatures for unmanaged air-conditioning units. DC75 labels the estimated percent of compressors with a duty cycle from 75 to 100 percent at the associated hour and temperature. Similarly, DC100 labels the percentage of compressors with a duty cycle equal to 100 percent. The DC100 percentages are subsets of the DC75 percentages.

As maximum temperature increases, it is apparent that more compressors are affected by cycling (refer to subsection 9.2.2.2). In addition, more compressors reach 100-percent duty cycle as maximum temperature increases thereby increasing maximum potential demand reductions. This finding correlates well with the data summarized in table 9-1 indicating a further consistency between observed empirical data and the results of simulated demand reductions. As seen in table 9-2, compressor duty cycles peak at about 6 p.m. It appears that a high percentage of compressors can be affected by a 25-percent cycling strategy during the probable summer TVA system peak period.

Figures 9-4 through 9-7 show a graphical comparison between observed managed and unmanaged median compressor run times for selected maximum temperatures. Note the similarity to figures 9-1 through 9-3. Unmanaged data appears consistent and reliable while the erratic pattern of the managed data is again apparent. These figures indicate that most of the unmanaged air-conditioning compressors had sufficiently long duty cycles during the probable TVA peak period to be effectively cycled and to shed a significant demand. However, the actual demand reductions are determined by the magnitude of the compressor hourly diversified kW demand.[6] The median compressor kW demand is 4.6 kW. At the TVA system peak, an estimate of 1.0-kW demand reduction is consistent with the findings

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5. In actuality, the raw median data generated by the algorithm of subsection 9.2.2.1 was smoothed by a regression technique which incorporated lagged temperature variables as well as daily maximum temperature. This process produced results which incorporated the effects of lagged temperature variables but could be, and subsequently were, referenced by maximum daily temperature.

6. Table A-17 provides a distribution of compressor nameplate ratings from the sample.

Table 9-2

PERCENT OF COMPRESSORS WITH GIVEN RUN TIMES

IN RELATION TO

HOUR OF DAY AND MAXIMUM DAILY TEMPERATURE (1980)

Hour of Day		Valley-Wide Average Maximum Daily Temperature (°F)											
		78	80	82	84	86	88	90	92	94	96	98	100
1300	DC 75[a]	0	4	8	11	4	13	19	28	35	40	46	51
	= DC100[b]	0	3	4	6	2	8	13	19	25	31	32	36
1400	DC 75	0	4	1	11	4	15	23	33	46	45	57	58
	= DC100	0	3	0	7	4	10	15	22	31	35	41	41
1500	DC 75	0	5	0	12	4	18	24	34	49	53	62	65
	= DC100	0	2	0	8	4	12	17	24	36	39	47	51
1600	DC 75	0	8	3	15	13	20	29	41	53	56	65	75
	= DC100	0	5	1	10	13	14	20	28	37	42	49	58
1700	DC 75	0	5	8	15	13	27	34	44	57	61	65	76
	= DC100	0	5	4	9	8	17	22	31	41	45	52	61
1800	DC 75	0	11	8	15	15	28	35	46	53	63	67	80
	= DC100	0	3	3	9	13	17	25	30	39	48	53	62
1900	DC 75	0	8	5	11	10	28	29	37	48	53	60	75
	= DC100	0	7	4	6	4	16	19	28	35	43	47	57
2000	DC 75	0	4	4	11	0	18	22	29	32	46	47	62
	= DC100	0	3	2	9	0	12	15	19	23	36	34	49
2100	DC 75	0	6	3	10	4	14	18	24	29	36	41	51
	= DC100	0	3	3	7	2	9	11	16	21	28	26	40
2200	DC 75	9	6	4	8	6	13	14	18	25	30	31	45
	= DC100	9	5	4	4	2	6	9	13	17	21	21	34

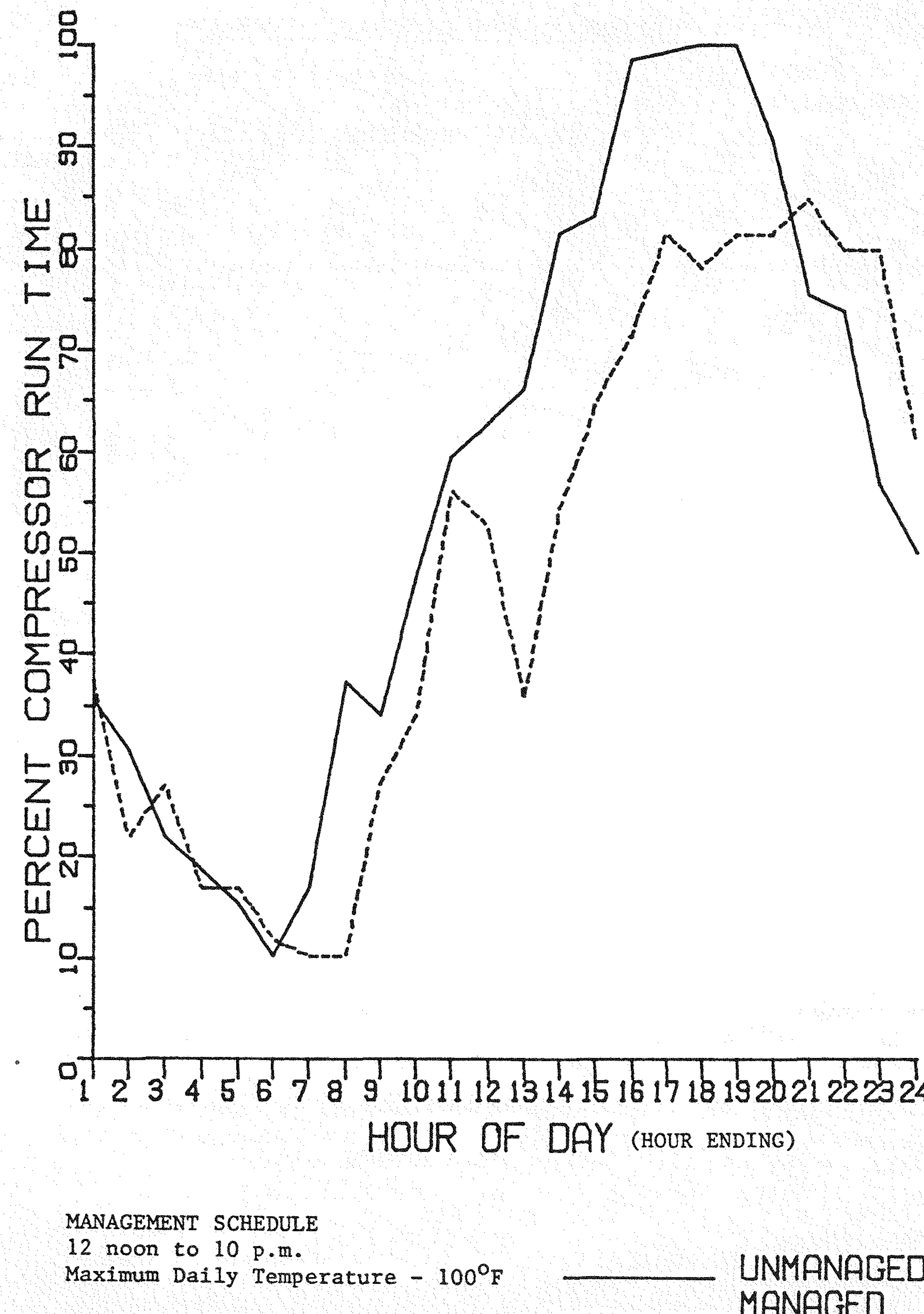
a. The percentages in the rows labeled DC75 represent the percent of air-conditioner compressors with a duty cycle from 75 to 100 percent at the associated maximum temperatures

b. The percentages in the rows labeled DC100 represent the percent of air-conditioner compressors with 100-percent duty cycles at the associated maximum temperatures. The DC100 percentages are a subset of the DC75 percentages

Figure 9-4

MANAGED AND UNMANAGED MEDIAN AIR-CONDITIONING
COMPRESSOR RUN TIME BY HOUR OF DAY

TVA VALLEY-WIDE
Summer 1980

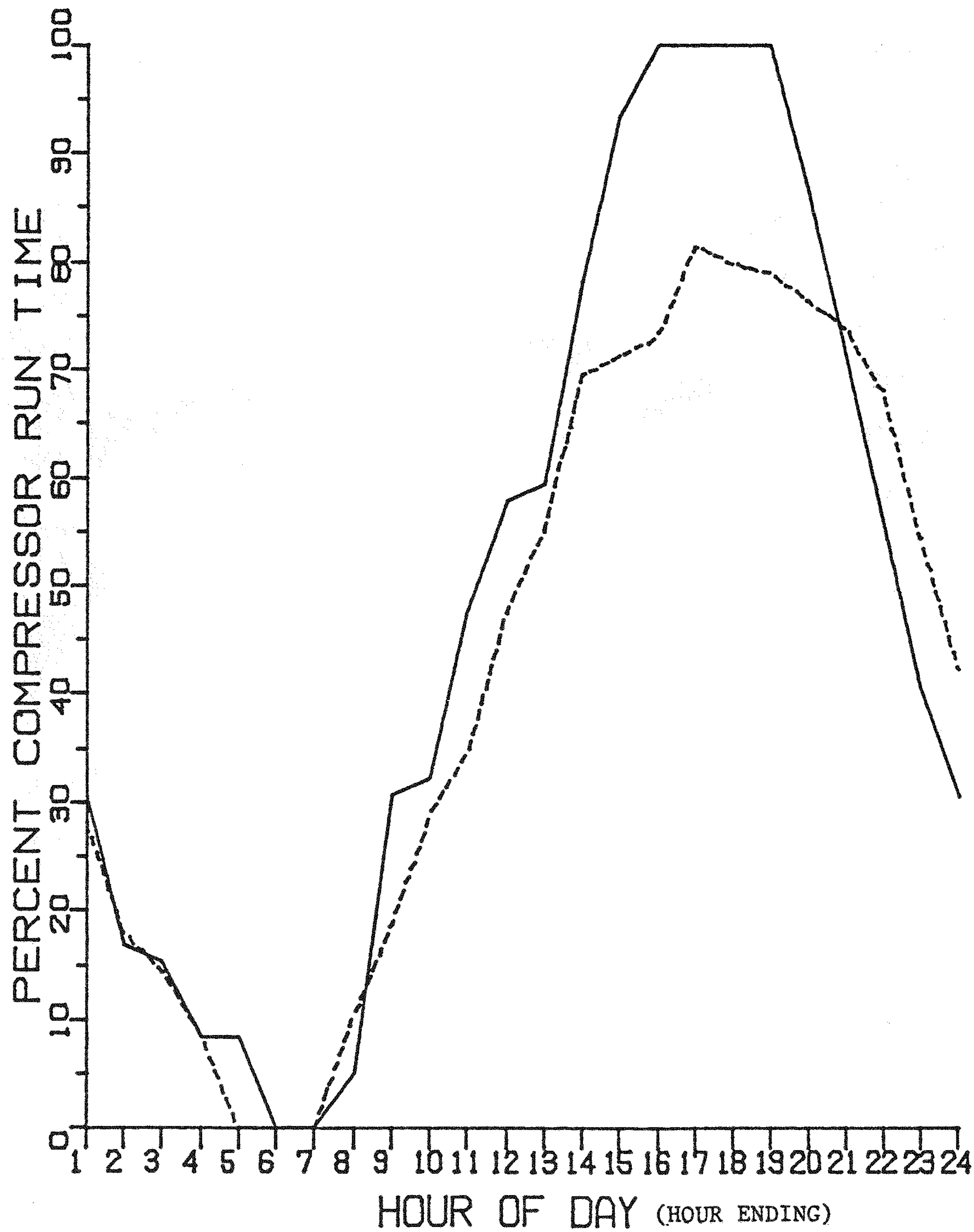


MANAGEMENT SCHEDULE
12 noon to 10 p.m.
Maximum Daily Temperature - 100°F

Figure 9-5

MANAGED AND UNMANAGED MEDIAN AIR-CONDITIONING
COMPRESSOR RUN TIME BY HOUR OF DAY

TVA VALLEY-WIDE
Summer 1980

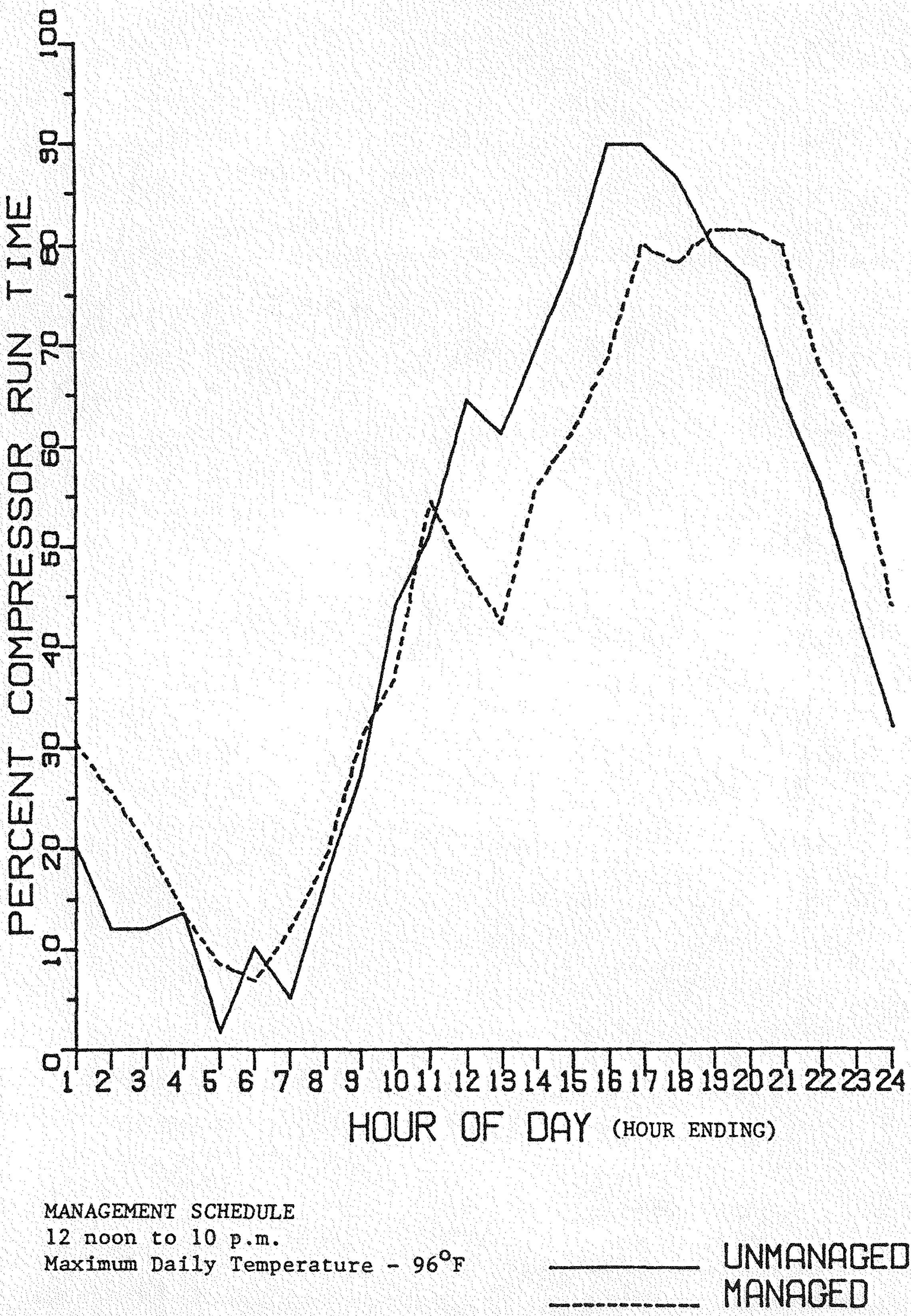


MANAGEMENT SCHEDULE
12 noon to 10 p.m.
Maximum Daily Temperature - 98°F

Figure 9-6

MANAGED AND UNMANAGED MEDIAN AIR-CONDITIONING
COMPRESSOR RUN TIME BY HOUR OF DAY

TVA VALLEY-WIDE
Summer 1980

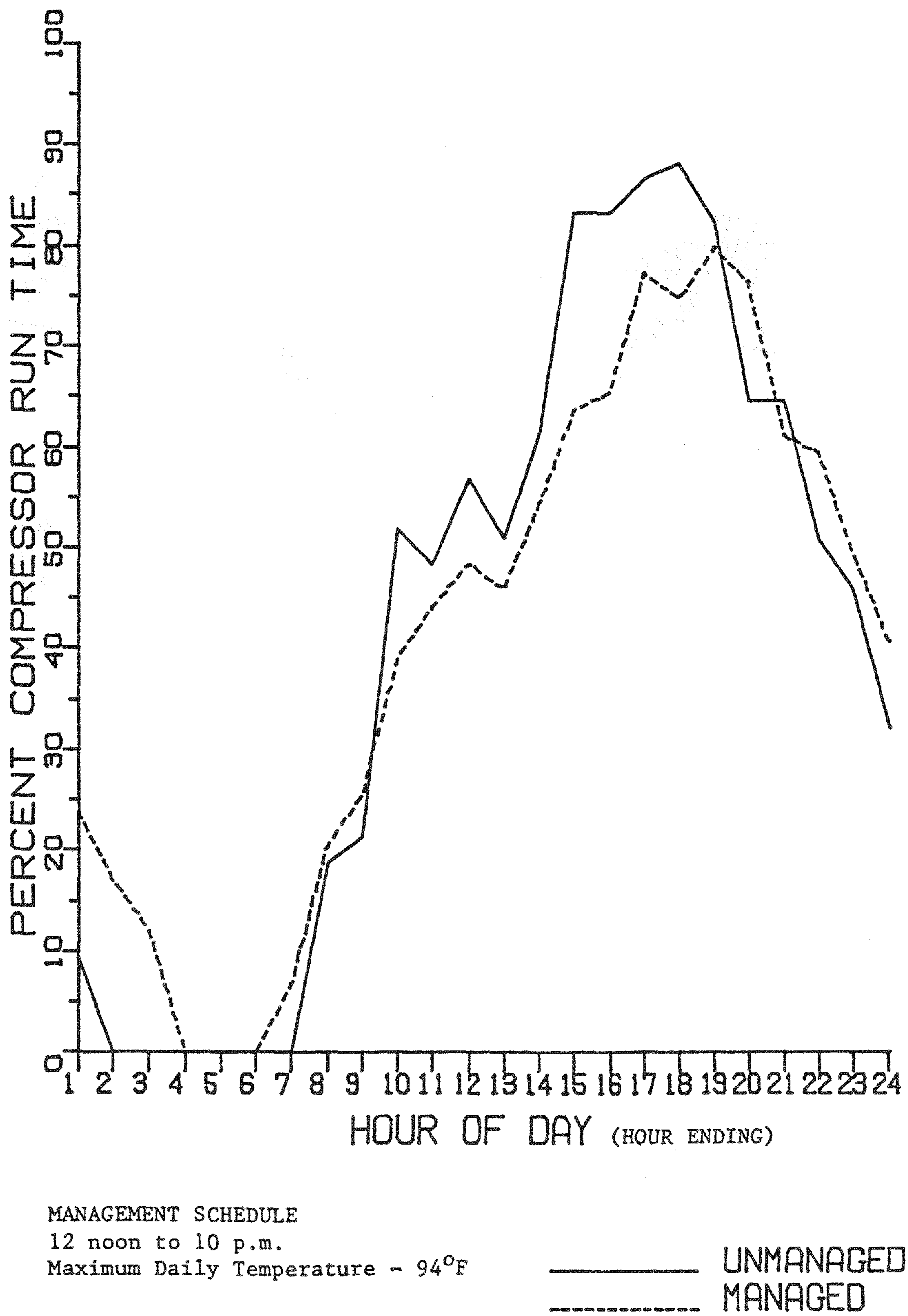


MANAGEMENT SCHEDULE
12 noon to 10 p.m.
Maximum Daily Temperature - 96°F

Figure 9-7

MANAGED AND UNMANAGED MEDIAN AIR-CONDITIONING
COMPRESSOR RUN TIME BY HOUR OF DAY

TVA VALLEY-WIDE
Summer 1980



MANAGEMENT SCHEDULE
12 noon to 10 p.m.
Maximum Daily Temperature - 94°F

presented in table A-17 in that a 25-percent reduction in a 4.6-kW demand (100-percent duty cycle) would yield a demand reduction of 1.15 kW.

9.3.3 Energy Shift

Although a preliminary analysis of the data hinted that a possible precooling effect might be present, regression analysis revealed that there was no significant difference between total energy use on managed and unmanaged days during the hours of 7 a.m. through 11 a.m. Energy use during this time period appears to have the same linear relationship with maximum daily temperature on both managed and unmanaged days.

Analysis of the data indicated a significant difference in air-conditioner energy use between managed and unmanaged days during the hours between 12 noon and 10 p.m. This was as expected. Figure 9-8 indicates that as maximum daily temperature increased the difference between managed and unmanaged energy use increased. Stated differently, more energy was shed as the maximum daily temperature increased.

Postcycling effects were also found to be significant. For the hours ending at 11 p.m. and 12 midnight, the significant difference between managed and unmanaged data is a function of maximum daily temperature. This effect is shown in figure 9-9. Figure 9-10 indicates a similar significant relationship for the hours of 1 a.m. to 6 a.m. when maximum daily temperature from the previous day is the independent variable. Therefore, as maximum daily temperature increased and more energy was shed during cycling, payback effects increased.

Total energy consumption for managed and unmanaged air-conditioning was compared. Again, the analysis indicated a significant difference between managed and unmanaged observations when the data was regressed against maximum daily temperature. As shown in figure 9-11, as maximum daily temperature increased, the difference in total daily air-conditioning energy use between managed and unmanaged air-conditioners increased. Although the differences appear significant, it may not be reasonable to state that less energy was actually used by managed air-conditioners. The postcycling analysis implies that more energy was shifted into the early morning hours of the next day as maximum daily temperature increased. Therefore, a portion of the energy shed during cycling may not have been accounted for until the next day. However, data for the next day was missing in many cases. Total daily energy use may not be sufficient to assess the energy shift. Perhaps hourly data for consecutive days would have been more appropriate for examining this question. However, as indicated earlier the existing data is discontinuous on a daily basis. Therefore, it is possible the total energy use hypothesis was not adequately tested.

Figure 9-8

MANAGED AND UNMANAGED AIR-CONDITIONING
COMPRESSOR RUN TIME BY TEMPERATURE

HOURS ENDING 1200 - 2200

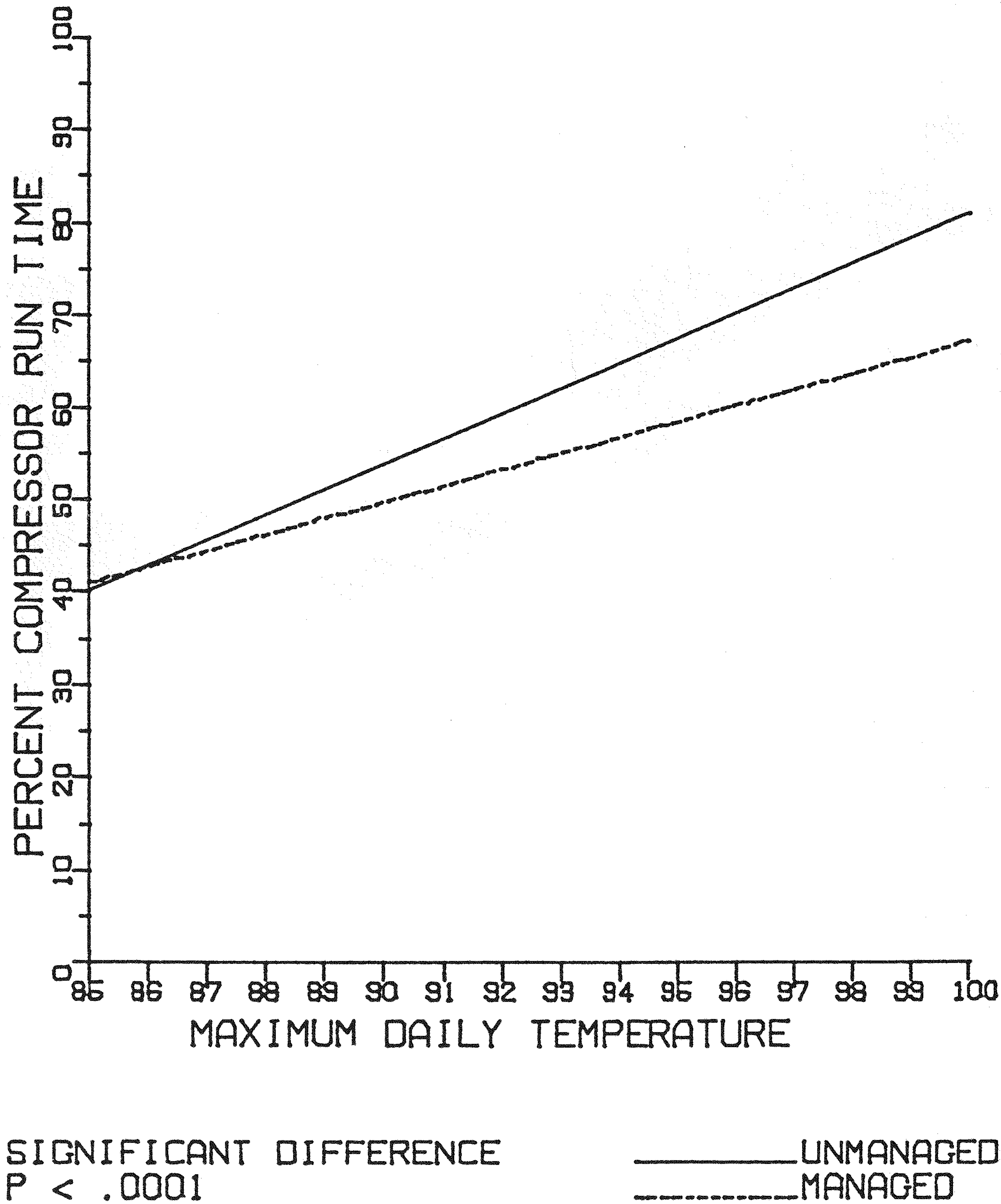


Figure 9-9

MANAGED AND UNMANAGED AIR-CONDITIONING
COMPRESSOR RUN TIME BY TEMPERATURE

HOURS ENDING 2300 - 2400

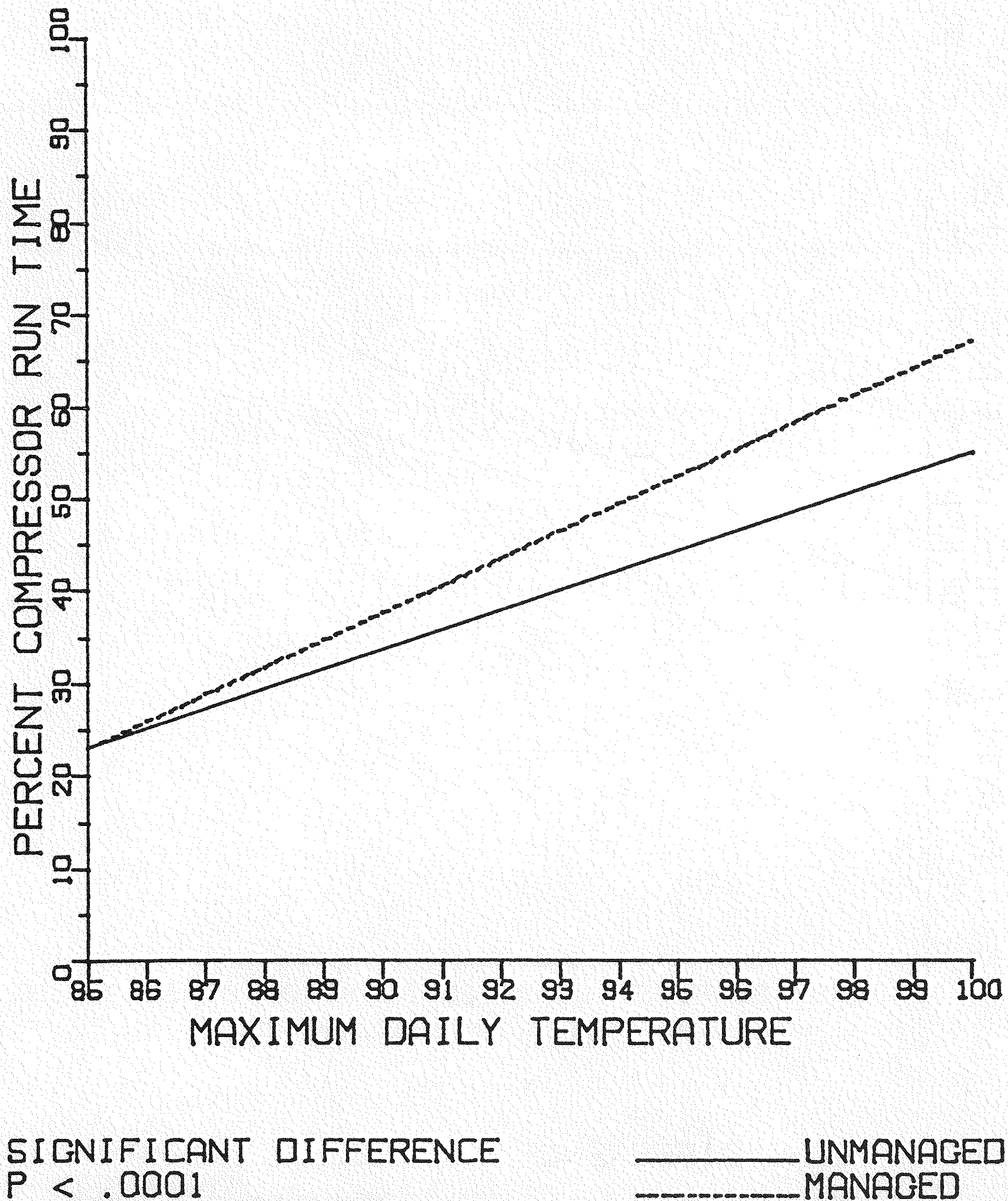
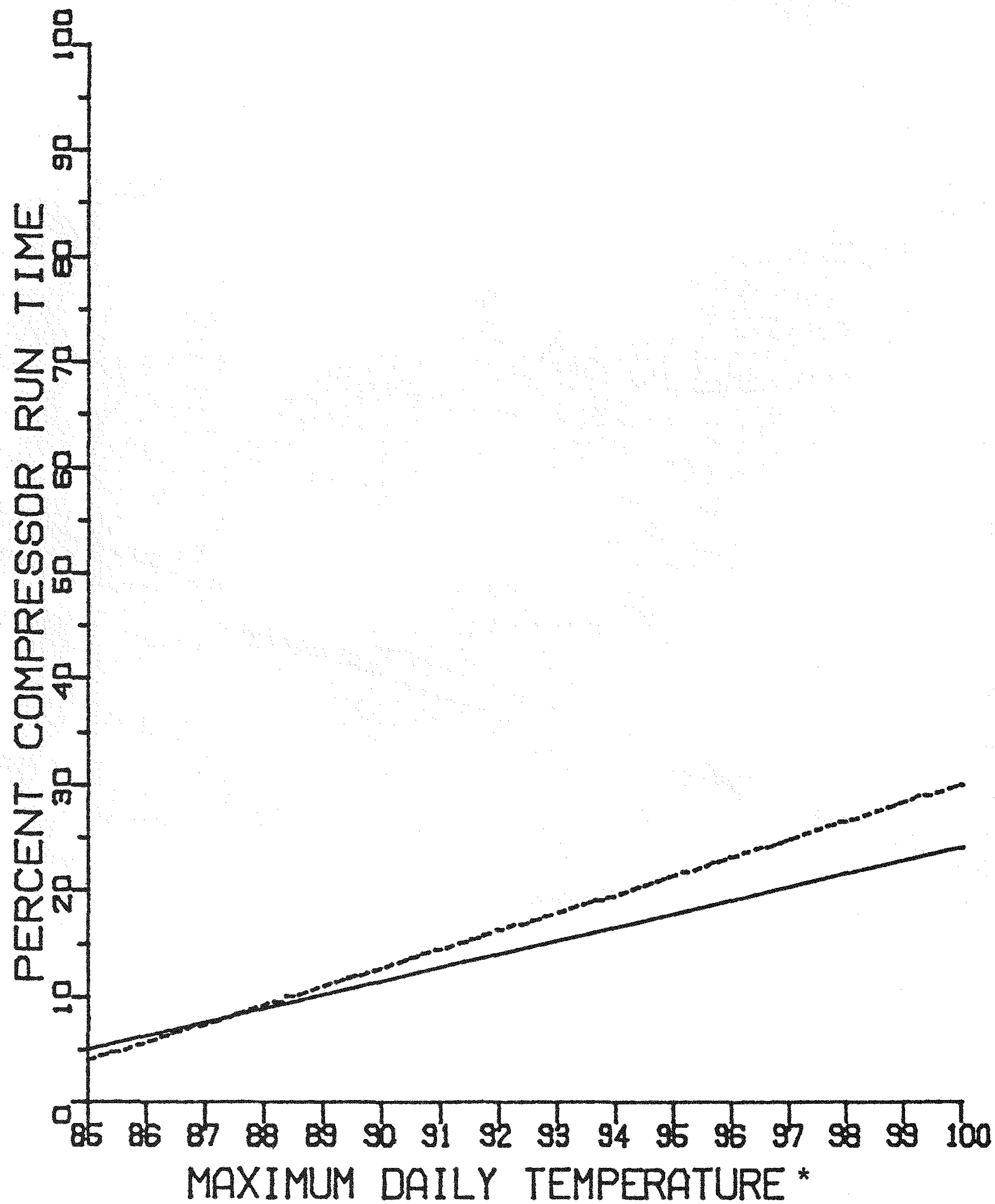


Figure 9-10

MANAGED AND UNMANAGED AIR-CONDITIONING
COMPRESSOR RUN TIME BY TEMPERATURE
HOURS ENDING 0100 - 0600



*MAXIMUM DAILY TEMPERATURE FROM THE PREVIOUS DAY

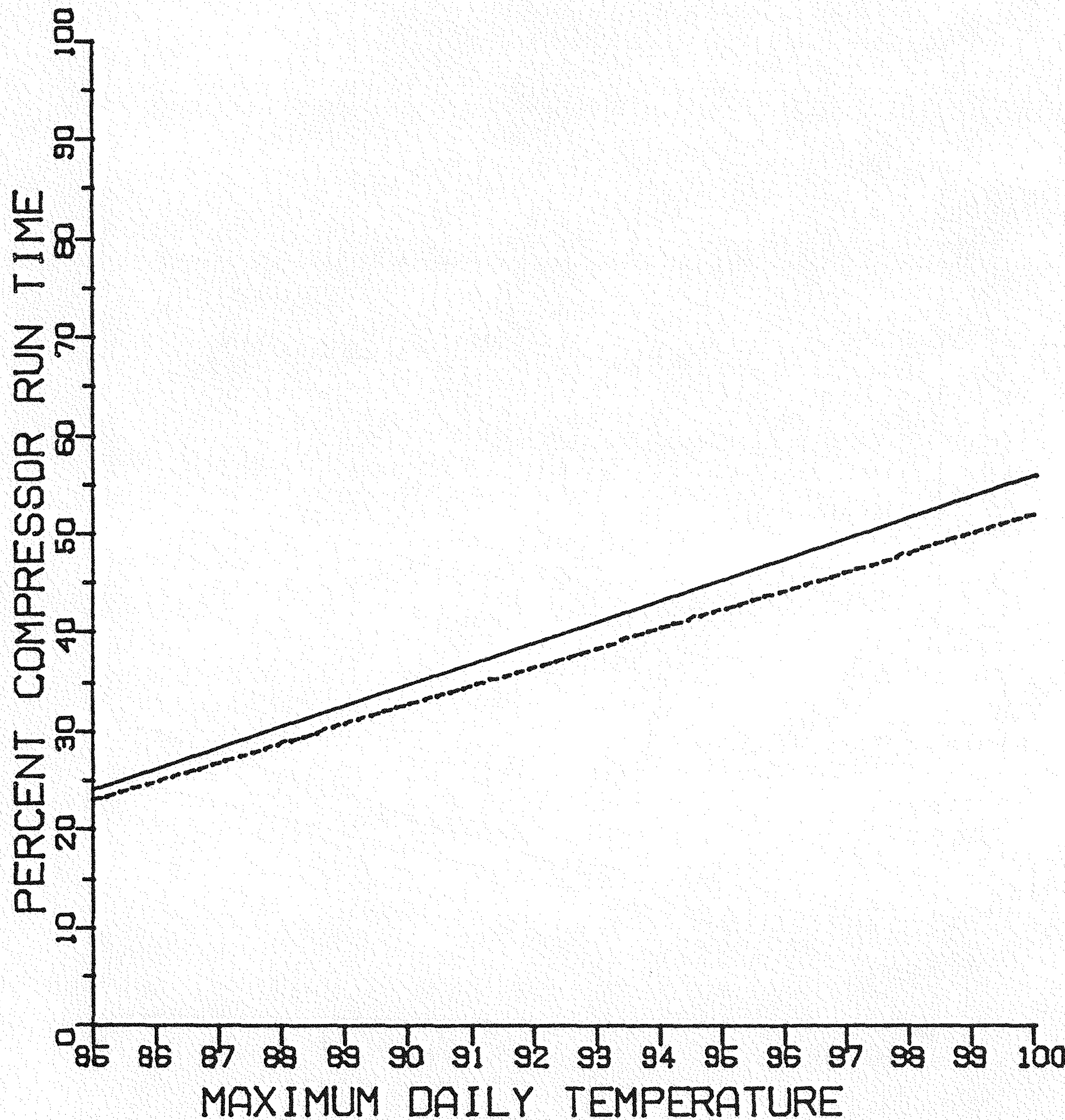
SIGNIFICANT DIFFERENCE
P < .0011

__________UNMANAGED
\- - - - - - - - -MANAGED

Figure 9-11

MANAGED AND UNMANAGED AIR-CONDITIONING
COMPRESSOR RUN TIME BY TEMPERATURE

HOURS ENDING 0100 - 2400



SIGNIFICANT DIFFERENCE
P < .0314

________UNMANAGED
- - - - - - -MANAGED

9.4 Summary

Cycling central air-conditioning units during the TVA system peak period can be effective in reducing the system peak demand. An estimate of 1.0-kW demand reduction per air-conditioning unit at system peak demand times and high temperatures is consistent with results previously reported by other utilities.[7] The majority of residential air-conditioning compressors have sufficient duty cycles during the TVA system peak to be affected by a 25-percent cycling strategy. The length of the duty cycle is a function of maximum daily temperature and hour of day. These facts suggest that an algorithm for determining optimal cycling schedules could be developed.

Although the interim report based on summer 1979 data reported a peak demand reduction of only 0.6 kW per air-conditioning unit, the results in this report (showing a 1.0-kW peak demand reduction potential for central air-conditioners) are not inconsistent with the earlier findings. One-minute compressor data was not available at the time of the earlier analysis so data editing for such occurrences as switch failures could not be accomplished. Further, as indicated in table A-14 the summer of 1979 was milder than the summer of 1980.

Significant energy shift effects were demonstrated to be a function of maximum daily temperature and/or the increase in energy shed during cycling. Although on a daily basis managed air-conditioning units appeared to use less energy than unmanaged units, some energy shed during cycling is paid back in the early morning hours of the next day, particularly at higher maximum temperatures. The data on which this report is based is not sufficient to determine whether or not energy conservation is a by-product of air-conditioning unit cycling.

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7. Arkansas Power and Light Company, 1979 and the American Electric Power Service Corporation, 1980.

10. SPACE HEATING MANAGEMENT

10.1 Introduction

The TVA system winter demand profile is not only a function of residential water heating but also of residential central forced-air electric resistance space heating. Because this type of heating can require a large kW demand, potential system benefits through cycling of these furnaces may be feasible. Several central forced-air electric furnaces were included as a part of the Water Heating/Space Conditioning Control Test since this type of electric heating system is more amenable to cycling than other types of electric heating systems. These forced-air heating units were cycled and monitored to gather hourly furnace demand data and to determine if significant hourly diversified demand reduction can be achieved through cycling.

10.2 Experimental Design

Table A-18 provides a description of the sample and monthly management schedules used in the electric furnace analysis.[1] Of the 47 homes, 14 had electric furnaces which were cycled while the other 33 homes were used as a control group. All 47 homes in the test sample used central forced-air electric resistance heating as the primary heating source.

Hourly diversified electric furnace demand data was recorded from November 1980 through March 1981, 7 days a week, 24 hours a day. Hourly weather conditions were obtained from regional weather sources. Management occurred on alternate weeks for those 14 homes originally equipped with receiver switches. When cycled, an electric furnace was denied electrical energy for 7.5 minutes out of every 30 minutes (i.e., a 25-percent cycling schedule).

Two analytical methods were employed. For the managed furnaces, ANACOVA was used to compare managed energy demand with unmanaged energy demand after adjustments for weather conditions.[2] The second method used was a comparison of managed furnace demand with the unmanaged furnace demand during similar managed days.[3] This

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1. Table A-19 presents related demographic characteristics of the sample. Both tables A-18 and A-19 are found in appendix A.

2. For a description of ANACOVA refer to footnote 4 of section 8.4.

3. This comparison was a comparison in performance between the 14 furnaces equipped with management equipment and the 33 homes without management equipment.

method allowed an independent control group to be compared with the managed group. Both control and managed group data was adjusted with respect to outside air temperature, home square feet, furnace capacity (Btuh), and inches of attic insulation.[4]

10.3 Empirical Results

ANACOVA results indicated that after adjustment for temperatures, no significant demand profile difference between managed and unmanaged days was present. Further, comparison of the control group data with that of the managed furnaces indicated no significant demand reduction at times of management.

Neither method of analysis revealed significant hourly demand reduction from cycling electric furnaces using the selected control strategy. Figure 10-1 illustrates this finding through a comparison of managed and unmanaged demand profiles for the TVA system winter peak day. The TVA system electrical demand is included to show the influence of electric space heating on the shape of the system demand profile. Although the managed and unmanaged demand profiles visually appear to be slightly different, there is no statistically significant difference between the two sets of profiles. The apparent differences between the managed and unmanaged observations are due to dissimilarities in home characteristics and local weather conditions. When these differences are removed by use of ANACOVA, the demand profiles are even more similar. Furthermore, the two profiles have the same shape which provides additional evidence that no alteration of the profile resulted from management.

A possible explanation of the lack of a significant demand reduction due to management of electric furnaces can be made if the following two assumptions are accepted: (1) all the heating elements of the sample's electric furnaces were functioning properly and (2) even though some furnaces feature sequentially activated heating elements, all heating elements were operating within a short period of time after service restoration, i.e., less than 5 minutes. With these assumptions, electric furnace hourly demand reductions can be approximated by the algorithm used in subsection 9.2.2.1 for estimating air-conditioning demand reductions.

Only if electric furnaces are operating with a 75-percent duty cycle when a 25-percent cycling schedule is imposed can a significant hourly diversified demand reduction be achieved.

According to appliance data collected, the average furnace kW demand rating for these furnaces in the sample was 12.56 kW. Therefore, the average 75-percent duty cycle diversified demand was 9.42 kW.

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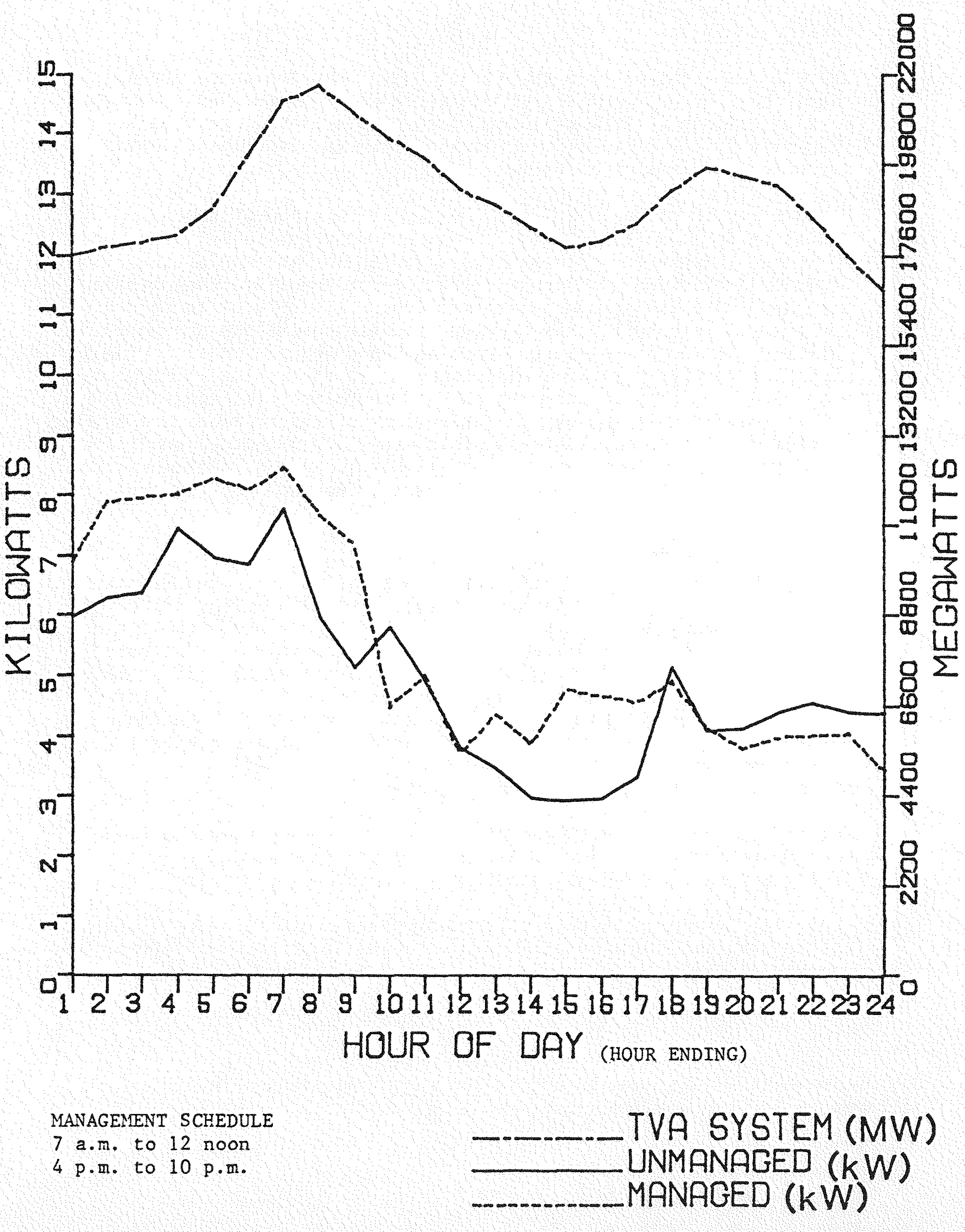
4. Again, ANACOVA was used to adjust for participant characteristics and outside air temperature which are all quantifiable variables.

Figure 10-1

MANAGED AND UNMANAGED CENTRAL ELECTRIC FURNACE LOAD PROFILES ON THE TVA SYSTEM PEAK DAY

February 12, 1981



MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

Figure 10-2, which depicts the relationship of predicted unmanaged electric furnace diversified demand and temperature at the time of daily peak, i.e., 8 a.m., shows that the 9.42-kW diversified demand is not present even at $0^{o}F$.[5] Therefore, a 25-percent cycling strategy would not be effective in reducing most residential furnace hourly diversified demands. In fact, a 50-percent run time would be equivalent to a 6.28-kW diversified demand and only at lower temperatures (less than $12^{o}F$) would this strategy begin to be effective in reducing demand. This analysis suggests that significant demand reductions can be achieved only with a longer cycling strategy than that used in the test and then only at very low temperatures. Further study is required to determine the effects of longer cycling schedules.

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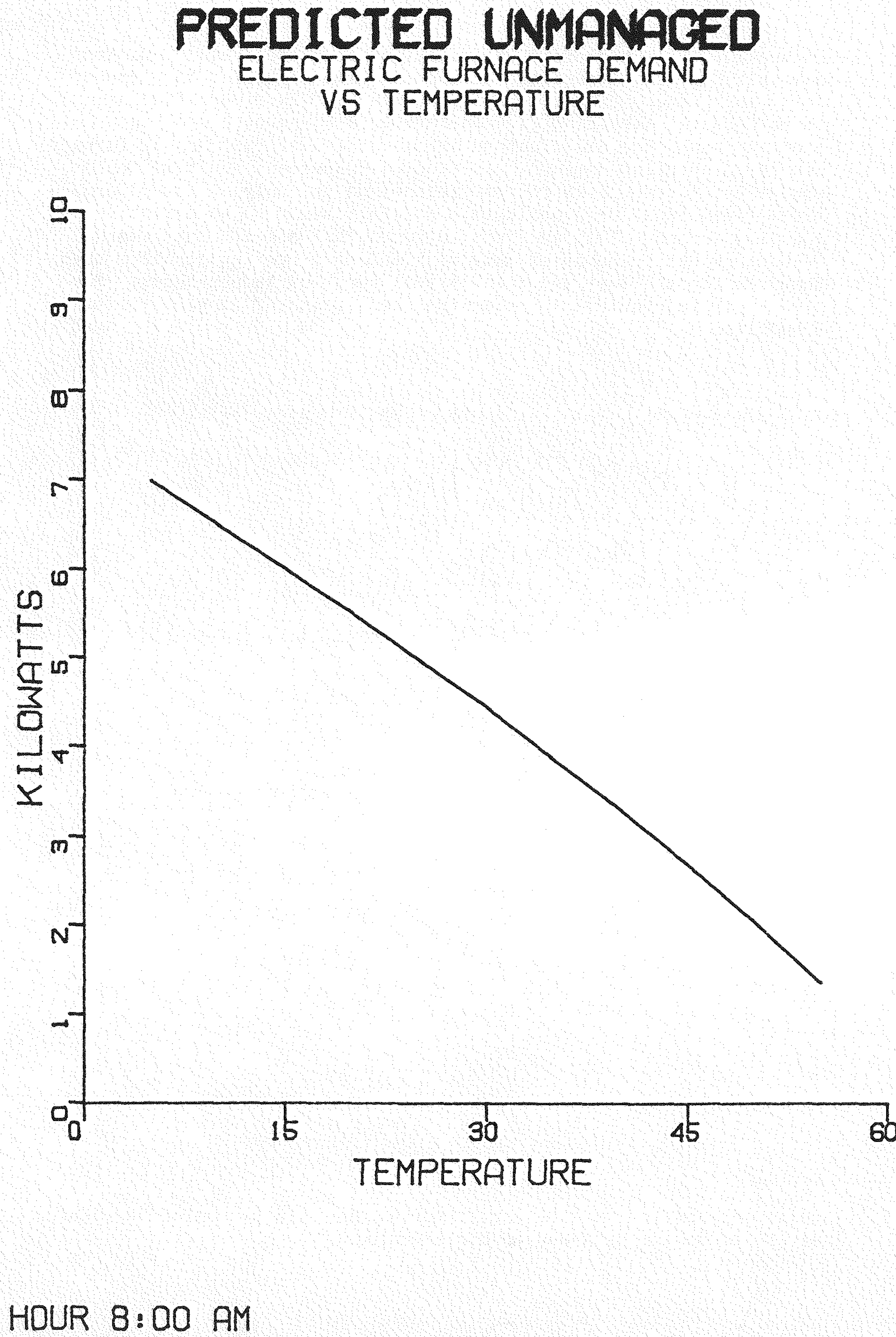
5. A cubic polynomial function was fitted to the data by use of regression analysis to determine these predicted values.

Figure 10-2


PREDICTED UNMANAGED
ELECTRIC FURNACE DEMAND
VS TEMPERATURE
KILOWATTS
0
1
2
3
4
5
6
7
8
9
10
0
15
30
45
60
TEMPERATURE
HOUR 8:00 AM

11. SUMMARY AND PROGRAM PLANS

11.1 Summary of Test Results

Summaries of the test results of cycling standard and storage water heaters, central air-conditioning, and central electric furnaces are presented below.

11.1.1 Water Heater Cycling

When compared to unmanaged standard water heaters, managed standard water heaters provided an average 1.36-kW peak demand reduction per unit for the winter months and an average 0.39-kW peak demand reduction per unit for the summer months. Managed storage water heaters obtained the same demand reductions as managed standard water heaters. Cumulative payback demand immediately after cycling would pose a problem to the TVA system if a phased return-to-service strategy were not implemented.

The posttest questionnaire indicated that the few reported cases of hot water unavailability were largely due to improper sizing of the water heater in relationship to a participant's hot water needs. Therefore, cycling properly sized water heaters during peak demand times promises significant TVA system peak demand reductions without causing a significant loss in hot water availability to the participant.

11.1.2 Air-Conditioning Cycling

The analysis indicated that an average 1.0-kW peak demand reduction per central air-conditioning unit can be achieved on days when the temperature reaches 100°F, while a 0.65-kW peak demand reduction per unit can be achieved when the maximum daily temperature reaches 96°F. When large load reductions are needed, usually on days with more extreme temperatures, the implied larger load reduction will be available. If a large group of residential central air-conditioning units were cycled, a significant reduction of the summer TVA electrical demand would result.

Energy paid back after cycling was not studied in great detail. The analysis indicated that as the maximum daily temperature increases, more energy is paid back in the early hours of the next day. Given this finding and the lack of consecutive days of daily data, appropriate analysis of energy payback could not be accomplished.

A posttest questionnaire to measure participant acceptance of load management technology indicated that most respondents did not experience significant discomfort during air-conditioning cycling. Of those that did report some discomfort, sizing factors such as number of square feet per ton of central air-conditioning did not appear to explain the discomfort. Thermostat settings and sizing factors probably interact to significantly affect home comfort levels during cycling.

11.1.3 Electric Furnace Cycling

The analysis of the forced-air electric furnace data indicated that a 25-percent off time during peak demand periods did not achieve significant demand reductions. Extrapolation of the data implied that at least a 50-percent off time would be necessary to achieve significant demand reductions through cycling. Therefore, further analysis of alternative cycling strategies and impacts on participant comfort levels should be completed before conclusions are made regarding the viability of cycling electric furnaces.

11.2 Future Programs

This section provides an overview and brief descriptions of the load management programs which are currently operational or being considered for implementation. The programs outlined below are the TVA Air-Conditioning Cycling Program, the Water Heater Cycling Program (both are promoted jointly through the Valley as the Cycle & Save Program), and the Offpeak Storage Water Heater Program, which as of November 1982 is not yet available to Valley consumers.

11.2.1 Cycle & Save Programs

The Cycle & Save Programs, which are sponsored by TVA and offered to Valley consumers by local power distributors, are primarily designed to shift electrical demand from peak to offpeak demand hours. This load shift can be accomplished by cycling (i.e., turning off) the appropriate appliance during periods of high demand.

The completely voluntary residential Cycle & Save Programs currently consist of air-conditioner cycling (with over 26,490 program enrollees as of July 31, 1982) and water heater cycling (with over 12,880 program enrollees as of July 31, 1982) in 30 distributorships.[1]

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1. Until 1987, under 50-kW commercial and industrial consumers will be included in the residential Cycle & Save Program.

Cycling is accomplished through an FM radio control system. This system consists of dual-function, radio-controlled receivers and remote relay kits which are installed on the consumer's premises. TVA's Division of Power System Operations initiates cycling using Motorola, Incorporated, computer/controllers. Transmitters send radio signals to receivers installed on central air-conditioner or heat pump compressors (in the cooling mode) and electric water heaters. Upon receiving a signal, the receivers cycle (interrupt service to) air-conditioner compressors (but not fans) for approximately 7.5 minutes out of each half hour during the control period and cycle water heaters for up to 4 hours.

The cycled appliances are grouped into blocks which are cycled as one integrated unit. The staggered cycling of blocks increases the period of reduced demand and decreases the probability of creating a new peak from demand surges as the appliances in each block are returned to service. To avoid creating new peaks, the load management program is specifically designed to fit the particular load pattern prevalent during each season of the year. In a power system emergency, all of the units can be interrupted simultaneously to benefit the TVA system and, subsequently, the distributors and their consumers.

The cost of furnishing, installing, inspecting, and maintaining the receiver switches is paid by TVA with no charge to the program participants. The receivers are installed by local electricians or distributor personnel. Selection of installers is the responsibility of the power distributor and installation costs are reimbursed by TVA.

Participant recruitment and consumer contact is the responsibility of energy advisors employed by TVA and/or the local power distributors. These advisors are also responsible for inspecting each equipment installation for proper conformance to accepted standards.

Residential consumers in air-conditioner cycling receive a $5 per month bill credit (June through September) and residential consumers participating in water heater cycling receive a $2 per month bill credit year round. Commercial and industrial participants receive a monthly bill credit of $2 (June through September) for each ton of controlled air-conditioning capacity. These credits are effective after the installation of the switch for as long as the consumer remains in the program.

By 1986, Cycle & Save air-conditioner cycling is expected to result in about a 140-MW reduction in peak demand (1.0-kW reduction per installation). Water heater cycling should produce about a 177-MW reduction in peak load demand (1.36-kW reduction per installation).

11.2.2 Storage Water Heater Program

The Storage Water Heater Program is being designed to shift energy consumption for residential electric water heating from peak to offpeak periods and to reduce peak demand on the TVA system. The program is expected to consist of two options: (1) time-of-day storage water heater and (2) storage water heater cycling.

Consumers who volunteer to participate in either storage option will usually have to purchase electric water heaters which are larger than would normally be needed. Use of an "oversized" storage water heater is necessary to ensure that the consumer will have an adequate supply of hot water during peak periods when the water heater heating element is not operating.[2] Under either the time-of-day or the cycling option, the power to the consumer's water heater will be interrupted for a period of up to 12 hours. The Storage Water Heater Program will generally be of interest to consumers who are replacing defective water heaters or to those installing water heaters in new construction.

Under the time-of-day option, energy shifting will be accomplished automatically through the use of load control equipment installed on a participant's water heater. The load control package will interrupt power to the water heater during peak periods. The signal for the interruption of power will be initiated by a preprogrammed solid-state timing device built into the time-of-day meter. Participants electing this option will be billed on a time-of-day rate. (Consumers will be charged less than normal for energy used during offpeak periods and more than normal for energy used during peak periods.) Potential savings from the time-of-day rate and a rebate to cover a portion of the storage water heater cost will provide an incentive for program participation.

Under the storage water heater cycling option, the consumer's electric water heater will be equipped with a radio-controlled receiver and the heater will be cycled by computer/controllers. Storage water heater cycling will differ from standard water heater cycling in that the off period will be longer for the storage water heaters.

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2. In some cases the consumer's present water heater is large enough to serve as a storage water heater.

11.3 Final Remarks

The Water Heating/Space Conditioning Control Test was an attempt to learn more about the rather complex issues that have to be confronted when residential appliances are load managed. Because much was learned about residential appliance load management, the test is considered to have been a success. It is hoped that questions left unanswered by this report will encourage other utilities, as well as TVA, to conduct future studies, tests, and demonstrations designed to increase the general level of load management knowledge.

APPENDIX A

REFERENCED APPENDIX

Table A-1

CONSUMER AWARENESS OF LOAD MANAGEMENT

Knowledge of Cycled Appliances

Participant Cycling Category	Response to Which Appliance Was Cycled: Correct Number	Incorrect Number	Number of Responses
Water heater only--standard and storage	45	43	88
Water heater and air-conditioning	28	6	34
Water heater and electric furnace	2	4	6
Total	75	53	128

Knowledge of Management Schedules

Consumer Response Categories	Number of Consumers Selecting Response
7 days per week, year round	69
7 days per week, alternating weeks	3
5 days per week, alternating weeks	5
Don't know or not sure	50
Total	127

Table A-2

KNOWLEDGE OF APPLIANCES THOUGHT CYCLED

VERSUS KNOWLEDGE OF APPLIANCES ACTUALLY CYCLED

Category of Cycling	Response to Which Appliance Was Cycled: Correct	Response to Which Appliance Was Cycled: Incorrect	Total Number of Responses
Water heating only	(45/51.56/0.84)*	(43/36.44/1.18)*	88
Water heating and space conditioning	(30/23.44/1.84)*	(10/16.56/2.60)*	40
Total number of responses	75	53	128

Chi-squared = 6.46
Degrees of freedom = 1

$P < .025$

*(Observed Frequency / Expected Frequency / $\frac{(\text{Observed-Expected})^2}{\text{Expected}}$)

Table A-3

WATER HEATING

CONSUMER REPORTS OF HOT WATER AVAILABILITY BEFORE AND DURING TEST

	Number of Responses				
	No Difference	Worse	Better	Not Sure	Total
Standard water heater	68	23	2	0	93
Storage water heater	23	1	5	3	32
Total	91	24	7	3	125

Table A-4

WATER HEATING

CONSUMER REPORTS OF HOT WATER AVAILABILITY BEFORE AND DURING TEST

Type of Water Heater	No Difference	Worse	Total
Standard	(68/72.01/0.22)*	(23/18.99/0.85)*	91
Storage	(23/18.99/0.85)*	(1/ 5.01/3.21)*	24
Total	91	24	115

Chi-squared = 5.13
Degrees of freedom = 1

$P < .025$

$$*\left(\begin{matrix}\text{Observed}\\ \text{Frequency}\end{matrix} \Big/ \begin{matrix}\text{Expected}\\ \text{Frequency}\end{matrix} \Big/ \frac{(\text{Observed-Expected})^2}{\text{Expected}} \right)$$

Table A-5

STANDARD WATER HEATERS

CONSUMER REPORTS OF HOT WATER AVAILABILITY BEFORE AND DURING TEST

Sizing Factor	No Difference	Worse	Total
Properly sized	(34/28.40/1.11)*	(4/ 9.60/3.27)*	38
Undersized	(34/39.60/0.79)*	(19/13.40/2.34)*	53
Total	68	23	91

Chi-squared = 7.51
Degrees of freedom = 1

$P < .005$

*(Observed Frequency / Expected Frequency / $\frac{(\text{Observed-Expected})^2}{\text{Expected}}$)

Table A-6

SPACE CONDITIONING

CONSUMER REPORTED COMFORT LEVEL OF HOME BEFORE AND DURING TEST

	Number of Responses					
	No Difference	Worse During Test	Don't Know or Not Sure	Total	Space Conditioning Total	
Air-conditioning cycled	34[a]	6[b]	1	41	46	Valid responses
Electric furnace cycled	5	0	0	5		
Mistakingly thought space conditioning was cycled	-	-	-	26	47	Invalid responses
Knew space conditioning wasn't cycled but responded to question	-	-	-	21		
Total	39	6	1	93	93	

a. Average home square feet per ton of central air-conditioning = 600
b. Average home square feet per ton of central air-conditioning = 583

Table A-7

STANDARD WATER HEATER EXPERIMENTAL DESIGN AND SAMPLE CHARACTERISTICS

	Cleveland	Huntsville	Jackson	Tri-County	Overall
Total standard water heaters	78	80	100	100	358
Median number of household inhabitants	3(75)	3(78)	4(63)	3(86)	3(302)
Median number of bathrooms	2(74)	2(78)	2(62)	1(86)	2(300)
Median size of water heaters (gallons)	30-50(75)	51-75(77)	30-50(63)	30-50(86)	30-50(301)
Percent with clothes washers*	93(75)	97(72)	92(61)	97(86)	95(294)
Percent with dishwashers*	59(75)	79(77)	65(62)	42(86)	60(300)

*Percentages, not median values
Subsample or sample sizes are indicated by parentheses

Management Schedules for Standard Water Heaters

Month	Year	a.m.	p.m.
April	1980	07-09	06-09
May	1980	08-11	04-07
June	1980	11-13	04-07
July	1980	11-13	03-06
August	1980	11-13	03-06
September	1980	07-10	05-08
October	1980	06-10	05-08
November	1980	07-09	05-08
December	1980	07-10	05-08
January	1981	08-09	05-08
February	1981	07-10	05-08
March	1981	07-10	05-08

Table A-8

STANDARD WATER HEATER LOAD PROFILE

VALLEY-WIDE AVERAGE

February 1981

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.29	.27	-
2	.19	.21	-
3	.19	.19	-
4	.18	.18	-
5	.23	.22	-
6	.42	.38	-
7	1.02	1.04	-
8	.04	1.40	1.36
9	0	1.01	1.01
10	.14	.83	.69
11	2.37	.70	-1.67
12	1.13	.62	- .51
13	.77	.60	- .18
14	.58	.47	- .11
15	.45	.44	-
16	.47	.52	-
17	.57	.63	-
18	.08	.73	.65
19	0	.97	.97
20	.05	.91	.86
21	2.09	.84	-1.25
22	1.22	.82	- .40
23	.95	.77	- .19
24	.56	.50	-
Total (kWh)	13.99	15.25	

MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 205

Table A-9

STANDARD WATER HEATER LOAD PROFILE

VALLEY-WIDE AVERAGE

July 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.19	.16	-
2	.15	.15	-
3	.13	.12	-
4	.14	.12	-
5	.16	.15	-
6	.26	.27	-
7	.50	.48	-
8	.57	.57	-
9	.53	.52	-
10	.51	.48	-
11	.44	.44	-
12	.08	.43	.35
13	.06	.38	.32
14	.84	.37	-.47
15	.37	.35	-
16	.09	.34	.24
17	0	.39	.39
18	.09	.47	.37
19	1.19	.52	-.67
20	.58	.46	-.12
21	.50	.51	-
22	.52	.52	-
23	.44	.45	-
24	.33	.27	-
Total (kWh)	8.67	8.92	

MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
3 p.m. to 6 p.m.

*P < .002
N = 285

Table A-10

STORAGE WATER HEATER EXPERIMENT DESIGN AND SAMPLE CHARACTERISTICS

	Cleveland	Huntsville	Jackson	Tri-County	Overall
Total storage water heaters	24	25	25	25	99
Median number household inhabitants	4(23)	4(21)	3(23)	3(16)	3(83)
Median number of bathrooms	2(23)	2(21)	2(22)	2(16)	2(82)
Percent with clothes washer*	100(23)	95(20)	96(23)	100(16)	98(82)
Percent with dishwasher*	91(23)	86(21)	74(23)	81(16)	83(83)

*Percentages, not median values
Subsample or sample sizes are indicated by parentheses

Management Schedules for Storage Water Heaters

Month	Year	a.m.	p.m.
April	1980	07-14	05-10
May	1980	-	12-11
June	1980	-	12-11
July	1980	-	12-11
August	1980	-	12-11
September	1980	06-13	05-10
October	1980	07-12	04-10
November	1980	07-12	04-09
December	1980	07-13	04-09
January	1981	08-13	05-11
February	1981	07-12	04-10
March	1981	07-12	04-10

Table A-11

STORAGE WATER HEATER LOAD PROFILE

VALLEY-WIDE AVERAGE

July 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.14	.22	- .92
2	.65	.19	- .46
3	.42	.14	- .28
4	.23	.15	-
5	.21	.14	-
6	.31	.25	-
7	.61	.64	-
8	.72	.63	-
9	.59	.50	-
10	.57	.55	-
11	.54	.56	-
12	.45	.52	-
13	.05	.45	.40
14	0	.45	.45
15	0	.38	.38
16	0	.41	.41
17	0	.44	.44
18	0	.62	.62
19	0	.56	.56
20	0	.57	.57
21	0	.71	.71
22	0	.55	.55
23	.09	.54	.45
24	2.92	.36	-2.56
Total (kWh)	9.50	10.53	

MANAGEMENT SCHEDULE
12 noon to 11 p.m.

*P < .002
N = 56

Table A-12

STORAGE WATER HEATER LOAD PROFILE

VALLEY-WIDE AVERAGE

February 1981

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.22	.47	- .75
2	.71	.33	- .38
3	.53	.31	-
4	.34	.23	-
5	.41	.30	-
6	.41	.40	-
7	.95	1.12	-
8	.01	1.62	1.61
9	-	1.29	1.29
10	-	.98	.98
11	-	.81	.81
12	.07	.63	.56
13	2.94	.65	-2.29
14	1.91	.58	-1.33
15	1.22	.59	-.63
16	.89	.63	-
17	.02	.76	.74
18	-	.84	.84
19	-	.99	.99
20	-	1.02	1.02
21	-	.98	.98
22	.04	.90	.86
23	2.87	.83	-2.04
24	1.93	.63	-1.30
Total (kWh)	16.47	17.89	

MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

*P < .002
N = 51

Table A-13

COMPARISON OF DAILY ENERGY USE FOR

STANDARD WATER HEATERS AND 120-GALLON STORAGE WATER HEATERS

Analysis of Covariance

Source of Variation	DF	SAS GLM Type IV Sum of Squares	F Value	Probability > F
Type of water heater	1	10.46	0.24	0.6238
Dishwasher	1	51.56	1.19	0.2766
(Dishwasher) (water heater type)*	1	61.46	1.42	0.2350
Number of bathrooms**	1	181.61	4.19	0.0418***
Number of inhabitants***	1	2,306.83	53.19	0.0001***

Estimated variance = 43.37

Degrees of freedom = 243

*Interactive variable
**Covariates
***Denotes significance at P 0.05

Table A-14

GEOGRAPHIC LOCATION OF MANAGED AIR-CONDITIONING PARTICIPANTS AND COOLING DEGREE DAYS

Sample Distribution

	Cleveland	Huntsville	Jackson	Tri-County	Total
Central air-conditioning	1	7	10	12	30
Heat pumps	17	17	24	3	61
Total	18	24	34	15	91

Number of Cooling Degree Days Base 65^{o}F

June 1 Through September 30

Year	Cleveland	Chattanooga	Huntsville
1975	1,108	1,193	1,286
1976	894	1,088	1,139
1977	1,424	1,814	1,677
1978	1,371	1,614	1,576
1979	1,057	1,277	1,262
1980	1,564	1,674	1,723

Chattanooga normal - 1,377
Huntsville normal - 1,507

Source: National Weather Service office normals based on the years of 1941 through 1970; there is no stated normal for Cleveland

Table A-15

DEMOGRAPHIC CHARACTERISTICS OF TEST PARTICIPANTS

WITH CENTRAL AIR-CONDITIONING SYSTEMS

MEDIAN VALUES

	Cleveland	Huntsville	Jackson	Tri-County	Valley-Wide
Number of household inhabitants	4(31)	3(38)	3(37)	3(24)	3(130)
Home square feet*	2,218(31)	2,143(38)	1,708(34)	1,663(24)	1,954(127)
Age of house (years)	6-10(31)	11-15(38)	1-5(37)	6-10(24)	6-10(130)
Inches of floor insulation	0(29)	0(36)	0(34)	0(24)	0(123)
Inches of wall insulation	3(26)	3(38)	4(34)	3(24)	3(122)
Inches of attic insulation	6(30)	6(34)	6(36)	6(23)	6(123)
Percent with storm windows**	60(30)	87(37)	73(37)	100(24)	79(128)
Air-conditioning capacity (Btuh)*	41,700(22)	48,400(25)	37,700(6)	35,900(23)	41,800(76)

*Mean value
**Percent, not median or mean value
Subsample or sample sizes are indicated by parentheses

Note: Sample sizes may total more than 91 because data contains information from some test participants without managed air-conditioners (managed water heaters only)

Table A-16

AREA REGRESSION MODELS FOR PREDICTING

HOURLY DIVERSIFIED DEMAND FOR UNMANAGED AIR-CONDITIONING

	Cleveland	Huntsville	Jackson	Tri-County	Valley-Wide
Significant Independent Variables	X1	X1	X1	X1	X1
	X2	X4	X2	X3	X2
	X4	X5	X3	X4	X4
	X5		X4	X5	X5
			X5		
R-Square	0.88	0.82	0.93	0.83	0.83

X1 = Present outside air temperature
X2 = One-hour temperature lag
X3 = Two-hour temperature lag
X4 = Three-hour temperature lag
X5 = Hourly relative humidity

Table A-17

DISTRIBUTION OF 100-PERCENT AIR-CONDITIONING RUN TIME DEMANDS

Connected Load (kW)	Percent of Sample	Cumulative Percent	Maximum Reduction at 25-Percent Cycling (kW)
2.0	1.49	1.49	0.50
2.6	1.49	2.98	0.65
2.9	1.49	4.47	0.73
3.4	5.97	10.44	0.85
3.5	2.99	13.43	0.88
3.6	1.49	14.92	0.90
3.7	2.99	17.91	0.93
3.8	1.49	19.40	0.95
3.9	7.46	26.86	0.98
4.0	2.99	29.85	1.00
4.1	1.49	31.34	1.03
4.2	2.99	34.33	1.05
4.3	8.96	43.29	1.08
4.4	1.49	44.78	1.10
4.5	4.48	49.26	1.13
4.6	1.49	50.75	1.15
4.7	1.49	52.24	1.18
4.8	4.48	56.72	1.20
4.9	1.49	58.21	1.23
5.0	1.49	59.70	1.25
5.1	1.49	61.19	1.28
5.2	4.48	65.67	1.30
5.3	5.97	71.64	1.33
5.4	4.48	76.12	1.35
5.6	1.49	77.61	1.40
5.8	1.49	79.10	1.45
5.9	2.99	82.09	1.48
6.0	2.99	85.08	1.50
6.3	1.49	86.57	1.58
6.4	2.99	89.56	1.60
6.6	4.48	94.04	1.65
6.8	1.49	95.53	1.70
7.0	1.49	97.02	1.75
7.2	1.49	98.51	1.80
7.7	1.49	100.00	1.93

Table A-18

SAMPLE DISTRIBUTION AND MANAGEMENT SCHEDULE FOR ELECTRIC FURNACES

Sample Distribution

	Cleveland	Huntsville	Jackson	Tri-County	Total
Managed	2	4	1	7	14
Unmanaged	9	12	0	12	33
Total	11	16	1	19	47

Management Schedule

Month	Year	a.m.	p.m.
November	1980	07-10	05-08
December	1980	07-12	05-10
January	1981	08-13	05-10
February	1981	07-12	04-10
March	1981	07-12	04-10

Table A-19

DEMOGRAPHIC CHARACTERISTICS OF CENTRAL ELECTRIC FURNACE PARTICIPANTS

MEDIAN VALUES

Managed	Cleveland	Huntsville	Jackson	Tri-County	Valley-Wide
Home square feet*	1,500(02)	1,857(07)	1,463(02)	1,711(07)	1,717(18)
Inches of floor insulation	4(02)	2(07)	0(03)	1(06)	1(18)
Inches of wall insulation	3(02)	3(07)	4(03)	3(07)	3(19)
Inches of attic insulation	5(02)	4(06)	6(03)	6(06)	6(17)
Electric furnace capacity (kW)*	12.3(02)	9.3(02)	4.4(01)	13.1(07)	11.6(12)
Unmanaged					
Home square feet*	1,876(10)	1,378(11)	-	1,311(09)	1,524(30)
Inches of floor insulation	3(11)	0(09)	-	0(07)	0(27)
Inches of wall insulation	3(11)	3(09)	-	3(08)	3(28)
Inches of attic insulation	10(11)	5(11)	-	6(08)	6(30)
Electric furnace capacity (kW)*	10.5(10)	14.1(12)	-	16.7(10)	13.8(32)

*Mean value
Subsample or sample sizes are indicated by parentheses

Note: Due to instrumentation difficulties, managed samples often totaled to more than the 14 homes that were actually used for the analysis

APPENDIX B

UNREFERENCED APPENDIX

Table B-1

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

April 1980

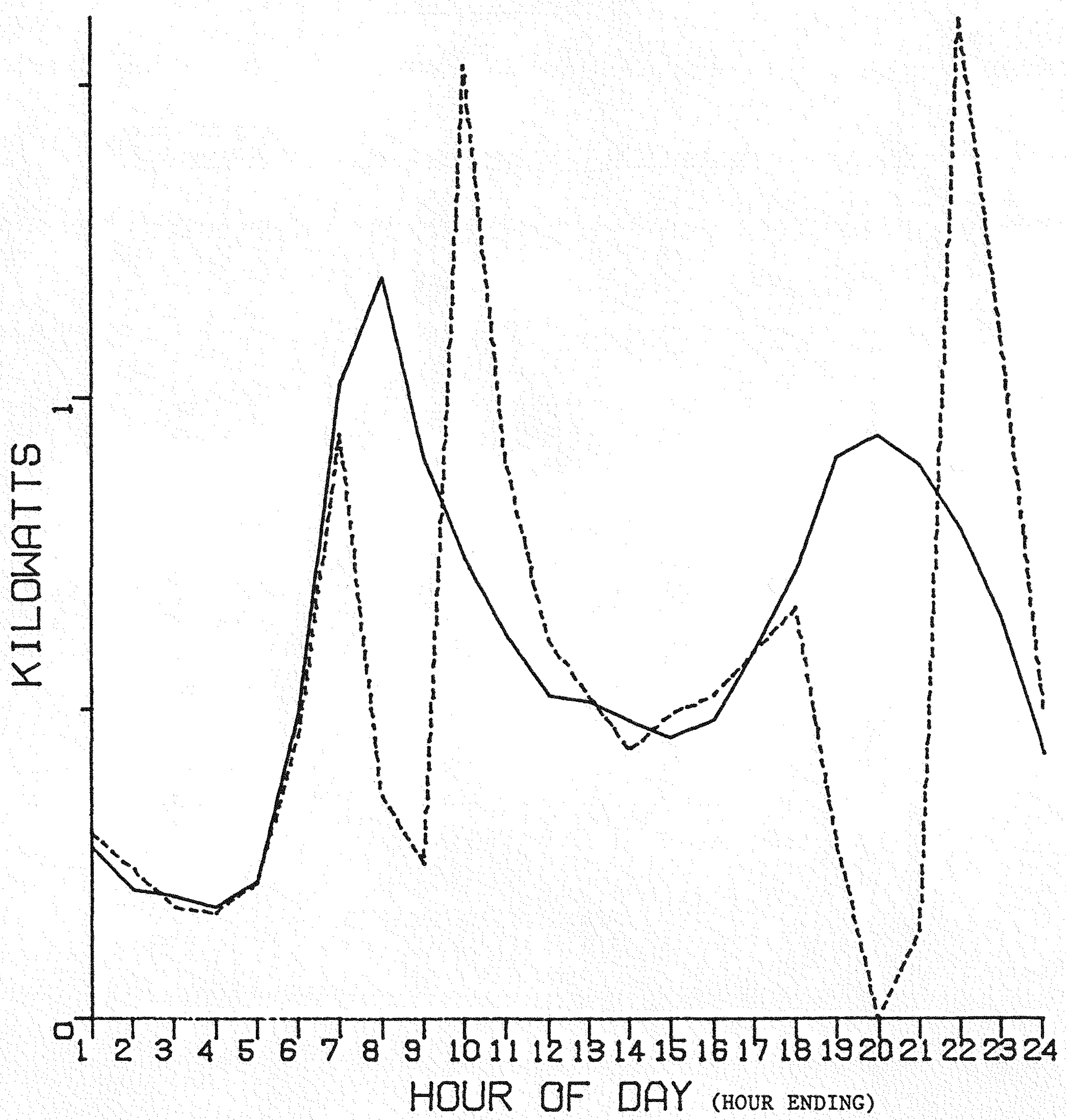
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.30	.28	-
2	.24	.21	-
3	.18	.20	-
4	.17	.18	-
5	.22	.22	-
6	.45	.49	-
7	.94	1.02	-
8	.36	1.19	.83
9	.25	.90	.65
10	1.53	.74	- .79
11	.89	.62	- .27
12	.61	.52	-
13	.52	.51	-
14	.43	.48	-
15	.49	.45	-
16	.52	.48	-
17	.59	.59	-
18	.66	.72	-
19	.28	.90	.62
20	0	.94	.94
21	.14	.89	.75
22	1.61	.79	- .82
23	1.10	.65	- .45
24	.50	.43	-
Total (kWh)	12.98	14.40	

MANAGEMENT SCHEDULE
7 a.m. to 9 a.m.
6 p.m. to 9 p.m.

*P < .002
N = 300

Figure B-1

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
APRIL 1980



MANAGEMENT SCHEDULE
7 a.m. to 9 a.m.
6 p.m. to 9 p.m.

------------ MANAGED
____________ UNMANAGED

Table B-2

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

May 1980

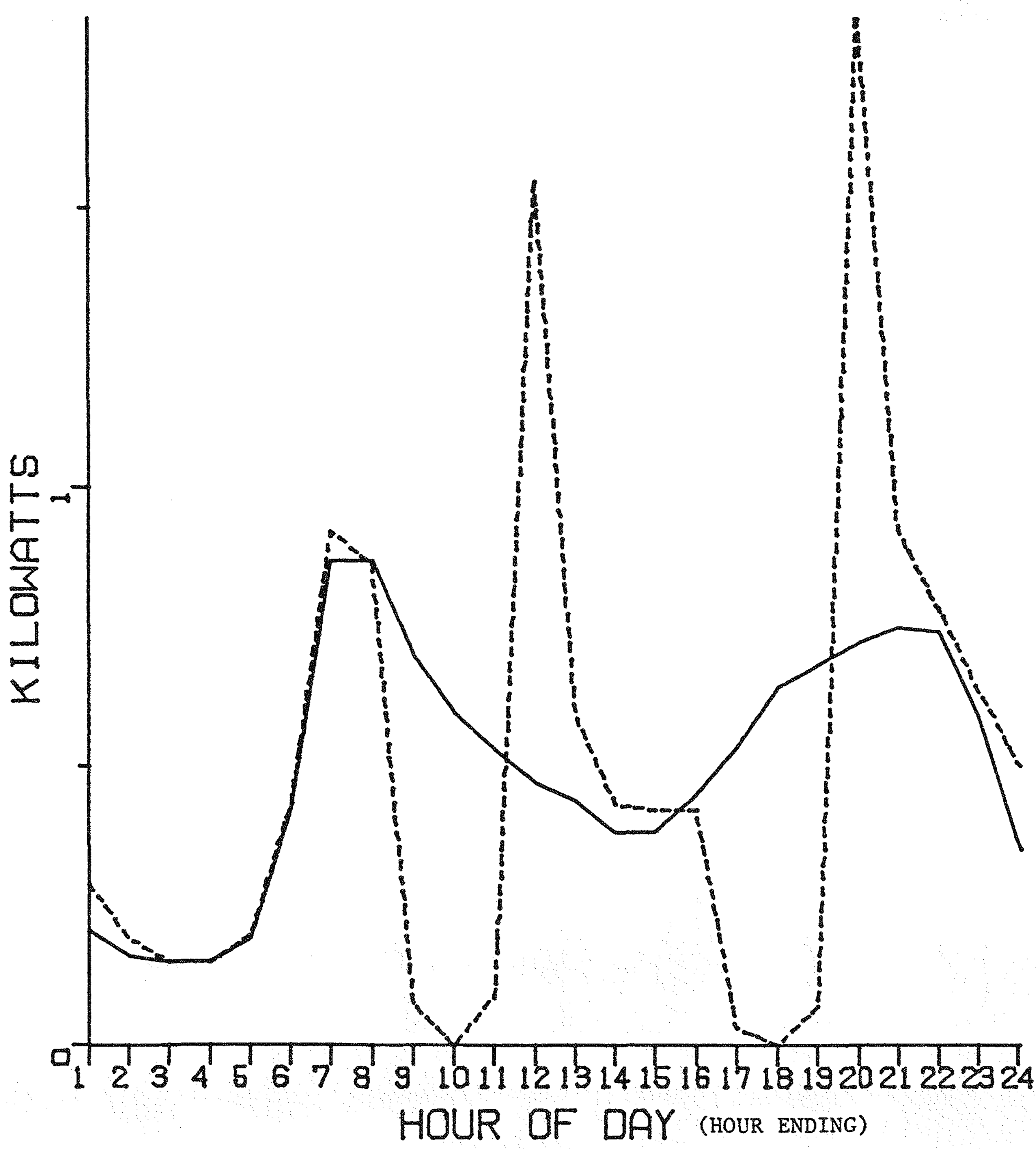
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.29	.21	-
2	.19	.16	-
3	.15	.15	-
4	.15	.16	-
5	.20	.19	-
6	.43	.42	-
7	.92	.87	-
8	.86	.87	-
9	.07	.70	.63
10	0	.60	.60
11	.09	.53	.44
12	1.55	.47	- 1.08
13	.59	.44	- .15
14	.43	.38	-
15	.42	.38	-
16	.42	.45	-
17	.03	.53	.50
18	0	.64	.64
19	.07	.68	.61
20	1.84	.72	- 1.12
21	.92	.75	- .17
22	.78	.74	-
23	.63	.59	-
24	.50	.35	-
Total (kWh)	11.53	11.98	

MANAGEMENT SCHEDULE
8 a.m. to 11 a.m.
4 p.m. to 7 p.m.

*P < .002
N = 302

Figure B-2

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
MAY 1980



MANAGEMENT SCHEDULE
8 a.m. to 11 a.m.
4 p.m. to 7 p.m.

Table B-3

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

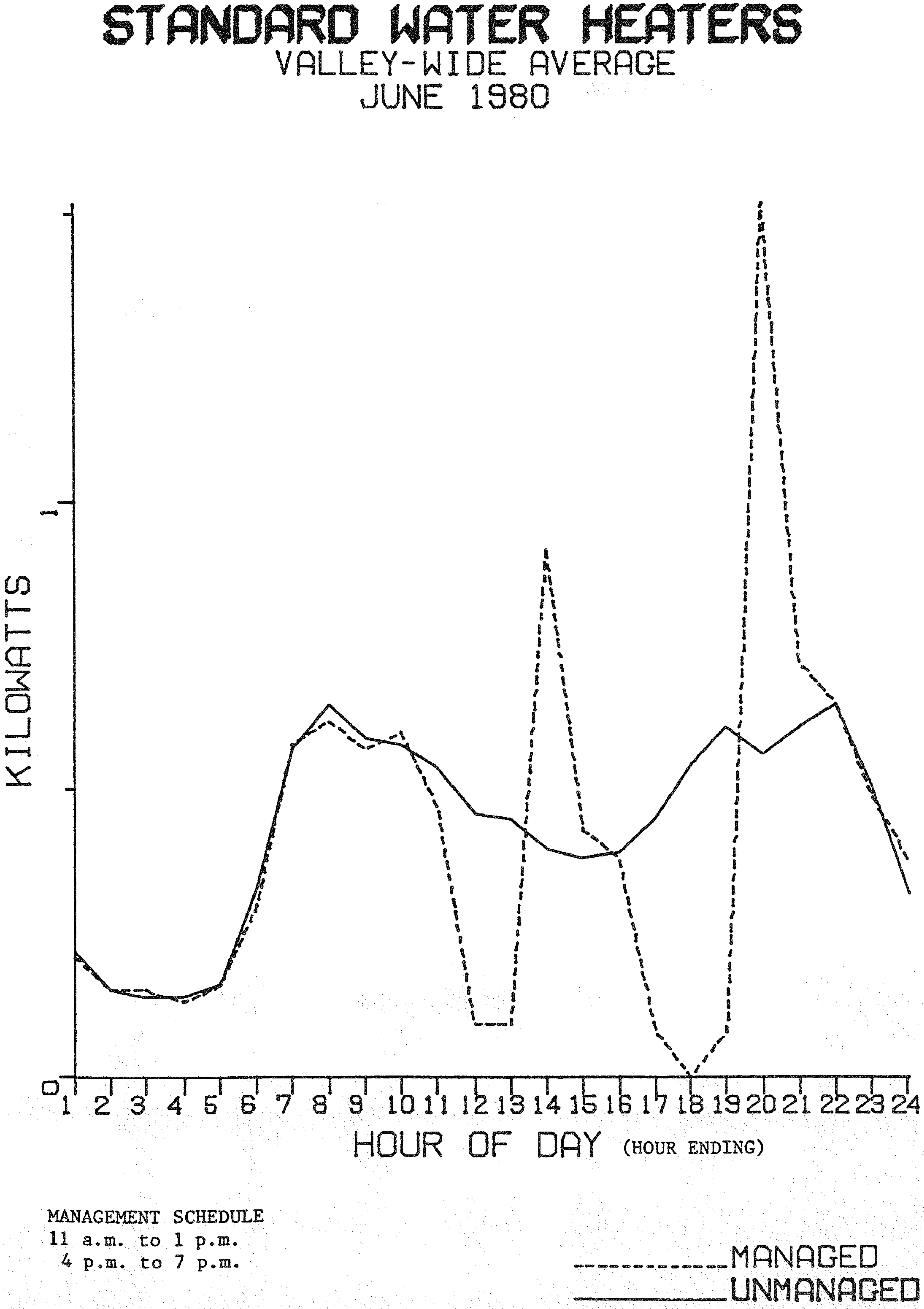
June 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.21	.22	-
2	.15	.15	-
3	.15	.14	-
4	.13	.14	-
5	.16	.16	-
6	.30	.33	-
7	.58	.57	-
8	.62	.65	-
9	.57	.59	-
10	.60	.58	-
11	.47	.54	-
12	.09	.46	.37
13	.09	.45	.36
14	.92	.40	- .52
15	.43	.38	-
16	.38	.39	-
17	.08	.45	.37
18	0	.54	.54
19	.08	.61	.53
20	1.52	.56	- .96
21	.72	.61	- .11
22	.65	.65	-
23	.49	.51	-
24	.38	.32	-
Total (kWh)	9.77	10.40	

MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
4 p.m. to 7 p.m.

*P < .002
N = 305

Figure B-3



MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
4 p.m. to 7 p.m.

Table B-4

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

August 1980

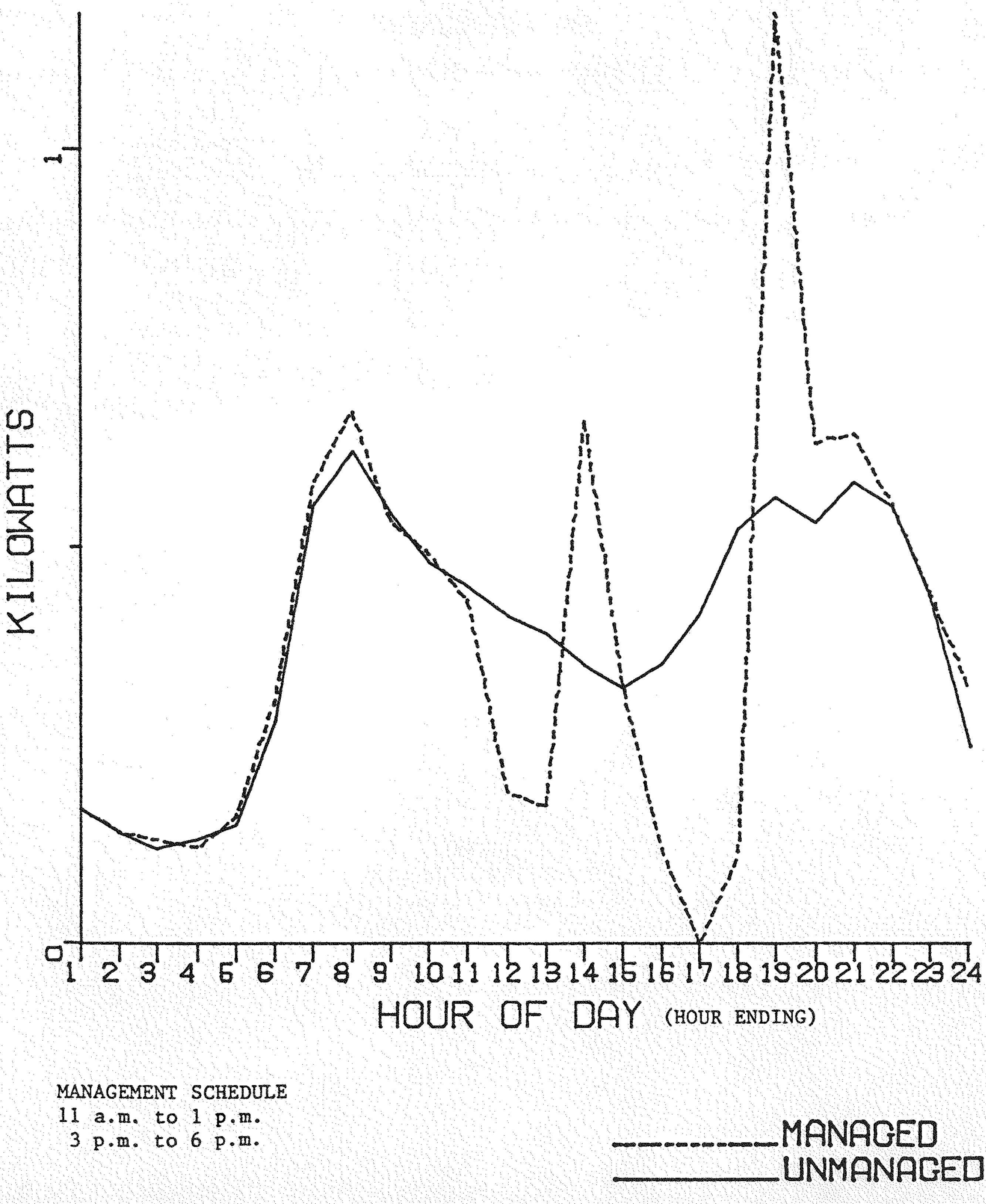
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.17	.17	-
2	.14	.14	-
3	.13	.12	-
4	.12	.13	-
5	.16	.15	-
6	.31	.28	-
7	.58	.55	-
8	.67	.62	-
9	.53	.54	-
10	.49	.48	-
11	.43	.45	-
12	.19	.41	.22
13	.17	.39	.22
14	.66	.35	- .31
15	.32	.32	-
16	.12	.35	.23
17	0	.41	.41
18	.11	.52	.41
19	1.17	.56	- .61
20	.63	.53	- .10
21	.64	.58	-
22	.55	.55	-
23	.44	.44	-
24	.32	.25	-
Total (kWh)	9.05	9.29	

MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
3 p.m. to 6 p.m.

*P < .002
N = 266

Figure B-4

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
AUGUST 1980



MANAGEMENT SCHEDULE
11 a.m. to 1 p.m.
3 p.m. to 6 p.m.

Table B-5

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

September 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.17	.16	-
2	.14	.14	-
2	.13	.13	-
4	.14	.14	-
5	.17	.17	-
6	.38	.39	-
7	.72	.76	-
8	.18	.72	.54
9	0	.51	.51
10	.08	.43	.35
11	1.29	.38	- .91
12	.40	.37	-
13	.31	.34	-
14	.38	.32	-
15	.34	.32	-
16	.36	.33	-
17	.40	.43	-
18	.10	.52	.42
19	0	.60	.60
20	.08	.68	.60
21	1.60	.63	- .97
22	.63	.54	-
23	.48	.44	-
24	.29	.24	-
Total (kWh)	8.77	9.69	

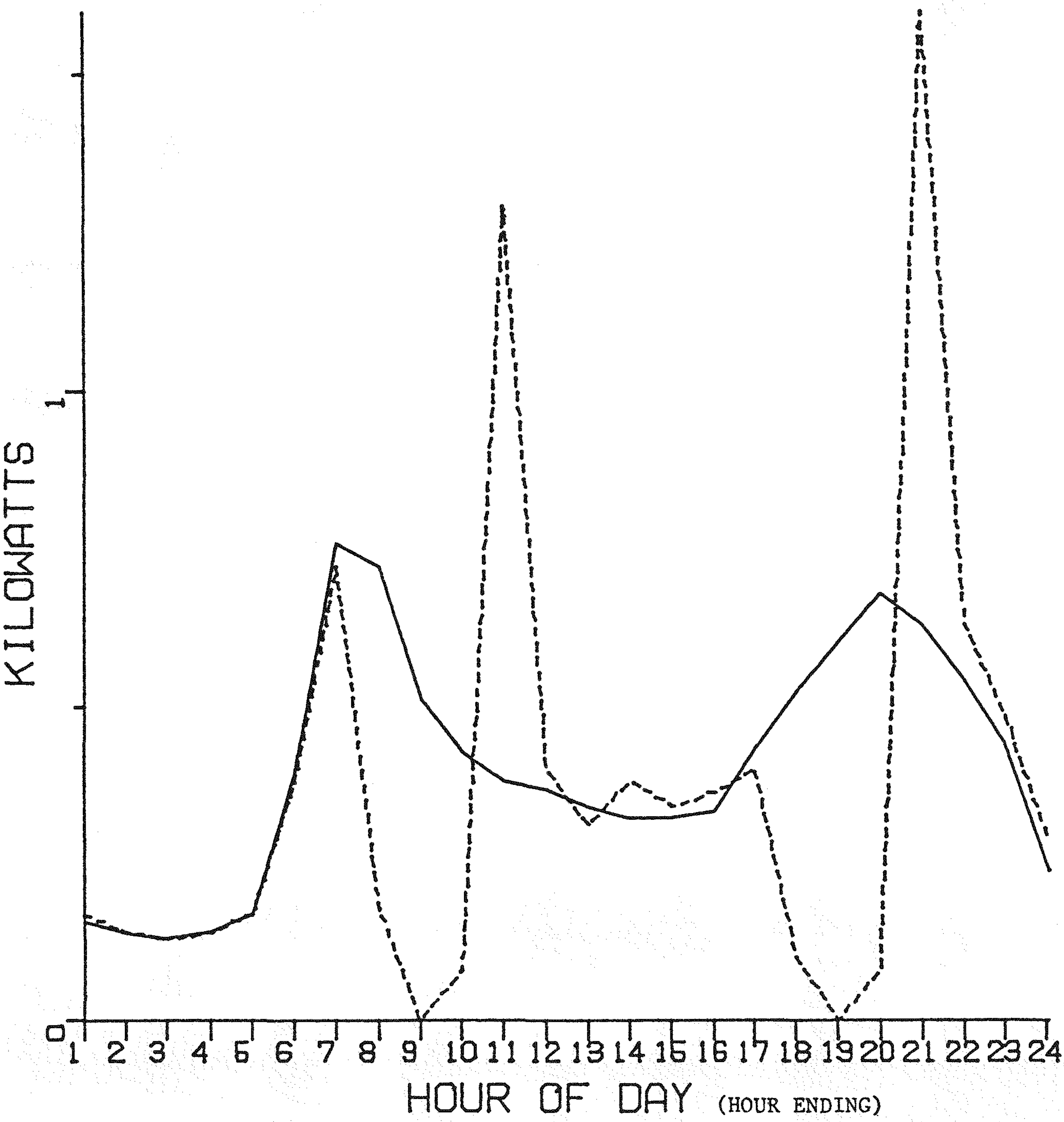
MANAGEMENT SCHEDULE
7 a.m. to 1 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 239

Figure B-5

STANDARD WATER HEATERS

VALLEY-WIDE AVERAGE
SEPTEMBER 1980



MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

-------------MANAGED
________UNMANAGED

Table B-6

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

October 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.18	.20	-
2	.18	.16	-
3	.15	.15	-
4	.15	.15	-
5	.18	.19	-
6	.35	.39	-
7	.06	.84	.78
8	0	.94	.94
9	0	.72	.72
10	.08	.56	.48
11	2.30	.48	- 1.82
12	.74	.44	- .30
13	.54	.41	- .13
14	.43	.40	-
15	.37	.38	-
16	.45	.44	-
17	.49	.52	-
18	.09	.62	.53
19	0	.74	.74
20	.03	.73	.70
21	1.88	.69	- 1.19
22	.88	.59	- .29
23	.65	.55	-
24	.40	.34	-
Total (kWh)	10.58	11.63	

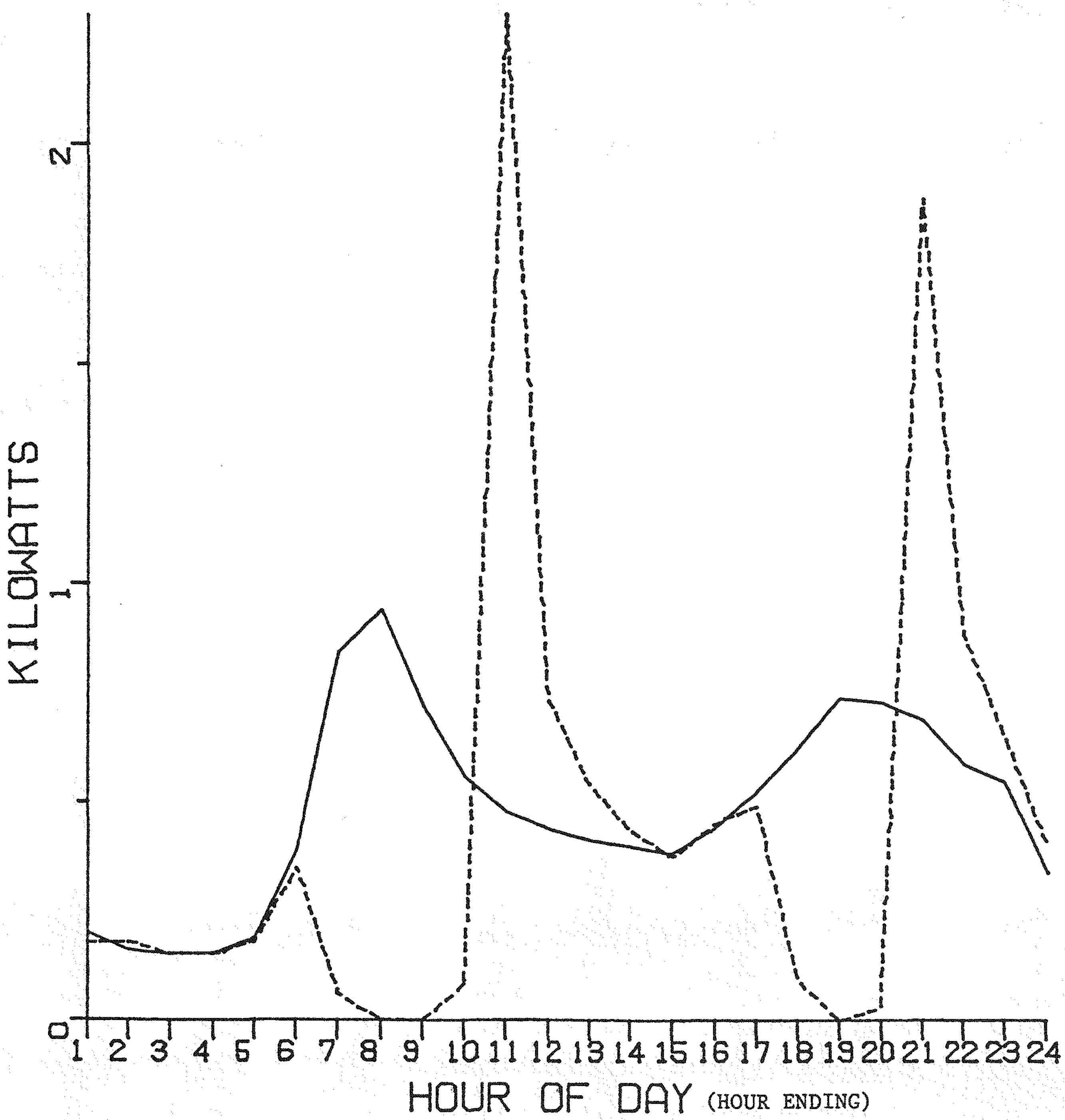
MANAGEMENT SCHEDULE
6 a.m. to 10 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 242

Figure B-6

STANDARD WATER HEATERS

VALLEY-WIDE AVERAGE
OCTOBER 1980



MANAGEMENT SCHEDULE
6 a.m. to 10 a.m.
5 p.m. to 8 p.m.

----------- MANAGED
___________ UNMANAGED

Table B-7

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

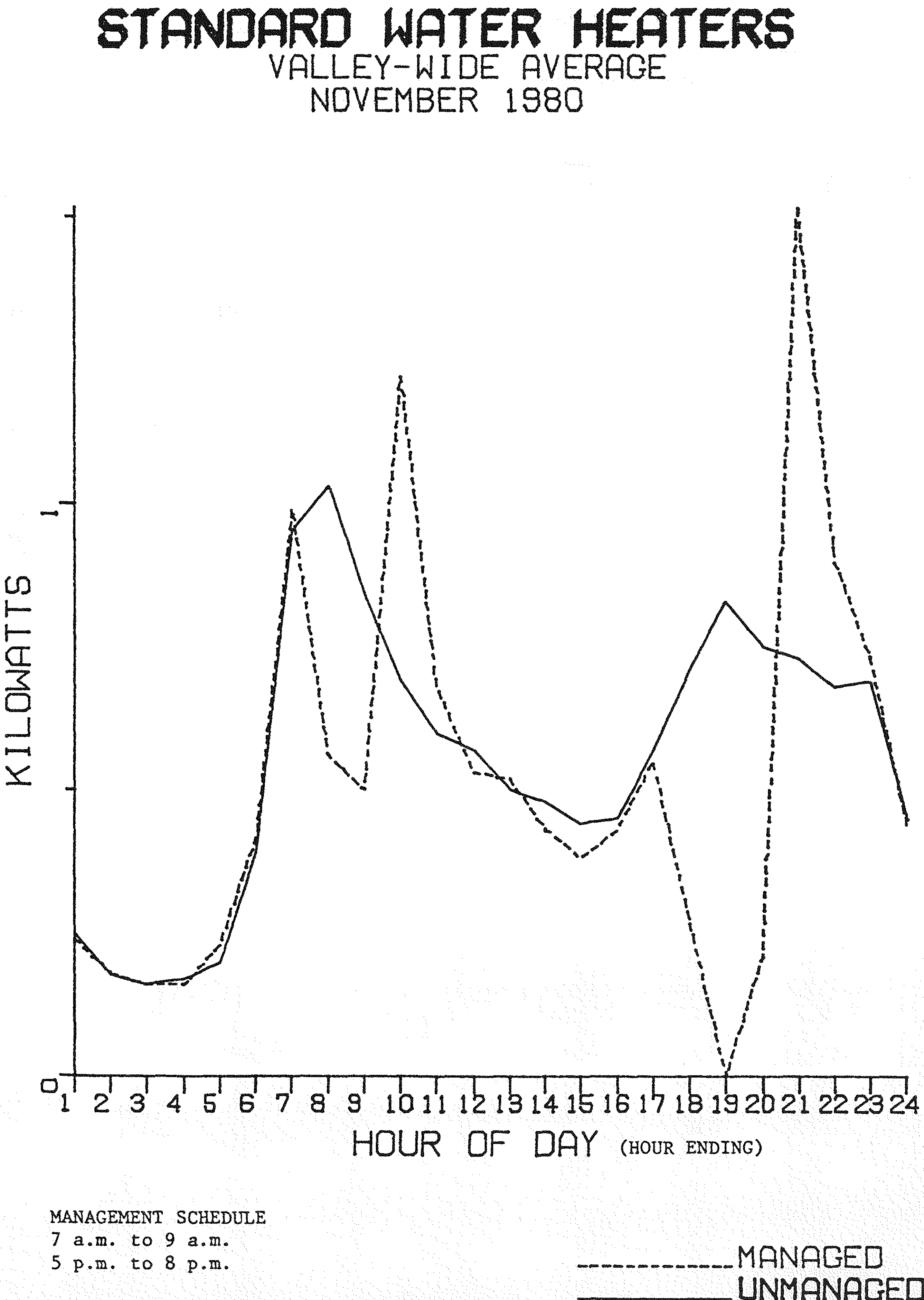
November 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.24	.24	-
2	.18	.18	-
3	.16	.16	-
4	.16	.17	-
5	.23	.20	-
6	.42	.39	-
7	.99	.95	-
8	.56	1.03	.47
9	.50	.84	.34
10	1.22	.69	- .53
11	.68	.60	-
12	.53	.57	-
13	.52	.50	-
14	.43	.48	-
15	.38	.44	-
16	.43	.45	-
17	.55	.57	-
18	.27	.71	.44
19	0	.83	.83
20	.21	.75	.54
21	1.52	.73	- .79
22	.90	.68	- .22
23	.73	.69	-
24	.44	.45	-
Total (kWh)	12.25	13.31	

MANAGEMENT SCHEDULE
7 a.m. to 9 a.m.
5 p.m. to 8 p.m.

*$P < .002$
N = 279

Figure B-7



MANAGEMENT SCHEDULE
7 a.m. to 9 a.m.
5 p.m. to 8 p.m.

Table B-8

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

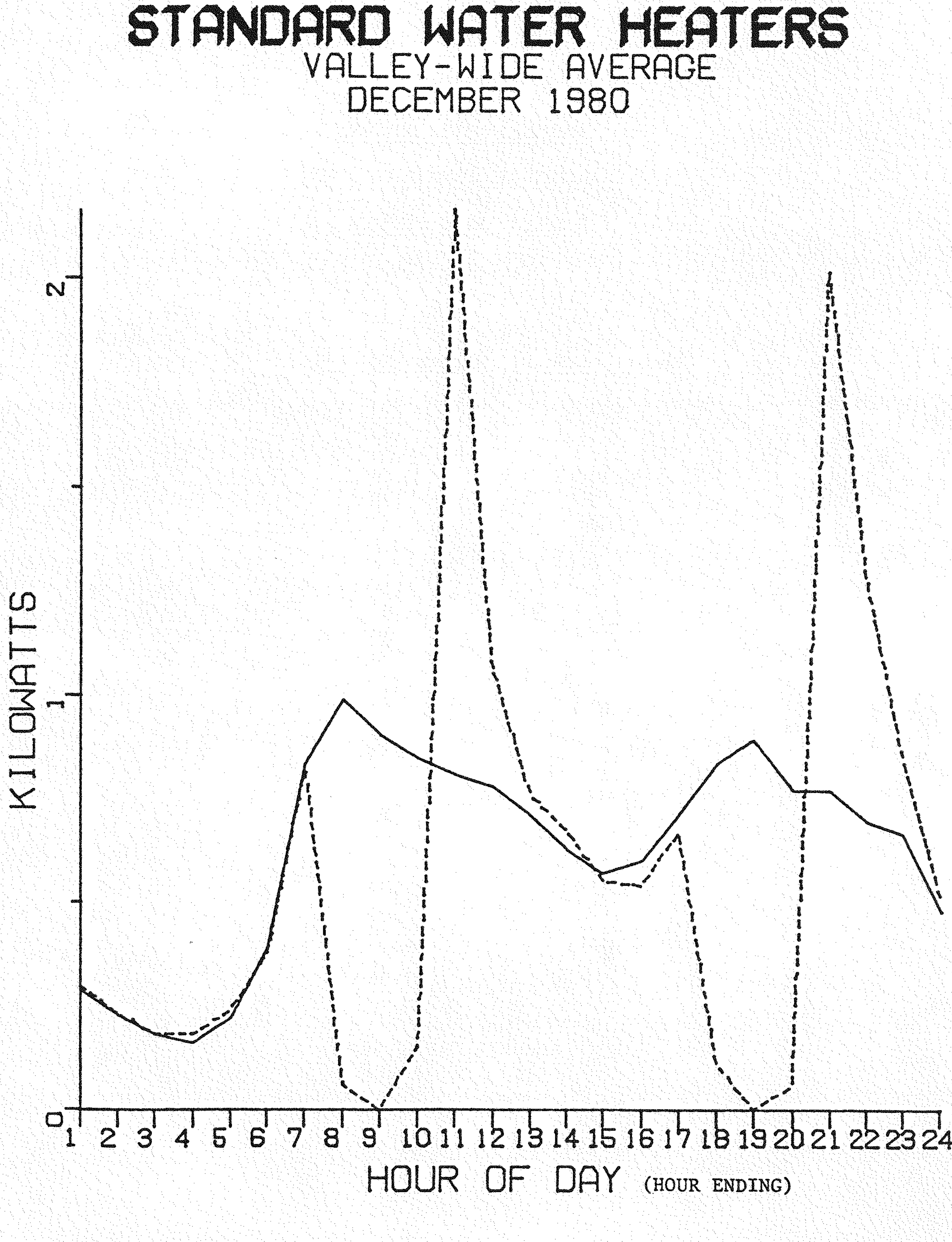
December 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.30	.29	-
2	.23	.23	-
3	.18	.18	-
4	.18	.16	-
5	.24	.22	-
6	.38	.39	-
7	.83	.83	-
8	.06	.99	.93
9	0	.90	.90
10	.14	.85	.71
11	2.17	.81	- 1.36
12	1.06	.78	- .28
13	.76	.71	-
14	.67	.63	-
15	.55	.57	-
16	.54	.60	-
17	.67	.71	-
18	.11	.83	.72
19	0	.89	.89
20	.06	.77	.71
21	2.02	.77	- 1.25
22	1.28	.70	- .58
23	.84	.67	- .17
24	.51	.48	-
Total (kWh)	13.78	14.96	

MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 282

Figure B-8



MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

Table B-9

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

January 1981

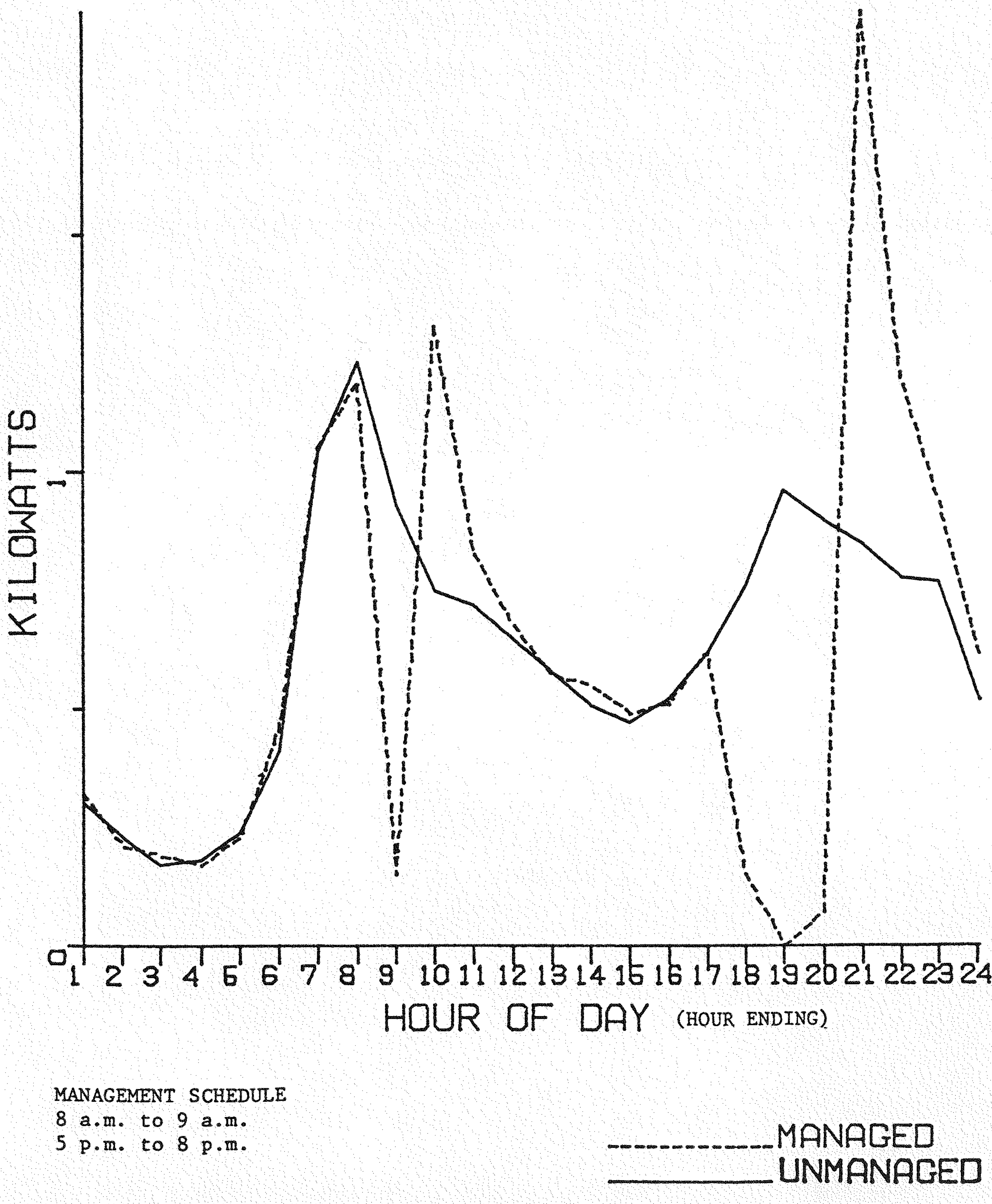
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.32	.30	-
2	.21	.23	-
3	.19	.17	-
4	.17	.18	-
5	.23	.24	-
6	.46	.41	-
7	1.05	1.04	-
8	1.19	1.23	-
9	.15	.93	.78
10	1.31	.75	- .56
11	.83	.72	- .11
12	.68	.65	-
13	.57	.58	-
14	.55	.51	-
15	.49	.47	-
16	.51	.52	-
17	.62	.62	-
18	.15	.76	.61
19	0	.96	.96
20	.07	.90	.83
21	1.97	.85	- 1.12
22	1.20	.78	- .42
23	.94	.77	- .17
24	.62	.52	-
Total (kWh)	14.48	15.09	

MANAGEMENT SCHEDULE
8 a.m. to 9 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 276

Figure B-9

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
JANUARY 1981



MANAGEMENT SCHEDULE
8 a.m. to 9 a.m.
5 p.m. to 8 p.m.

Table B-10

STANDARD WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

March 1981

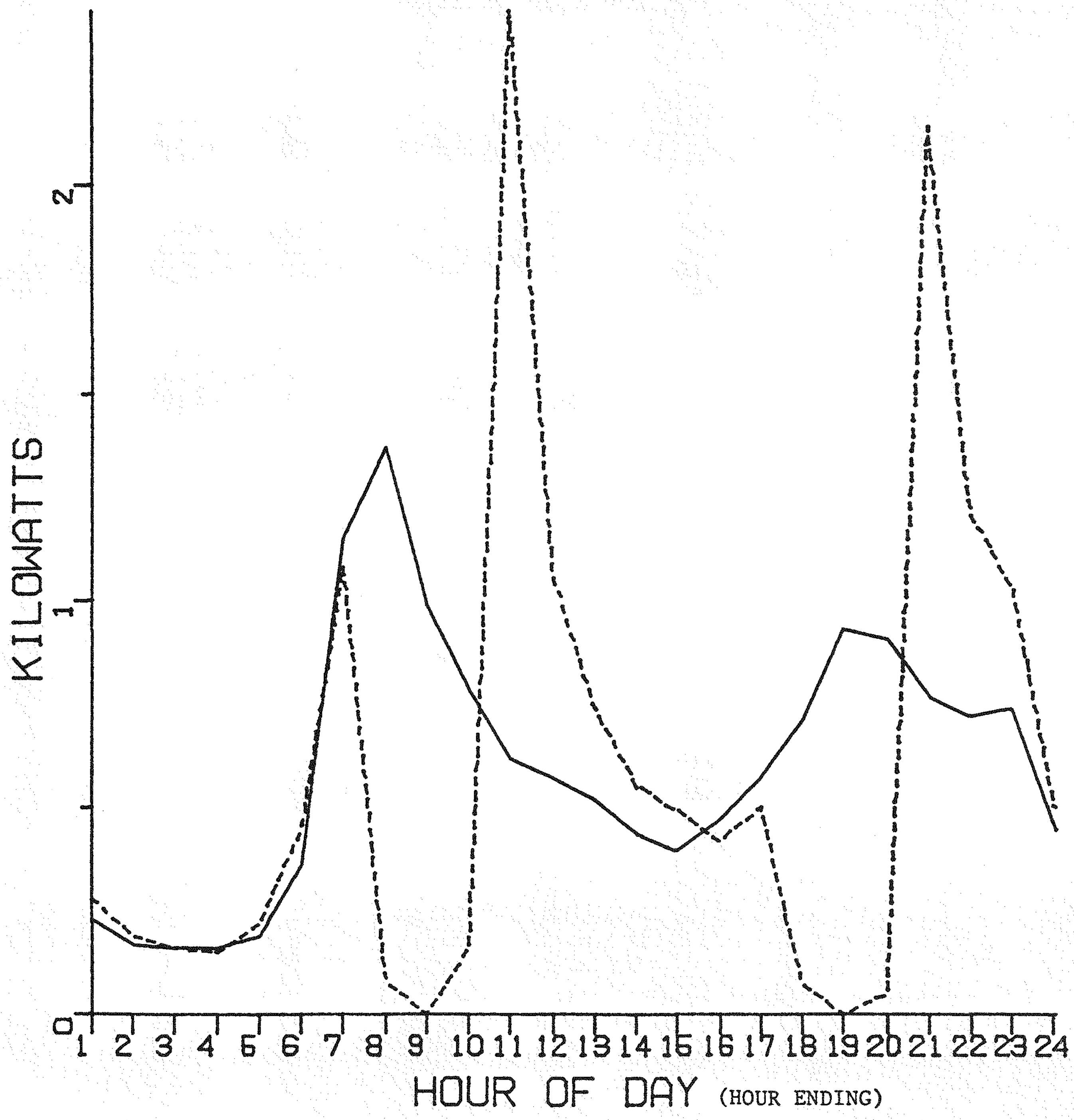
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.28	.23	-
2	.19	.17	-
3	.16	.16	-
4	.15	.16	-
5	.22	.19	-
6	.42	.36	-
7	1.08	1.15	-
8	.08	1.37	1.29
9	0	.99	.99
10	.16	.79	.63
11	2.42	.62	- 1.80
12	1.06	.57	- .49
13	.74	.52	- .22
14	.55	.44	-
15	.49	.39	-
16	.42	.47	-
17	.50	.57	-
18	.07	.71	.64
19	0	.93	.93
20	.05	.91	.86
21	2.14	.77	- 1.37
22	1.20	.72	- .48
23	1.03	.74	- .29
24	.50	45	-
Total (kWh)	13.91	14.38	

MANAGEMENT SCHEDULE
7 a.m. to 1 a.m.
5 p.m. to 8 p.m.

*P < .002
N = 146

Figure B-10

STANDARD WATER HEATERS
VALLEY-WIDE AVERAGE
MARCH 1981



MANAGEMENT SCHEDULE
7 a.m. to 10 a.m.
5 p.m. to 8 p.m.

Table B-11

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

April 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.89	.35	- .54
2	.51	.27	- .24
3	.35	.23	- .12
4	.27	.23	-
5	.24	.19	-
6	.42	.39	-
7	1.14	1.20	-
8	.19	1.35	1.16
9	0	1.00	1.00
10	0	.77	.77
11	0	.64	.64
12	0	.64	.64
13	0	.56	.56
14	.05	.47	.42
15	2.55	.46	-2.09
16	1.72	.47	-1.25
17	1.18	.55	- .63
18	.32	.69	.37
19	0	.80	.80
20	0	.93	.93
21	0	.98	.98
22	.05	.92	.87
23	2.65	.73	-1.92
24	1.71	.58	-1.13
Total (kWh)	14.24	15.40	

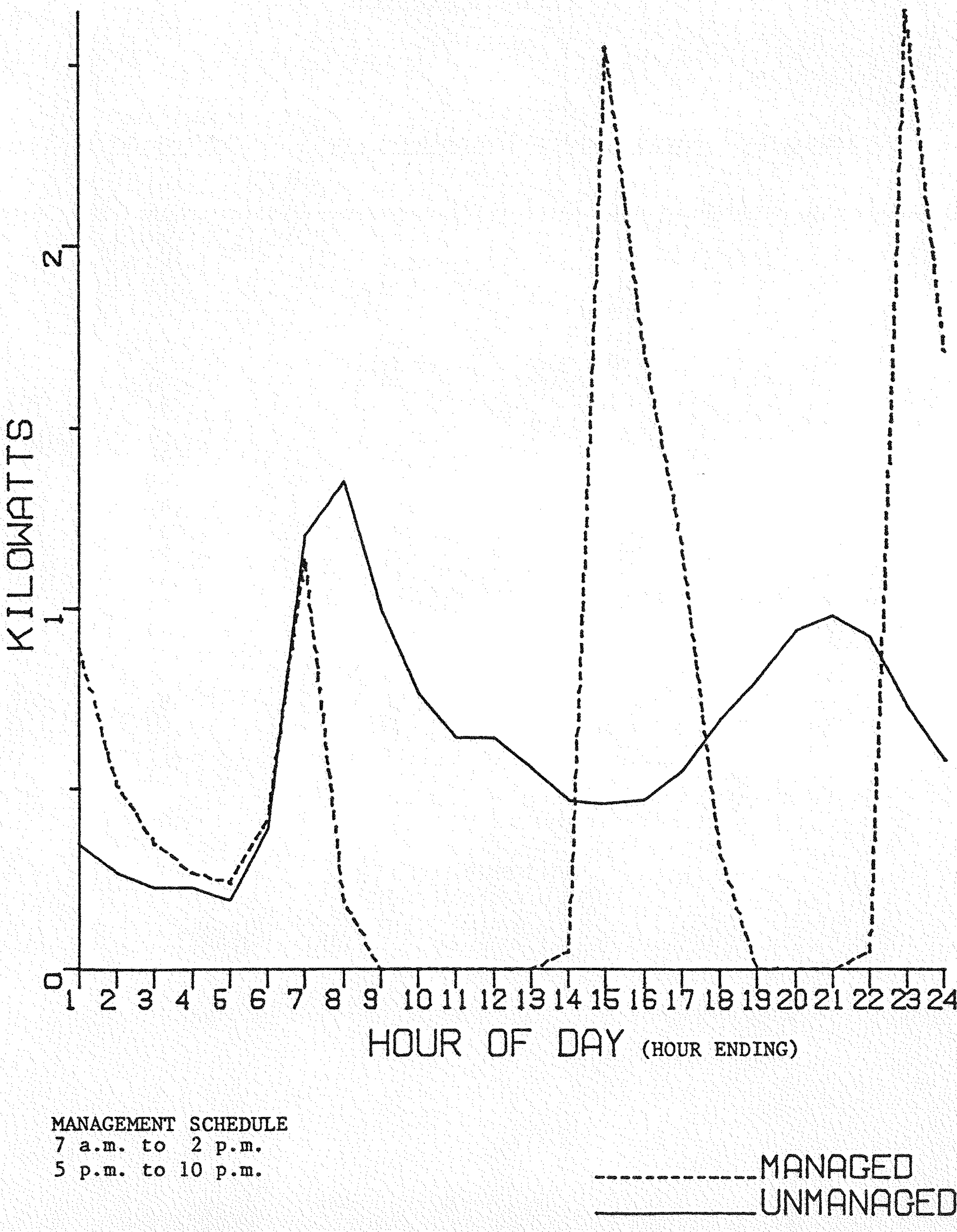
MANAGEMENT SCHEDULE
7 a.m. to 2 p.m.
5 p.m. to 10 p.m.

*P < .002
N = 56

Figure B-11

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
APRIL 1980



MANAGEMENT SCHEDULE
7 a.m. to 2 p.m.
5 p.m. to 10 p.m.

Table B-12

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

May 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.80	.29	-1.51
2	.90	.24	- .66
3	.48	.19	- .29
4	.30	.20	- .10
5	.28	.17	- .11
6	.35	.33	-
7	1.12	1.01	-
8	1.19	1.12	-
9	.94	.83	-
10	.79	.73	-
11	.69	.63	-
12	.61	.58	-
13	.04	.54	.50
14	0	.53	.53
15	0	.46	.46
16	0	.49	.49
17	0	.55	.55
18	0	.66	.66
19	0	.73	.73
20	0	.74	.74
21	0	.81	.81
22	0	.80	.80
23	.08	.72	.64
24	3.41	.43	-2.98
Total (kWh)	12.98	13.78	

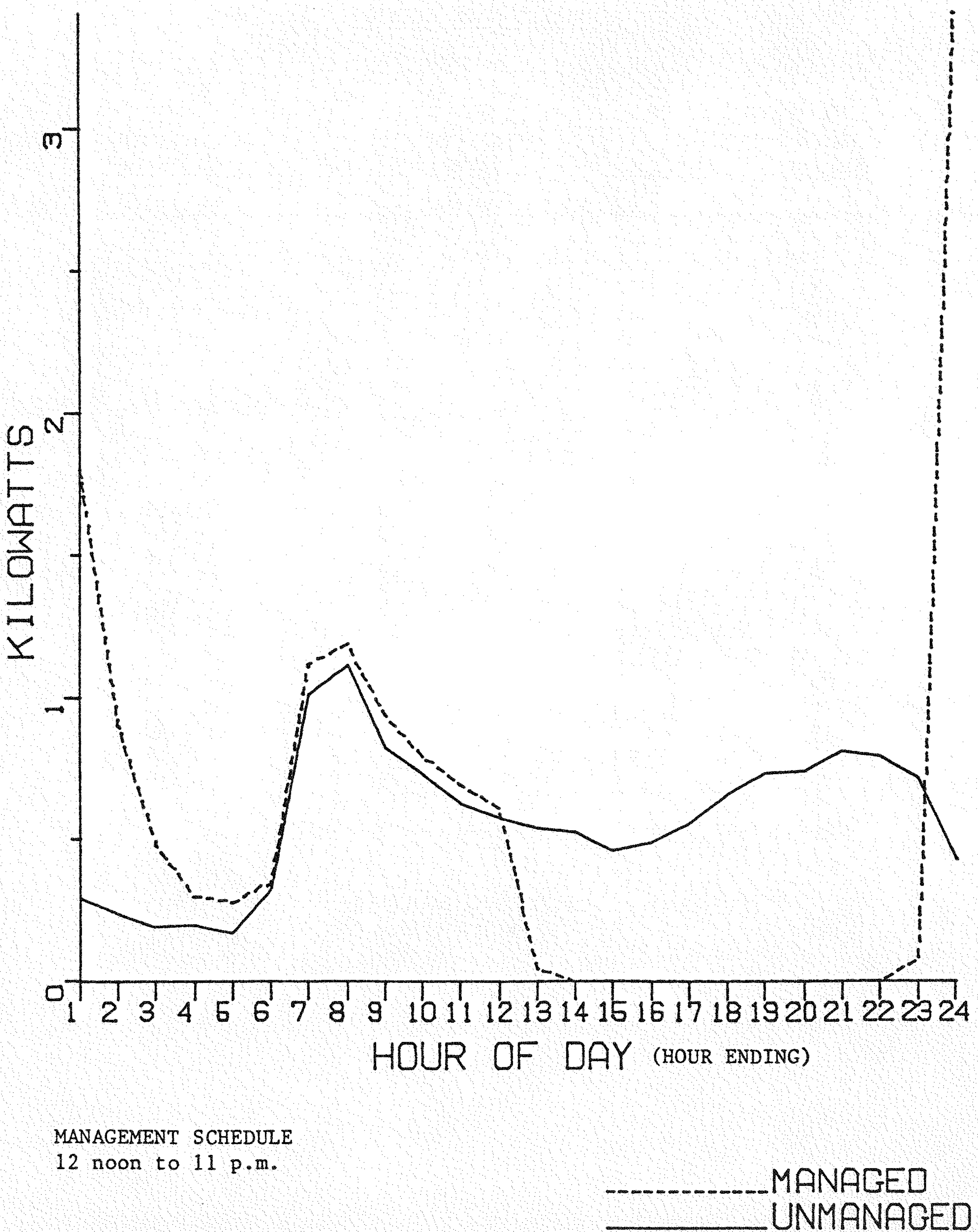
MANAGEMENT SCHEDULE
12 noon to 11 p.m.

*P < .002
N = 63

Figure B-12

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
MAY 1980



MANAGEMENT SCHEDULE
12 noon to 11 p.m.

Table B-13

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

June 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.12	.26	- .86
2	.56	.21	- .35
3	.40	.19	- .21
4	.23	.17	-
5	.27	.19	-
6	.29	.28	-
7	.61	.65	-
8	.79	.80	-
9	.66	.79	-
10	.70	.75	-
11	.70	.65	-
12	.55	.63	-
13	.08	.59	.51
14	0	.55	.55
15	0	.52	.52
16	0	.51	.51
17	0	.57	.57
18	0	.63	.63
19	0	.59	.59
20	0	.66	.66
21	0	.79	.79
22	0	.77	.77
23	.08	.64	.56
24	2.97	.49	-2.48
Total (kWh)	10.01	12.88	

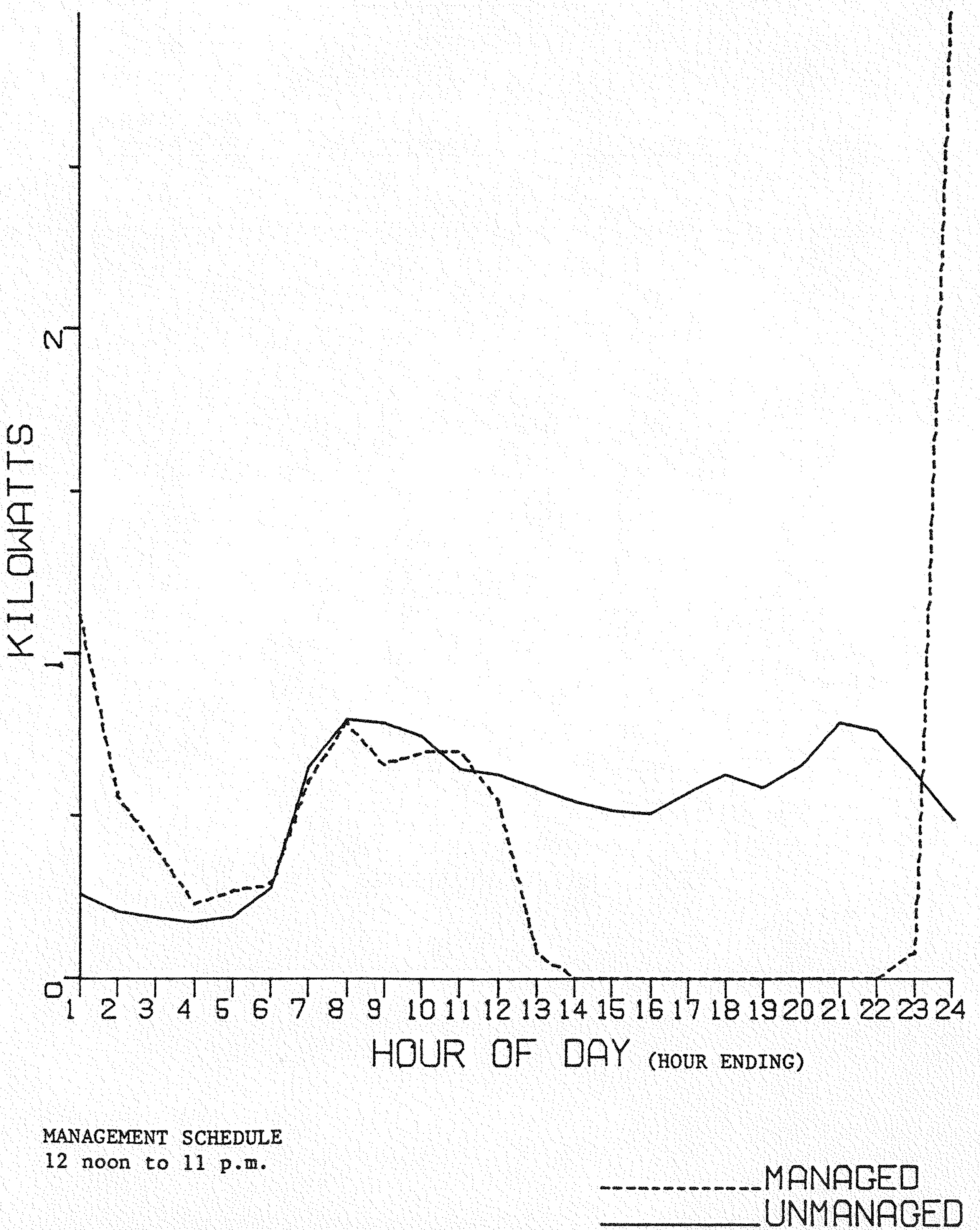
MANAGEMENT SCHEDULE
12 noon to 11 p.m.

*P < .002
N = 51

Figure B-13

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
JUNE 1980



MANAGEMENT SCHEDULE
12 noon to 11 p.m.

Table B-14

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

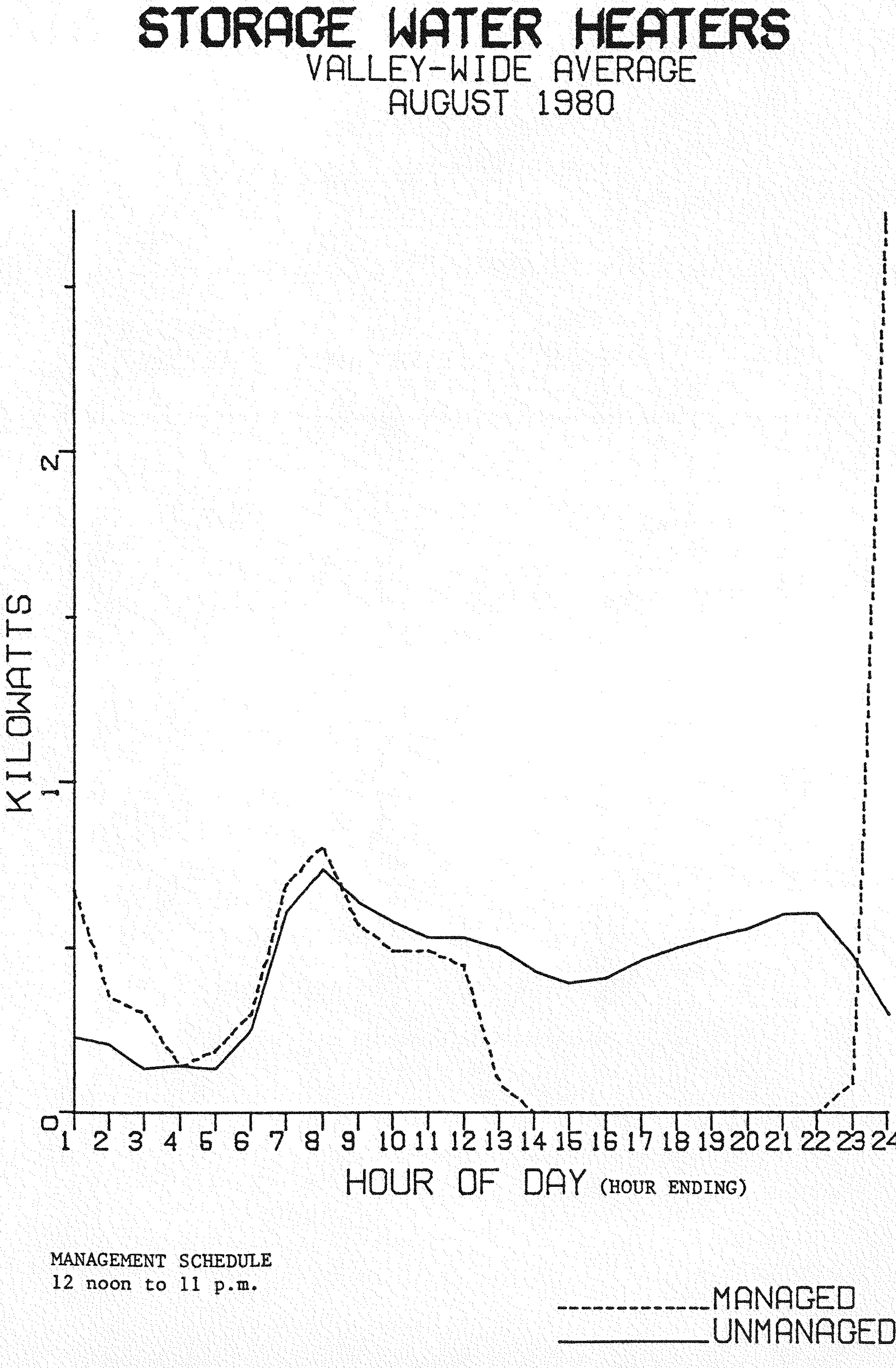
August 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.67	.23	- .44
2	.35	.21	- .14
3	.30	.13	- .17
4	.14	.14	-
5	.19	.13	-
6	.30	.25	-
7	.69	.61	-
8	.81	.74	-
9	.57	.64	-
10	.49	.58	-
11	.49	.53	-
12	.44	.53	-
13	.09	.50	.41
14	0	.43	.43
15	0	.39	.39
16	0	.41	.41
17	0	.46	.46
18	0	.50	.50
19	0	.53	.53
20	0	.56	.56
21	0	.60	.60
22	0	.61	.61
23	.09	.48	.39
24	2.73	.30	-2.43
Total (kWh)	8.35	10.49	

MANAGEMENT SCHEDULE
12 noon to 11 p.m.

*P < .002
N = 47

Figure B-14



MANAGEMENT SCHEDULE
12 noon to 11 p.m.

Table B-15

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

September 1980

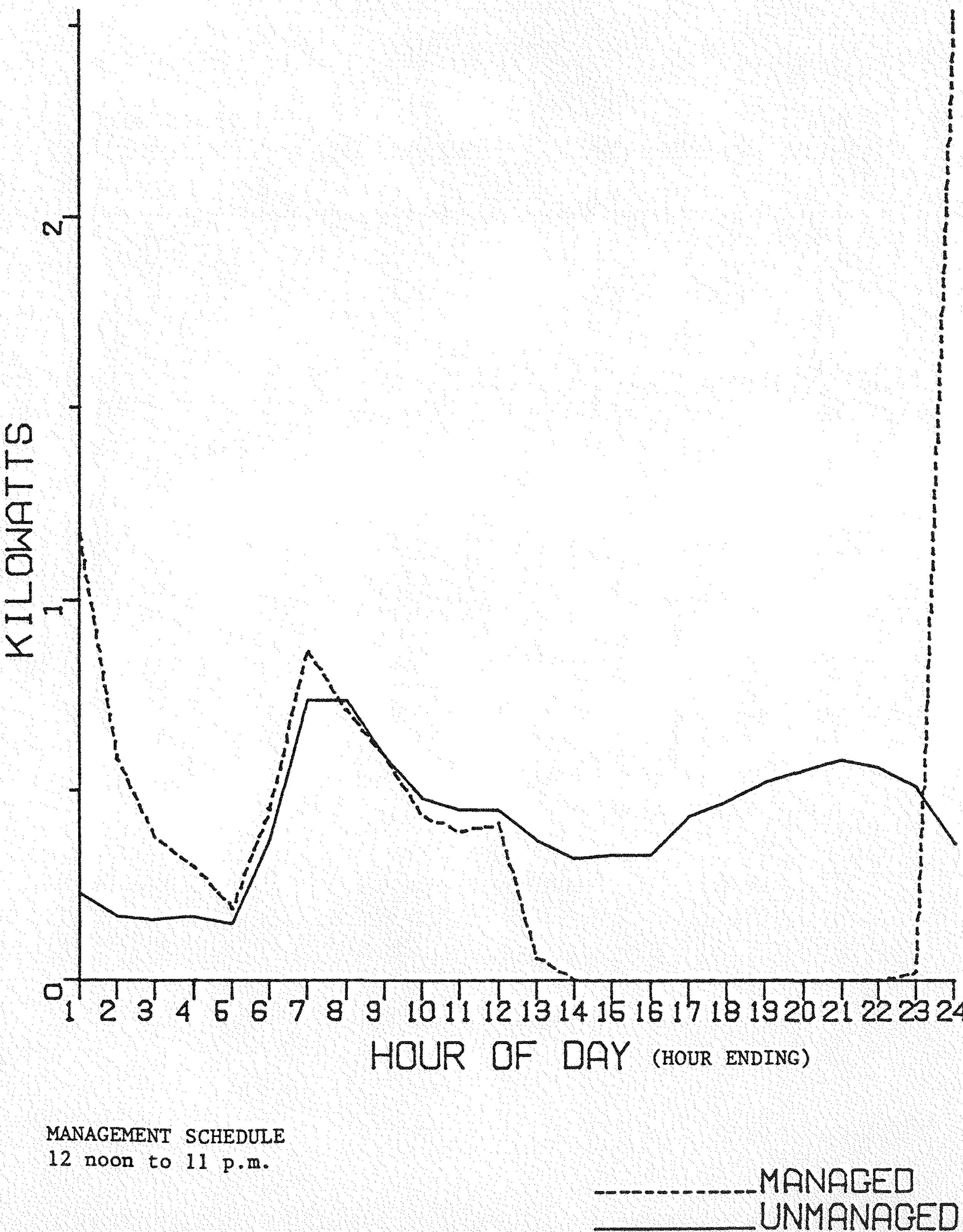
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.17	.23	- .94
2	.58	.17	- .41
3	.37	.16	- .21
4	.30	.17	- .13
5	.19	.15	-
6	.45	.37	-
7	.87	.73	-
8	.71	.73	-
9	.59	.59	-
10	.43	.48	-
11	.39	.45	-
12	.41	.45	-
13	.06	.37	.31
14	0	.32	.32
15	0	.33	.33
16	0	.33	.33
17	0	.43	.43
18	0	.47	.47
19	0	.52	.52
20	0	.55	.55
21	0	.58	.58
22	0	.56	.56
23	.02	.51	.49
24	2.54	.36	-2.18
Total (kWh)	9.08	10.01	

MANAGEMENT SCHEDULE
12 noon to 11 p.m.

*P < .002
N = 42

Figure B-15

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
SEPTEMBER 1980



MANAGEMENT SCHEDULE
12 noon to 11 p.m.

Table B-16

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

September 1980

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.22	.23	-
2	.23	.19	-
3	.17	.17	-
4	.16	.17	-
5	.21	.14	-
6	.27	.37	-
7	.01	.75	.74
8	0	.82	.82
9	0	.58	.58
10	0	.52	.52
11	0	.46	.46
12	0	.48	.48
13	.11	.45	.34
14	2.55	.34	-2.21
15	1.15	.37	- .78
16	.81	.38	- .43
17	.58	.44	-
18	.15	.56	.41
19	0	.57	.57
20	.08	.64	.56
21	1.75	.64	-1.11
22	.80	.55	-
23	.65	.55	-
24	.45	.39	-
Total (kWh)	10.35	10.76	

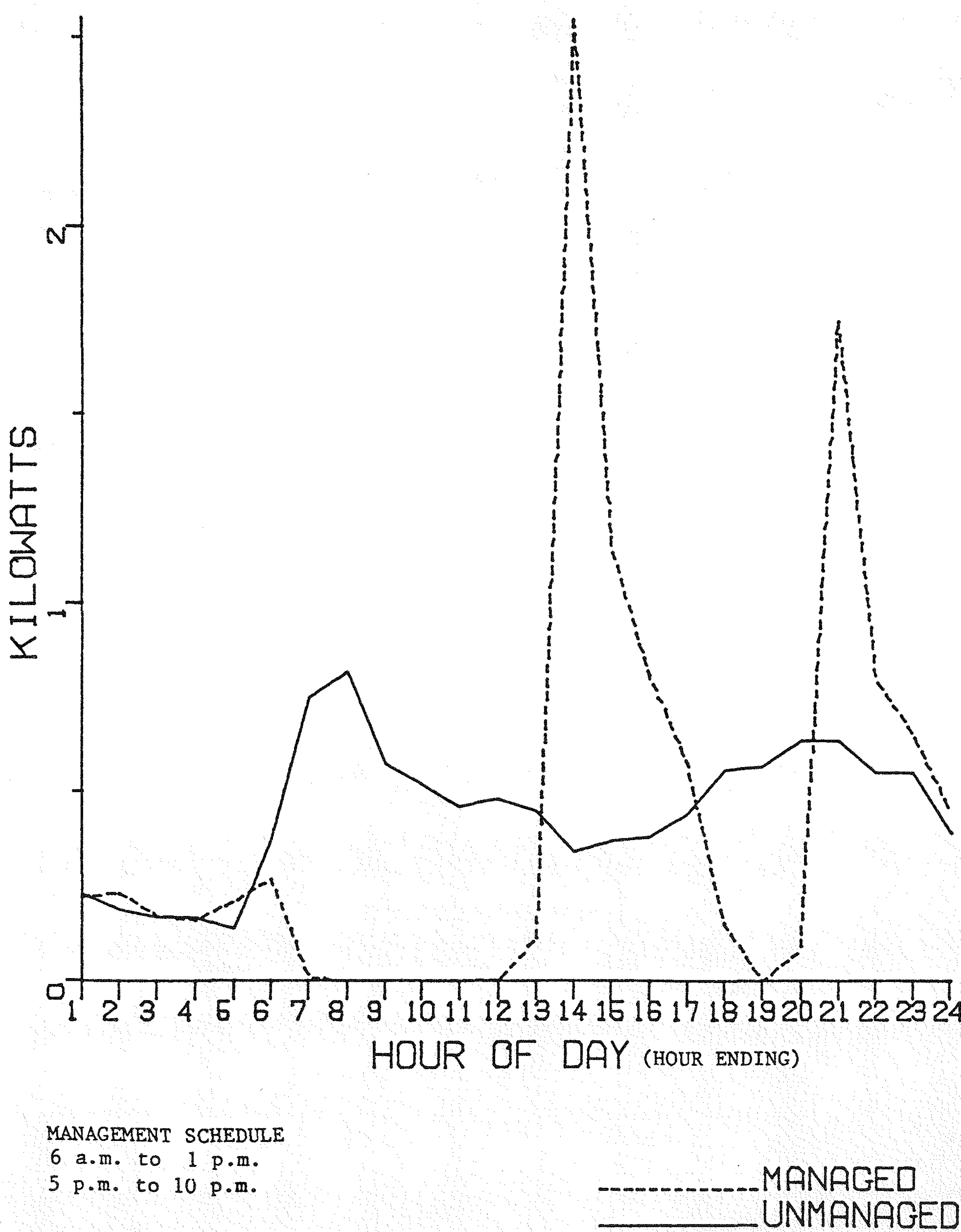
MANAGEMENT SCHEDULE
6 a.m. to 1 p.m.
5 p.m. to 10 p.m.

*P < .002
N = 54

Figure B-16

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
SEPTEMBER 1980



MANAGEMENT SCHEDULE
6 a.m. to 1 p.m.
5 p.m. to 10 p.m.

Table B-17

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

October 1980

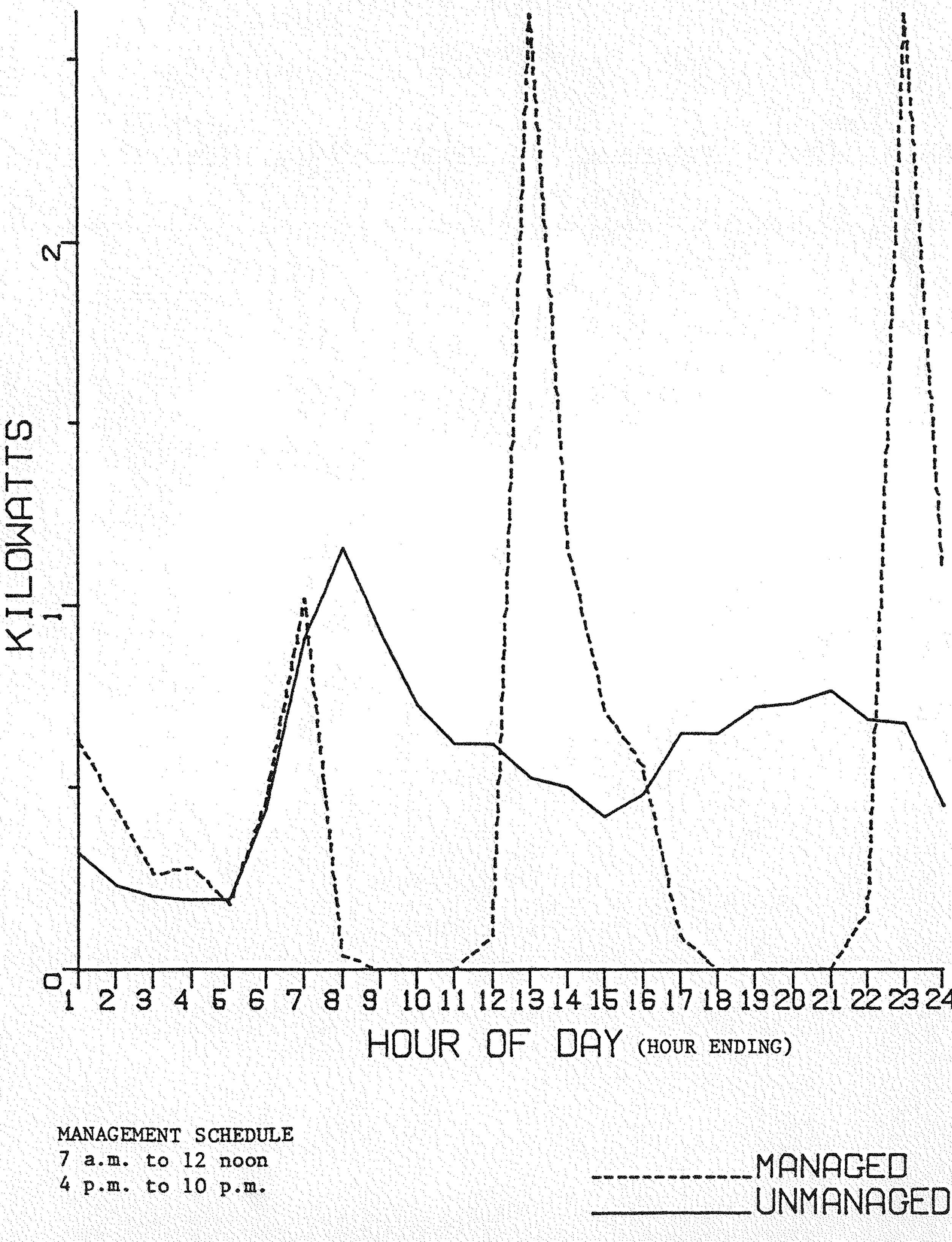
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.63	.32	-
2	.44	.23	-
3	.26	.20	-
4	.28	.19	-
5	.18	.19	-
6	.47	.44	-
7	1.02	.91	-
8	.04	1.16	1.12
9	0	.93	.93
10	0	.73	.73
11	0	.62	.62
12	.09	.62	.53
13	2.62	.53	-2.09
14	1.16	.50	- .66
15	.71	.42	- .29
16	.56	.48	-
17	.09	.65	.56
18	0	.65	.65
19	0	.72	.72
20	0	.73	.73
21	0	.77	.77
22	.16	.69	.53
23	2.63	.68	-1.95
24	1.10	.45	- .65
Total (kWh)	12.44	13.81	

MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

*P < .002
N = 54

Figure B-17

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
OCTOBER 1980



MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

Table B-18

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

November 1980

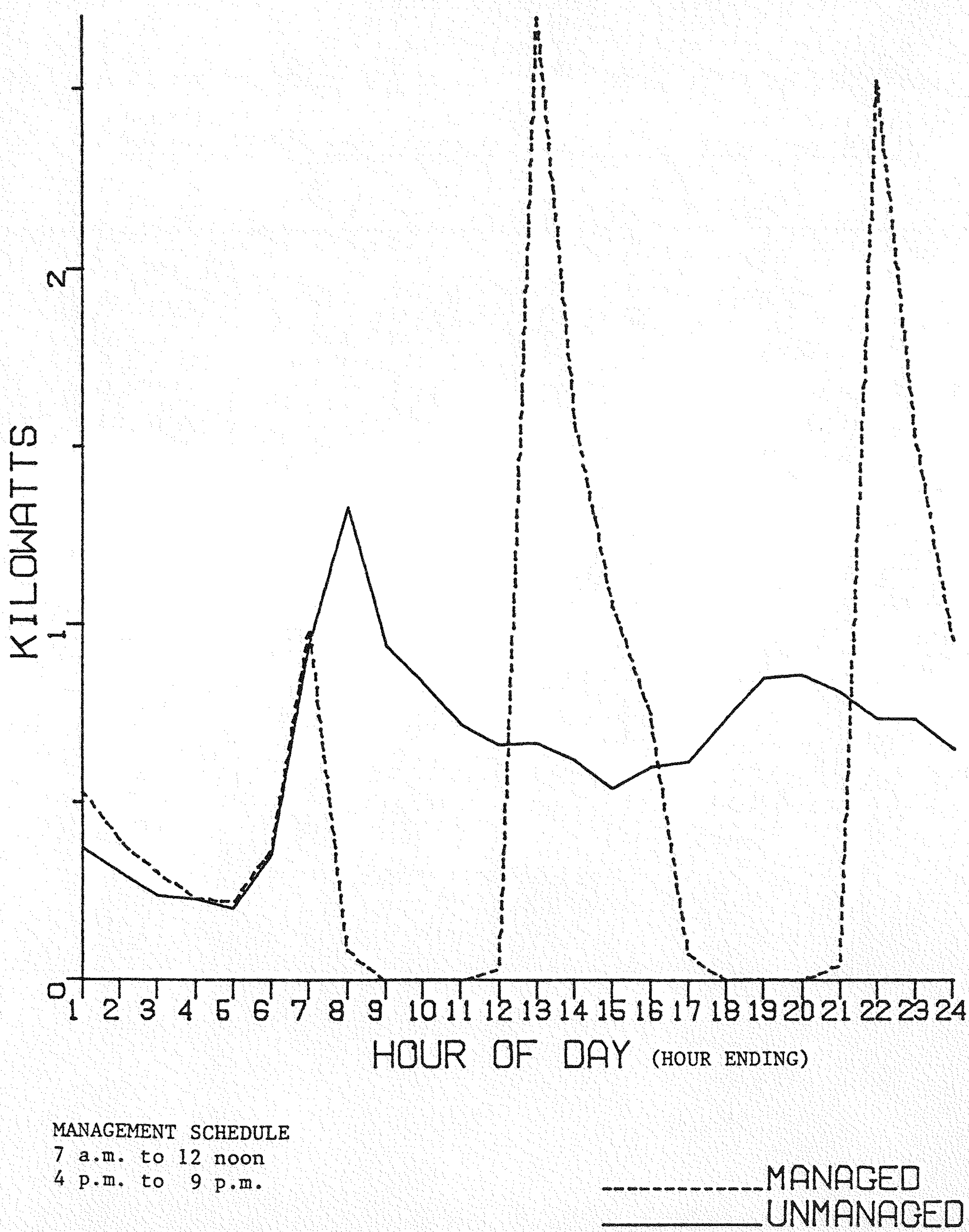
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.53	.37	-
2	.39	.30	-
3	.30	.24	-
4	.23	.23	-
5	.22	.20	-
6	.37	.35	-
7	.99	.94	-
8	.08	1.33	1.25
9	0	.94	.94
10	0	.84	.84
11	0	.72	.72
12	.03	.66	.63
13	2.71	.67	-2.04
14	1.57	.62	- .95
15	1.05	.54	- .51
16	.75	.60	-
17	.07	.61	.54
18	0	.74	.74
19	0	.85	.85
20	0	.86	.86
21	.04	.81	.77
22	2.53	.74	-1.79
23	1.53	.74	- .79
24	.95	.65	-
Total (kWh)	14.34	15.55	

MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 9 p.m.

*P < .002
N = 49

Figure B-18

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
NOVEMBER 1980



MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 9 p.m.

Table B-19

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

December 1980

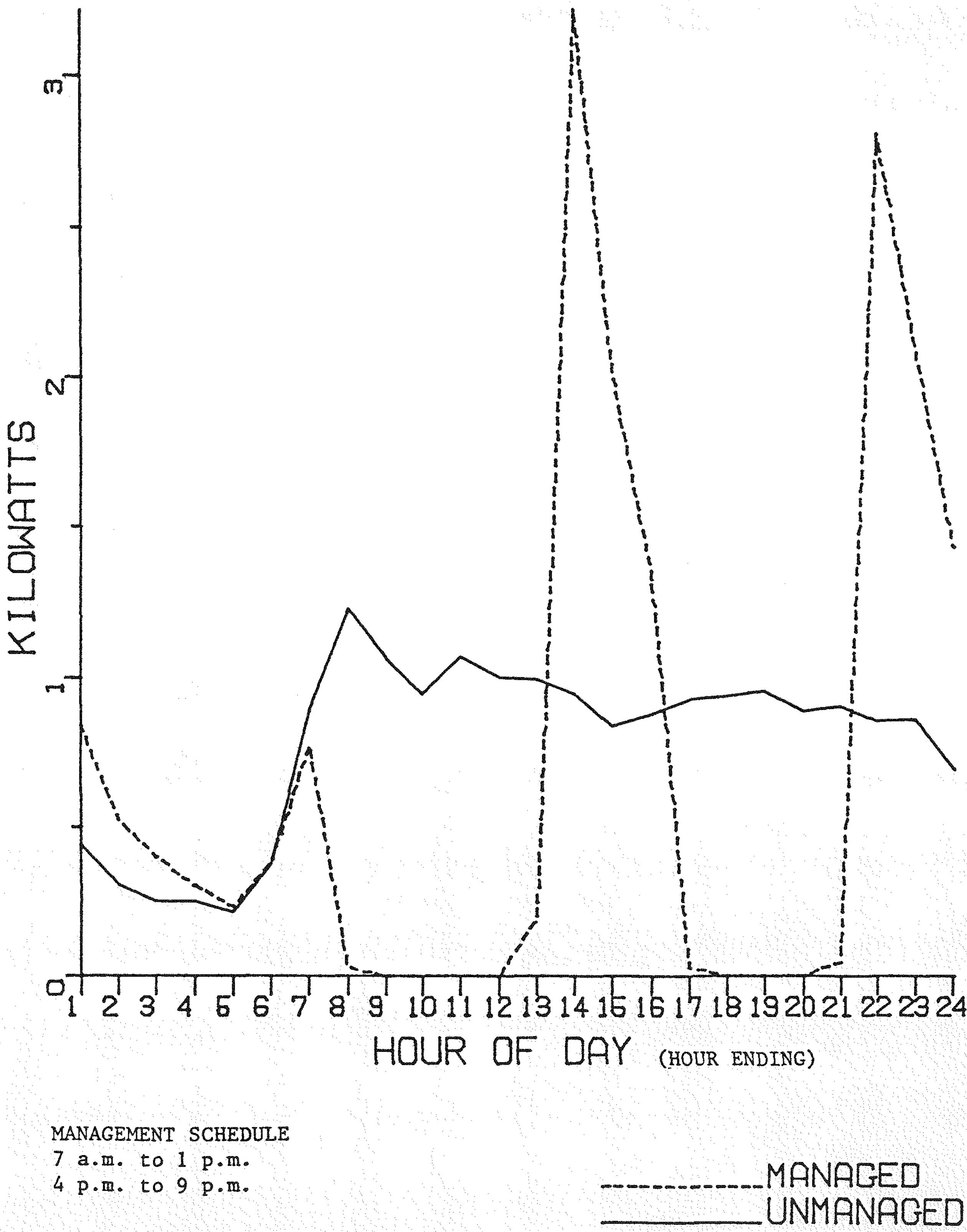
Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	.84	.44	- .40
2	.52	.31	- .21
3	.40	.25	- .15
4	.30	.25	-
5	.23	.21	-
6	.38	.37	-
7	.77	.89	-
8	.03	1.23	1.20
9	0	1.06	1.06
10	0	.94	.94
11	0	1.07	1.07
12	0	1.00	1.00
13	.19	.99	.80
14	3.22	.94	-2.28
15	2.00	.83	-1.17
16	1.35	.87	- .48
17	.03	.92	.89
18	0	.93	.93
19	0	.95	.95
20	0	.88	.88
21	.05	.90	.85
22	2.80	.85	-1.95
23	2.09	.86	-1.23
24	1.43	.69	- .74
Total (kWh)	16.63	18.63	

MANAGEMENT SCHEDULE
7 a.m. to 1 p.m.
4 p.m. to 9 p.m.

*P < .002
N = 60

Figure B-19

STORAGE WATER HEATERS
VALLEY-WIDE AVERAGE
DECEMBER 1980



MANAGEMENT SCHEDULE
7 a.m. to 1 p.m.
4 p.m. to 9 p.m.

Table B-20

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

January 1981

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.70	.49	-1.21
2	1.10	.37	- .73
3	.78	.28	- .50
4	.54	.27	- .27
5	.46	.24	- .22
6	.59	.48	-
7	1.13	1.08	-
8	1.61	1.60	-
9	.08	1.21	1.13
10	0	1.00	1.00
11	0	.97	.97
12	0	.85	.85
13	.04	.80	.76
14	2.83	.77	-2.06
15	1.71	.63	-1.08
16	1.35	.70	- .65
17	1.06	.75	- .31
18	.17	.87	.70
19	0	.94	.94
20	0	1.02	1.02
21	0	1.04	1.04
22	0	1.01	1.01
23	0	.88	.88
24	2.59	.70	-1.89
Total (kWh)	17.74	18.95	

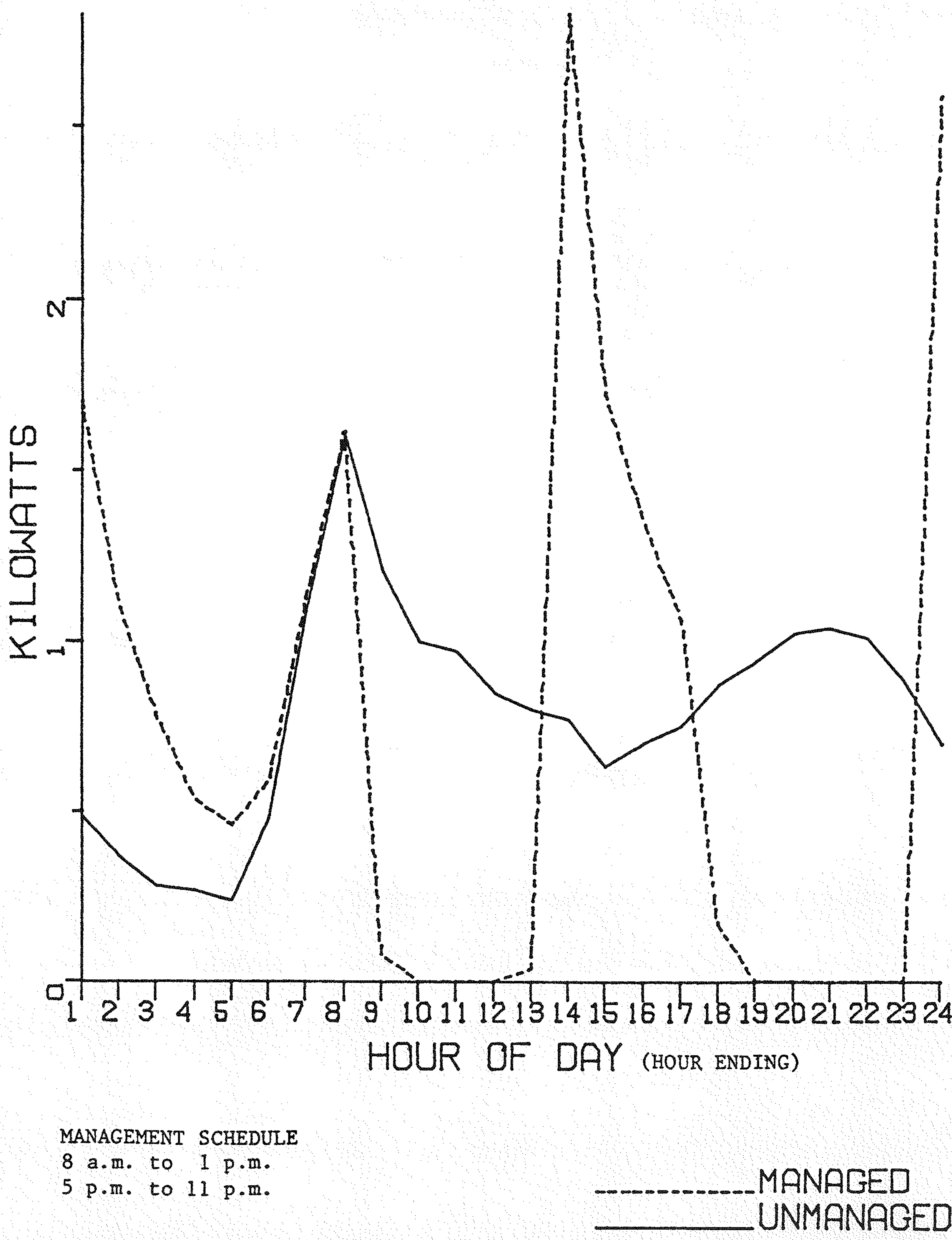
MANAGEMENT SCHEDULE
8 a.m. to 1 p.m.
5 p.m. to 11 p.m.

*P < .002
N = 57

Figure B-20

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
JANUARY 1981



MANAGEMENT SCHEDULE
8 a.m. to 1 p.m.
5 p.m. to 11 p.m.

Table B-21

STORAGE WATER HEATERS

MANAGED AND UNMANAGED LOADS

VALLEY-WIDE AVERAGE

March 1981

Hour Ending	Managed (kW)	Unmanaged (kW)	Significant Difference*
1	1.15	.33	- .82
2	.53	.27	- .26
3	.48	.27	- .21
4	.33	.23	-
5	.35	.20	-
6	.45	.45	-
7	.92	1.16	-
8	.08	1.59	1.51
9	0	1.01	1.01
10	0	.72	.72
11	0	.69	.69
12	.05	.62	.57
13	2.87	.57	-2.30
14	1.93	.64	-1.29
15	1.27	.52	- .75
16	.89	.52	- .37
17	.01	.64	.63
18	0	.67	.67
19	0	.85	.85
20	0	.76	.76
21	0	.98	.98
22	.04	.83	.79
23	2.77	.68	-2.09
24	1.98	.57	-1.41
Total (kWh)	16.10	15.77	

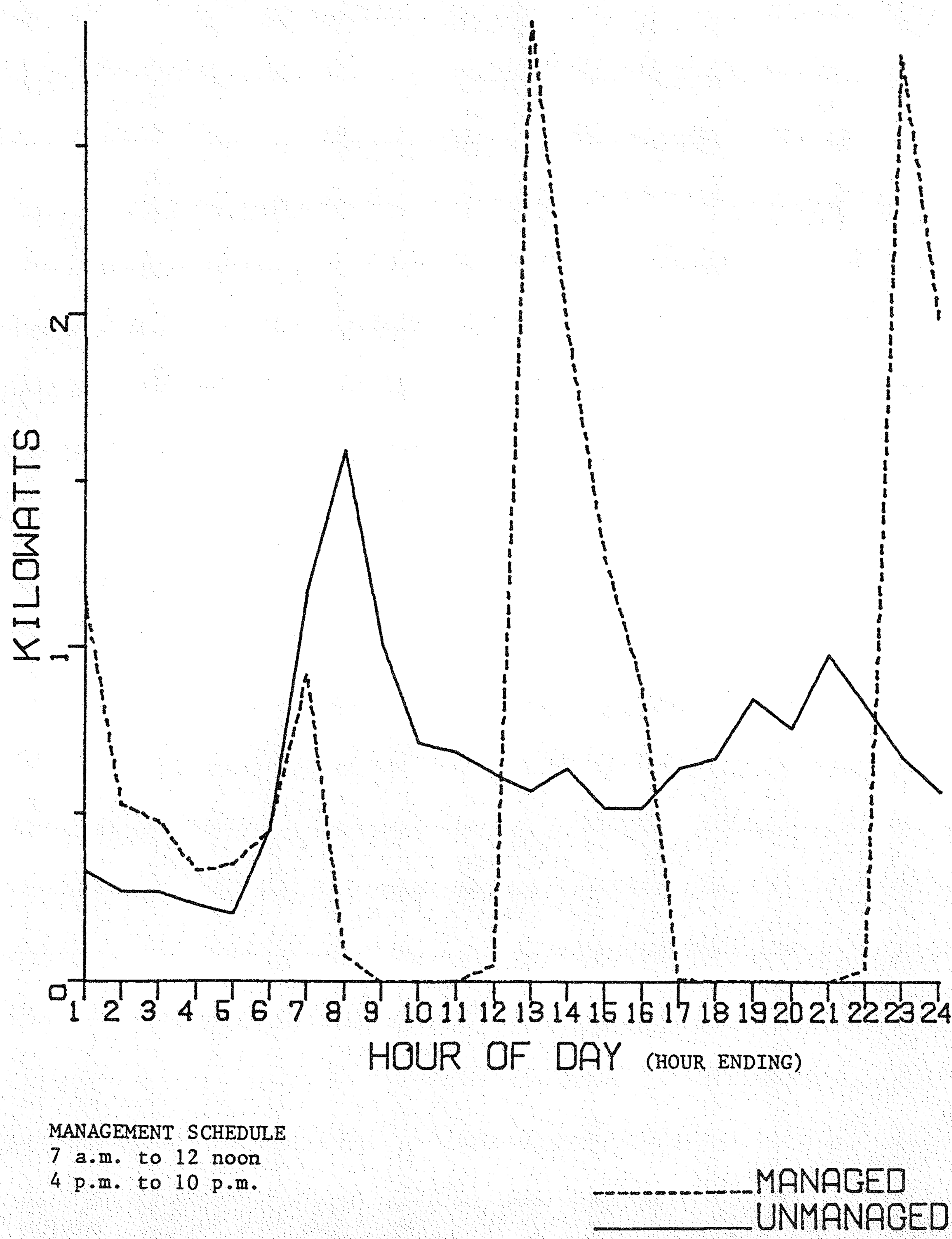
MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.

*P < .002
N = 41

Figure B-21

STORAGE WATER HEATERS

VALLEY-WIDE AVERAGE
MARCH 1981



MANAGEMENT SCHEDULE
7 a.m. to 12 noon
4 p.m. to 10 p.m.