SIMULATION BASED INVESTIGATION OF DIRECT LOAD CONTROL OF RESIDENTIAL AIR-CONDITIONERS

by

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INTRODUCTION

Justification

In the power industry, an increasing concern is controlling the size of seasonal load peaks. Large peaks have brought utilities face to face with three concurrent options; 1. depending on expensive peak generation capacity, 2. building expensive additional baseload generation facilities, and/or 3. developing ways to moderate the size of system peaks. Many utilities are finding that the cost of the first two options are making the third option more and more attractive. Controlling system peaks can allow a utility to reduce the need to utilize peak generation capacity which is expensive to run. It also can allow utilities to defer construction of new baseload facilities which are expensive to build.

Most utilities (excluding some Northern utilities) experience their largest peaks in the summer. This is due to the increasing saturation level of electrical central air-conditioning. It is theorized that by exercising some sort of load control on air-conditioners during peak generation hours, a utility can significantly reduce its peak without adversely affecting customer satisfaction.

Purpose

The purpose of this research was to investigate the effects of direct load control of residential air-conditioning (a/c) systems. Of special interest was how direct load control affected two quantities: 1. the demand of a group of houses, 2. the typical inside temperature of a controlled house.

There are two ways in which this investigation can be accomplished:

1. A field experiment can be conducted by installing load control equipment in homes. The equipment controls the air-conditioning systems according to the desired control scheme. Data gathered from these experiments can then be analyzed to determine what, if any, effects resulted from the load control.
2. Computer simulation can be undertaken utilizing a mathematical model of the air-conditioning system. Predictions are made on how the system will respond under given circumstances. Cases with and without load control can be simulated and compared to predict what effect load control will have in actual implementations.

<u>Previous Work</u>

Researchers have done previous work with field experimentation and with computer modeling.

Field experiments have been undertaken to examine several different varieties of direct or indirect load control. Cycling during peak hours, mandatory disconnection during peak hours, and changing service voltage are some of the more common methods. The interest of the present research primarily lies with cycling during the peak hours of the day.

Some of the field studies include:

The Hickory Load Management Project undertaken by the Detroit Edison Company of Detroit, Michigan, has been documented by Strocker [10], and by Davis, Krupa, and Diedzic [11]. This project centered on direct load control of residential a/c's. The a/c's were cycled off for 15 minutes of each hour over a 5 hour period. This was dome each day the outside temperature reached or exceeded 75 F. The researchers primarily concerned themselves with the net impact on operating expenses. They found the effect of their experiment to be of no value as an operating tool.

Nordell has documented a field direct load management experiment undertaken for Northern States Power in Minneapolis Minnesota. This experiment involved both residential and commercial a/c's. The a/c's were forced off 50% of the time during a six hour period. Net impact of control included:

1. A 30% demand relief during control.
2. A 30% demand increase following control.

3. An average space temperature rise of 2 degrees by the end of control [8].

Strickler and Noell of Southern California Edison have reported on the a/c cycling program utilized by their company. The program is systemwide involving approximately 100,000 a/c's. Air-conditioners are controlled according to one of three options: 50, 67, or 100% according to the amount of time the a/c would be off during the control period. The program is said to reduce demand by 1.95 kW per customer at the generation level with no consumption effects [7].

As part of the Athens Automation and Control Experiment conducted on the distribution system of Athens, Tennessee, load control experiments have been conducted on heat pumps in the winter. The heat pumps were forced off up to 50% of the time from 6 a.m. to 9 a.m. on weekday mornings when the forecast temperatures fall in the desired range. Results indicated that the load control resulted in a higher energy use by the heat pumps. This experiment has been documented by Reed, Broadwater, and Chandrasekaran [6].

The results of these experiments have been mixed. Some experiments have shown results indicating direct load control shows much promise for reducing seasonal demand peaks. Others have indicated that load control can have marginal results in certain situations.

Computer modeling has also been conducted by several researchers:

Pahwa and Brice [1], Bargiotas and Birdwell [3], Chan and Ackerman [4], Chong and Malhami [5], and Ihara and Schweppe [2] have all developed mathematical models for a/c systems. Some are based on the physical heating and cooling processes while others are based on utility data and probability models. The level of the models varies from being simple with one or two variables to being very complex with five or more variables.

Pahwa and Brice modeled the dynamic behavior of the residential a/c system from fundamental physical principles of heat transfer and storage. Then a scheme for identifying the model parameters via the maximum likelihood method was developed. However, no effort was made to utilize the results to simulate direct load control [1].

Ihara and Schweppe utilized their model to simulate cold load pickup. They modelled individual houses to predict the magnitude and duration of overloads following a power outage. They also acknowledged the possibility of simulating load control in a similar fashion [2].

Bargiotas and Birdwell have also simulated direct load control with their model. However, their work was conducted on a limited basis. They confined their investigation to a single house. They forced the a/c off for a variety of time lengths in a 30 minute period. They found that control forced inside temperature out of the temperature band allowed by the thermostat. They also found that control caused the unit cycles to synchronize with the control cycles. This caused a loss of diversity among control customers [3].

Chan and Ackerman presented a physically-based methodology for synthesizing residential heating, ventilating, and a/c load. This methodology was then tested against utility data. They concluded that their method was accurate in estimating residential a/c load. They also simulated some load management experiments, comparing the results to simulated uncontrolled days. They turned the a/c off for 75 minutes out of 5 hours. It was discovered that inside temperature rose by 1 to 2 F as a result of control. These simulations were done primarily to validate their methodology for predicting load shape and no effort to seriously investigate direct load control was made [4].

The work done by Chong and Malhami also concentrated on cold load pickup. They also modelled the elementary component loads of a power system. The loads were aggregated to determine the percent of space heaters that would be on after a power outage. Their methodologies, if not specific equations, are also applicable to simulating load control.

Choice of Method

For this investigation of load control, computer modeling and simulation was chosen as the mode of investigation. There are several reasons why this choice was made:

1. Computer simulation allows more direct control over experimental conditions. Conditions for field experiments are subject to fluctuations of the weather. In simulation, the researcher sets the conditions in which he is interested. Case in point: several of the previously mentioned field studies were unable to arrange identical conditions for both the controlled and uncontrolled cases. They were forced to base their conclusions on results with built-in errors. Computer simulation allows the researcher to compare controlled and uncontrolled situations under exactly identical situations.

2. Many different experiments can be conducted in a short amount of time. This allows the researcher to easily change control strategies, environemtnal conditions, and cooling and heating properties of the house. In a field experiment, months or years can be required to get satis-

factory results. More time is then required to determine the effect of the many experimental variables. Thus, each implemented change takes a considerable length of time to produce helpful feedback.

3. Suggestions for improvements derived from simulation results can be implemented in a shorter amount of time.

4. The economic resources needed to conduct computer simulations are much less than those needed for field experimentation. Most of the necessary resources were already available.

5. In a computer simulation, the researcher is involved in the process on a very intimate level. This makes it easier to produce meaningful insight and understanding from the data being analyzed.

It must be mentioned, however, that there are weaknesses inherent in computer simulations. These include:

1. A computer model can only reflect an idealized version of the real situation.

2. There are no reasonable ways to accurately simulate every facet of a real situation.

3. A computer simulation can only predict what will happen in the real situation.

4. A computer simulation is unable to account for the

real-life problems that are almost always encountered in any process.

Remainder of the Report

First, details on the development of the mathematical model used in the simulations will be given. Following this, the development of the simulation techniques will be detailed and the performance and results of the actual simulations will be reported. Finally, conclusions developed from the simulations will be presented.

MODEL DEVELOPMENT

In the introduction to this report, it was mentioned that several researchers have developed mathematical models for modeling residential a/c systems. Several of these models consider thermodynamic details of an entire house. Others represent the process at the thermostat level. Some of these models are also complex, taking into account many factors which are unnecessary for an investigation such as the present one. In some models, factors specific to a particular house are taken into account, which can be very difficult to measure. Complex weather data not particularly relevant to this research is also incorporated in some models. In fact, Bargiotas and Birdwell [3] conclude in their report that a model omitting some of the weather variables in their model will perform just as well.

For these simulations, a model which is a simplification of some of the more complex models was chosen. Many of the separate factors considered in the more complex models were lumped together to represent an a/c system at the thermostat level. The resultant model is very similar to a preliminary model used by Ihara and Schweppe [2].

The model breaks down into two subsets:

1. The thermostat model.
2. The equations that describe the thermodynamic

heating and cooling processes of the system.

<u>Thermostat Model</u>

The chosen thermostat model can be described by two quantities;

1. a temperature setting, Ts, and
2. a thermostat deadband, deltaT, on either side of Ts.

Once the a/c turns on, it will run until the thermostat temperature reaches Ts - deltaT. Once the a/c cycles off, it will remain off until the thermostat temperature reaches Ts + deltaT. If power is interrupted while the a/c is running, the a/c will still run when power is restored unless the thermostat temperature reached Ts - deltaT. If power is interrupted while the a/c is off, the a/c will remain off when power is resumed unless the thermostat temperature rose above Ts + deltaT. This thermostat model is identical to that used by Pahwa and Brice [1].

<u>Thermodynamic Model of Heating and Cooling Processes</u>

The heating and cooling processes are represented by two differential equations:

1. Heating stage (when a/c is off):

   The rate of change of the thermostat temperature of the house is determined by the heating coefficient of the house times the difference between the thermostat temperature and the driving temperature. (The driving temperature is the temperature of the structure of the house. This temperature is usually higher the the outside temperature because of heat storage in the structure and it also lags the outside temperature by a few hours. In this study, the driving temperature is assumed to be 5 degrees greater than the outside temperature and lag the outside temperature by 2 hours during the daytime.) The differential equation describing the heating process is:

$$\frac{d\,T(t)}{dt} = \beta\left[\,Tdrive - T(t)\,\right]$$

where,

T(t) is the thermostat temperature of the house (degF).

Tdrive is the driving temperature of the system, considered to be a constant for the solution of the differential equation (degF).

β is the heating coefficient of the house (1/min).

2. Cooling phase (while a/c is on):

In the cooling phase, the rate of change of the thermostat temperature is altered by the rate at which cooling is supplied by the a/c. The differential equation is:

$$\frac{d\,T(t)}{dt} = \beta\left[\text{Tdrive} - T(t)\right] - \alpha$$

where,

α is the rate at which the a/c supplies cooling to the house (degF/min).

Further Mathematical Development

In order to utilize the derived model in simulations, further mathematical development was needed. The given heating and cooling differential equations were solved using Laplace Transforms. The resulting equations are as follows:

heating case:

$$T(t) = \text{Tdrive} + \left[T(0) - \text{Tdrive}\right]e^{-\beta t}$$

cooling case:

$$T(t) = \text{Tdrive} - \frac{\alpha}{\beta} + \left[T(0) + \frac{\alpha}{\beta} - \text{Tdrive}\right]e^{-\beta t}$$

where T(0) is the inside temperature at t=0.

These equations can be manipulated algebraically to obtain heating and cooling times to reach a specified temperature, T(t). The resulting expressions are:

heating case:

$$t = \frac{-1}{\beta} \ln\left[\frac{T(t) - Tdrive}{T(0) - Tdrive} \right]$$

cooling case:

$$t = \frac{-1}{\beta} \ln\left[\frac{T(t) + (\alpha/\beta) - Tdrive}{T(0) + (\alpha/\beta) - Tdrive} \right]$$

These expressions make it possible to determine when the inside temperature makes the themostat turn the a/c on and off. This in turn allows the model to predict when the a/c goes on and off over a specified length of time (given intial conditions: initial temperature and whether the a/c is initially on or off).

Demand Calculations

Knowing when the a/c goes on and off allows demand calculations to be made. It is assumed that when the a/c is running, it is running at full power. This assumption is not strictly true in actual cases. In actual cases, the demand of the a/c is affected by service voltage, outside temperature, fluid pressure and other such factors. However, consideration of such factors is beyond the scope of this research. These factors will generally produce only small effects. Therefore the assumption of an ideal a/c with constant demand will still produce realistic results.

For ease of calculation, the demand is given the value of 1 when the a/c is running and 0 when it is not. Therefore, to calculate average demand for a period of time one simply needs to add up the total on-time during that period and divide by the length of the period. If the a/c is on for the entire period, the average demand is 1. Likewise, if the a/c is off for the entire period, the average demand is 0.

<u>Inside Temperature</u>

The inside temperature is one of the variables of interest in this simulation. The on/off times are determined according to the behavior of the inside temperature at the thermostat. At each transition the temperature is recorded. This allows calculations of average inside temperature over specified periods of time. The mathematical development of this is as follows:

The average value of a function over an interval (a,b) is known to be :

$$\frac{1}{b-a} \int_a^b f(x)\,dx$$

Apply this to the heating case:

$$\text{Tave} = \frac{1}{t - t_0} \int_{t_0}^{t} \left[\text{Tdrive} + \left[T(t_0) - \text{Tdrive} \right] e^{-\beta(x - t_0)} \right] dx$$

$$= \frac{1}{t - t_0} \left[\text{Tdrive} * x + \left[T(t_0) - \text{Tdrive} \right] \left[\frac{-1}{\beta} \right] \left[\frac{1}{e^{-\beta t_0}} \right] \left[e^{-\beta x} \right] \right]_{t_0}^{t}$$

$$= \text{Tdrive} - \left[\frac{T(t_0) - \text{Tdrive}}{(t - t_0)\, \beta\, e^{-\beta t_0}} \right] * \left[e^{-\beta t} - e^{-\beta t_0} \right]$$

cooling case:

using a similar development

$$\text{Tave} = \text{Tdrive} - \frac{\alpha}{\beta} - \left[\frac{T(t_0) + (\alpha/\beta) - \text{Tdrive}}{(t - t_0)\ \beta\ e^{-\beta t_0}} \right] * \left[e^{-\beta t} - e^{-\beta t_0} \right]$$

<u>Duty Cycle</u>

For the purpose of some simulations it was necessary to define the duty cycle of the a/c. Duty cycle was defined as follows:

duty cycle=(on time)/(on time + off time)

on-time - time which is required for the a/c to force the inside temperature from Ts+deltaT to Ts-deltaT.

off-time - time which is required (with the a/c off) for the inside temperature to rise from Ts-deltaT to Ts+deltaT.

Driving Temperature

Two different types of driving temperatures were used in simulations:

1. Constant driving temperature - Tdrive is constant over the entire period for which simulation is performed. This allows conclusions to be drawn about the steady state conditions.
2. Piece-wise constant sinusoidal driving temperature - Tdrive approximates a sinusoidally varying curve (with a specified peak value) over the period of simulation. Tdrive's value at any transition time is defined by a sinusoidal curve. At noon and midnight the driving temperature is 85 F. The sinusoidal curve then rises to specified peak temperature, T_peak, at 6 p.m. The equation of the sinusoid is:

   $$Tdrive = 85 + (T\_peak-85)*\sin(.00436332t)$$

   At each transition Tdrive is updated. The next temperature and time calculation is made using the updated value of Tdrive. This driving temperature more closely approximates the real life case.

Control Types

Two different types of control were used in simulations:

1. Centralized control where a group of houses is automatically cycled off for a specified number of minutes out of a period of time. Most commonly, control was exercised 7.5 out of 30 minutes. Also, a control strategy of 2.5 out of 10 minutes was used.
2. Decentralized load leveler control where the actual control times vary from house to house. Each house is forced to be off for the first 7.5 minutes that the thermostat calls for cooling. The a/c is then allowed 22.5 minutes of actual running time before the control cycle starts over.

SIMULATION DEVELOPMENT

Using the model developed in the previous section, direct load control experiments were simulated. However, in developing these simulations, certain assumptions had to be made. This section will detail the assumptions and define the following quantities:

1. Initial Conditions.
2. Houses used in simulation.
3. Development of computer codes.

Initial Conditions

The initial conditions of the a/c system are random within two constraints:

1. The temperature is assumed to be within the band from Ts+deltaT to Ts-deltaT.
2. The a/c is assumed to be either on or off.

The initial temperature is determined by a uniformly distributed random number generated by a random number generater, GGUBS, obtained from the IMSL subroutine library. Thus the temperature is random within the specified band.

The initial state of the a/c is also determined by a random number. A separate random number is generated and its value determines whether the a/c is initially on or off. The probabilities of being initially on and being initially off are equal.

This process is performed by a subroutine named RANDOM.

<u>Houses Used in Simulation</u>

Four cases of houses were used in simulation:

1. House with a small a/c and adequate insulation. At Tdrive=90 F the a/c is barely able to drive the inside temperature to the point where the a/c turns off. Ten minutes are needed to force the inside temperature from Ts-deltaT to Ts+deltaT. This case is referred to as case 1.
2. House with a medium a/c and adequate insulation. At Tdrive=90 F the a/c cools the inside temperature from Ts+deltaT to Ts-deltaT in 10 minutes. The heating time from Ts-deltaT to Ts+deltaT is also 10 minutes. This case is referred to as case 2.
3. House with a large a/c and adequate insulation. At Tdrive=90 F the a/c drives the inside temperature from Ts+deltaT to Ts-deltaT in 6.4 minutes. The heating time is 10 minutes. This case is referred to as case 3.
4. House with a large a/c and very good insulation. At Tdrive=90 F the a/c drives the inside temperature from Ts+deltaT to Ts-deltaT in 5.2 minutes. The heating time is 15 minutes. This case is refer-

red to as case 4.

The first three cases were used in virtually every simulation that was performed. In some instances, case 1 was dropped because the results were known beforehand to be trivial. The fourth case was used in a few simulations.

Computer Codes

Using the assumptions and developments that have been detailed in this and the previous section, Computer codes were developed to perform the desired simulations. The codes were written in FORTRAN-77 and listings of these codes are shown in Appendix B.

These computer codes are capable of producing simulated data for both controlled and uncontrolled cases. Both types of control were simulated.

Once data were generated, load curves were generated by simulating a specified number of individual houses for specified periods of time. Demand for corresponding time periods for each house were added together to obtain aggregate load curve. These load curves were then normalized to a kW/house basis (each house has a maximum normalized demand of 1).

Temperature data were also calculated for the load curves. It was calculated either of two ways:

1. On an aggregate basis by summing all the houses together and normalizing to a per house basis.

2. A typical house from the group was used.

CONSTANT DRIVING TEMPERATURE SIMULATIONS

This section details the simulations that were performed using a constant value for Tdrive.

Sample Size Simulations

Two different sets of simulations were undertaken to examine the effect of the number of houses in the load curve (or, sample size). The simulations were done over two different lengths of time, 30 hours and 10 hours. The method of control used throughout was centralized control with 7.5 out of each 30 minutes automatically off.

30 Hour Simulation

In this set of simulations, load curves were generated for cases 1-3 over a period of 30 hours with a driving temperature of 90 F. The following statements define the simulation constraints:

1. Load curves of 1-100 houses were generated.
2. Both controlled and uncontrolled load curves were generated for the selected sample sizes.
3. Cases 1-3 were used.
4. Average demand reduction between the controlled and uncontrolled cases was calculated for each hour of the 30 hour period.
5. The 30 average hourly demand reductions for the 30 hour period were considered as a data set. An average and standard deviation were

calculated for the data set.

6. Ten independent trials were performed for samples sizes up to 21 houses. For sample sizes of 50 and 100 houses, 5 independent trials were performed.

The purpose of this simulation was two fold; 1. To study the effects of control on demand reduction and 2. To study the effect of sample size on the variance of demand reduction. Samples of the resulting data are shown in data tables I, II, and III. The remaining data are presented in Appendix A.

<u>Results</u>

From the data generated, the following results are evident:

case 1: In this case, the demand reduction levels out at around 23%. This is because the a/c has to run most of the time in the uncontrolled state to keep up with the driving temperature. When control is applied, the a/c is forced to run less than it would like resulting in nearly maximum savings. The standard deviation does not vary wildly for any size of load curve. However the standard deviations for the separate trials seem to settle to very steady level of around 4% at a sample size of 21 houses. A sample of the data for this case is shown in data table I.

(Further substantiation of these conclusions is shown in tables A-1 through A-4 in Appendix A.)

Table I: Average Hourly Demand Reduction and Standard Deviation of the Hourly Demand Reductions Over a 30 Hour Period for Case 1.

Trial	Avg. Hourly Dem. Red.	Stan. Dev.
1	22.7%	4.0%
2	22.6%	3.9%
3	22.6%	4.9%
4	22.6%	4.0%
5	22.7%	3.8%
6	22.6%	3.9%
7	22.6%	4.0%
8	22.6%	4.3%
9	22.7%	3.9%
10	22.6%	4.0%

Sample Size: 21 houses

case 2: In this case, the average hourly demand reduction seems to level out at about 2.8%. The standard deviations of the separate trials level out at around .4% for the load curves of 10 houses (see table A-6). A sample of the data for this case is shown in table II. (Further data is shown in tables A-5 through A-8 in Appendix A.)

case 3: This case shows essentially no demand reduction and in fact, can show an increase. The standard deviations for the trials at each size of load curve show that for some hours, there was an increase. The standard deviations of the separate trials level out at a value between .5% and 1.4%. This occurs at a sample size of 21 houses. A sample data table for this case is shown in table III. (Further data is shown in tables A-9 through A-12 in Appendix A.)

Table II: Average Hourly Demand Reduction and Standard Deviation of the Hourly Demand Reductions Over a 30 Hour Period for Case 2.

Trial	Avg. Hourly Dem. Red.	Stan. Dev.
1	2.8%	0.4%
2	2.8%	0.4%
3	2.8%	0.4%
4	2.8%	0.5%
5	2.8%	0.5%
6	2.8%	0.3%
7	2.8%	0.3%
8	2.9%	0.6%
9	2.8%	0.4%
10	2.8%	0.4%

Sample Size: 20 houses

Table III: Average Hourly Demand Reduction and Standard Deviation for the Hourly Demand Reductions Over a 30 Hour Period for Case 3.

Trial	Avg. Hourly Dem. Red.	Stan. Dev.
1	0.1%	1.1%
2	0.1%	1.1%
3	0.1%	1.2%
4	0.1%	0.7%
5	0.1%	1.4%
6	0.1%	0.7%
7	0.1%	0.5%
8	0.1%	0.6%
9	0.1%	0.8%
10	0.1%	0.9%

Sample Size: 21 houses

From these cases, it can be concluded that a sample size around 20 houses will be enough to have sufficiently small variance in the hourly demand reduction.

<u>10 Hour Simulation</u>

To gather information about the demand reduction in individual hours of a period, another set of simulations was needed. In this set of simulations, load curves were generated for a period of 10 hours. It was hypothesized that the systems reached steady-state operation fairly quickly, making a 10 hour period sufficient for this simulation. Once again Tdrive=90 F. The simulations had the following characteristics:

1. Load curves of 1-100 houses were generated (also a 500 house load curve was generated for case 3).
2. Load curves were generated for cases 1-4.
3. Ten independent trials were run at each sample size for each case.
4. Controlled and uncontrolled load curves were generated at each sample size and for each case.
5. Demand Reduction was calculated on an hourly basis.
6. Corresponding hourly demand reductions from separate trials were grouped together. First hour demand reductions with first hour demand

reductions, second hour demand reductions with second hour demand reductions and so on.

7. For each group of hourly demand reductions, an average and standard deviation were calculated.

The purposes of this simulation were; 1. To gather further information on the sample size necessary to reduce the variation of the data to a reasonable level and 2. To ascertain if indeed steady-state operation is reached fairly quickly.

Results

The average demand reduction for each hour as well as error bars of + or - 2 standard deviations were plotted for each sample size for each of the four cases. A sample of the plots are shown in Figs 1-5. This shows the plots for case 4. The plots for the remaining cases are shown in Appendix B (case 1: Figs B-1 through B-5, case 2: Figs B-6 through B-10, case 3: Figs B-11 through B-16). In each case the size of the error bars decreased as the size of the sample increased. However, the rate at which the error bars decreased seemed to drop considerably after the 21-house samples. This leads to the conclusion that a sample size of 21 houses is sufficiently large to reduce the variability of the simulated data to a reasonable

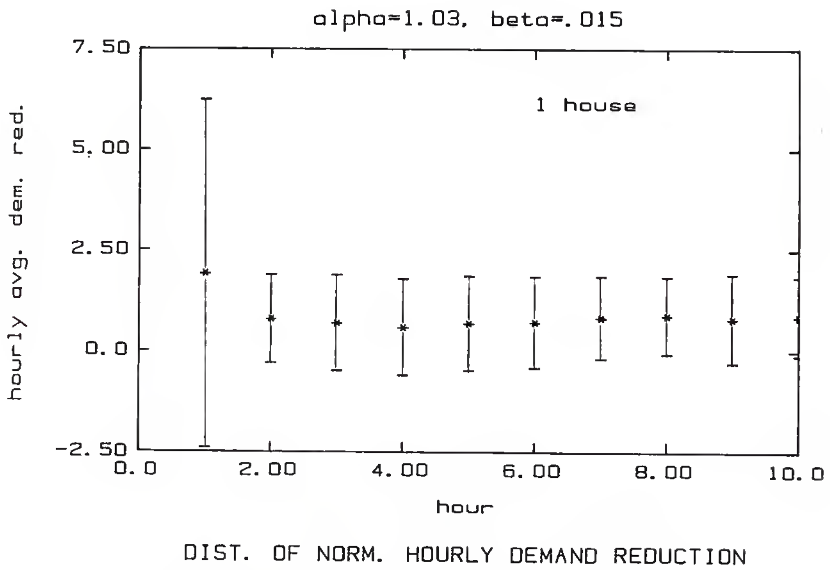

Fig. 1: Hourly Average Demand Reduction Upon Control (in Percent) for Each of 10 Hours for a Case 4 House With a Constant Driving Temperature of 90 F.

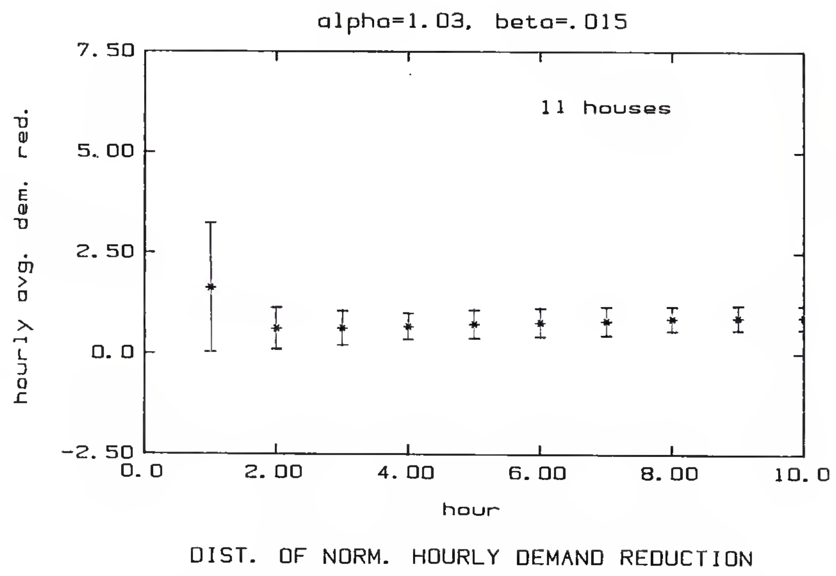

Fig. 2: Hourly Average Demand Reduction Upon Control (in Percent) for 11 Case 4 Houses With a Constant Driving Temperature of 90 F.

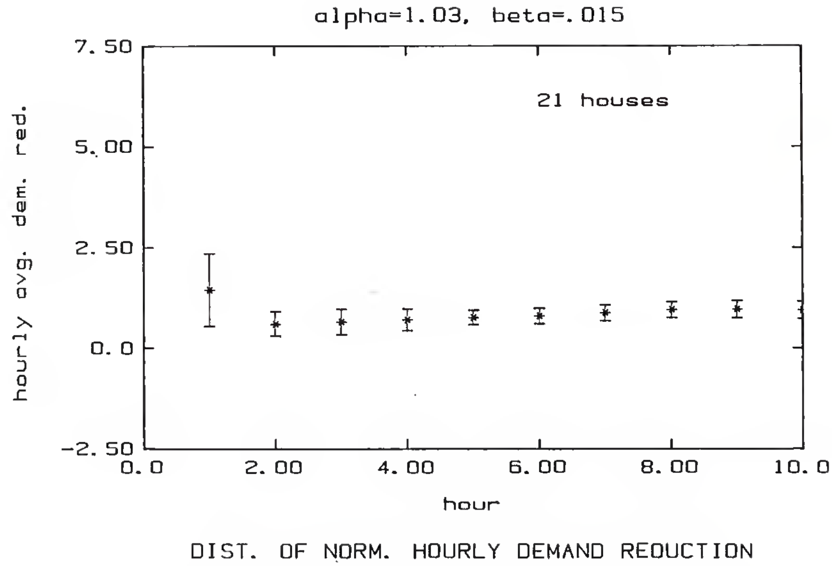

Fig. 3: Hourly Average Demand Reductipn Upon Control (in Percent) for 21 Case 4 Houses With a Constant Driving Temperature of 90 F.

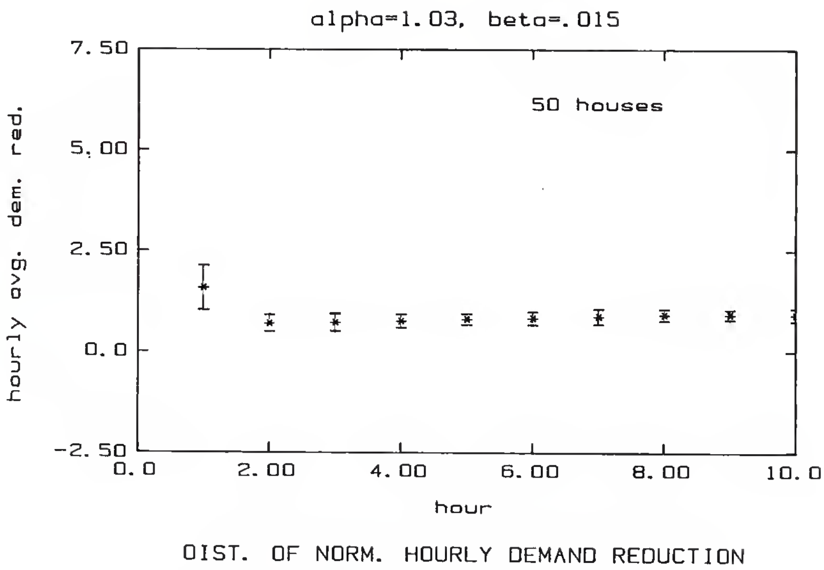

Fig. 4: Hourly Average Demand Reduction Upon Control (in Percent) for 50 Case 4 Houses With a Constant Driving Temperature of 90 F.

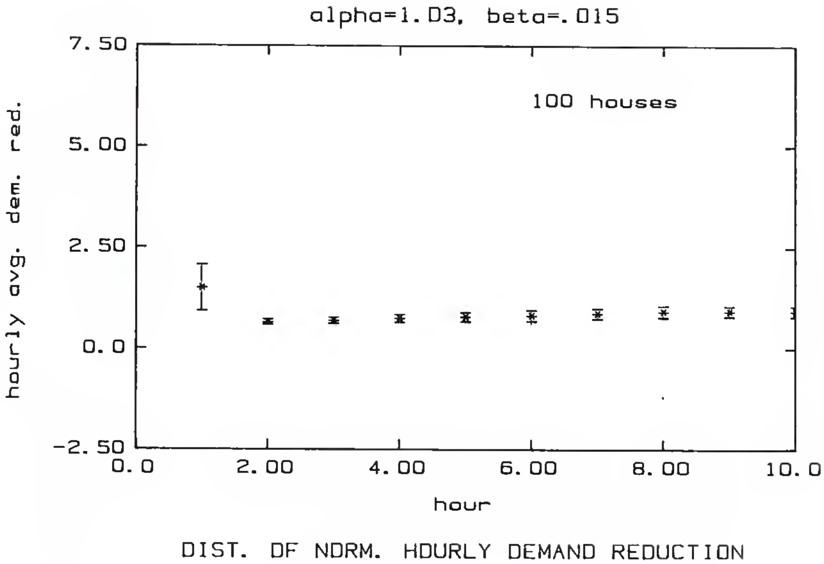

Fig. 5: Hourly Average Demand Reduction Upon Control (in Percent) for 100 Case 4 Houses With a Constant Driving Temperature of 90 F.

level.

It is also noticed from Figs. 1-5 and Appendix B that transient effects are effectively gone after the first hour. This vindicates the use of a 10 hour period.

Starting Conditions Simulation

To examine the effects of the initial conditions on the results, 3 sets of initial conditions were simulated:

1. All a/c'c initially on, starting temperatures random.
2. All a/c'c initially off, starting temperatures random.
3. All a/c'c randomly off and on, starting temperatures random.

These cases were simulated at Tdrive=95 F for cases 1-3 with load curves of 20 houses. The demand for controlled and uncontrolled cases was averaged on an hourly basis over 10 hours and plotted. Examples of the plots are shown in Figs. 6-8. The remaining plots are shown in Appendix C.

Results

In all three cases, the controlled case seems largely unaffected by the changes in starting conditions. This is because the control forces the houses to get into a pattern of consumption which averages smoothly on an hourly basis.

In case 1 the uncontrolled case is only affected in the first hour because regardless of initial conditions,

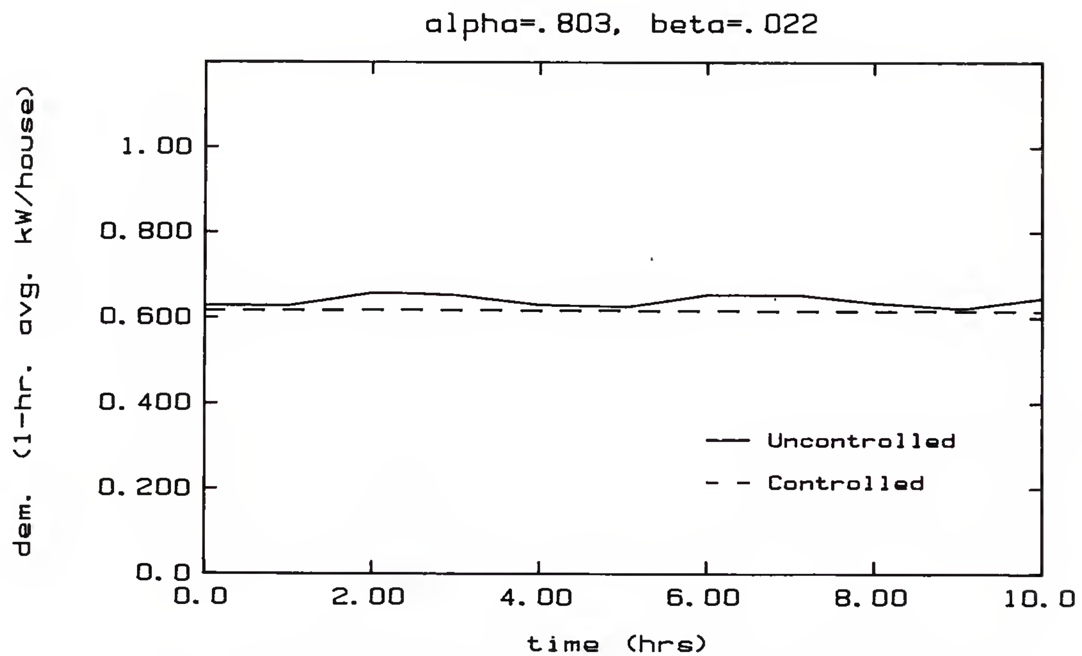

Fig. 6: One-Hour Average Demand for 20 Case 2 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With All 20 Air-Conditioners Initially On.

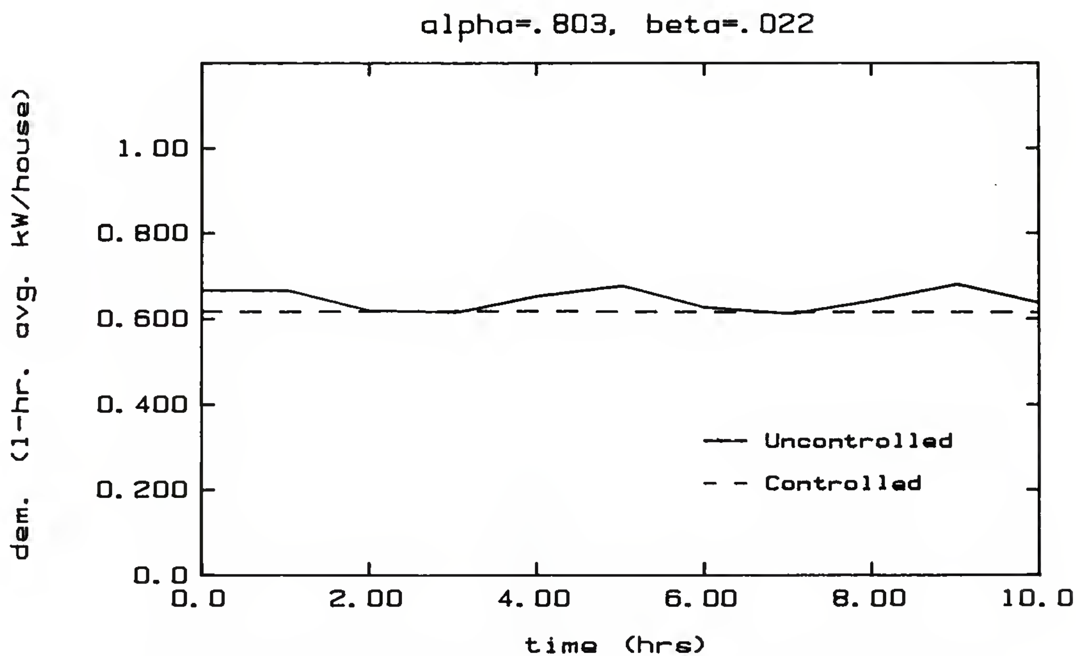

Fig. 7: One-Hour Average Demand for 20 Case 2 Houses (Normalized to a kW/house Basis) over a 10 Hour Period With All 20 Air-Conditioners Initially Off.

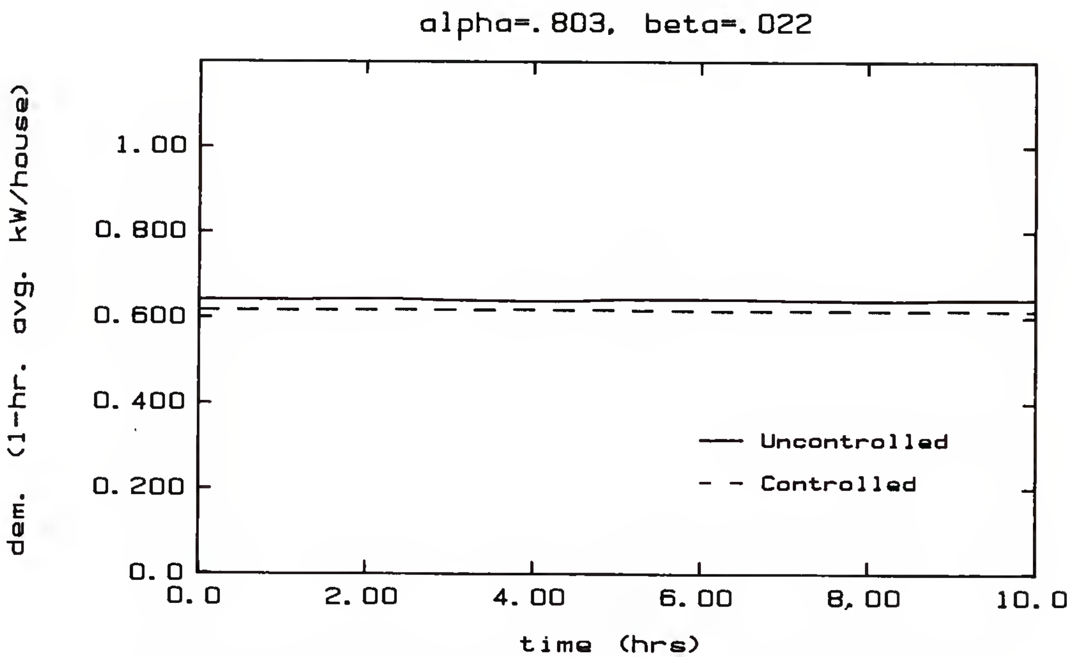

Fig. 8: One-Hour Average Demand for 20 Case 2 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With the Air-Conditioners Randomly On and Off.

the a/c will be forced to run all the time.

In cases 2 and 3 however, the uncontrolled case shows that the difference in initial conditions makes a difference. For the cases where the a/c's are either all off or on, noticable fluctuations are present in the hourly demand averages (see Figs. 6 and 7 as well as Figs C-1, C-2, C-4, and C-5). This is because the initial states force the houses into a consumption pattern that is repeated throughout the 10 hour period. The pattern differs from the controlled pattern because the uncontrolled case does not force the a/c's off regularly.

The completely random set of initial conditions produced hourly demand curves with much smaller variations. This can be seen by comparing Fig. 8 with Figs. 6 and 7 (also Figs C-3, C-6, and C-9 with previously mentioned Appendix C plots).
This confirms that the scheme used to make the initial states random was effective.

<u>Effect of Natural Duty Cycle on Demand Reduction</u>

From the sample size simulations detailed earlier, it is noticed that the effectiveness of control varies according to a/c size. It is hypothesized that this is due to variations in the natural (uncontrolled) duty cycles of the a/c's. Nordell has stated that control is only effective if the forced (controlled) duty cycle is greater than the natural duty factor of the a/c [9]. Gustafson reported a similar hypothesis [12] Neither Gustafson nor Nordell offered data to substantiate their claims. This set of simulations purposes to determine if this relationship between the natural and forced duty cycles has this proposed effect.

Demand reduction curves were simulated with the following criteria:

1. Load curves were comprised of 20 houses.
2. Controlled and uncontrolled load curves were simulated.
3. Percent demand reduction = uncontrolled demand - controlled demand, normalized for 20 houses.
4. Hourly demand reduction was averaged for the final 9 hours of a 10 hour period. The first hour was not included to eliminate the transient effects.
5. Natural duty cycles for the a/c's were varied from around 30% to 100%.
6. At each value of duty cycle, 10 independent trials were run.
7. Demand reduction was averaged for the 10 trials. A corresponding standard deviation was also calculated.
8. Percent demand reduction was plotted as a function

of duty cycle.

These simulations were performed for both types of control.

Centralized Control

Percent demand reduction curves were generated for simulations utilizing centralized control for cases 1-4. This was done using two different control strategies; 1. control 7.5 out of 30 minutes and, 2. control 2.5 out of 10 minutes. These control strategies were chosen because both have a maximum controlled duty cycle of 75%.

Results

From the demand reduction plots it can be seen that demand reduction is minimal until the duty cycle reaches the 75% point (for example, refer to Figs. 9 and 10 also see Figs D-1, D-3, D-4, D-8, D-10, and D-11). This is the point where the natural duty cycle of the a/c exceeds the maximum controlled duty cycle. This occurred in every case. When the natural duty cycle of the a/c is larger than the maximum controlled duty cycle during control, the a/c is able to run enough to satisfy its needs. Once the natural duty cycle reaches 75%, however, the a/c is no longer able to keep up with the heat load when control forces a duty cycle of 75%. This causes the inside temperature to rise and net demand reductions are

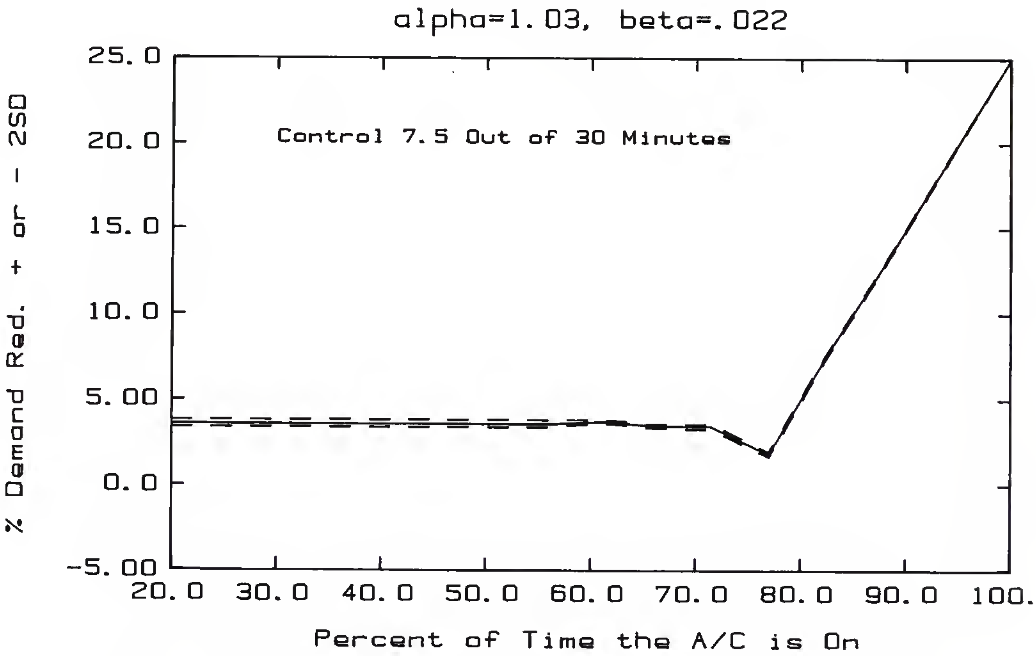

Fig. 9: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

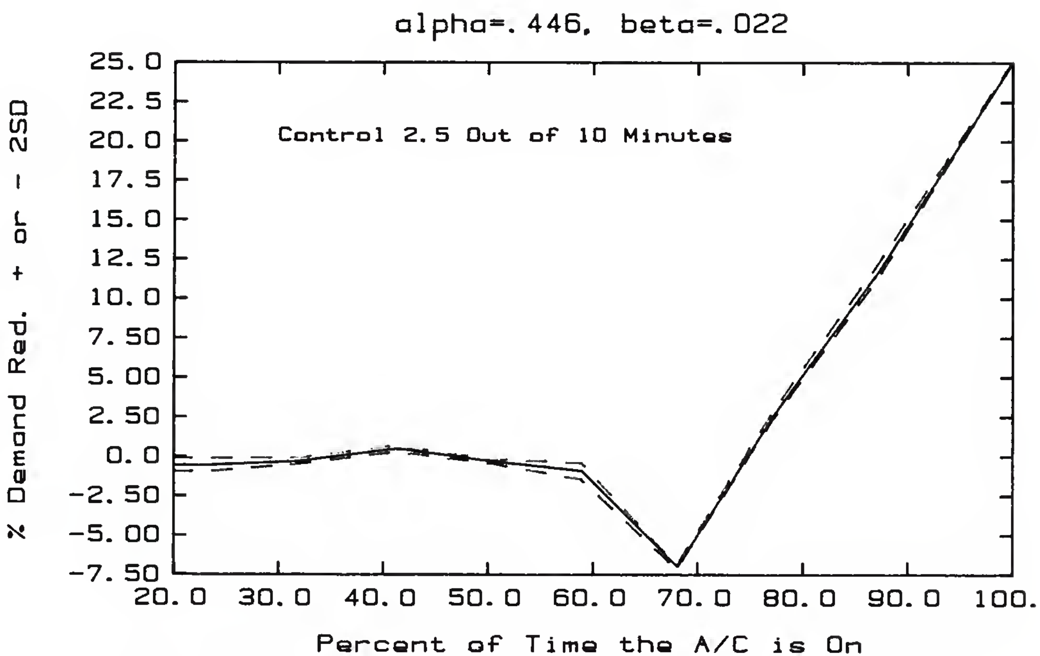

Fig. 10: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

seen.

The temperature rise for these is seen in Figs 11-14 (see also Figs D-2, D-5, D-6, D-7, D-9, D-12, D-13, and D-14). By comparing the uncontrolled temperature with the controlled temperature it can be seen that the controlled temperature diverges from the uncontrolled temperature where the demand reduction varies from 0. It diverges in the direction that the demand reduction varies from 0. This shows the correlation between inside temperature and demand reduction.

One other interesting effect is apparent from Figs. 9 and 10. Just before the demand reduction starts to rise toward maximum reduction a dip is seen. The exact cause of this is not known for sure. It is hypothesized that some sort of resonance phenomenon is responsible, which is a function of interaction between natural heating and cooling times and control times. The interaction between the heating and cooling times and the control strategy might force the system into a situation where the a/c is reaching the lower limit of the temperature band when control begins. At the end of control, the a/c will turn immediately on regardless of the temperature. Thus, almost a full extra period of on time is required, producing a rise in demand from the uncontrolled case. Such a condition could exist for each case. However, the size of the

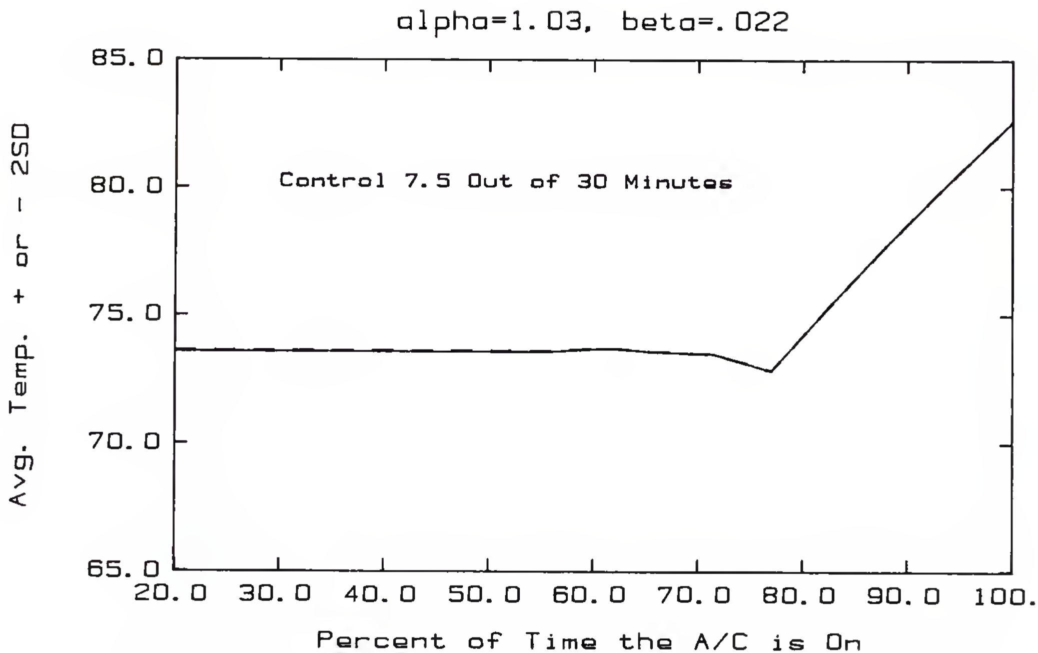

Fig. 11: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

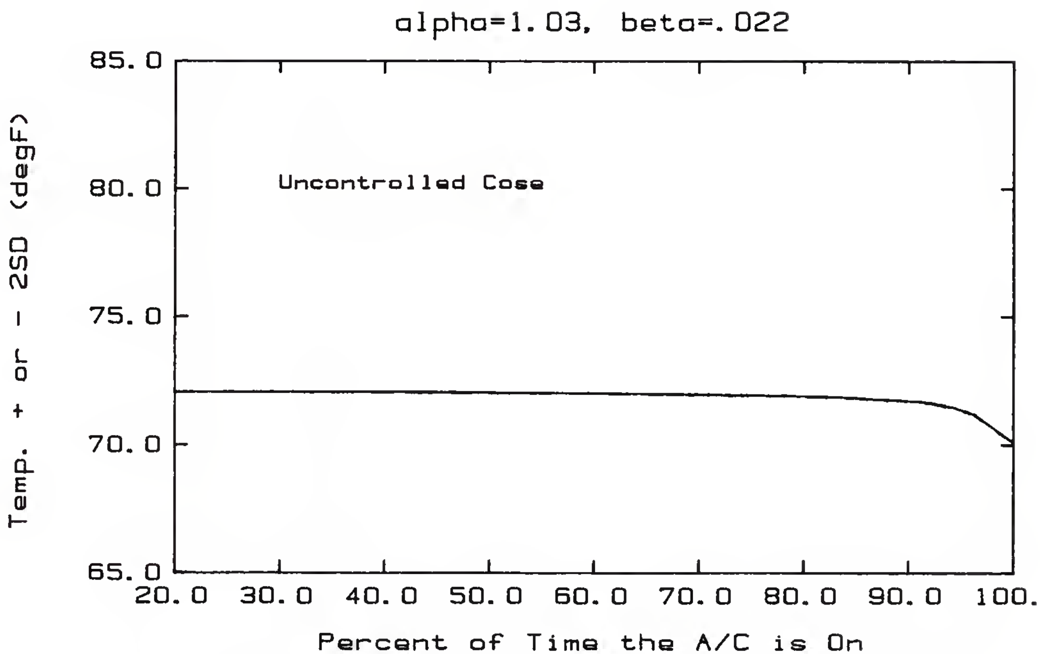

Fig. 12: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. This Case is Uncontrolled.

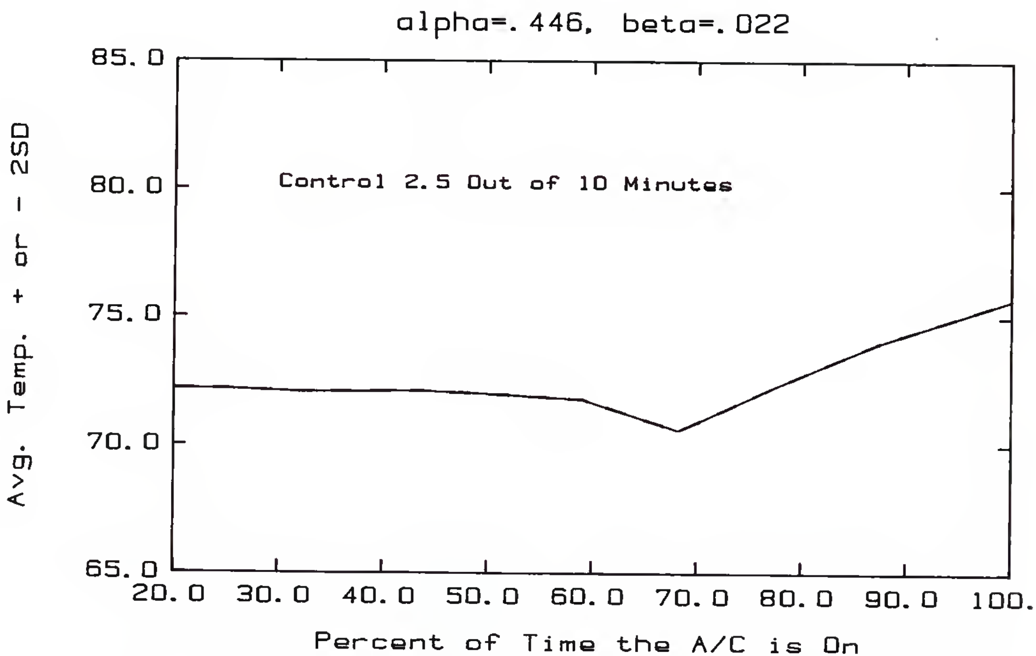

Fig. 13: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

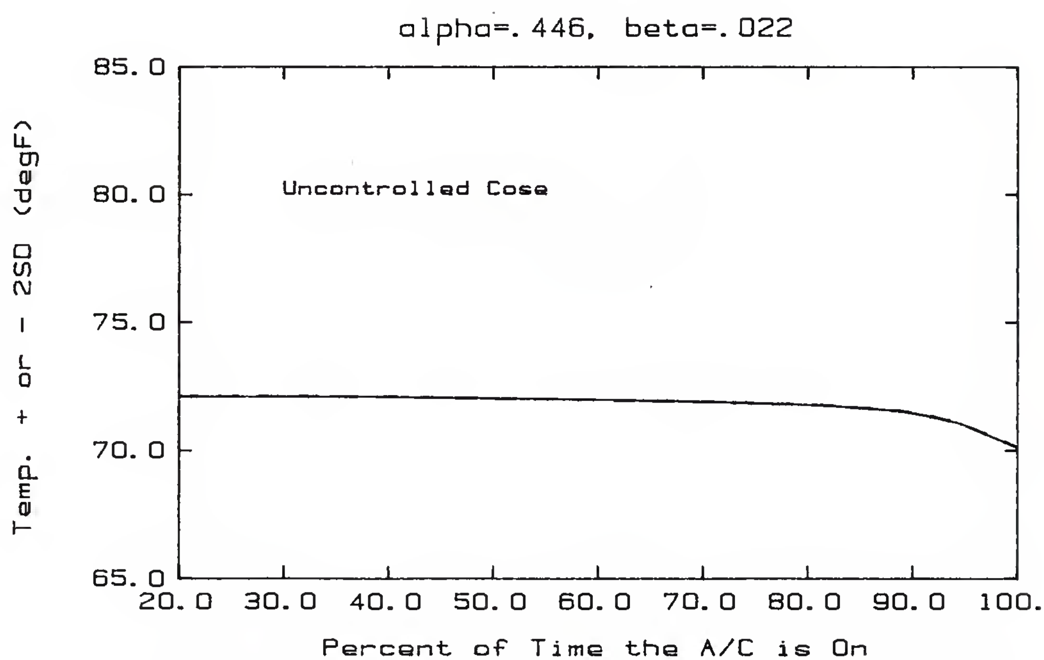

Fig. 14: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. This Case is Uncontrolled.

dip appears to be different for each case. Plots with more plotted points around the dips for Figs. 9 and 10 are shown in Figs E-1 and E-2 in Appendix E.

Load Leveler Control

For the load leveler control scheme the demand reduction simulations were run for cases 1-3.

Results

The results of this simulation were very similar to those for the centralized case. Significant demand reduction was not achieved until the natural duty cycle passed 75%. This number also corresponded to the maximum controlled duty cycle. Examples of these results are shown in Figs. 15 and 16 (see also Fig. F-1).

Also, once again, the temperature of the controlled case diverges where the demand reduction varies from 0. This is shown in Figs. 17 and 18 (compare to uncontrolled case shown in Figs. 12 and 14 compare also Fig. D-5 to Fig. F-2).

The demand reduction dip noticed in the centralized control case is also evident with the load leveler. See Figs. 15 and 16 as well as the remaining case shown in Appendix F.

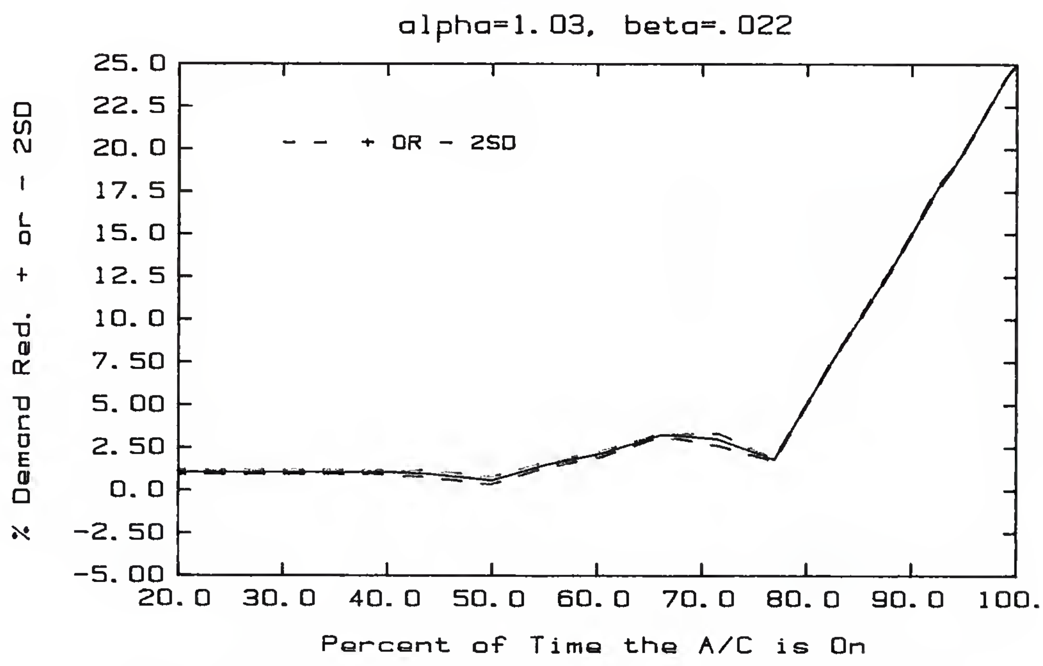

Fig. 15: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Load Leveler type.

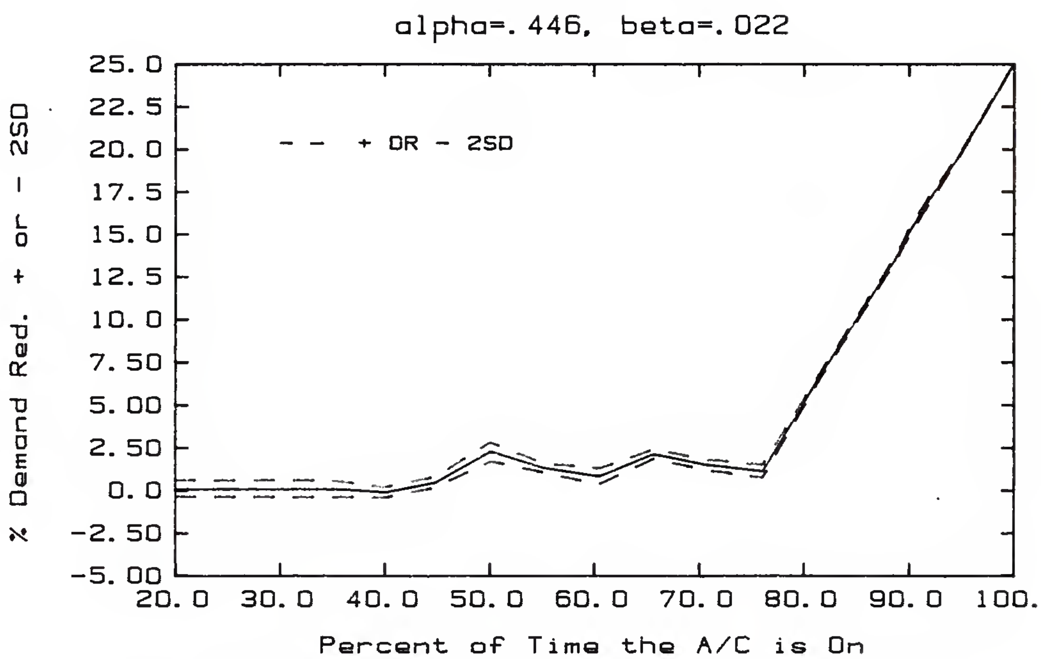

Fig. 16: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Load Leveler type.

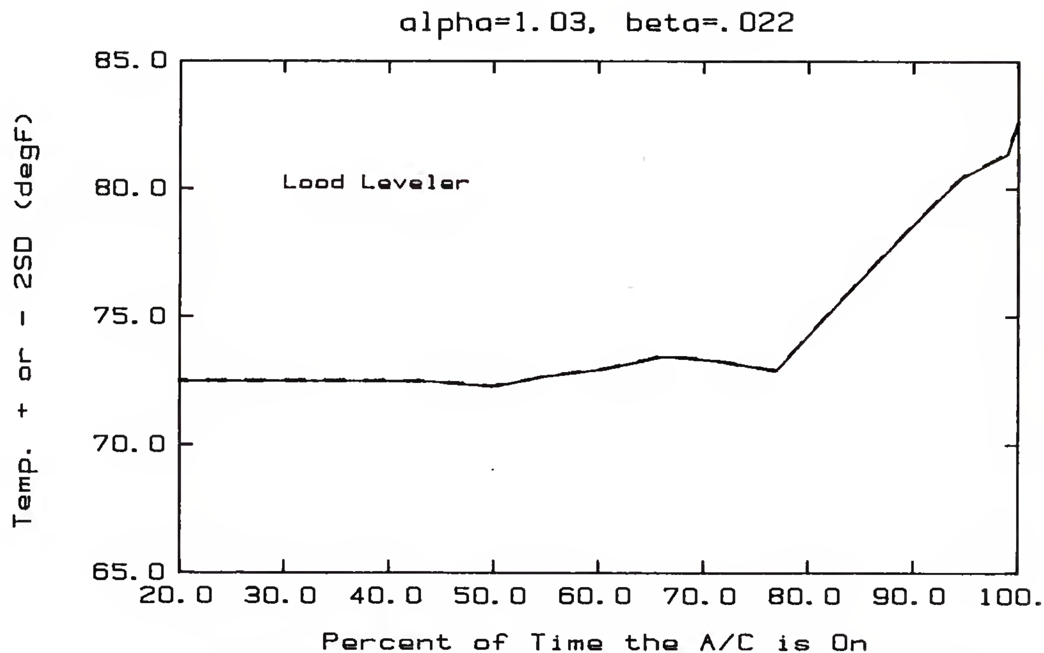

Fig. 17: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Load Leveler type.

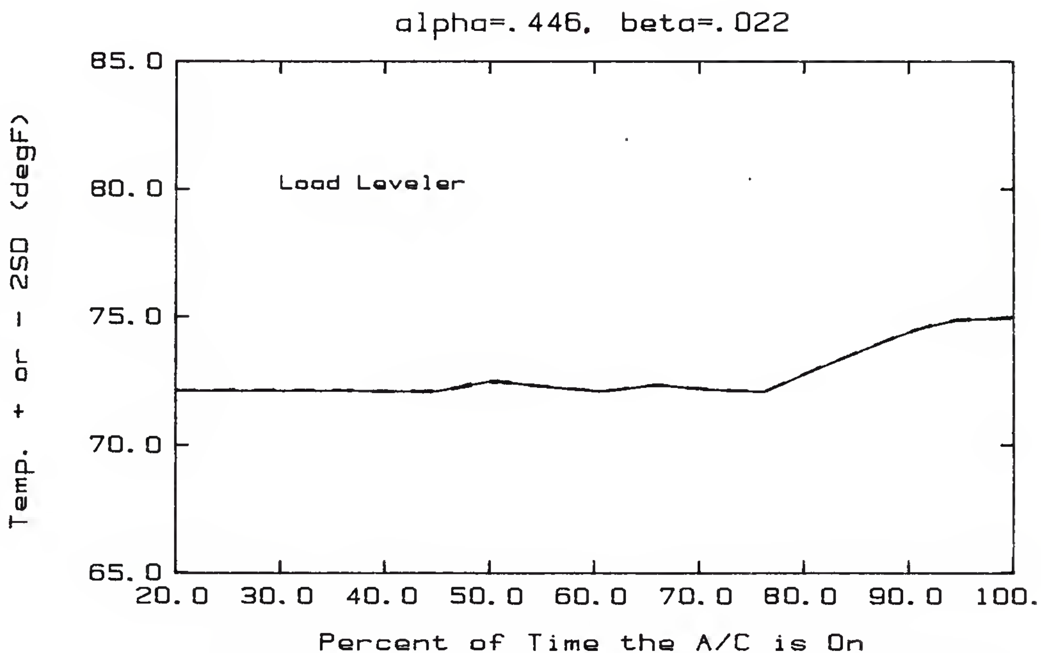

Fig. 18: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Load Leveler type.

Diurnally Varying Driving Temperature Simulations

Simulations were performed for which the driving temperature varied diurnally. The driving temperature was piece-wise constant sinusoidal as mentioned earlier. The temperature at noon and midnight was set at 85 F. The peak temperature occurred at 6 and was varied according to the needs of the simulations. It is assumed that the driving temperature is 5 degrees higher than the outside temperature and lags the outside temperature by 2 hours. On a typical summer afternoon the outside temperature peaks at 4 p.m. while this driving temperature peaks at 6 p.m. The driving temperature is higher than the outside temperature because of the heat stored in the structure of the house.

This piece wise constant sinusoidal temperature very nearly approximates an actual afternoon. The 12 hours included in the simulation are from 12 noon to 12 midnight. Simulations were performed with both types of control, centralized and load leveler.

Centralized Control Simulations

Centralized control simulations were performed with the following characteristics:

1. Part of the day was uncontrolled and part was controlled. The first two hours (12 noon to 2 p.m.) were uncontrolled, the next six (2 p.m. to 8 p.m.) controlled, and the final four (8 p.m. to 12

midnight) uncontrolled. This allowed a view of the effects of starting and stopping control.

2. Control was exercised by automatically turning all a/c's off for the first 7.5 minutes of each half hour during the control period.
3. Load curves of 20 houses were used.
4. Cases 1-3 were simulated to see the effects on different classes of houses.
5. Peak temperatures were varied from 90 - 110 F by 5 degrees per simulation (case 1 was only simulated at 90 and 95).
6. One-hour aggregate average demand and one-hour average temperature for a typical house were calculated and plotted.
7. Five-minute aggregate average demand and five-minute average temperature of a typical house from the sample were calculated and plotted.
8. Demand was calculated for 20 houses and normalized to a kW/house basis.
9. In the afore-mentioned plots the data points are an average over either 5 minutes or 60 minutes (depending on the type of plot). The data points are placed at the end of the 5 or 60 minute period. Then a curve is drawn through the data

points for ease of viewing. Another possible way was to draw a histogram plot.

Uncontrolled days were also simulated under the same load conditions. These curves were compared with the days that included control.

Results

Several things were noticed from the demand and temperature curves mentioned earlier.

For case 1, peak temperatures of 90 and 95 produced a large reduction in demand. This is because the temperature was high enough and the a/c small enough that the a/c was forced to run almost all the time to try to keep up with the driving temperature in the uncontrolled case. When control is exercised, the a/c is not allowed to run as much as it requires. Therefore, demand is reduced and inside temperature rises in the controlled case. This is seen best in Figs. 19 and 20 (see also Figs. G-2 and G-4 in Appendix G).

For case 2, small demand reductions at best were evident when the peak temperatures were 90, 95, and 100 F (see Figs. H-1 through H-3). Reductions were accompanied by a small rise in average inside temperature (see Figs. H-6 through H-8). When the peak tempertures reached 105 and 110 F, large demand reductions were seen. This is because the natural duty cycle of the a/c's reaches a

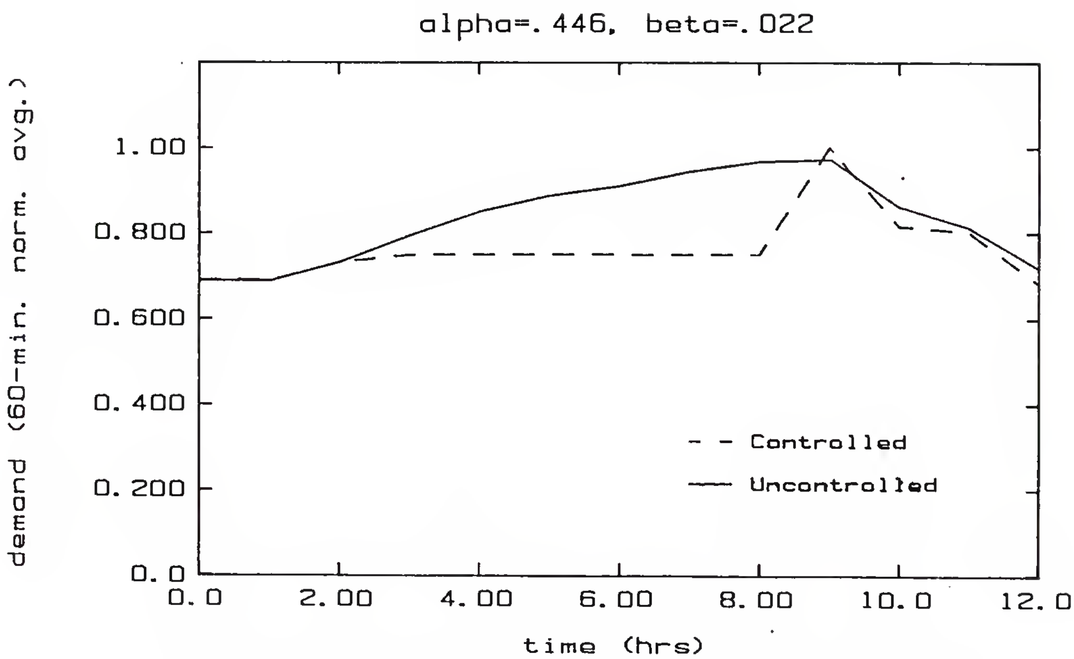

Fig. 19: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

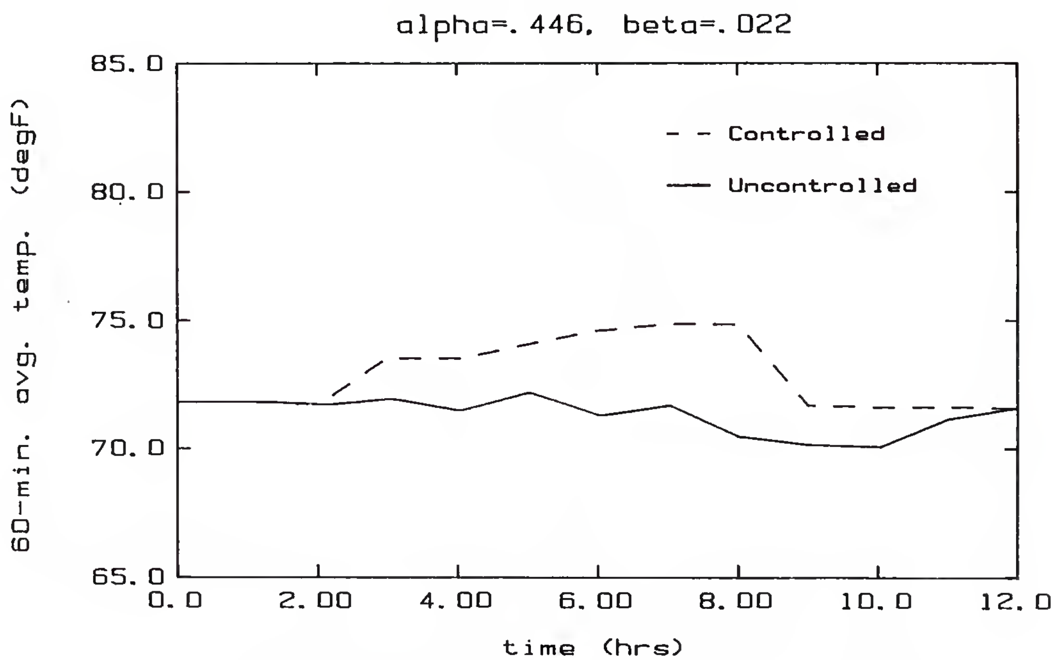

Fig. 20: Sixty-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=90.F) Over a 12 Hour Period. Control is Centralized.

higher level. Control forces the a/c's to run less than they need to in order to keep pace with the driving temperature. This results in a demand reduction and a rise in average inside temperature. Examples of these results are shown in Figs. 21 and 22 (see also H-5 and H-10). These results are consistent with what was seen earlier in the plots of percent demand reduction as a function of duty cycle. Remaining plots for case 2 are shown in Appendix H.

Case 3 showed small demand reductions at best at the lower temperatures (see Figs. I-1 to I-3). At the higher peak temperatures the demand curves showed a definite small demand reduction. For example, see Fig 23 (also Fig I-5). However, the peak temperature never did get high enough to force case 3 to show larger demand reduction. Where demand reductions were evident, they were accompanied by a corresponding rise in average inside temperature. For example see Fig. 24 (also, see Figs I-6, I-7, I-8 and I-10).

This shows that the potential for demand reduction is dependent upon the class of house that is being controlled. For houses with larger a/c's, it is doubtful that the days would ever get hot enough to achieve very significant demand reductions. For houses with smaller a/c's it is likely that demand reductions would be achieved. It is

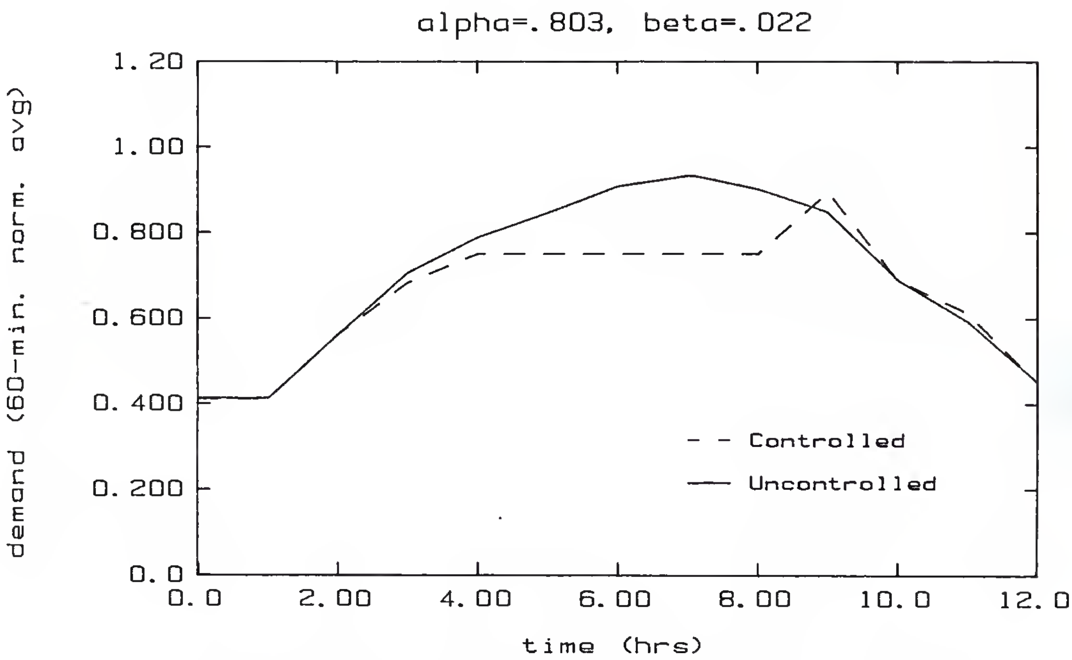

Fig. 21: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

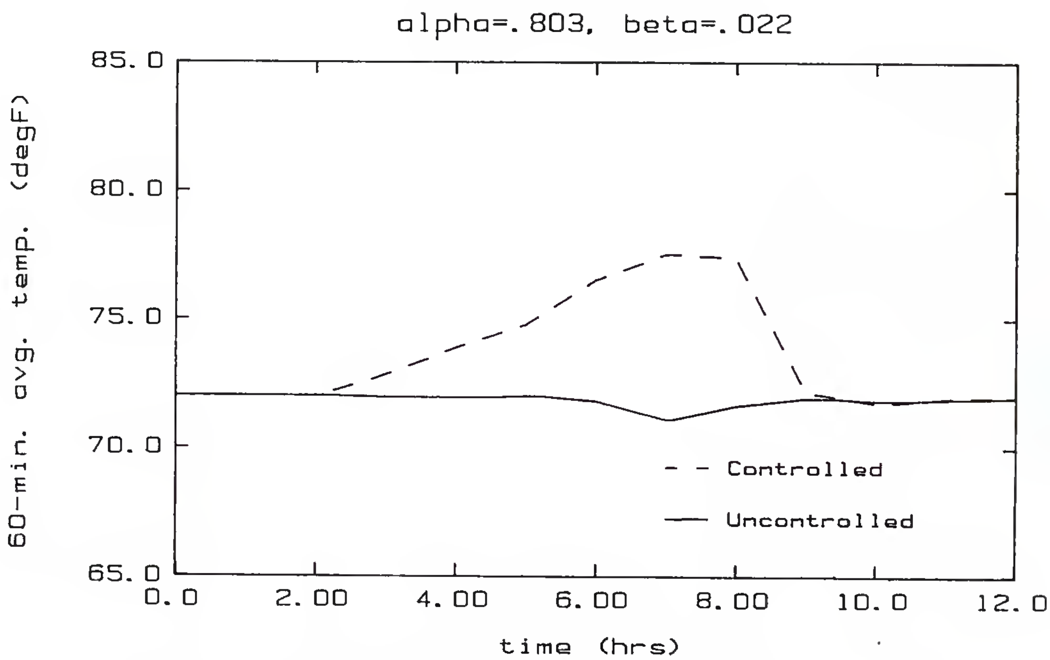

Fig. 22: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

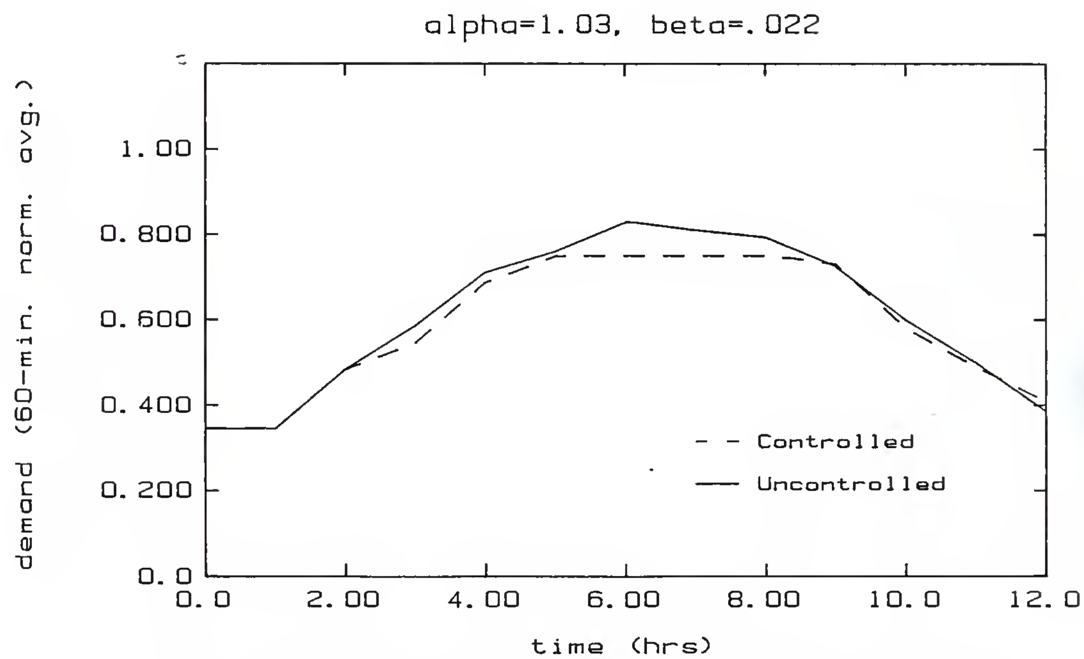

Fig. 23: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

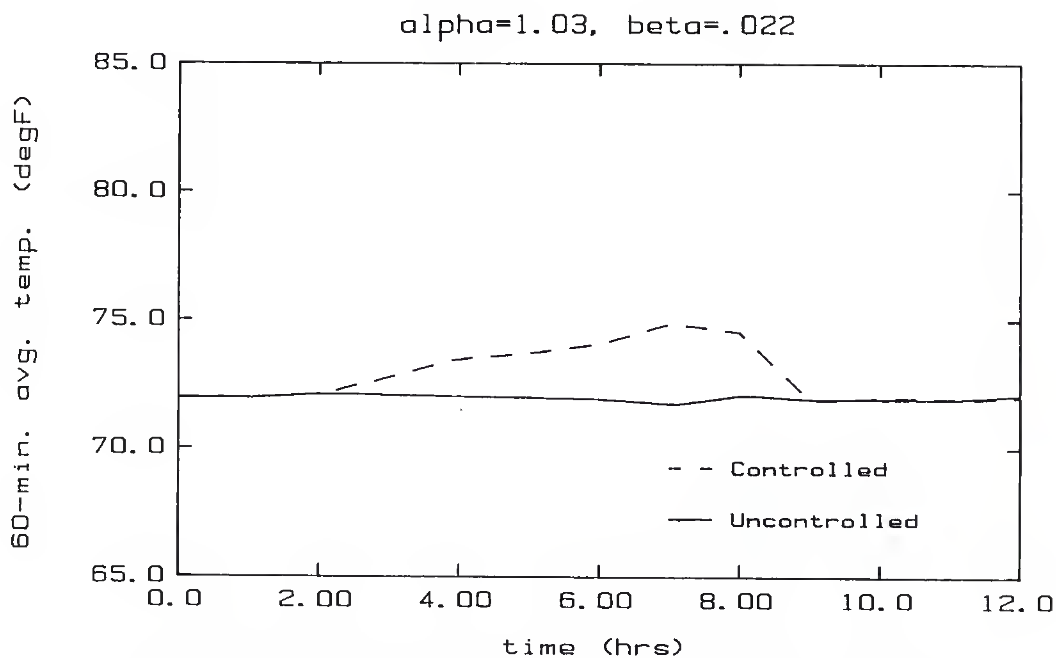

Fig. 24: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Centralized.

also evident that demand reduction is achieved at the cost of raising average inside temperature.

Once control was released, the controlled demand curves tended to overshooot the demand of the uncontrolled case. This is shown especially well in Fig. 19 (see also Fig H-4). This was due to the a/c trying to catch up for the rise in inside temperature. The rise in inside temperature forces tha a/c's to run continuously for a long time to reduce the inside temperature to a comfortable level. It should be noted that this is more prominent as the peak temperature brought the natural duty cycle of the a/c closer to the 100% mark.

Figs. 25a and 25b show an examples of the 5-minute demand curves under controlled and uncontrolled conditions. It was noticed that control tended to remove the natural diversity of the a/c's. This becomes more severe at higher peak temperatures. The synchronization tended to produce large oscillations in the demand both during and after control. The 5-minute average temperatures of a typical house for the above cases are shown in Figs. 26a and 26b. From these plots it can be seen that control forces the 5-minute average temperature to rise well above the thermostat set temperature. Also it can be seen that control forces the temperature oscillations to be more frequent. Further examples of the above-mentioned effects

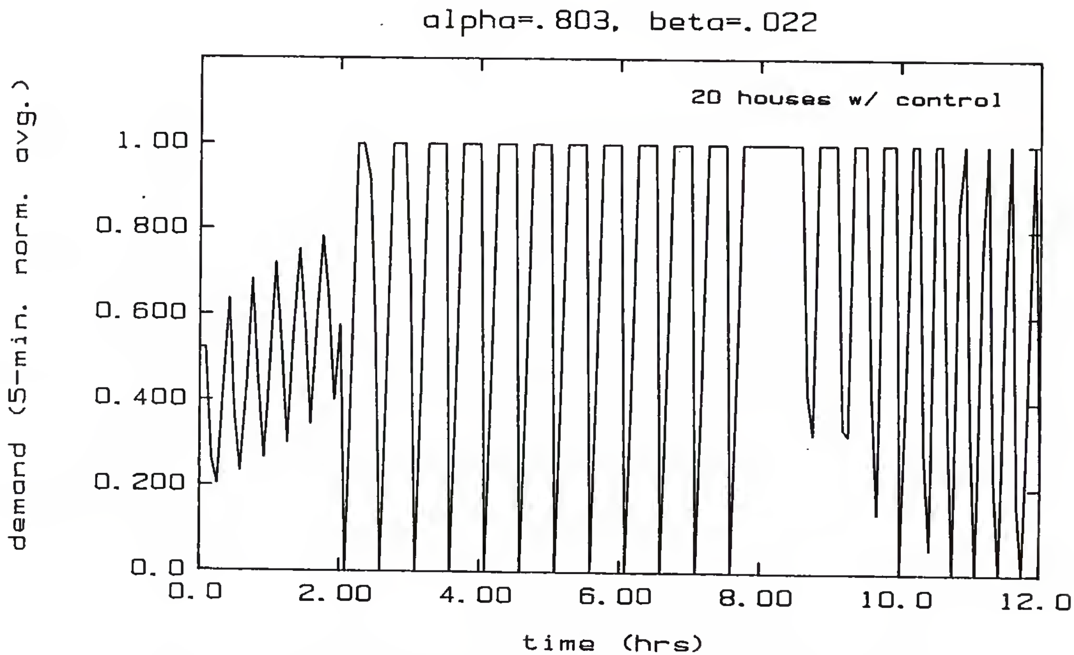

Fig. 25a: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

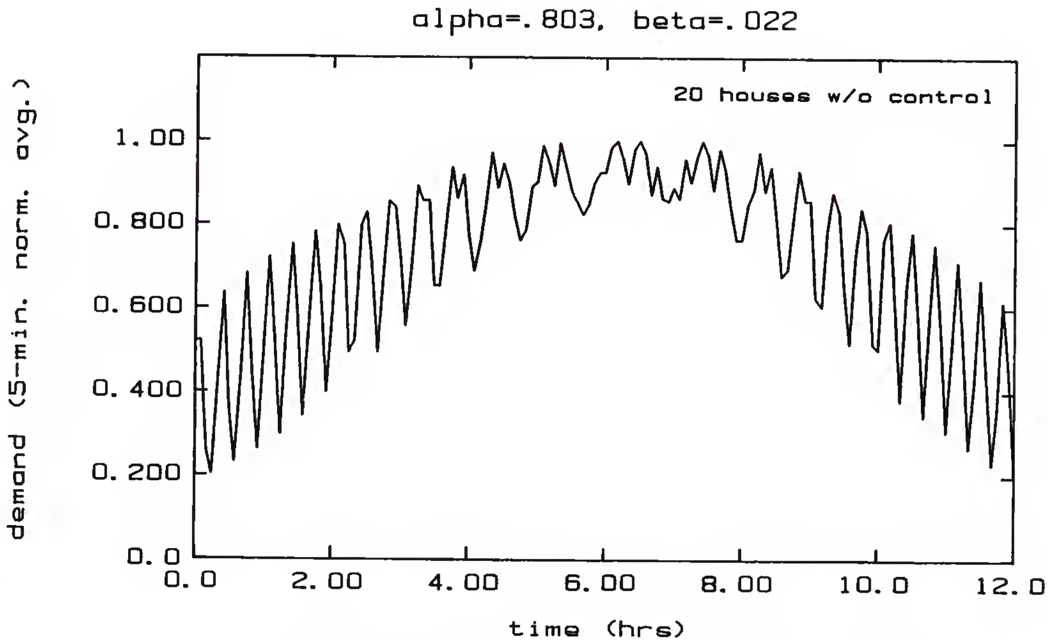

Fig. 25b: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

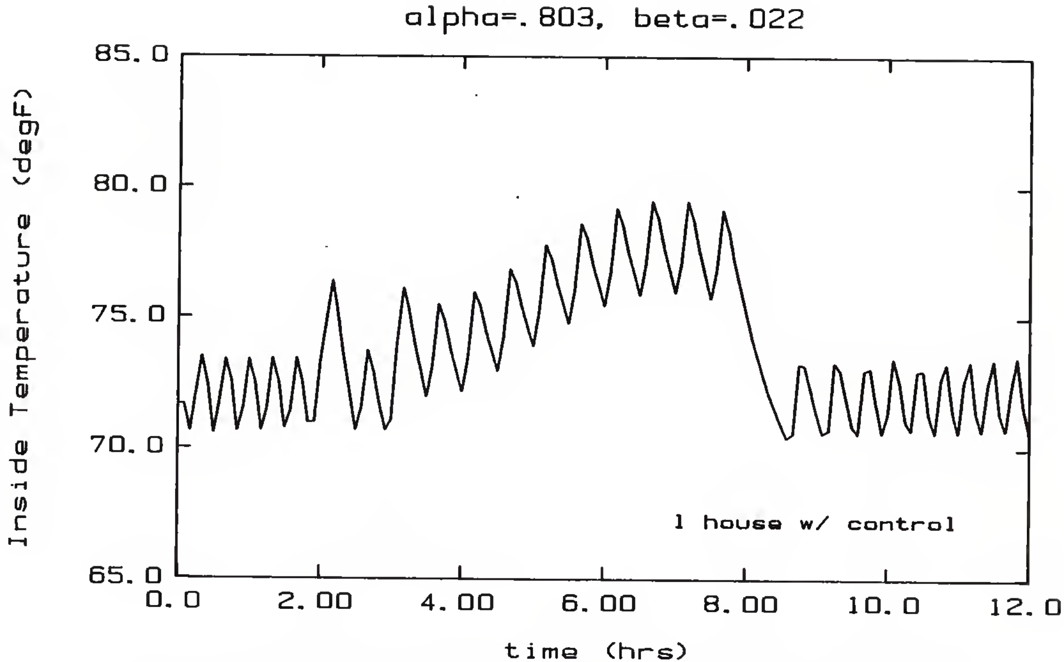

Fig. 26a: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

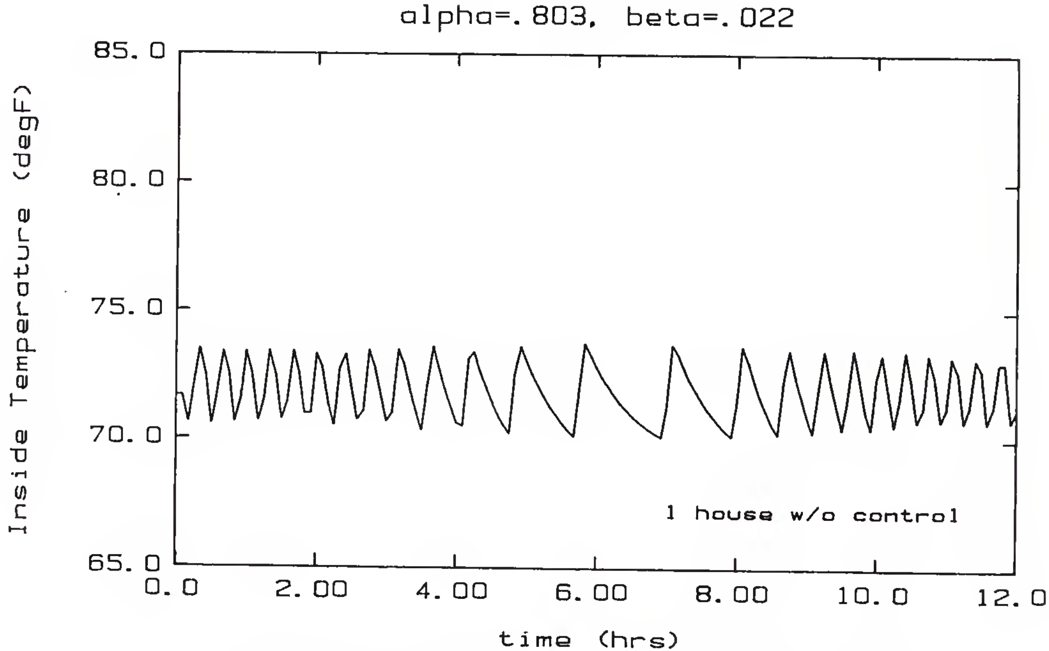

Fig. 26b: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105.F) Over a 12 Hour Period.

can be seen in the 5-minute demand and temperature plots in Appendices G, H, and I.

For case 2, the effects on the demand and temperature curves seen at peak temperatures of 105 and 110 F mirror those which occurred in case 1 at peak temperatures of 90 and 95 F. This is due to the effect of the increase of the natural duty cycle at the higher peak temperatures for case 2. If even higher peak temperatures were used, the same effect would be seen in case 3.

Load Leveler Simulations

Load leveler simulations were performed with the following criteria:

1. Simulations were performed for peak temperatures of 100, 105, and 110 F.
2. Control started at Tdrive=100 F and ended at Tdrive=93 F.
3. Load curves had 20 houses.
4. Cases 2 and 3 were simulated (case 1 was simulated at Tdrive=100 F but the results were trivial).
5. Demand and temperature calculations were identical to those for centralized control. The data is also plotted in the same manner as the plots for centralized control.
6. Control was exercised as stated earlier for load leveler control.

The purposes of performing these simulations were to determine the effects of load leveler control and to compare the two methods of control.

Results

For case 1, the load leveler produces a very large demand reduction and rise in inside temperature. For example see Figs. 27 and 28. These results occur because the load leveler only exercises control when Tdrive is greater than 100 F. At these temperatures, the case 1 a/c runs continuously in the uncontrolled state. When control forces the a/c off, demand reduction and a temperature rise are the results. Five minute demand and temperature plots for case 1 are shown in Figs. J-1 and J-2 in Appendix J.

For case 2, a small demand reduction is seen at a peak temperature of 100 F (see Fig. K-1, Appendix K). With a higher value of T_peak, a larger demand reduction is seen. For example, see Fig. 29 (also Fig. K-3). Once again, demand reduction is always accompanied by a rise in inside temperature. See Fig. 30 (also Figs. K-4 to K-6).

The results seen with case 3 are very similar to those seen earlier using centralized control. Demand reductions are small because Tdrive never gets high enough to force large demand reduction. For example, see Fig. 31

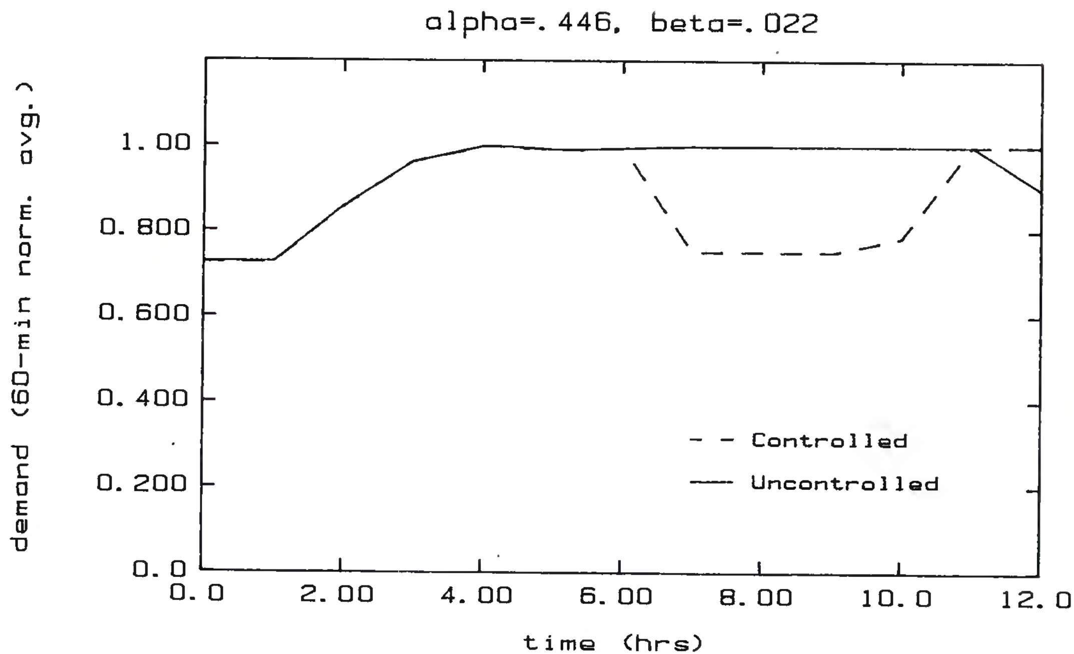

Fig. 27: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

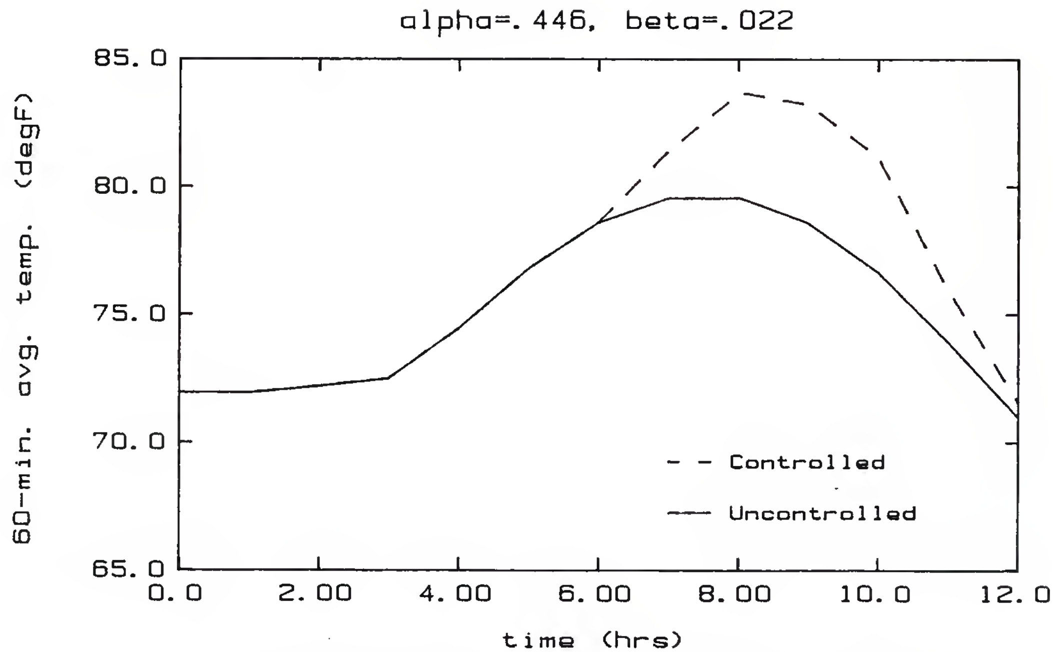

Fig. 28: Sixty-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

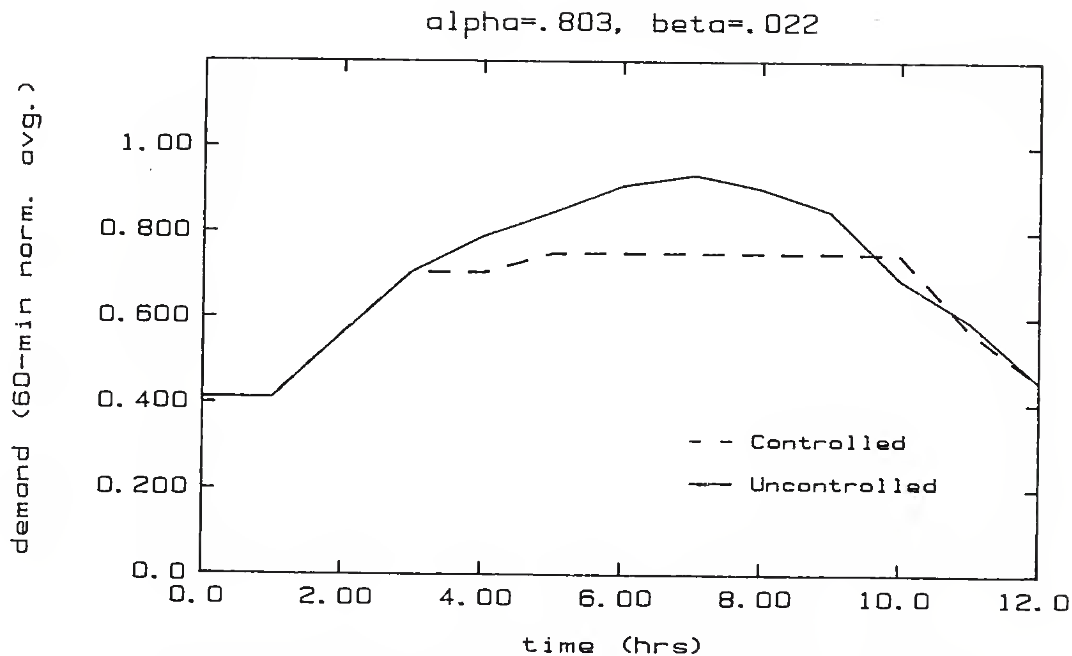

Fig. 29: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

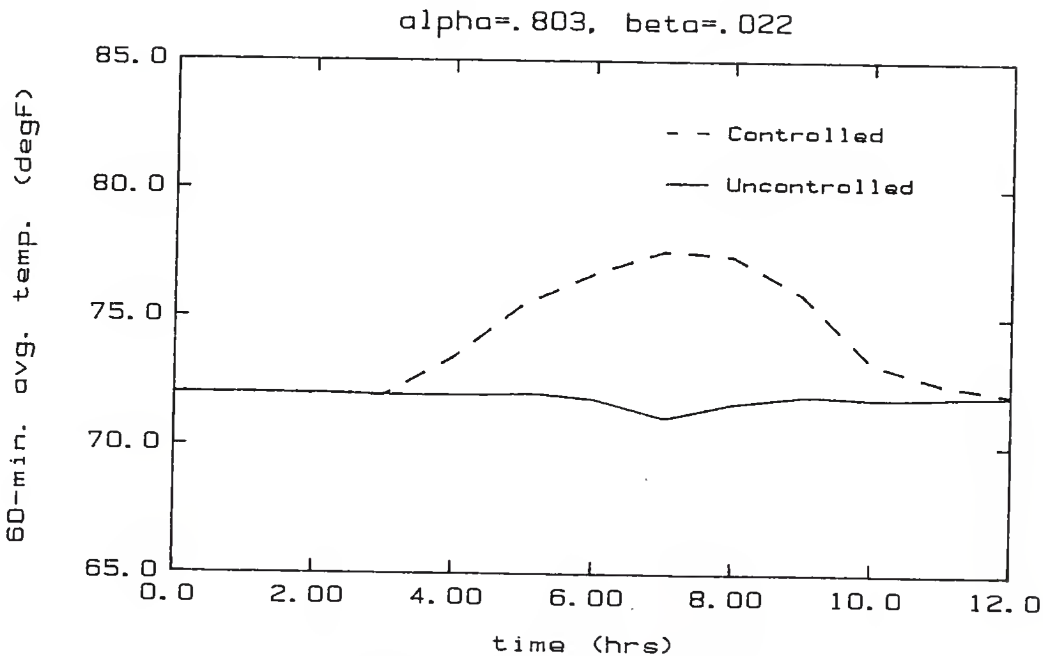

Fig. 30: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

(also Figs. L-1 and L-3, Appendix L). Average inside temperature rises where demand reductions are seen. This is shown in Fig. 32 (also see Figs. L-4 and L-6).

Upon comparing the load leveler control plots with centralized control plots, several things are apparent.

The demand reductions produced by the load leveler during the peak period were similar to those produced by centralized control. However, a significant difference is seen in the demand pattern in the period following the release of centralized control. This can be seen by comparing identical cases from Appendices G-L. Load leveler control decreased the size of after control demand peaks (compare Figs. 27 and 21 as well as Figs. K-3 and H-5). This occurs because the load leveler doesn't cease control until the driving temperature is sufficiently reduced. This forces the a/c to reduce the inside temperature at a slower rate than if it were released of control earlier in the day. This same effect could be achieved by the centralized control by either making control temperature dependent or increasing the length of the control period.

The temperature effects of the load leveler are similar to those seen for the centralized control. One exception is that the temperature didn't drop as rapidly at the end of the day with the load leveler. To see this compare Fig. 30 with Fig. 22. This occurred because the load

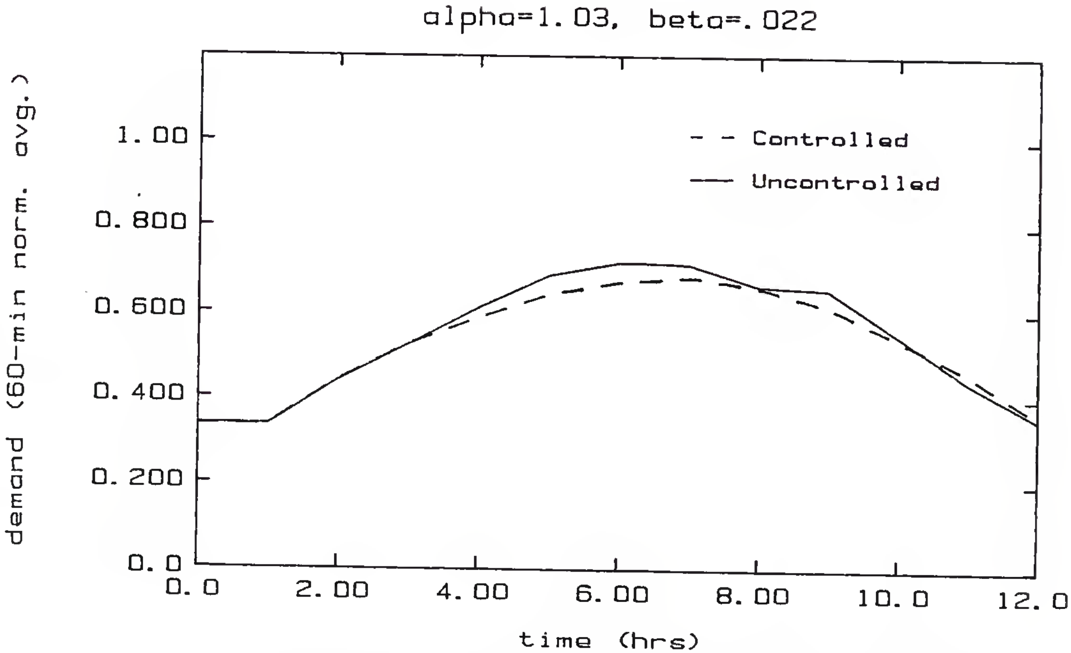

Fig. 31: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

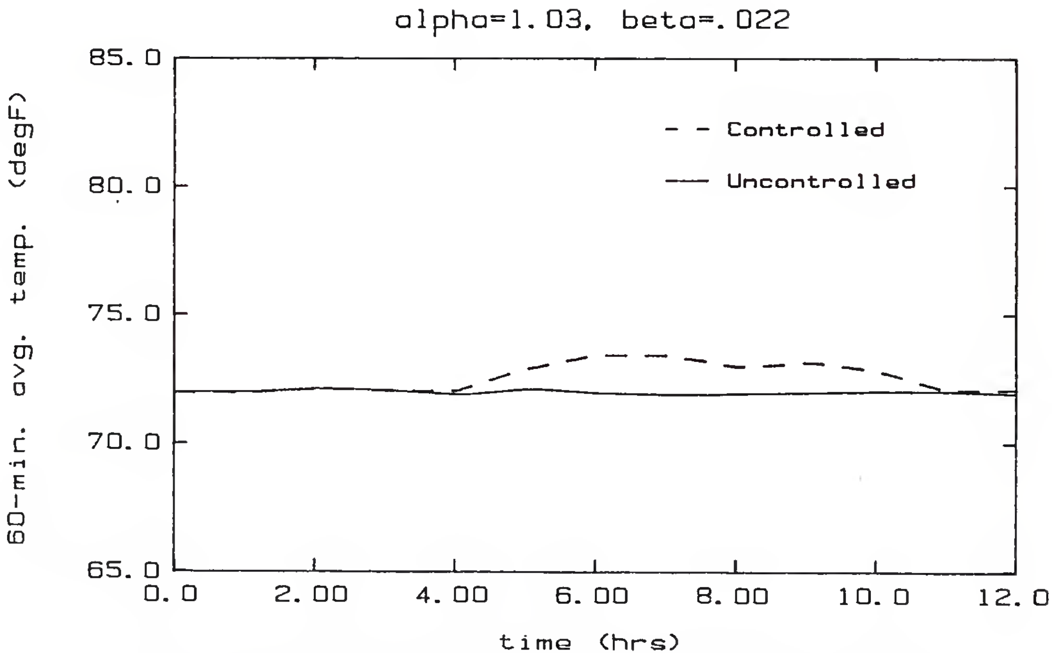

Fig. 32: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

leveler is temperature controlled. Control does not cease at a set time. Instead it continues until the driving temperature is sufficiently lowered.

Another significant difference in the two control methods can be seen by looking at the 5-minute demand curves. The load leveler did not remove the natural diversity of the houses. This is because each house is controlled independently. This resulted in smaller oscillations in 5-minute average demand. To see this compare Figs. 25 and 33 (also compare Figs. L-9 and I-20, Figs. L-8 and I-19, Figs. 1_7 and I-18, Figs. K-9 and H-20, Figs. K-8 and H-19, as well as Figs. K-7 and H-18). Also notice that once control starts the load leveler control sets a repetitive pattern of demand in the cases where the natural duty cycle is higher than 75%. If the number of houses in the sample were very large then the demand curve should be a straight line at 0.75. More sophisticated central control strategies (in which instead of synchronized control, staggered control is exercised) could achieve the same result. The corresponding 5-minute average temperature plot is shown in Fig. 34. This plot shows that the load leveler forces the temperature to decrease more slowly toward the end of the 12 hour period than the centralized control case. This is due to the temperature-controlled nature of the load leveler control.

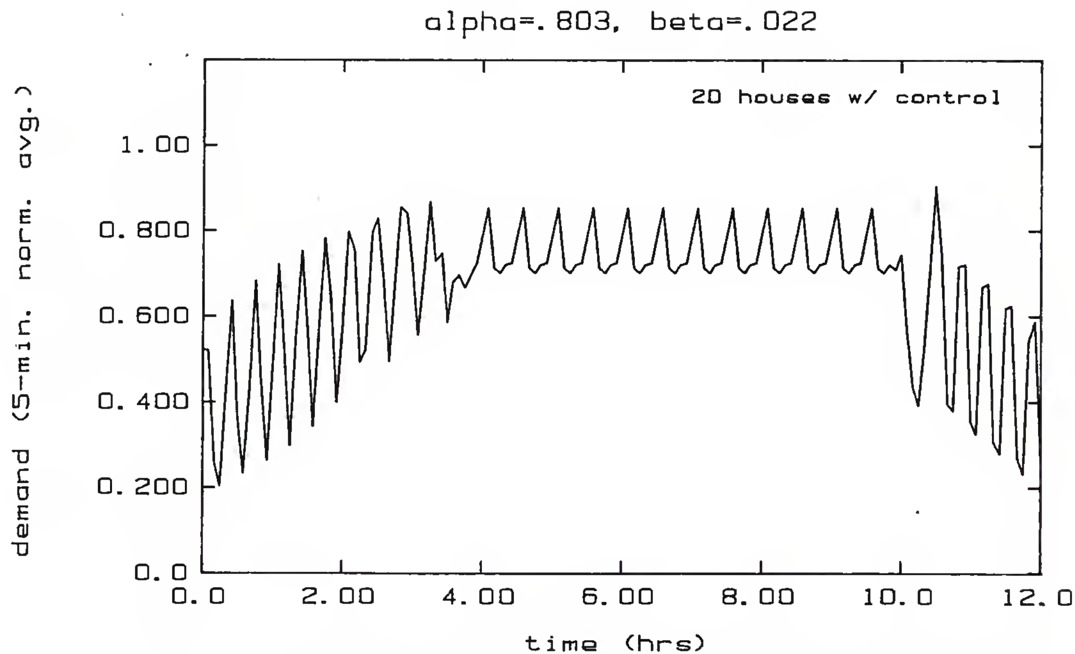

Fig. 33: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

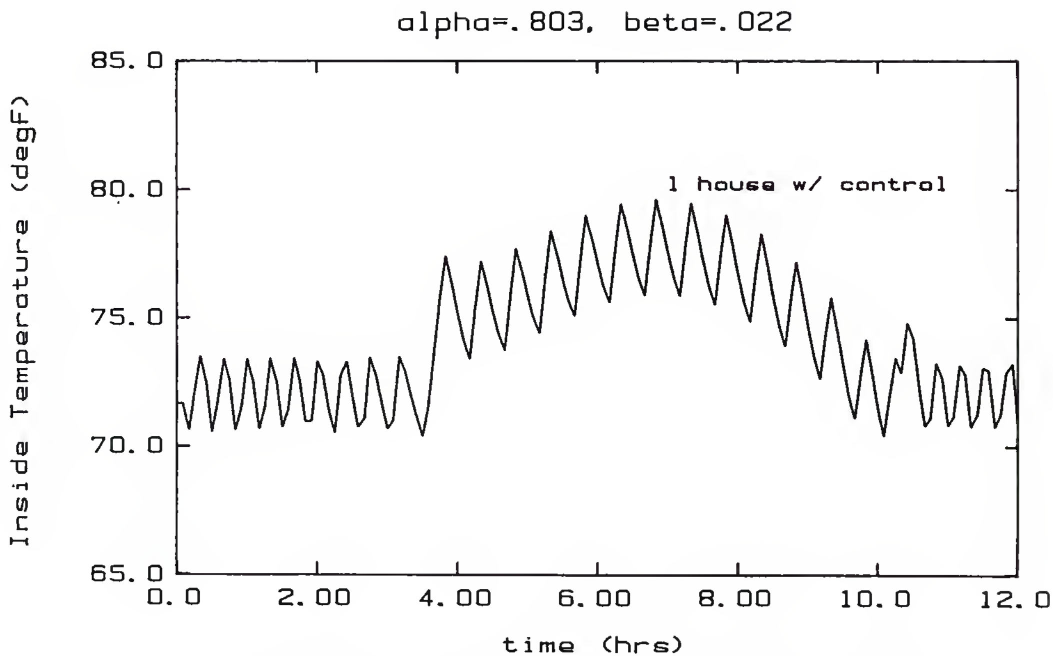

Fig. 34: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

CONCLUSIONS

In the last 20 years, it has become clear that peak electricity demands cannot be allowed to rise at the current rate. The costs incurred by utilities in building the new generation facilities needed to meet the peak demand are prohibitive. Also, the current peaks, which can be much higher than average daily demand, force utilities to rely on expensive peak generating facilities. These reasons alone make it imperative that utilities and customers look for ways to reduce peak demands.

It is theorized that direct load control can be used to help alleviate the problem of rising peak demand. Some experimental work has been done by utilities and independent researchers alike to determine if this is indeed the case. Most of the work done has taken the form of field experiments. So far, very little in the way of conclusive results have been produced. Some work has shown control to be beneficial while other work has not.

This research centered on computer modelling and simulating direct load control experiments on residential customers. The loads of interest were the air-conditioners (a/c's) used by residential customers. Load control was performed in two different ways:

1. Centralized control where the loads are controlled from one central location. The control schemes and

times are identical for each house.

2. Load leveller control where a device is installed at each house to determine exactly when control takes place for that particular house.

Details of the development and utilization of the model have been presented in this report. The remainder of this section will present the major findings of the research as well as some suggestions for further work.

Major Findings

1. Load control will only be effective if the maximum forced duty cycle during control is less than the natural duty cycle if the a/c is uncontrolled. In fact, if this is not the case, it is possible that load control will have adverse effects. Some cases were found where controlling produced a net increase in demand compared to the uncontrolled case.

2. Demand reductions are always accompanied by a rise in the inside temperature of the house. Demand reductions are achieved only by forcing the a/c to be off when the thermostat calls for cooling. This forces the inside temperature to rise above the temperature desired by the thermostat.

3. Load leveler control was observed to have some advantages over centralized control.

a. The load leveler proved to be more effective in limiting after-control peaks in demand. In some cases, centralized control can produce an after-control peak which is larger than the daily peak would have been had control not been used. This was due to the nature of the control period lengths for the two types of control. Actually, a different specification of control period for centralized control could produce similar results. However, the load leveler does this automatically.

b. The load leveler preserves the natural diversity (perhaps even enhances it) of the houses. Centralized control was observed to produce a synchronicity among the houses. This would place undue stress on utility equipment, reducing useful life. The control strategy of centralized control could be altered to eliminate the sychronicity. However, the load leveler does this automatically as a result of the nature of the device.

4. The temperature and demand effects of the two types of control proved to be very similar.

<u>Suggestions for Further Research</u>

From this research, it seems pertinent that some further investigation of load leveler control be undertaken. It would be very interesting to determine how this type of control fares in actual field tests. Load leveler control could then be compared with centralized control in terms of field experiment results.

It is hypothesized that load leveler control should be less expensive to implement than centralized control. Detailed studies of this hypothesis need to be undertaken.

There were some interesting effects that showed up in simulating load control experiments. The cases where load control actually produced a net gain in demand could be investigated further. It is hypothesized that some sort of resonance phenomenon could be present. This could be between the natural heating and cooling times and control strategy at particular driving temperatures. It is quite possible that such a situation exists for each class of house examined in this research. It could be interesting and useful to know what is the cause of this phenomenon.

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APPENDIX A

DATA TABLES FOR CASES 1-3 FOR 30 HOUR SIMULATION WITH SAMPLE SIZES FROM 1-100 HOUSES USING CONSTANT DRIVING TEMPERATURE

DATA FOR CASE 1:

TABLE C-1: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	22.8%	5.4%
2	22.8%	5.3%
3	22.7%	5.7%
4	22.8%	5.8%
5	22.4%	5.8%
6	22.4%	6.0%
7	22.8%	5.3%
8	22.8%	5.8%
9	22.8%	5.8%
10	22.6%	5.4%

Sample Size: 1 house

Table C-2: Average Demand Reduction and Standard Deviation for a 30 Hour Period

Trial	Avg. Dem. Red.	Stan. Dev.
1	22.7%	3.7%
2	22.6%	5.0%
3	22.6%	4.2%
4	22.7%	3.4%
5	22.6%	3.9%
6	22.6%	2.9%
7	22.7%	4.4%
8	22.7%	3.2%
9	22.6%	4.2%
10	22.7%	4.8%

Sample Size: 11 houses

Table C-3: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	22.6%	4.2%
2	22.6%	4.2%
3	22.7%	3.9%
4	22.6%	3.7%
5	22.7%	3.5%

Sample Size: 50 houses

Table C-4: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	22.6%	3.9%
2	22.6%	4.2%
3	22.6%	4.1%
4	22.7%	4.0%
5	22.7%	3.8%

Sample Size: 100 houses

DATA FOR CASE 2:

Table C-5: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	2.8%	0.0%
2	2.8%	0.0%
3	2.7%	0.1%
4	2.7%	0.1%
5	2.9%	0.9%
6	3.0%	1.0%
7	2.9%	0.5%
8	2.7%	0.1%
9	2.8%	0.4%
10	2.8%	0.2%

Sample Size: 1 house

Table C-6: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	2.8%	0.4%
2	2.8%	0.4%
3	2.8%	0.3%
4	2.8%	0.4%
5	2.8%	0.3%
6	2.9%	0.6%
7	2.8%	0.3%
8	2.8%	0.3%
9	2.8%	0.3%
10	2.8%	0.5%

Sample Size: 10 houses

Table C-7: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	2.8%	0.4%
2	2.8%	0.4%
3	2.8%	0.4%
4	2.8%	0.5%
5	2.8%	0.5%

Sample Size: 50 houses

Table C-8: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	2.8%	0.4%
2	2.8%	0.4%
3	2.8%	0.4%
4	2.8%	0.4%
5	2.8%	0.4%

Sample Size: 100 houses

CASE 3 DATA:

Table C-9: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	0.1%	3.4%
2	0.1%	3.3%
3	0.1%	4.1%
4	0.1%	3.7%
5	0.1%	3.1%
6	0.1%	3.3%
7	0.1%	3.5%
8	0.1%	3.9%
9	0.1%	3.3%
10	0.0%	2.7%

Sample Size: 1 house

Table C-10: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	0.1%	1.4%
2	0.1%	1.3%
3	0.1%	0.9%
4	0.1%	0.8%
5	0.1%	0.8%
6	0.1%	1.4%
7	0.1%	2.3%
8	0.1%	0.9%
9	0.1%	0.8%
10	0.1%	1.7%

Sample Size: 11 houses

Table C-11: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	0.1%	0.7%
2	0.1%	0.9%
3	0.1%	1.1%
4	0.1%	0.7%
5	0.1%	1.0%

Sample Size: 50 houses

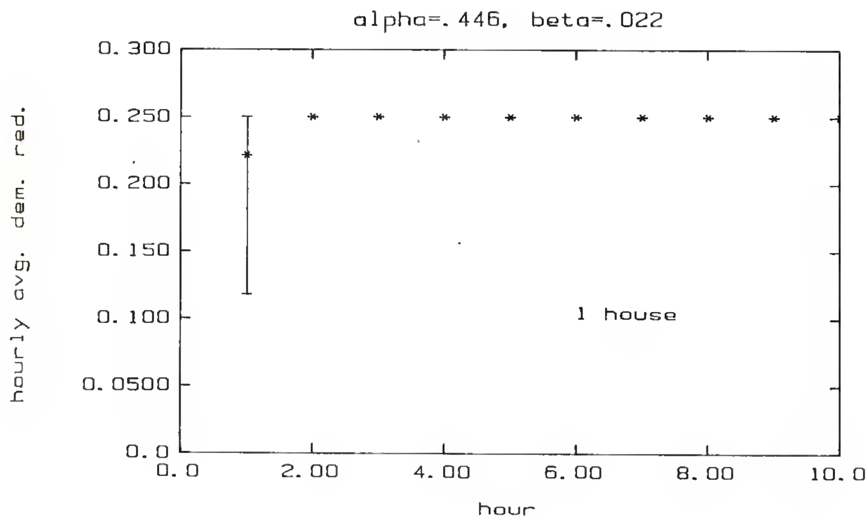
Table C-12: Average Demand Reduction and Standard Deviation for a 30 Hour Period.

Trial	Avg. Dem. Red.	Stan. Dev.
1	0.1%	0.5%
2	0.1%	0.5%
3	0.1%	0.6%
4	0.1%	0.8%
5	0.1%	1.0%

Sample Size: 100 houses

APPENDIX B

PLOTS OF HOURLY AVERAGE DEMAND REDUCTION UPON CONTROL (IN PERCENT) FOR EACH OF 10 HOURS FOR CASES 1-3. SAMPLE SIZES VARY FROM 1-100 HOUSES WITH A CONSTANT DRIVING TEMPERATURE OF 90 F. PLOTS SHOW AVERAGE HOURLY DEMAND REDUCTION PLUS OR MINUS TWO STANDARD DEVIATIONS



DIST. OF NORM. HOURLY DEMAND REDUCTION

Fig. B-1: Hourly Average Demand Reduction Upon Control (in Percent) for Each of 10 Hours for a Case 1 House With a Constant Driving Temperature of 90 F.

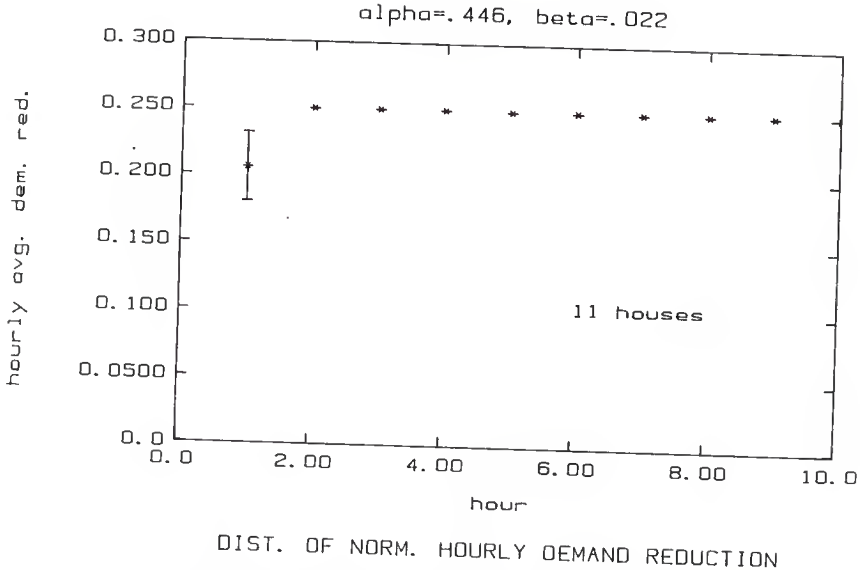


Fig. B-2: Hourly Average Demand Reduction Upon Control (in Percent) for 11 Case 1 Houses With a Constant Driving Temperature of 90 F.

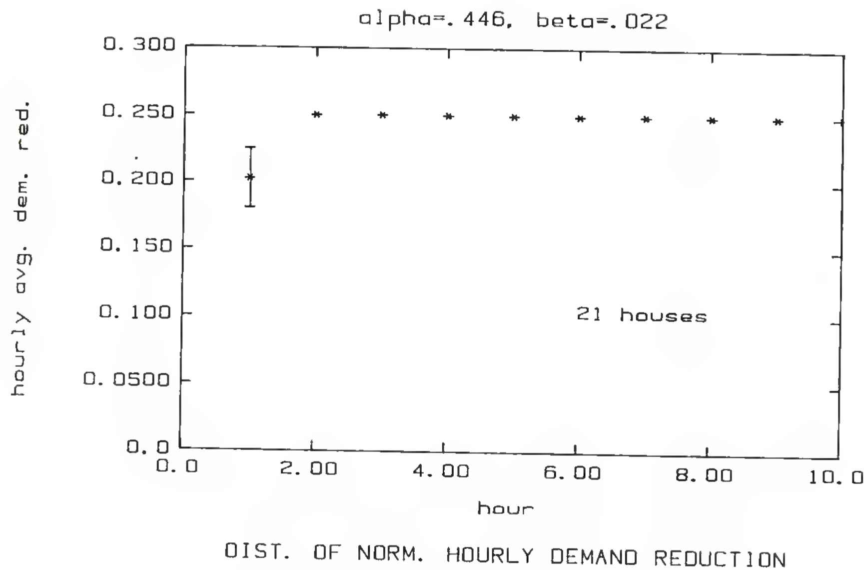


Fig. B-3: Hourly Average Demand Reduction Upon Control (in Percent) for 21 Case 1 Houses With a Constant Driving Temperature of 90 F.

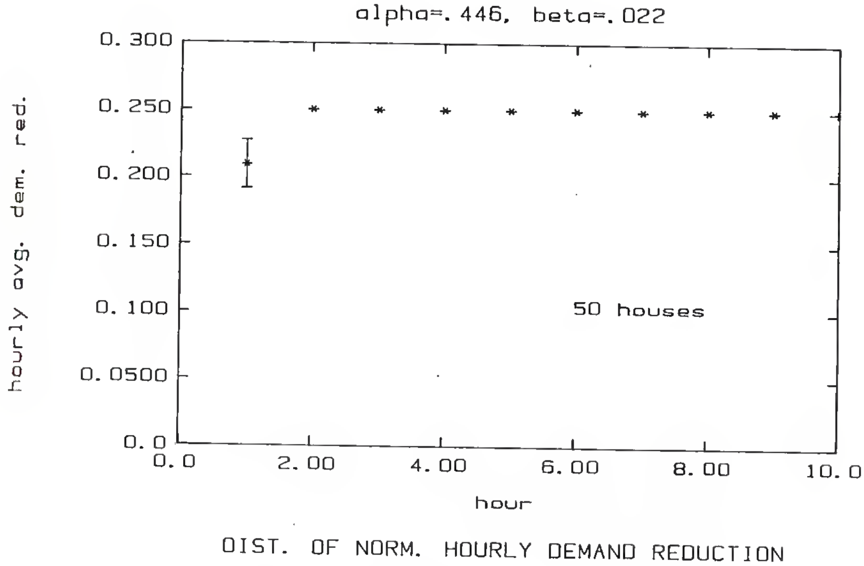


Fig. B-4: Hourly Average Demand Reduction Upon Control (in Percent) for 50 Case 1 Houses With a Constant Driving Temperature of 90 F.

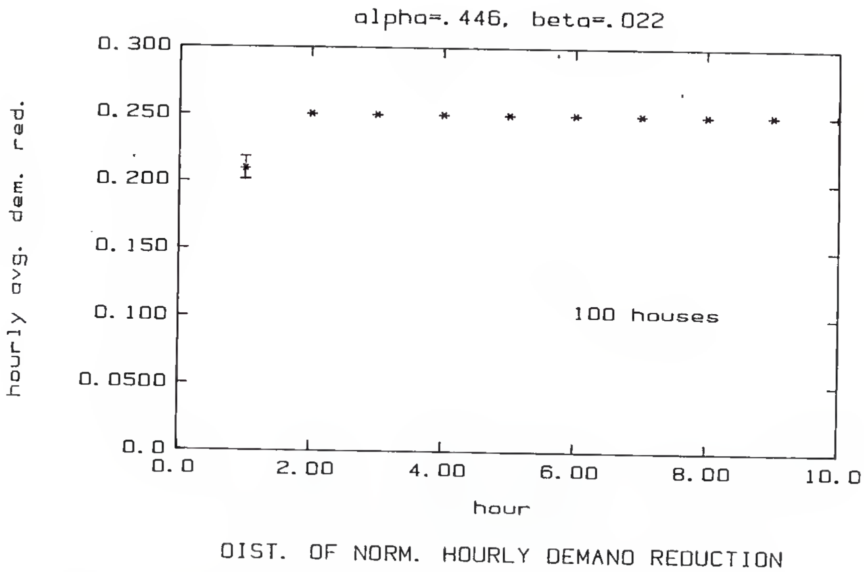


Fig. B-5: Hourly Average Demand Reduction Upon Control (in Percent) for 100 Case 1 Houses With a Constant Driving Temperature of 90 F.

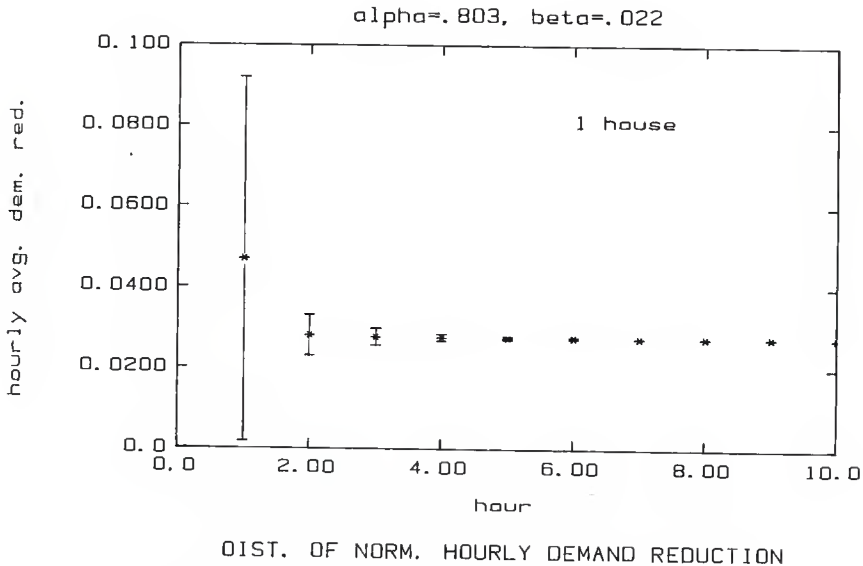


Fig. B-6: Hourly Average Demand Reduction Upon Control (in Percent) for Each of 10 Hours for a Case 2 House With a Constant Driving Temperature of 90 F.

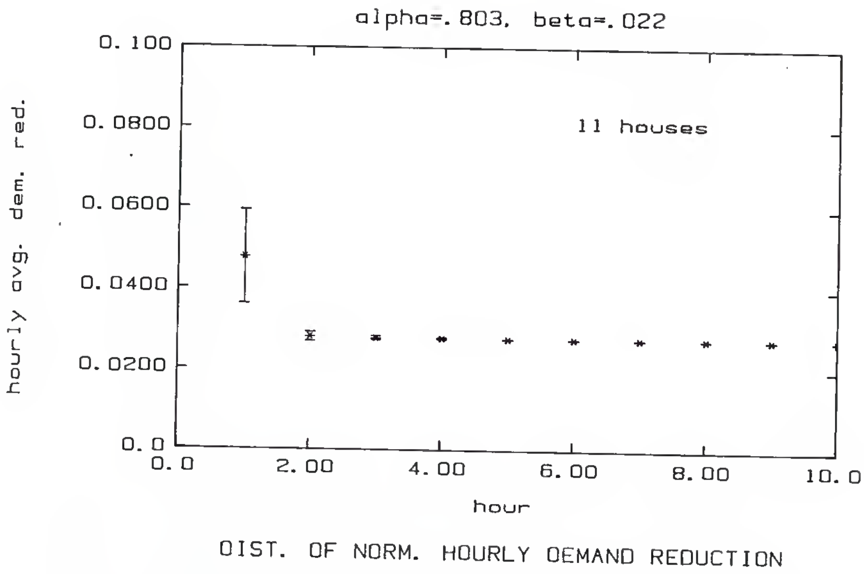


Fig. B-7: Hourly Average Demand Reduction Upon Control (in Percent) for 11 Case 2 Houses With a Constant Driving Temperature of 90 F.

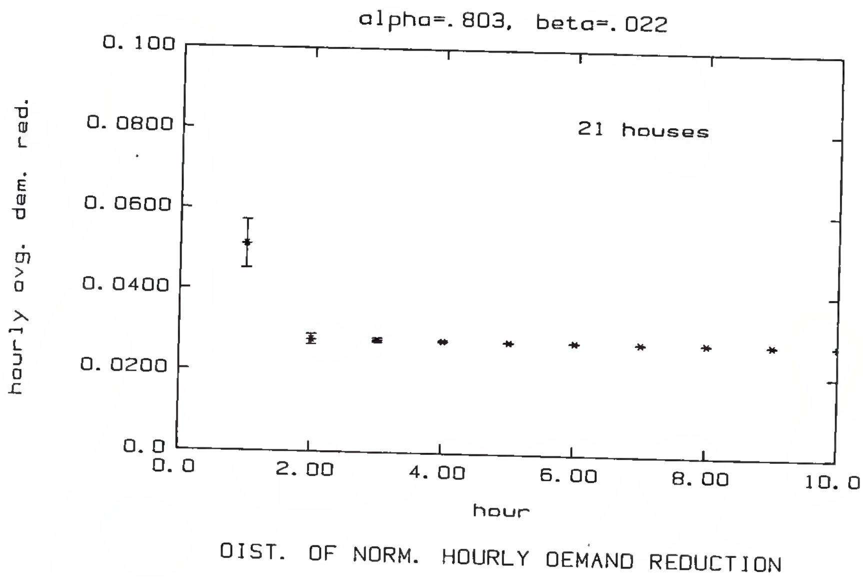
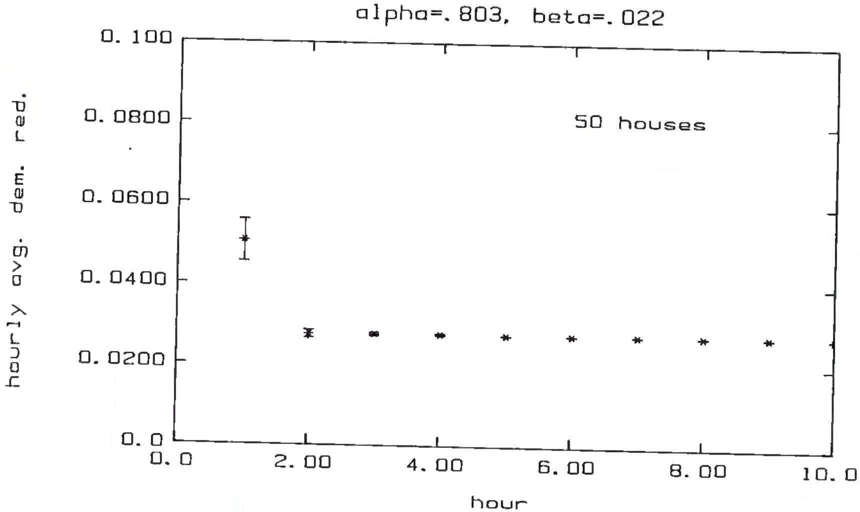


Fig. B-8: Hourly Average Demand Reduction Upon Control (in Percent) for 21 Case 2 Houses With a Constant Driving Temperature of 90 F.



DIST. OF NORM. HOURLY DEMAND REDUCTION

Fig. B-9: Hourly Average Demand Reduction Upon Control (in Percent) for 50 Case 2 Houses With a Constant Driving Temperature of 90 F.

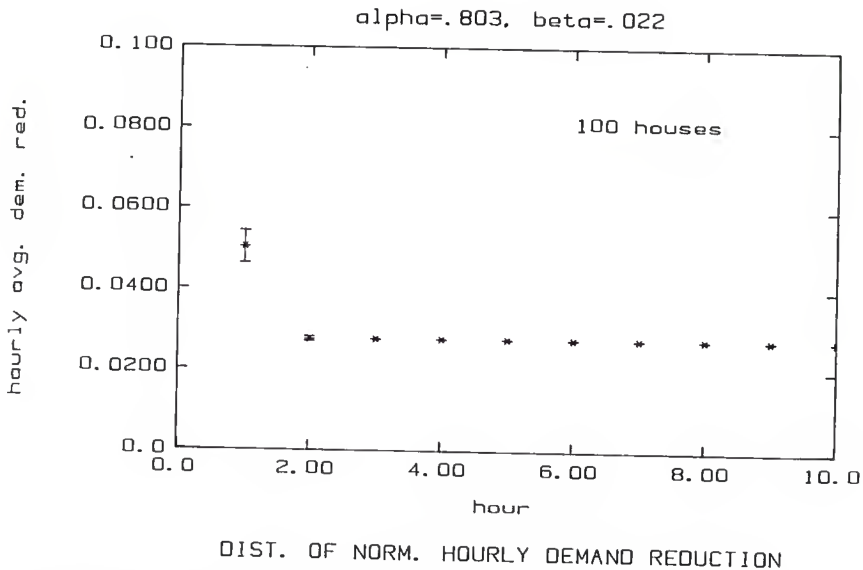


Fig. B-10: Hourly Average Demand Reduction Upon Control (in Percent) for 100 Case 2 Houses With a Constant Driving Temperature of 90 F.

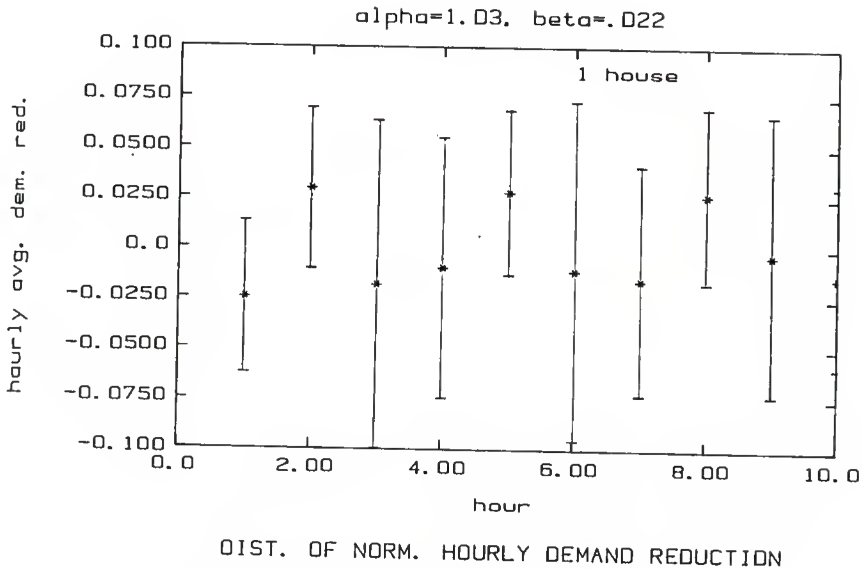


Fig. B-11: Hourly Average Demand Reduction Upon Control (in Percent) for Each of 10 Hours for a Case 3 House With a Constant Driving Temperature of 90 F.

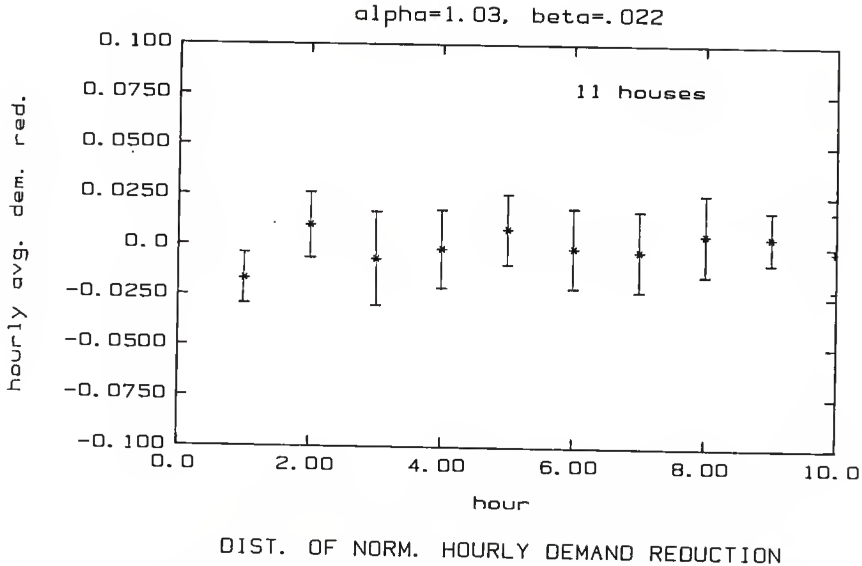
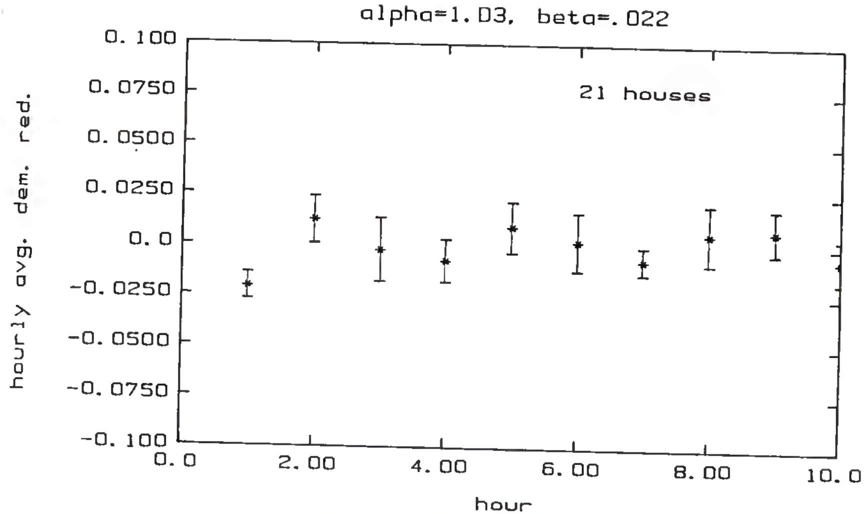


Fig. B-12: Hourly Average Demand Reduction Upon Control (in Percent) for 11 Case 3 Houses With a Constant Driving Temperature of 90 F.



DIST. OF NORM. HOURLY DEMAND REDUCTION

Fig. B-13: Hourly Average Demand Reduction Upon Control (in Percent) for 21 Case 3 Houses With a Constant Driving Temperature of 90 F.

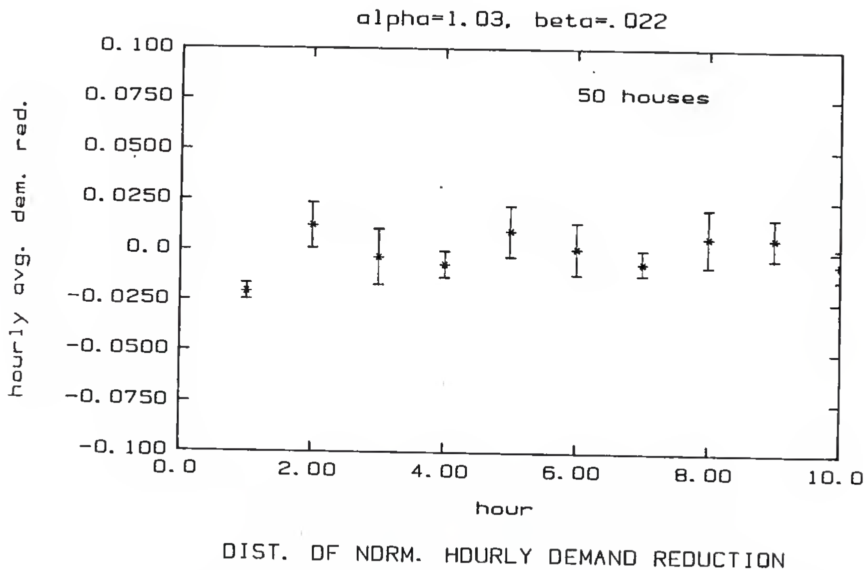


Fig. B-14: Hourly Average Demand Reduction Upon Control (in Percent) for 50 Case 3 Houses With a Constant Driving Temperature of 90 F.

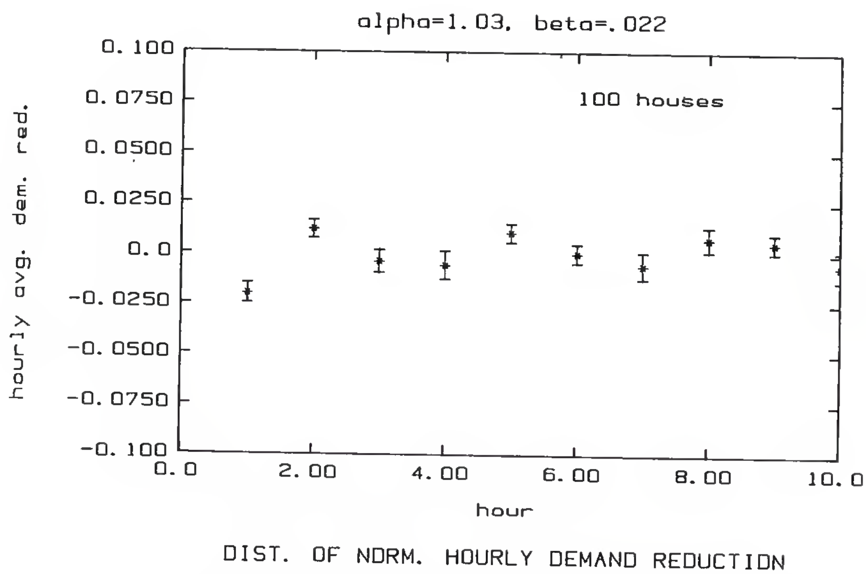


Fig. B-15: Hourly Average Demand Reduction Upon Control (in Percent) for 100 Case 3 Houses With a Constant Driving Temperature of 90 F.

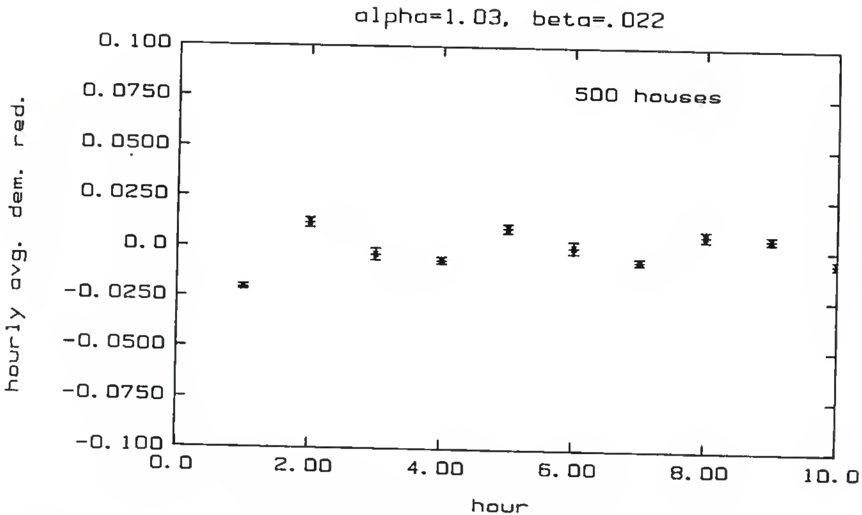


Fig. B-16: Hourly Average Demand Reduction Upon Control (in Percent) for 500 Case 3 Houses With a Constant Driving Temperature of 90 F.

APPENDIX C

PLOTS OF ONE-HOUR AVERAGE DEMAND
OVER A 10 HOUR PERIOD WITH AND WITHOUT
CONTROL. CASES 1 AND 3 ARE SHOWN.
THREE DIFFERENT SETS OF STARTING
CONDITIONS ARE USED

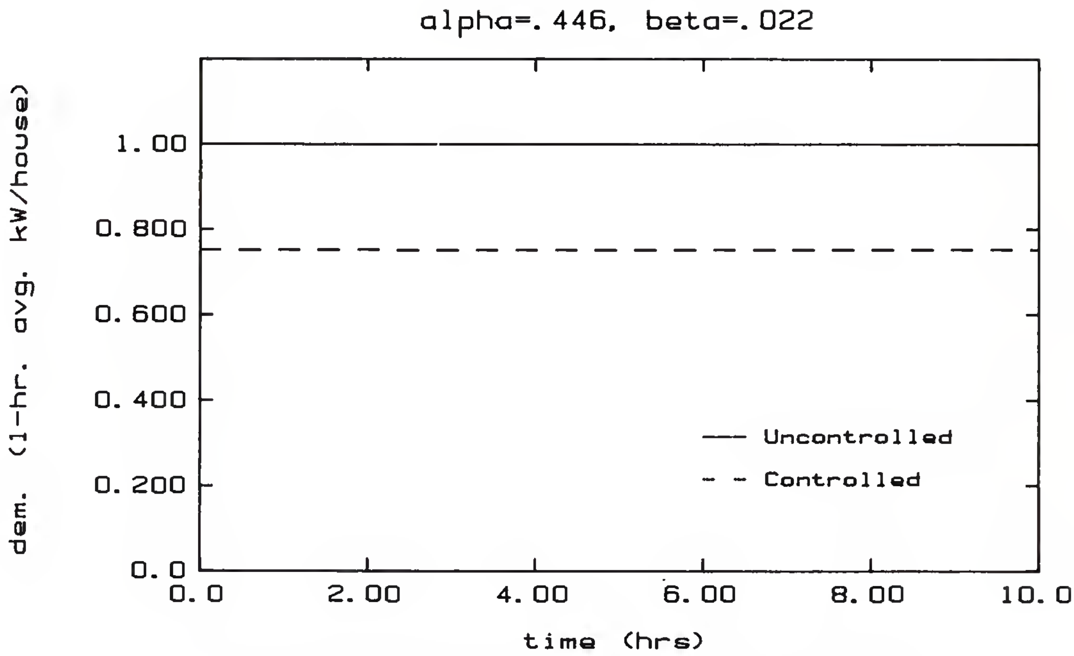


Fig. C-1: One-Hour Average Demand for 20 Case 1 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With All 20 Air-Conditioners Initially On.

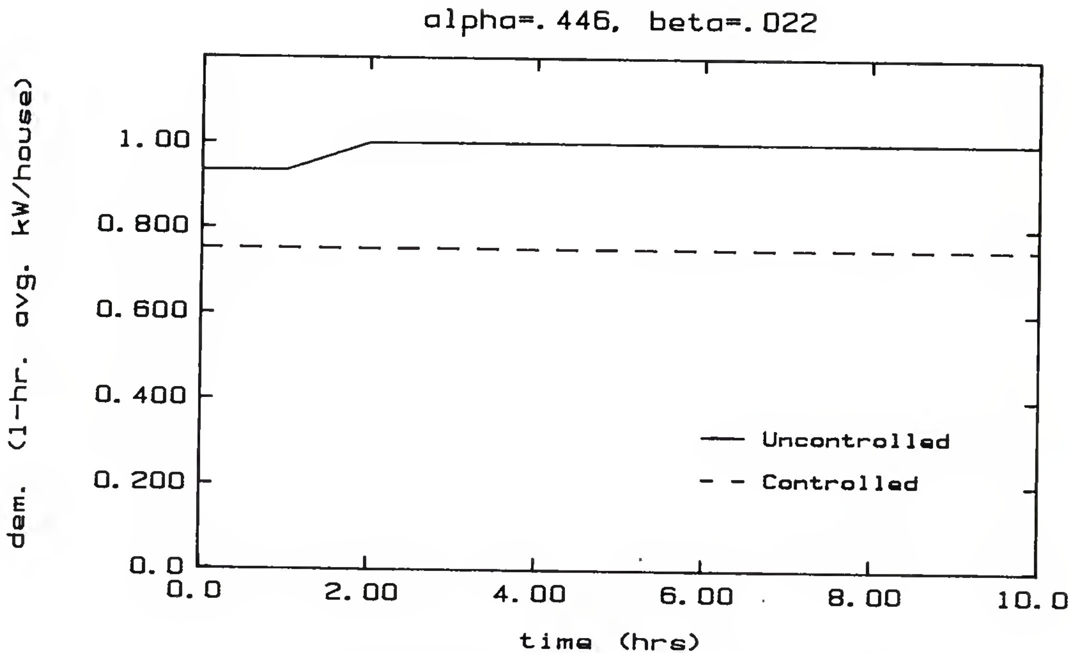


Fig. C-2: One-Hour Average Demand for 20 Case 1 Houses (Normalized to a kW/house Basis) over a 10 Hour Period With All 20 Air-Conditioners Initially Off.

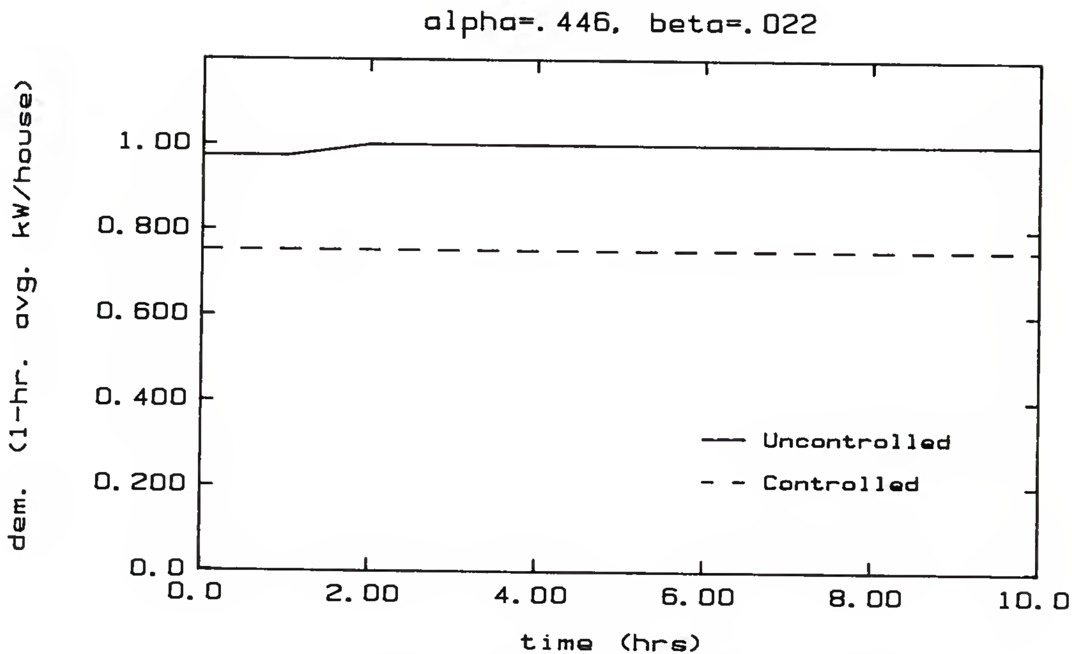


Fig. C-3: One-Hour Average Demand for 20 Case 1 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With the Air-Conditioners Randomly On and Off.

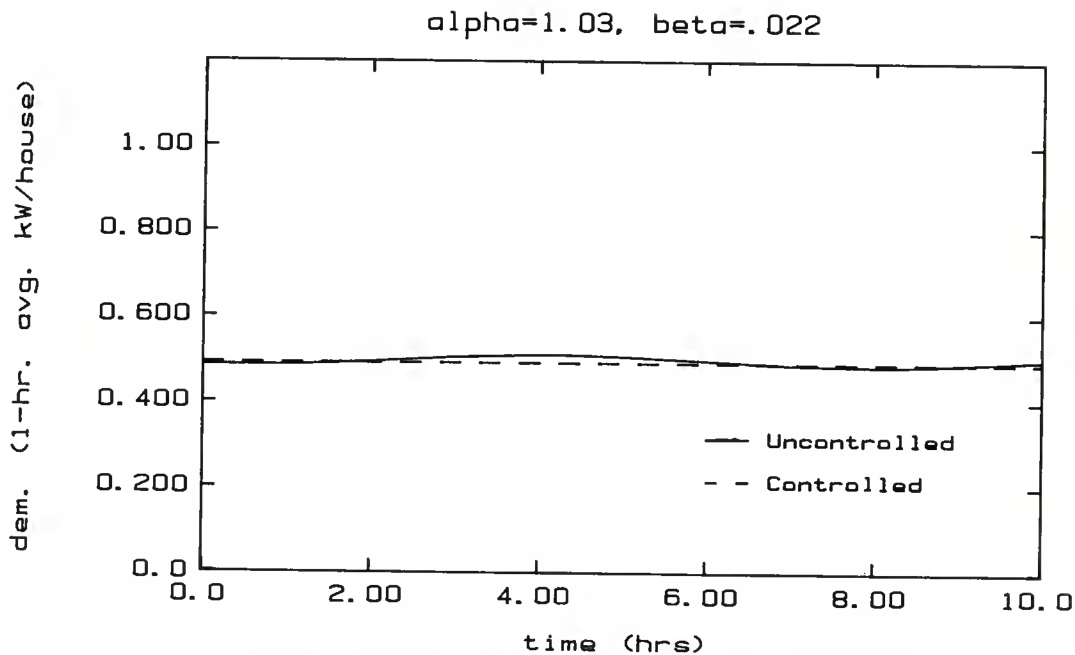


Fig. C-4: One Hour Average Demand for 20 Case 3 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With All 20 Air-Conditioners Initially On.

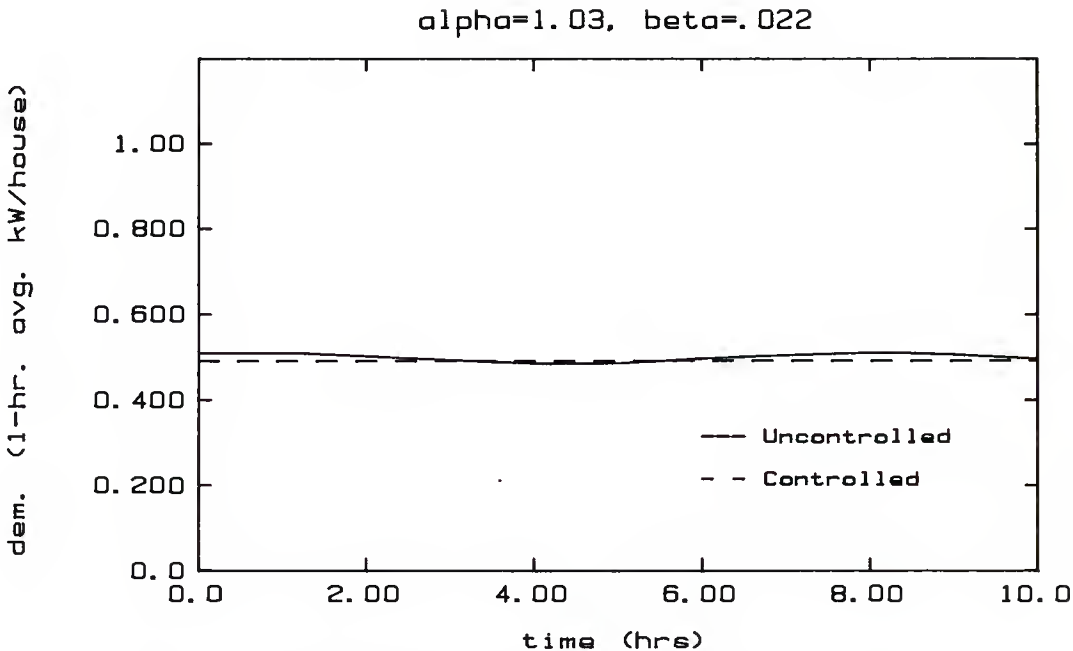


Fig. C-5: One-Hour Average Demand for 20 Case 3 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With All 20 Air-Conditioners Initially Off.

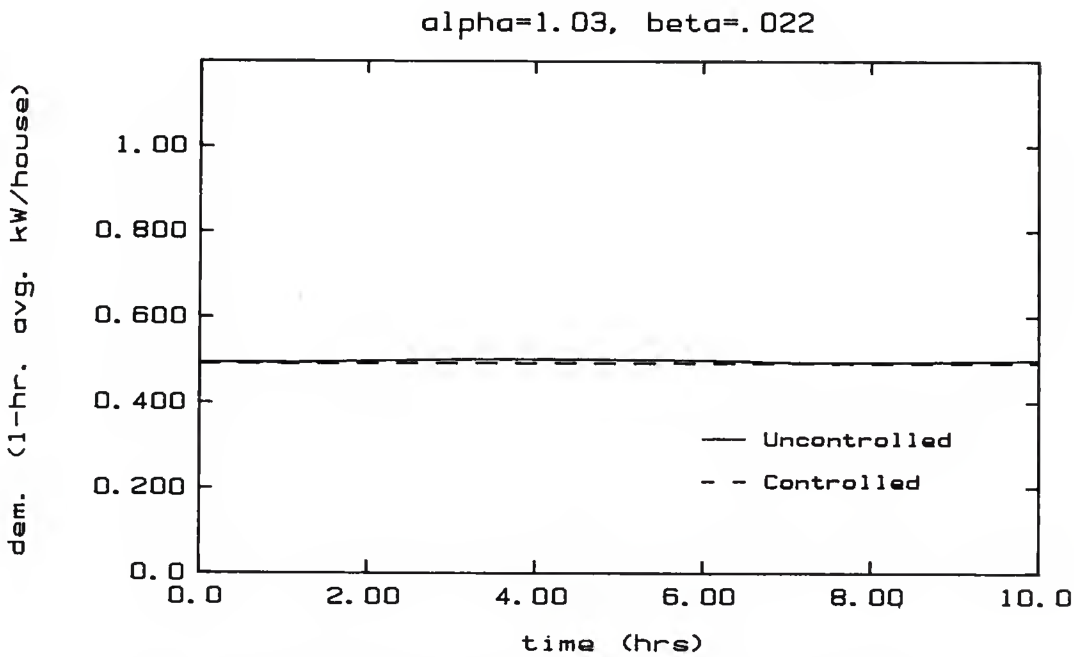


Fig. C-6: One-Hour Average Demand for 20 Case 3 Houses (Normalized to a kW/house Basis) Over a 10 Hour Period With All 20 Air-Conditioners Randomly On and Off.

APPENDIX D

PERCENT DEMAND REDUCTION AND AVERAGE AGGREGATE TEMPERATURE PLUS OR MINUS TWO STANDARD DEVIATIONS AS A FUNCTION OF THE NATURAL DUTY CYCLE OF THE AIR CONDITIONER. METHOD OF CONTROL FOR THESE PLOTS IS CENTRALIZED WITH VARYING STRATEGIES

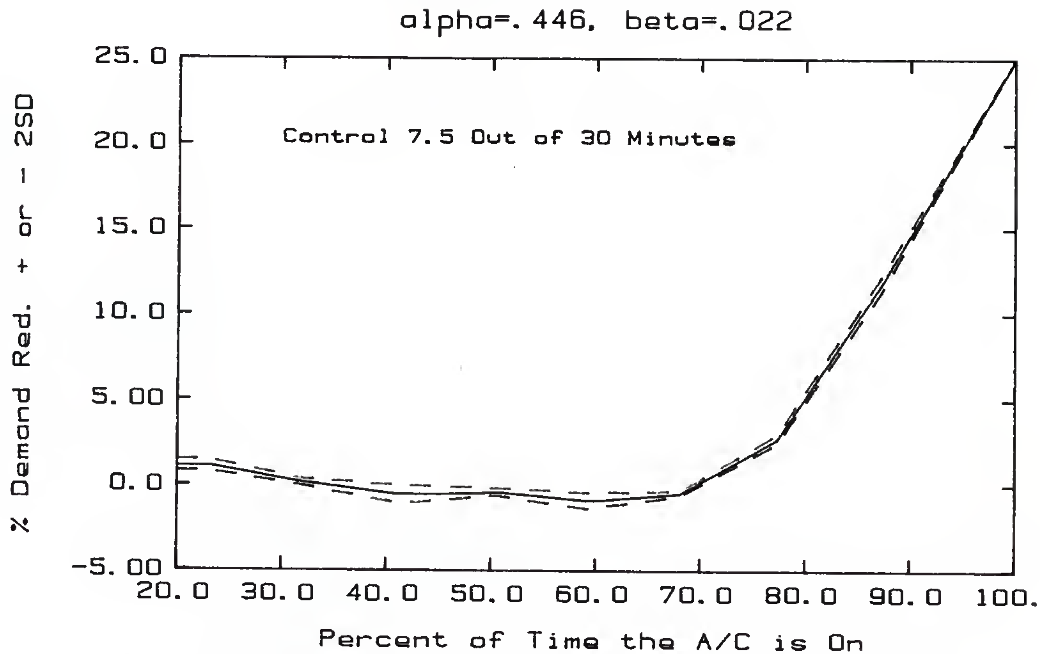


Fig. D-1: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

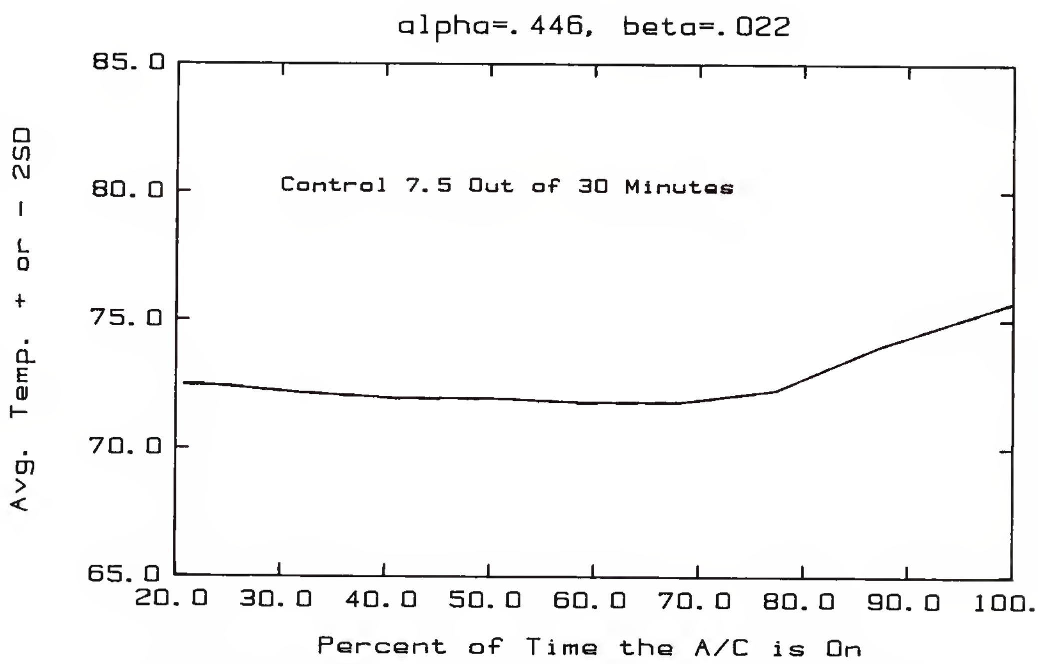


Fig. D-2: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1'Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

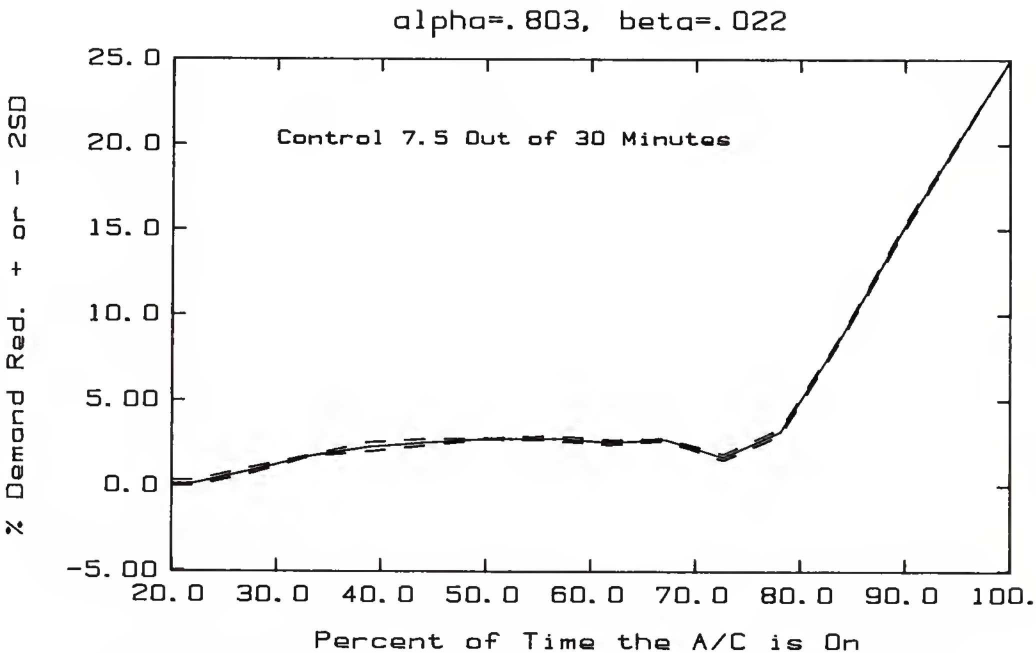


Fig. D-3: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

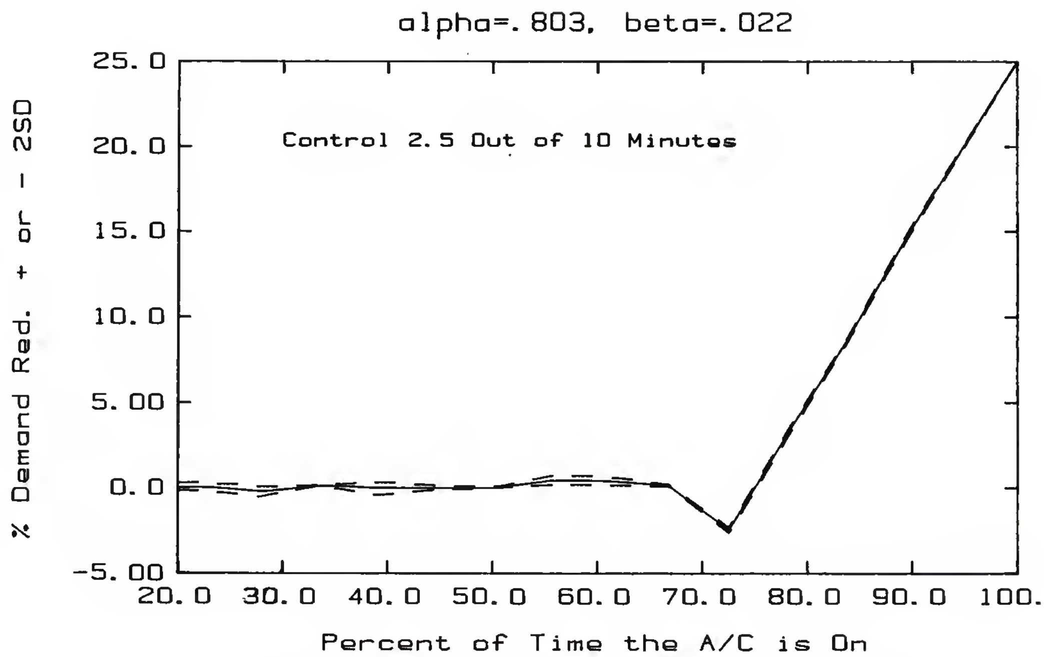


Fig. D-4: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

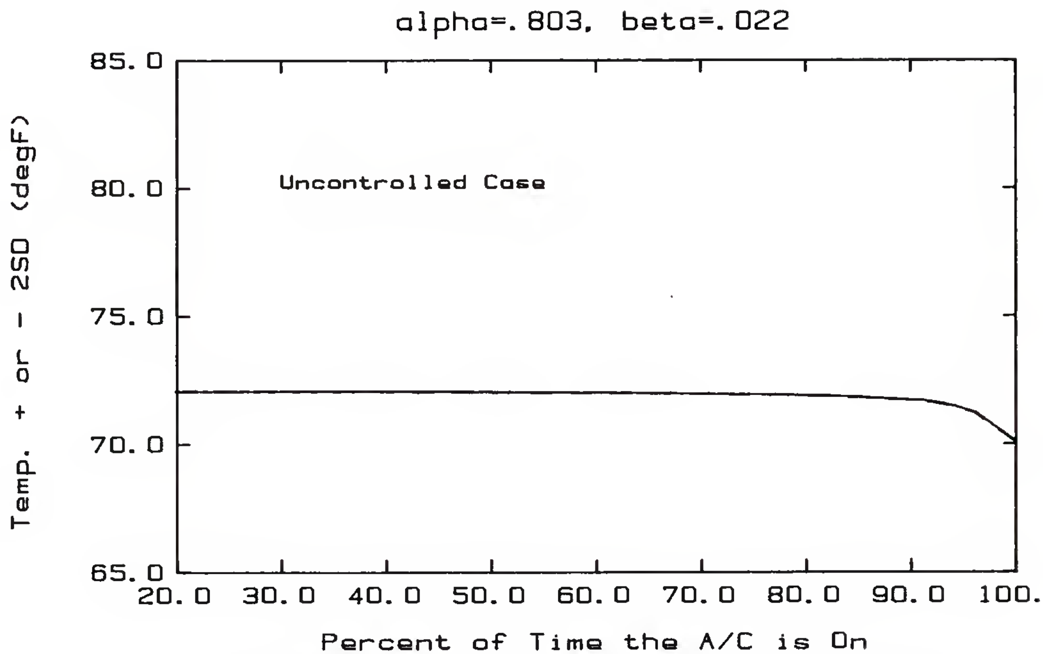


Fig. D-5: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. This Case is Uncontrolled.

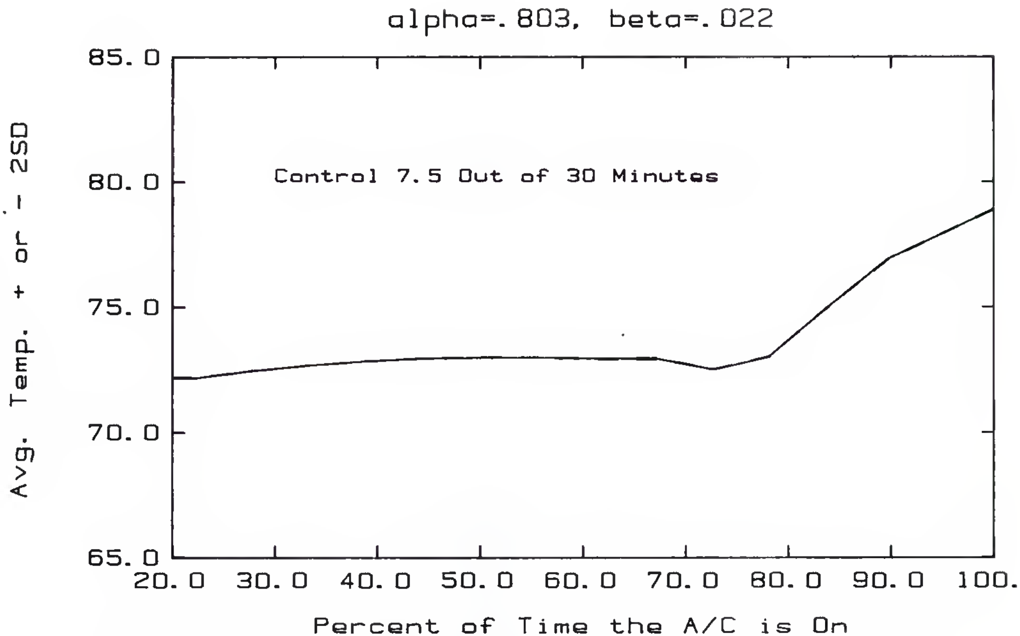


Fig. D-6: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

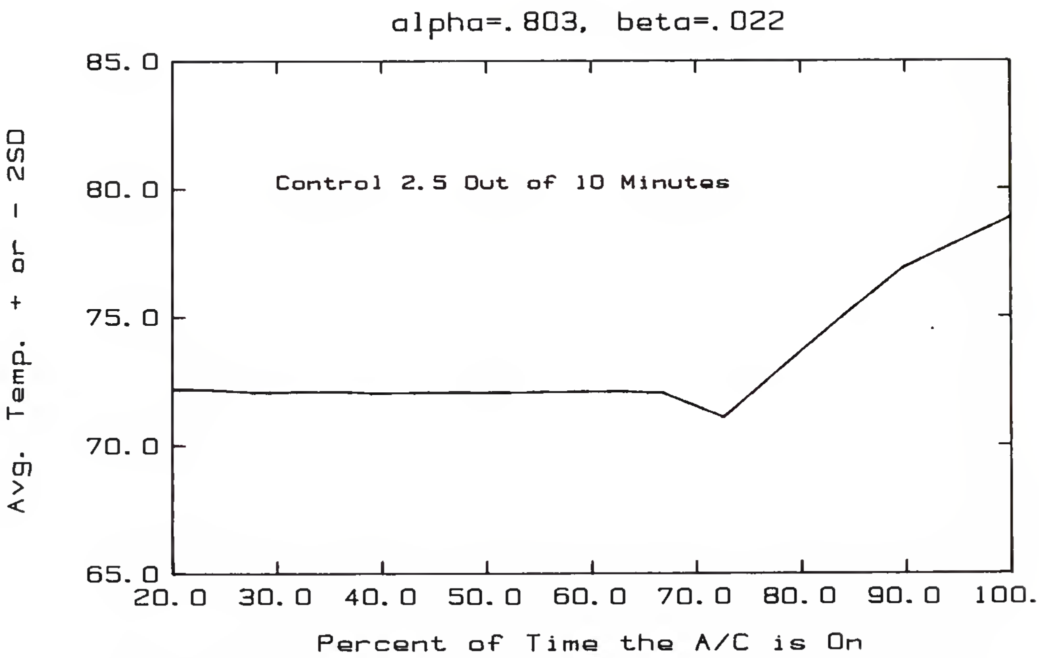


Fig. D-7: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

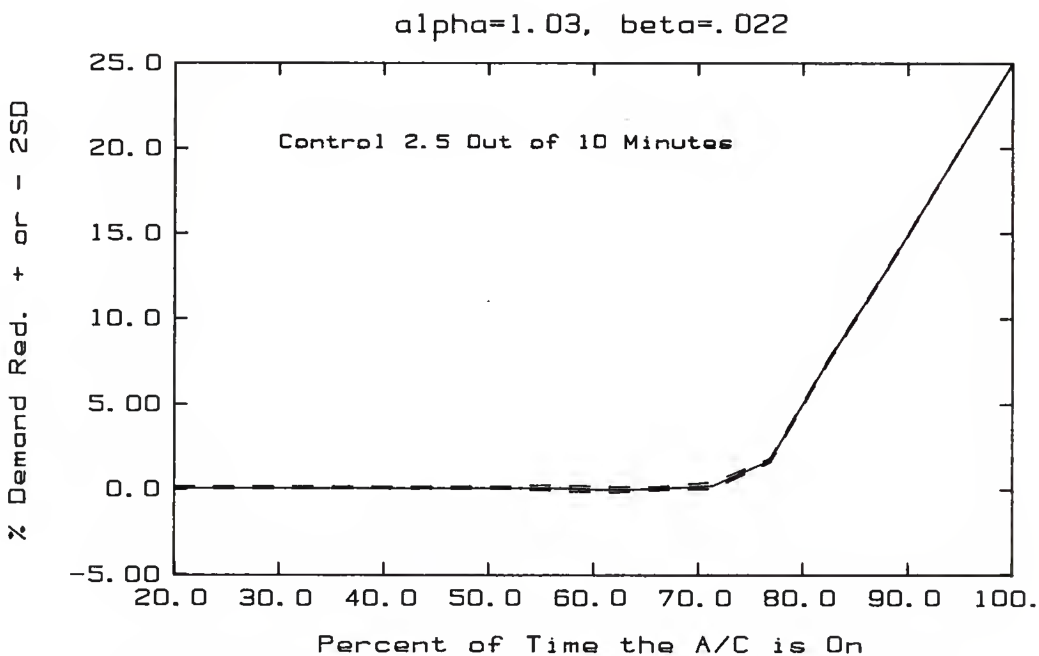


Fig. D-8: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

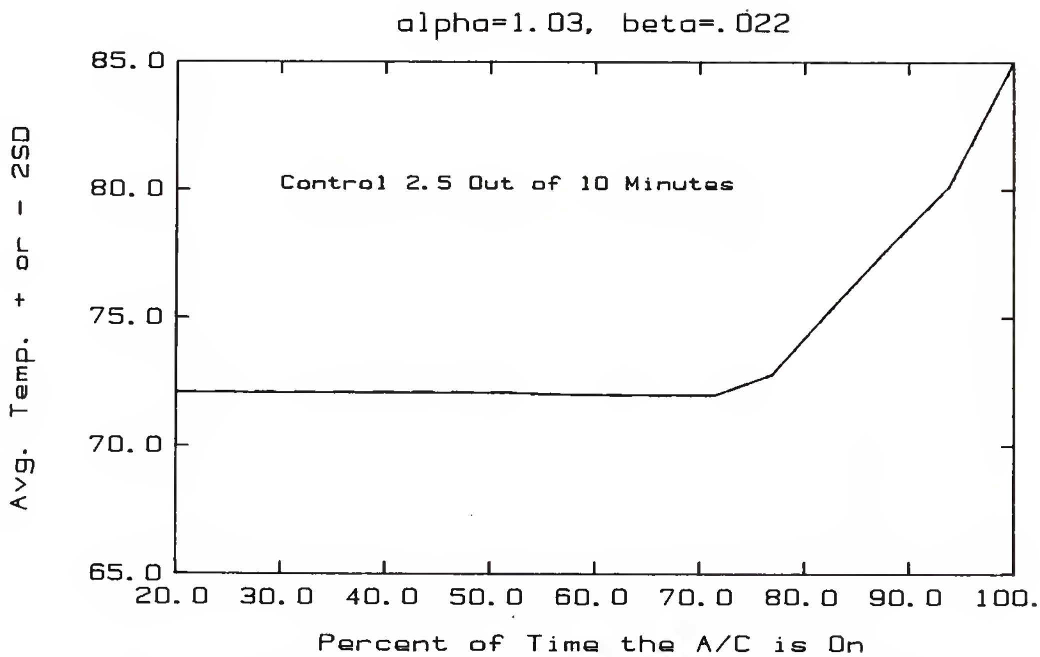


Fig. D-9: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

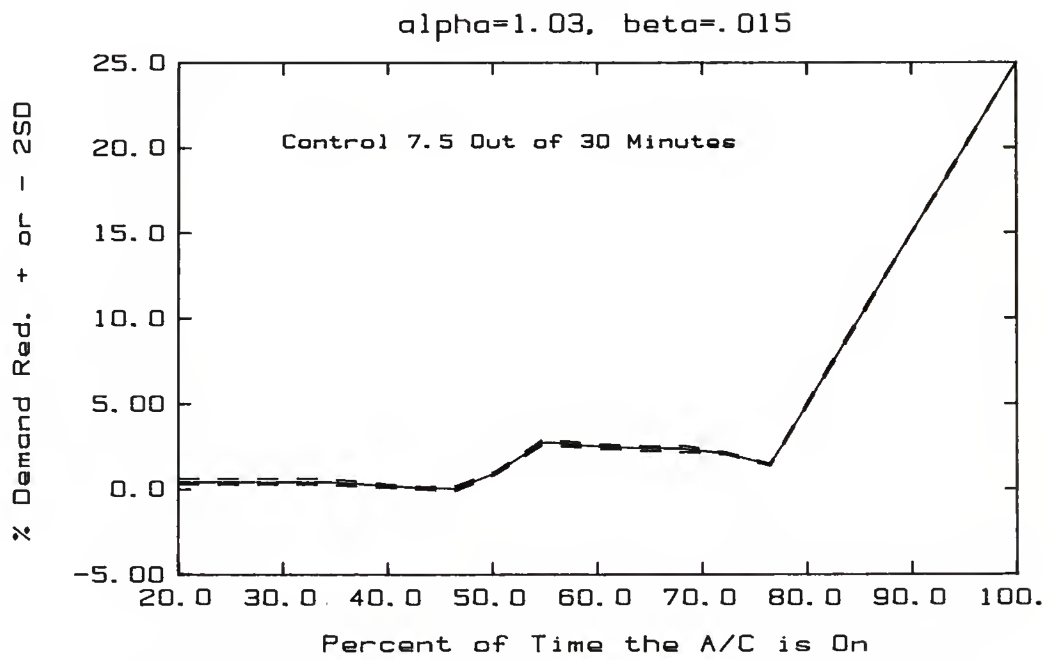


Fig. D-10: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

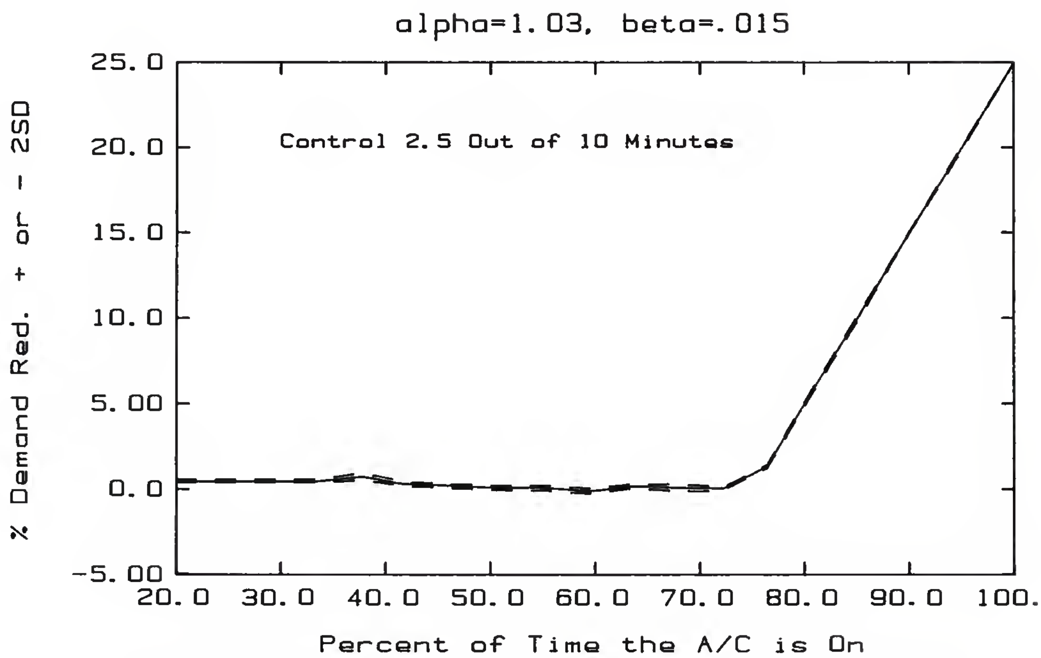


Fig. D-11: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes.

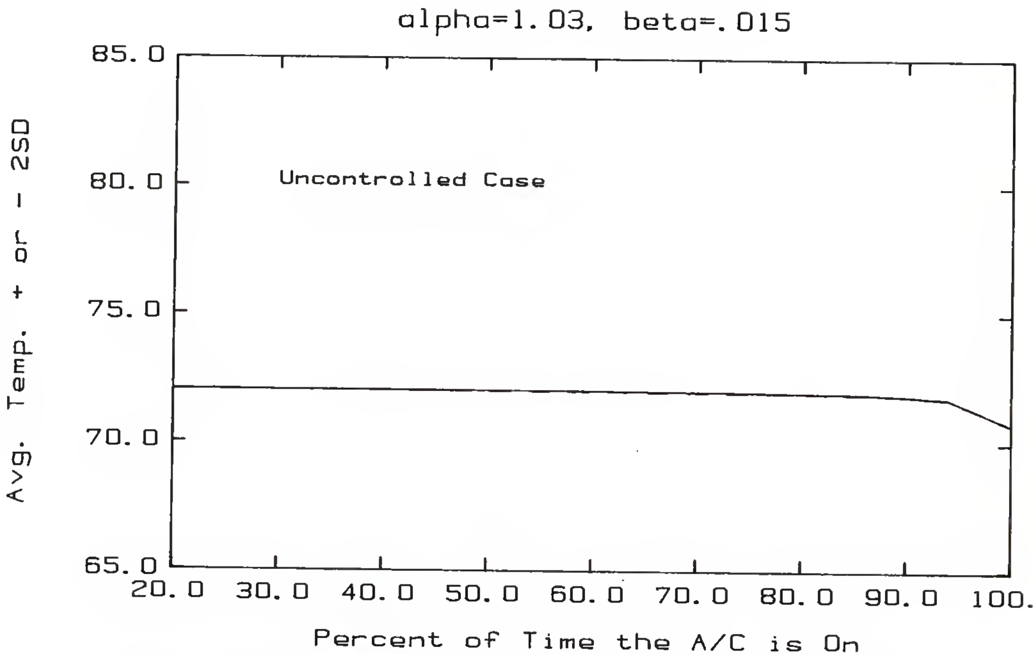


Fig. D-12: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. This Case is Uncontrolled.

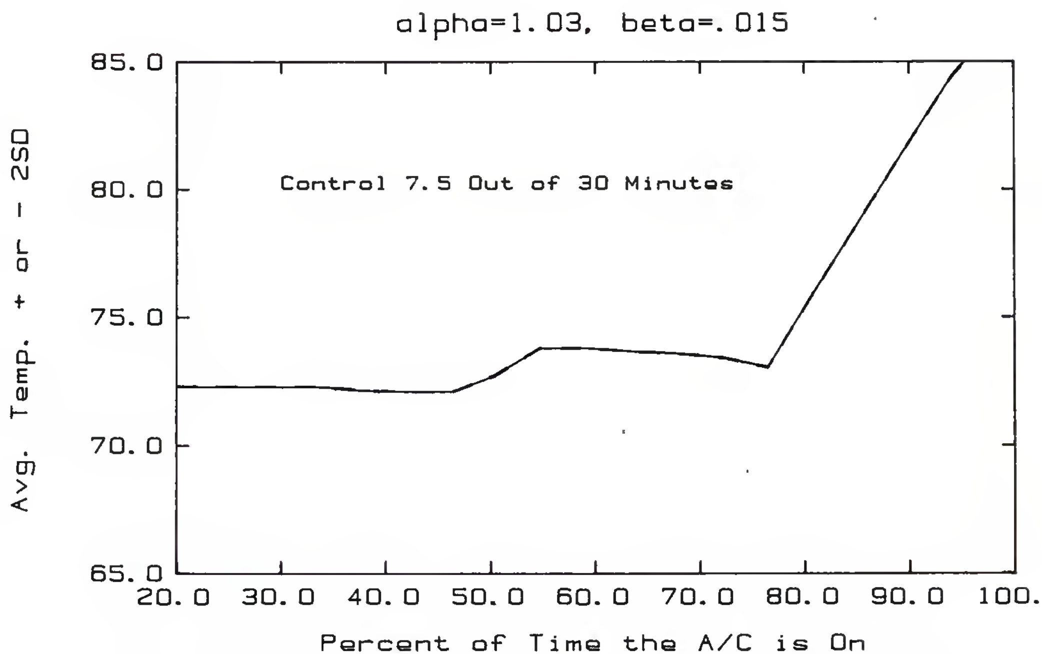


Fig. D-13: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes.

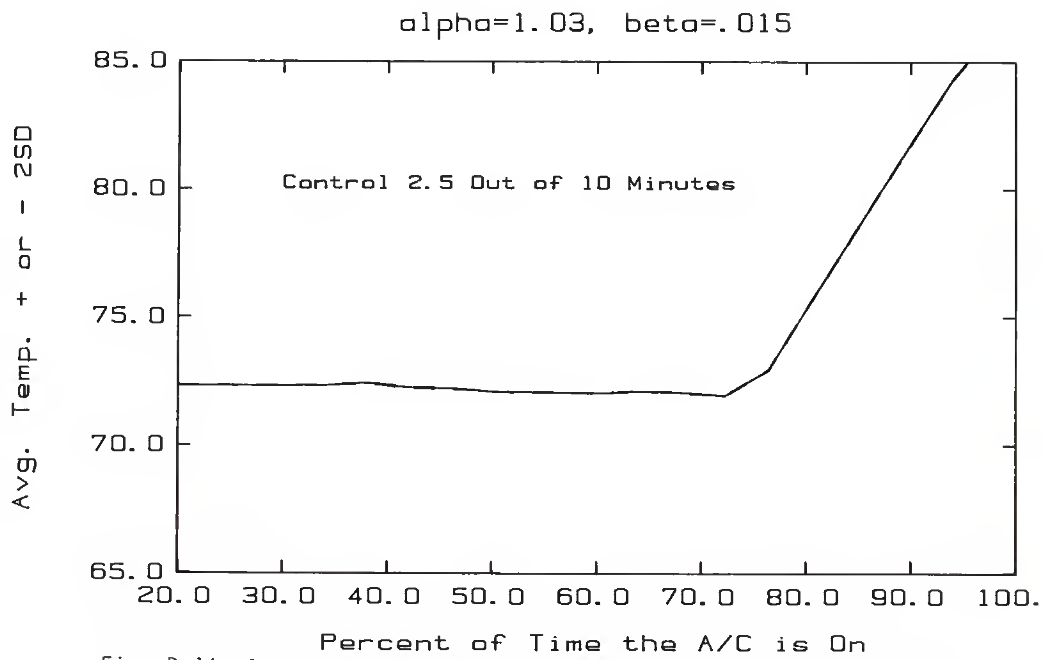


Fig. D-14: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 2.5 Out of Each 10 Minutes.

APPENDIX E

REPLICATIONS OF FIGS. 9 AND 10 WITH MORE DATA POINTS BETWEEN DUTY CYCLES OF 60 AND 80

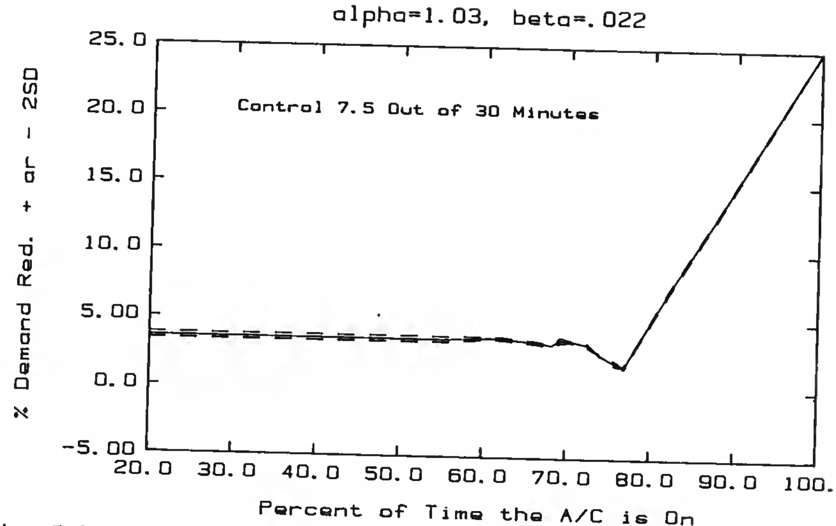
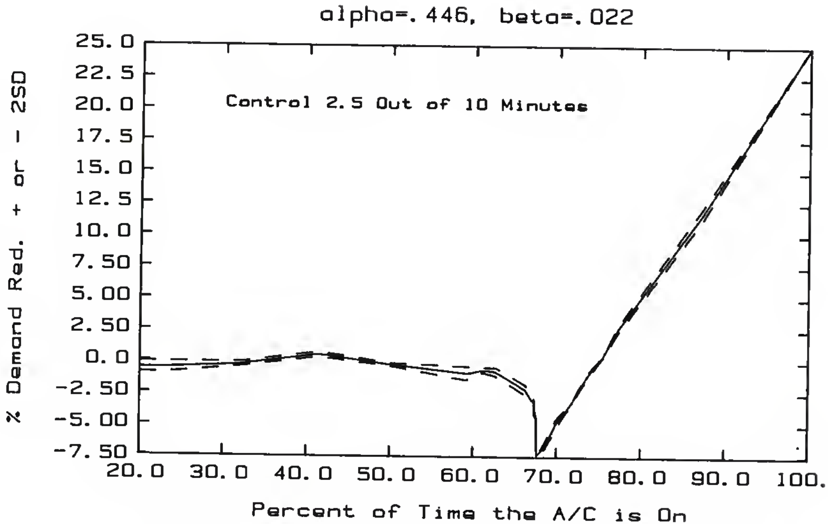


Fig. E-1: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 3 Houses. Control is Centralized and Exercised 7.5 out of Each 30 Minutes. This Plot Includes Extra Points Between Duty Cycles of 60 and 80.



Demand Reduction as a Function of On Time

Fig. E-2: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 1 Houses. Control is Centralized and Exercised 2.5 out of Each 10 Minutes. This Plot Includes Extra Points Between Duty Cycles of 60 and 80.

APPENDIX F

CASE 2 PLOTS OF PERCENT DEMAND REDUCTION AND AVERAGE AGGREGATE TEMPERATURE PLUS OR MINUS TWO STANDARD DEVIATIONS AS A FUNCTION OF THE NATURAL DUTY CYCLE OF THE AIR CONDITIONER. METHOD OF CONTROL IS LOAD LEVELER TYPE.

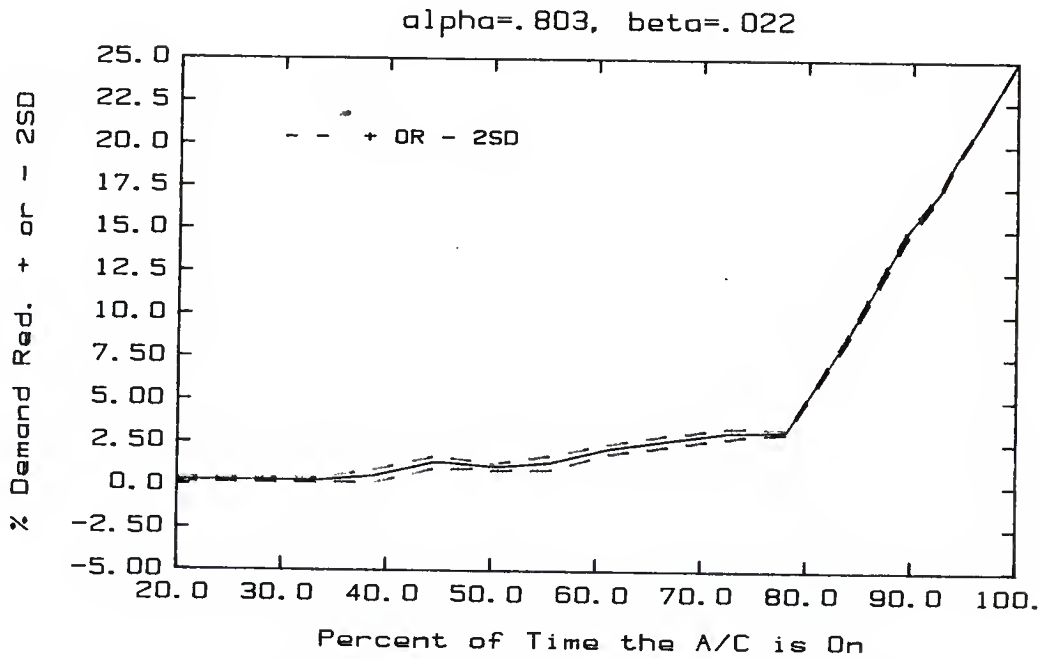


Fig. F-1: Percent Demand Reduction Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Load Leveler type.

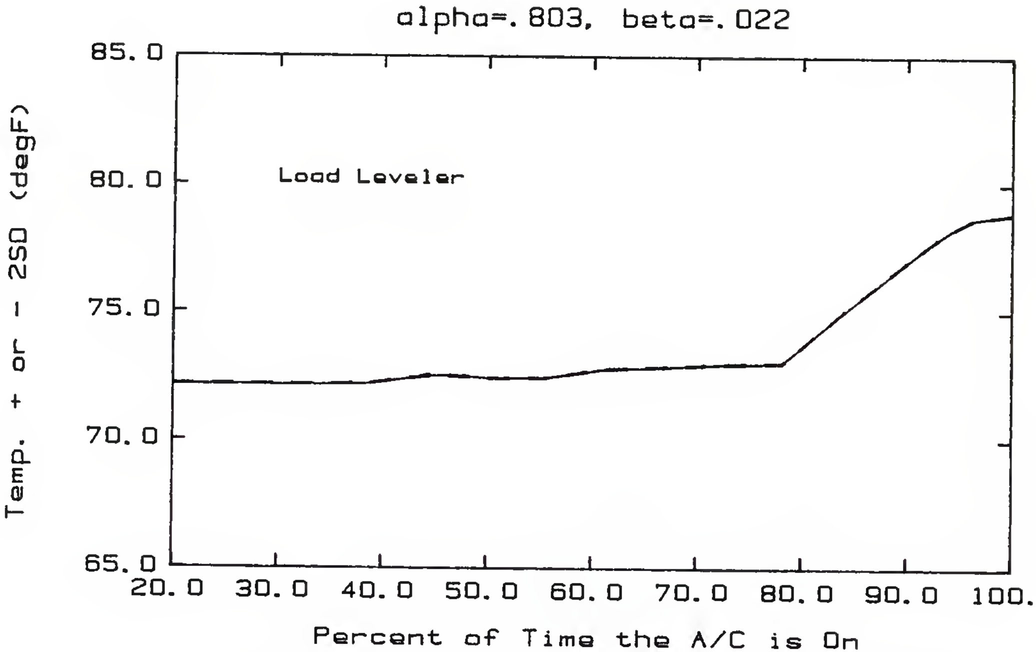


Fig. F-2: Average Aggregate Temperature Plus or Minus Two Standard Deviations as a Function of the Natural Duty Cycle of the Air-Conditioners for 20 Case 2 Houses. Control is Load Leveler type.

APPENDIX G

PLOTS OF 5 AND 60 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 AND 60 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 1. CONTROL IS CENTRALIZED

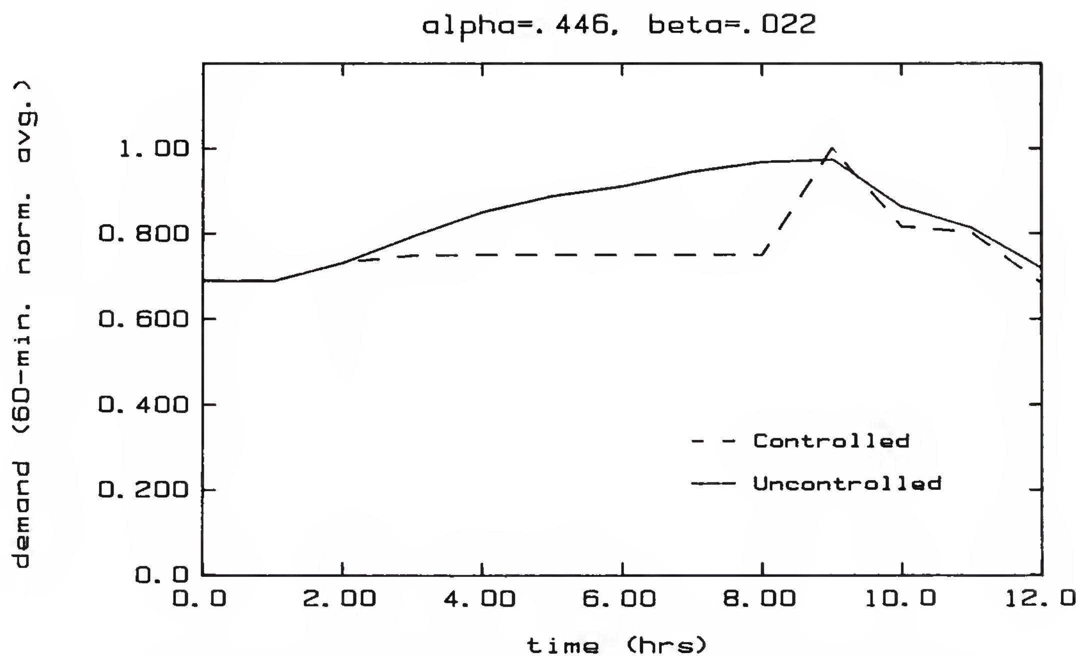


Fig. G-1: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Centralized. Driving Temperatures is Piece-wise Constant With a Peak Value of 90 F.

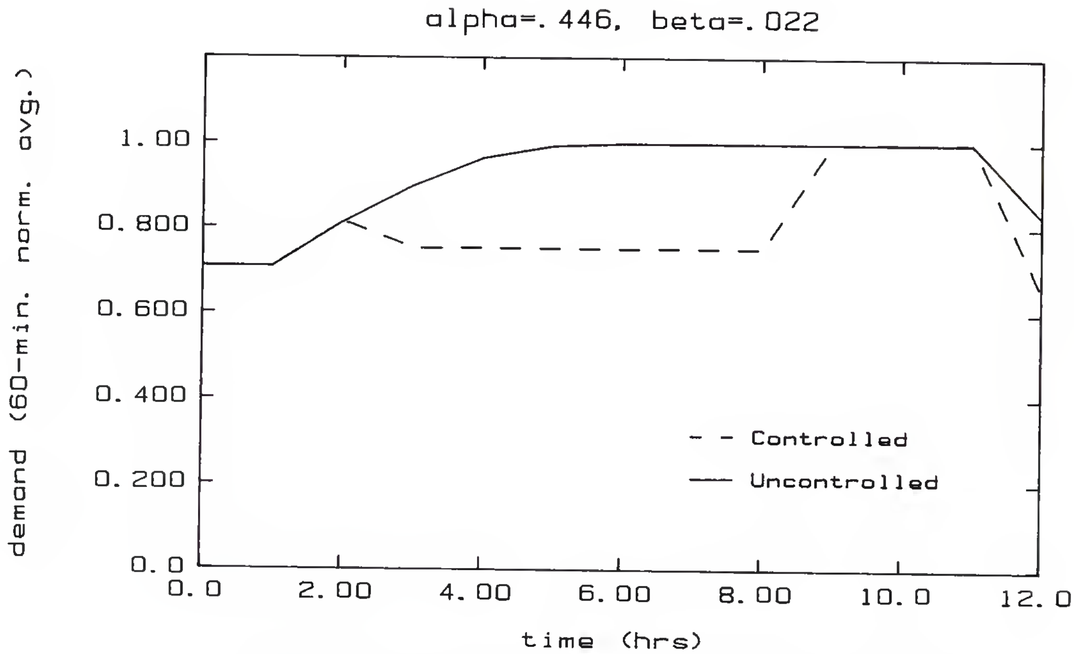


Fig. G-2: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

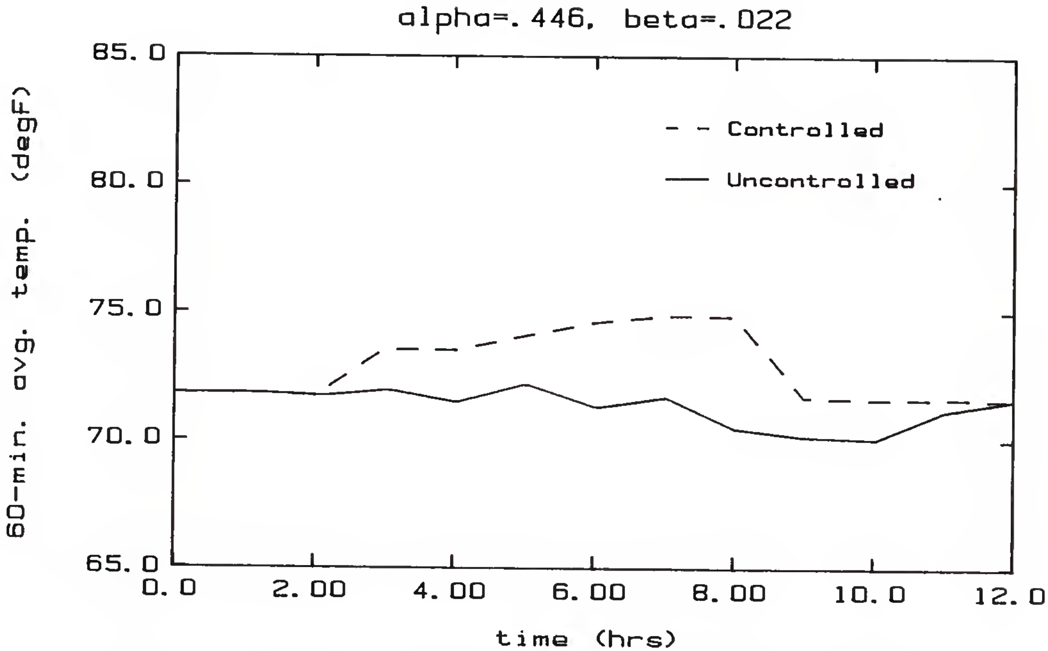


Fig. G-3: Sixty-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period. Control is Centralized.

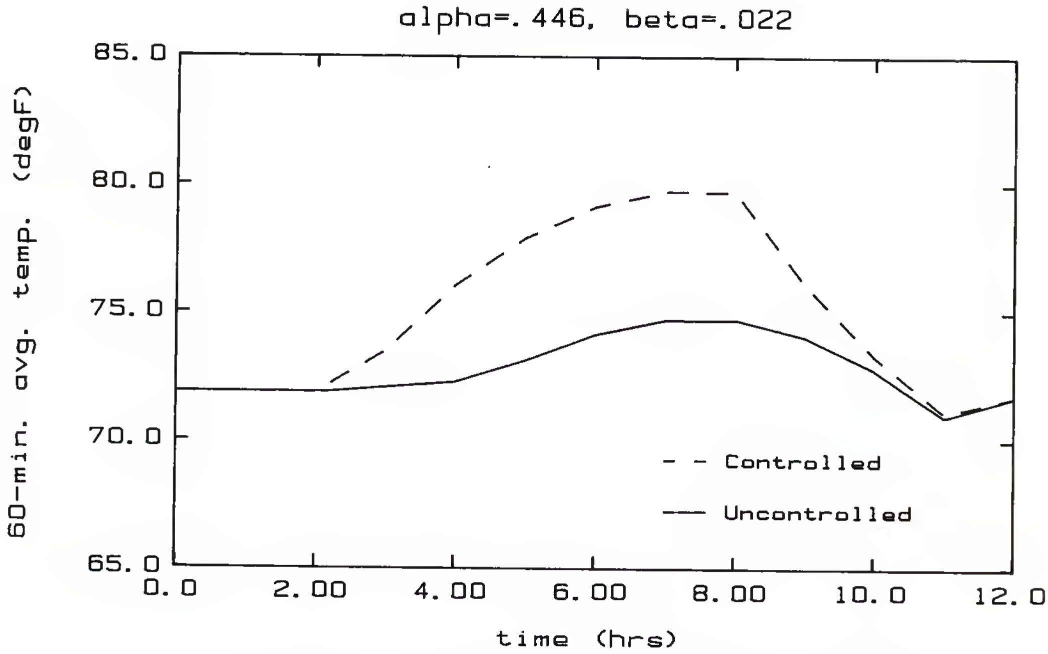


Fig. G-4: Sixty-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

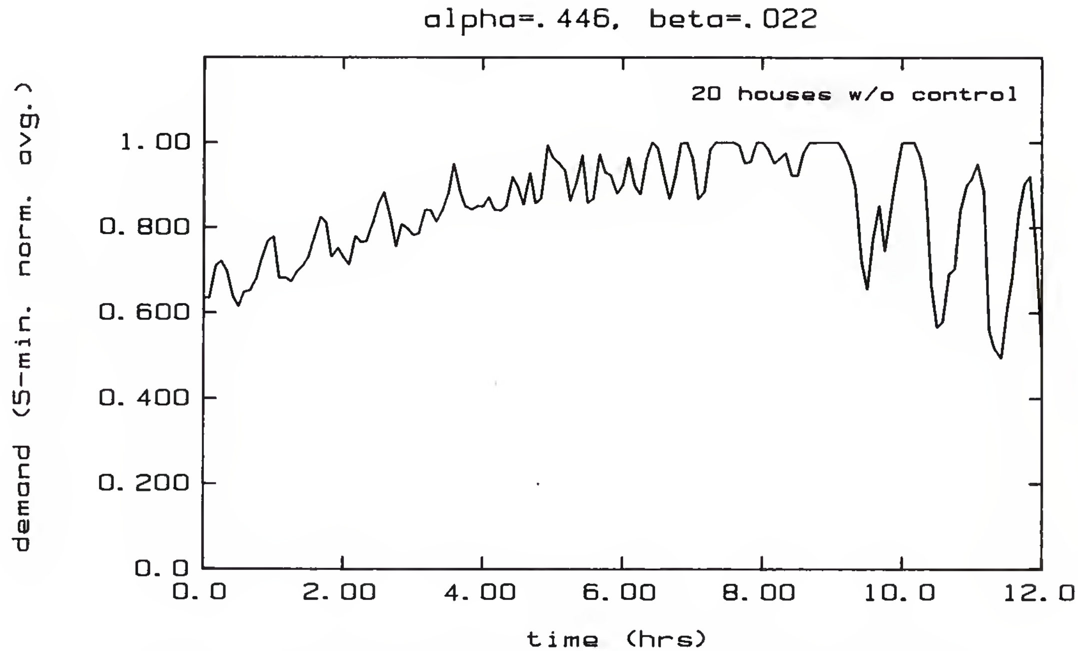


Fig. G-5: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

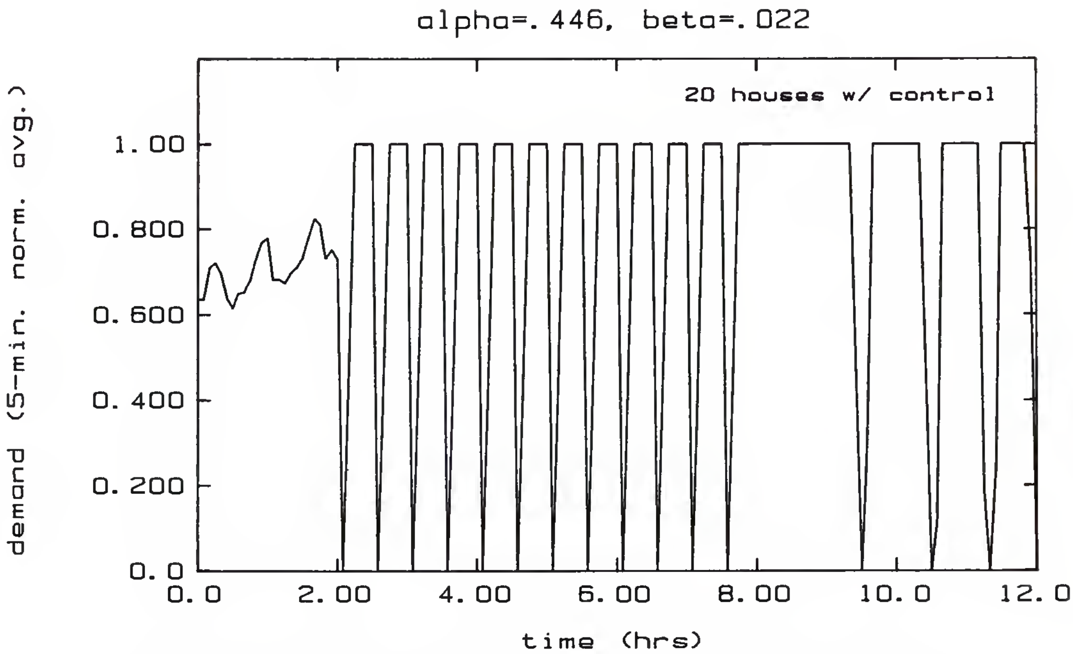


Fig. G-6: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

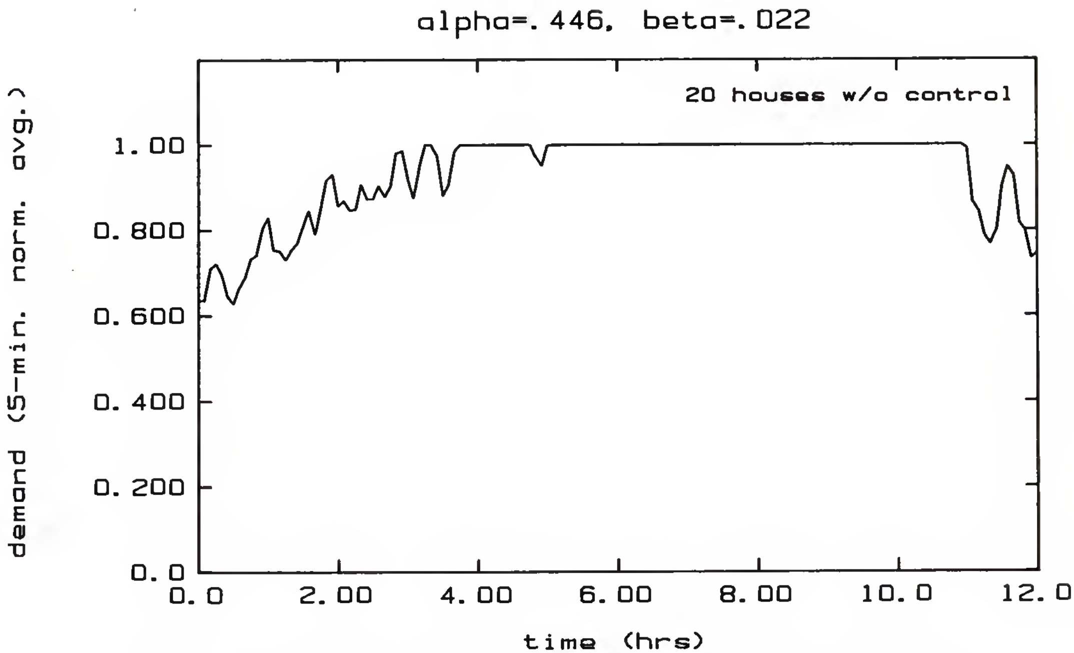


Fig. G-7: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period For Case 1 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

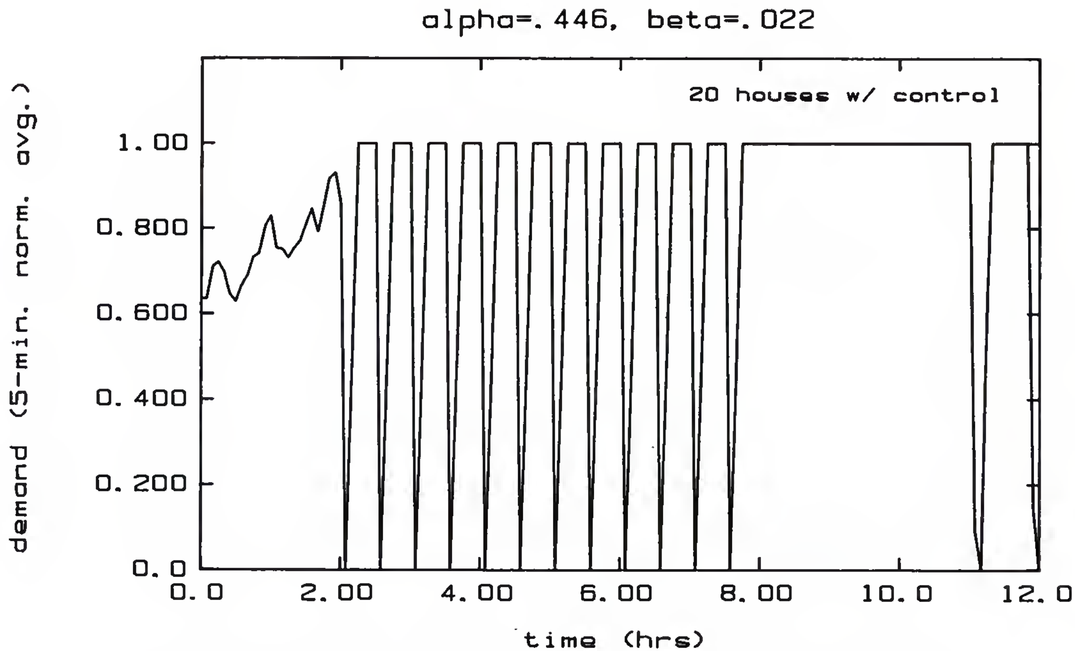


Fig. G-8: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

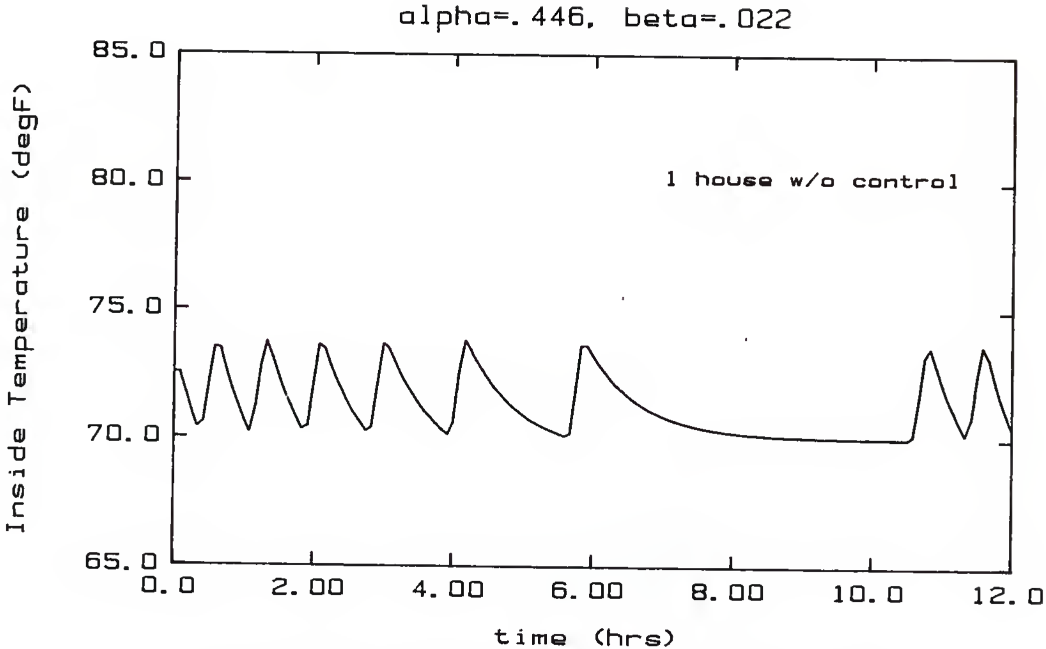


Fig. G-9: Five-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period.

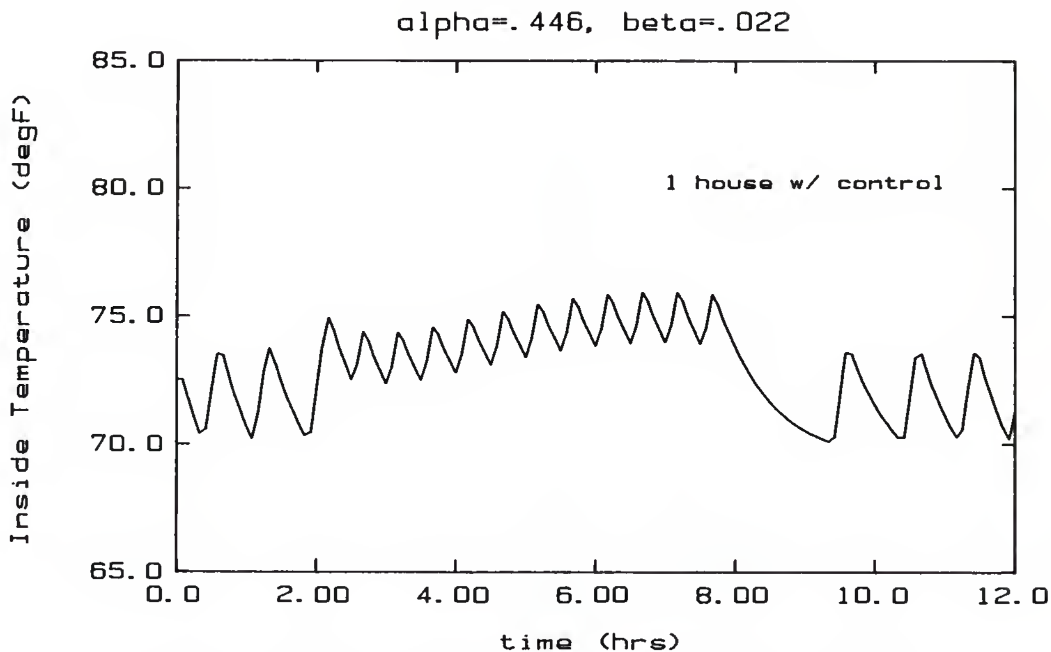


Fig. G-10: Five-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period. Control is Centralized.

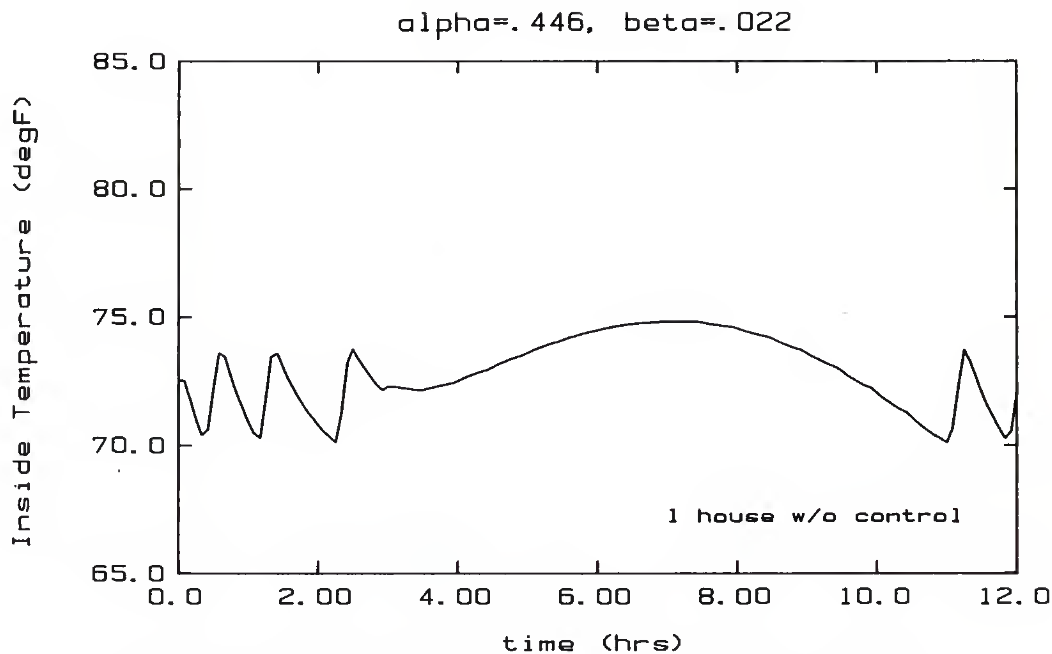


Fig. G-11: Five-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period.

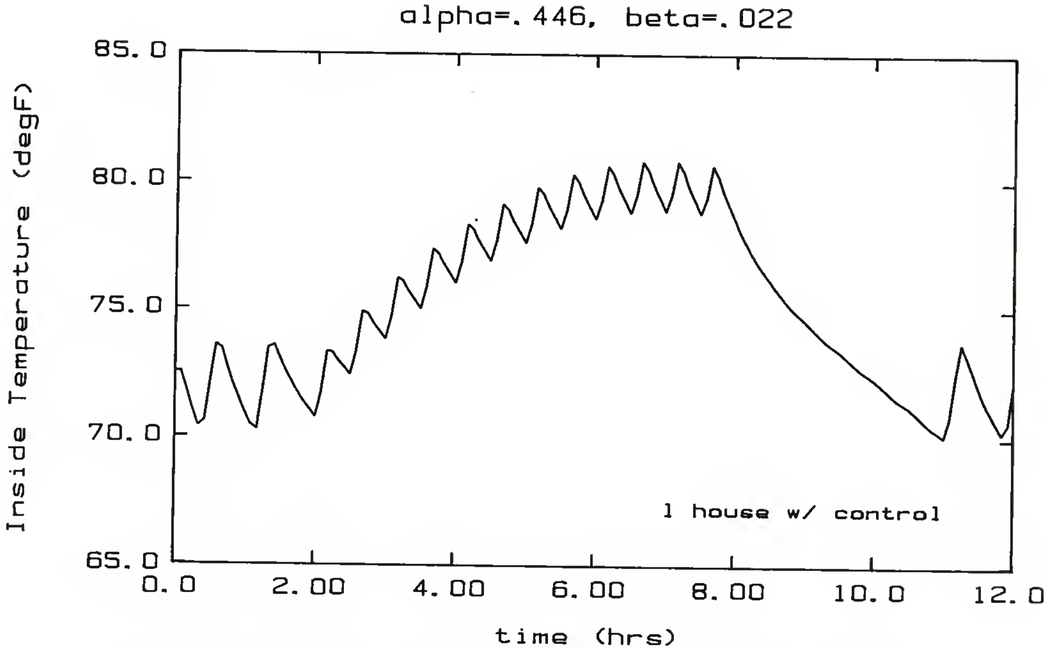


Fig. G-12: Five-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

APPENDIX H

PLOTS OF 5 AND 60 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 AND 60 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 2. CONTROL IS CENTRALIZED

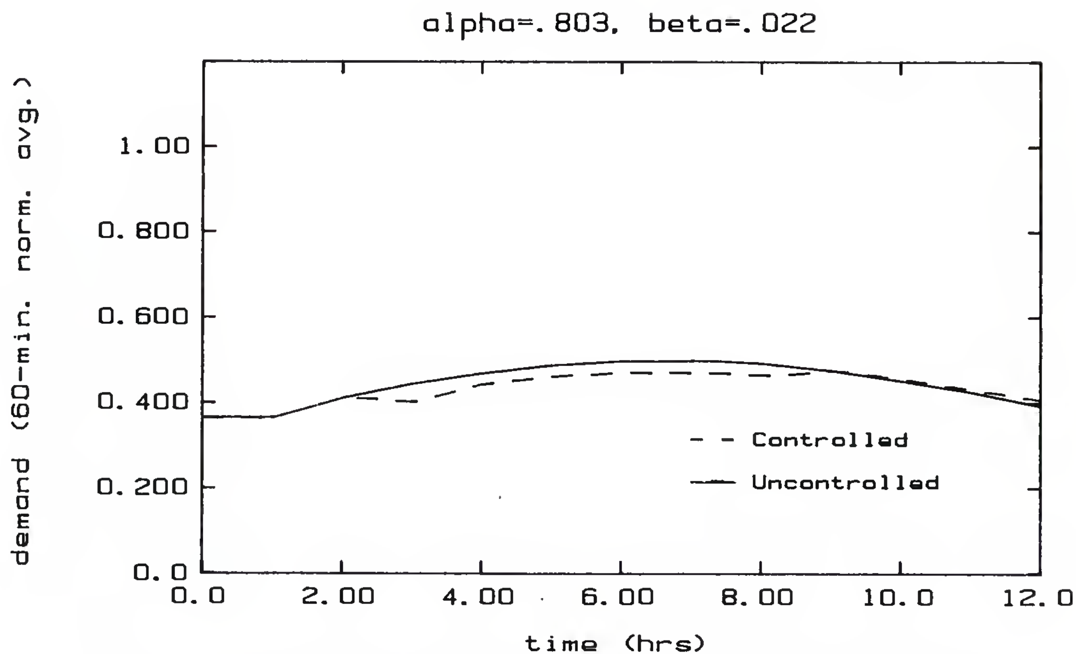


Fig. H-1: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

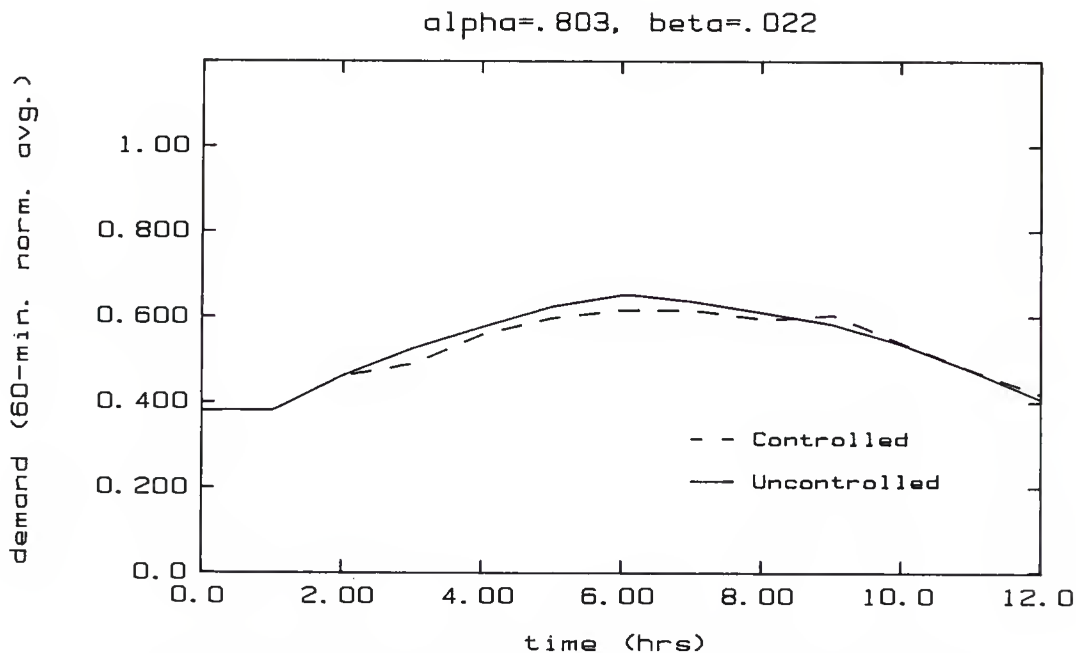


Fig. H-2: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F. .

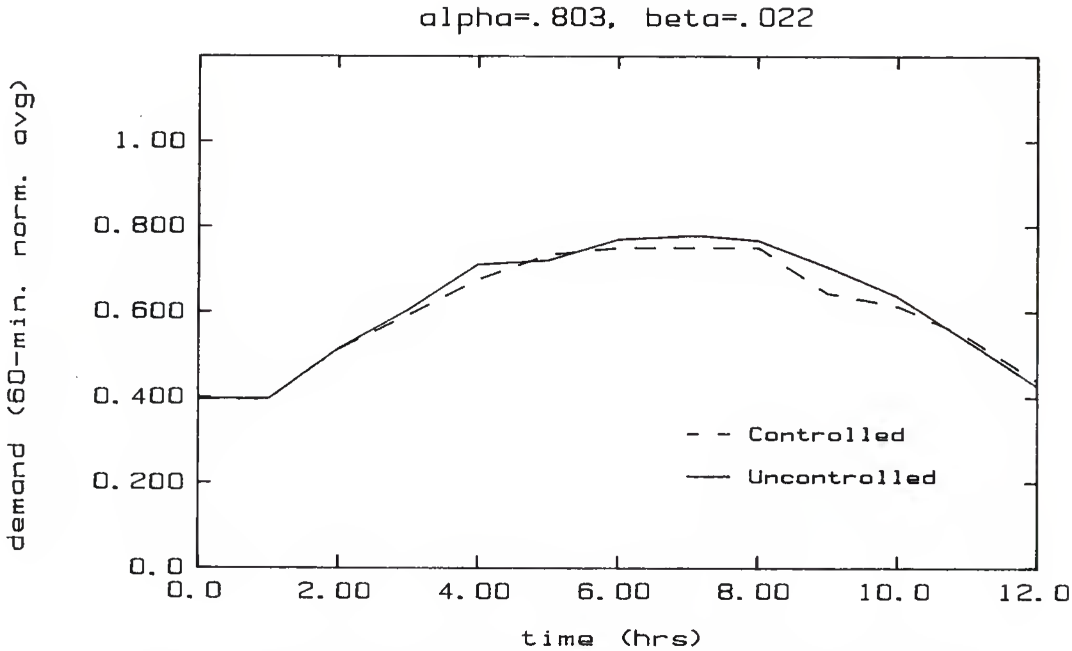


Fig. H-3: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

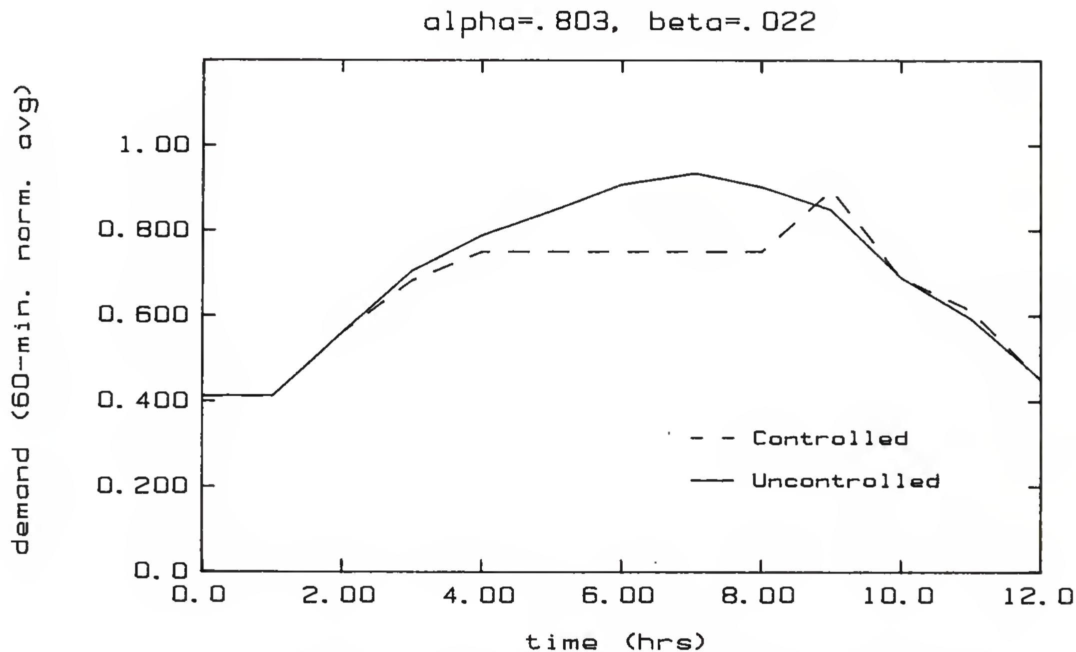


Fig. H-4: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

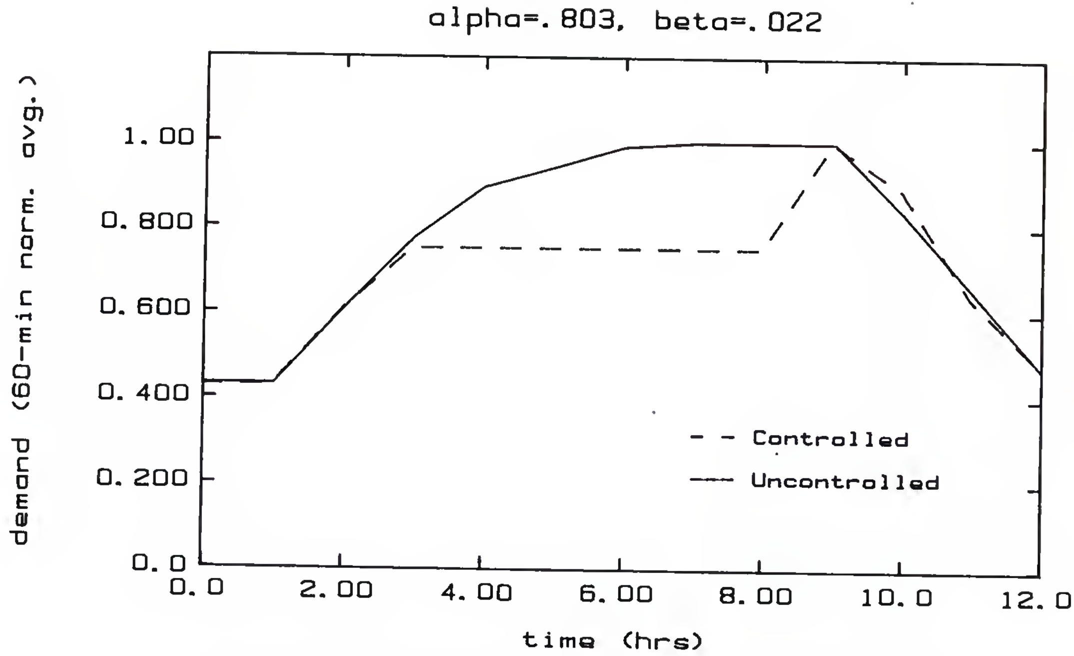


Fig. H-5: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period For Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

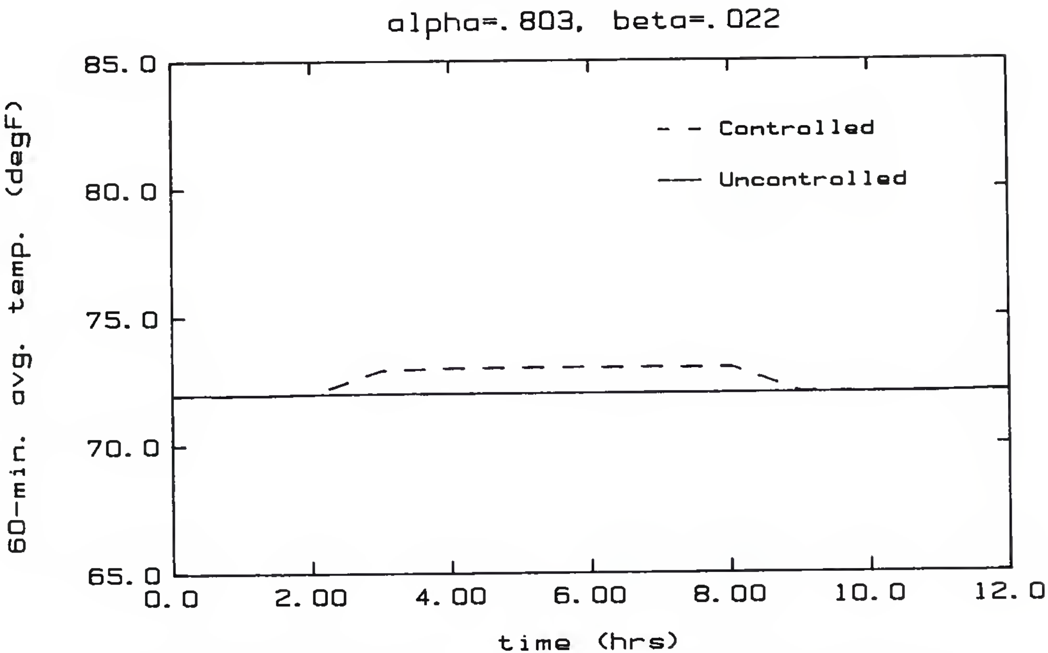


Fig. H-6: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period. Control is Centralized.

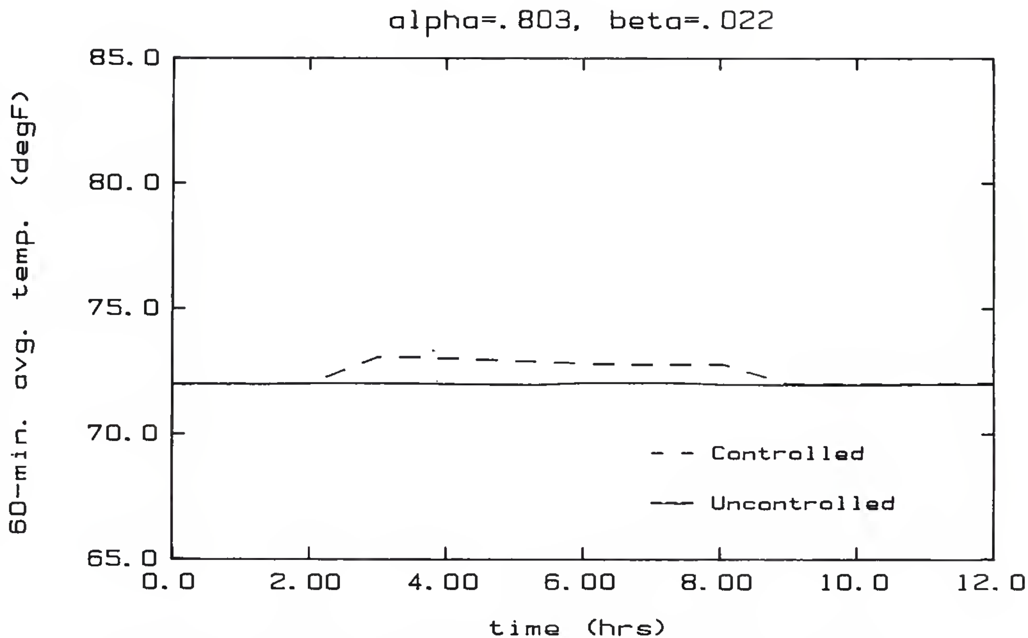


Fig. H-7: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

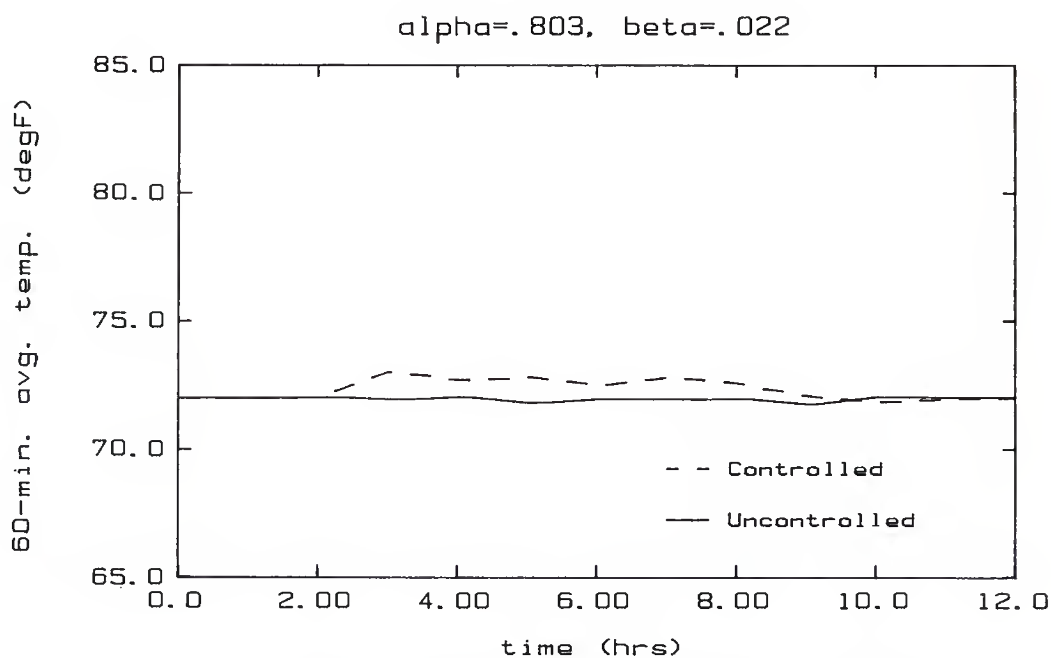


Fig. H-8: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Centralized.

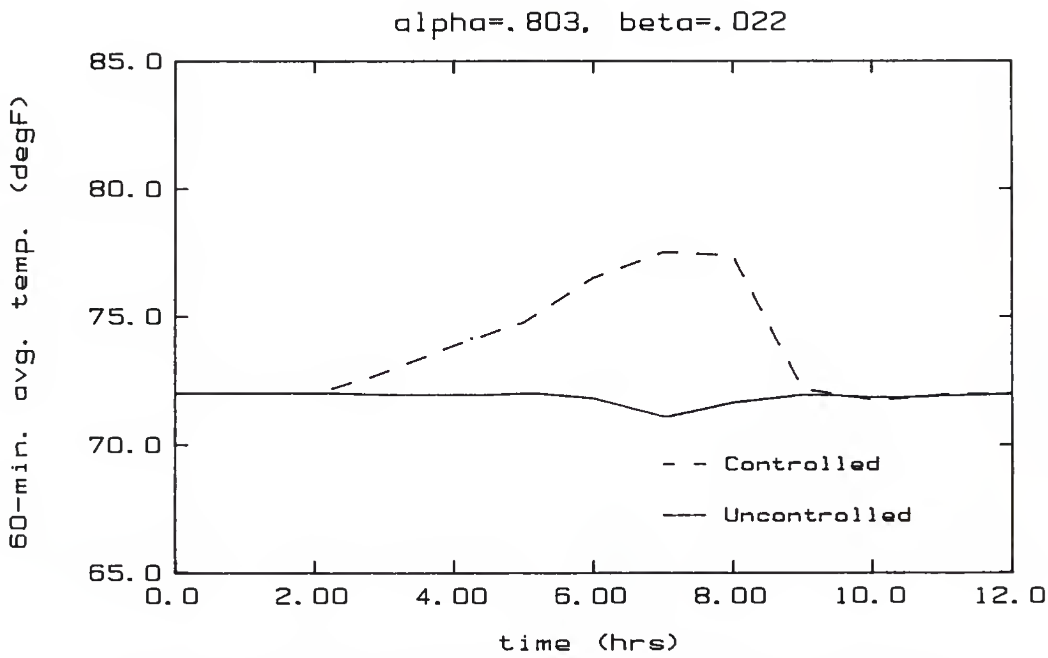


Fig. H-9: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

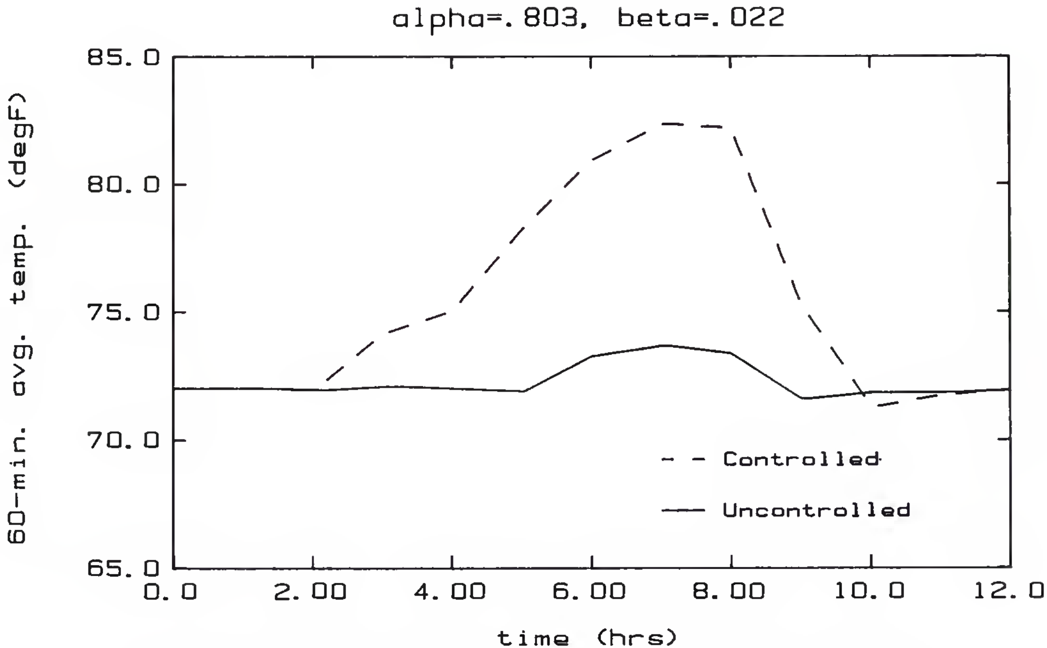


Fig. H-10: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Centralized.

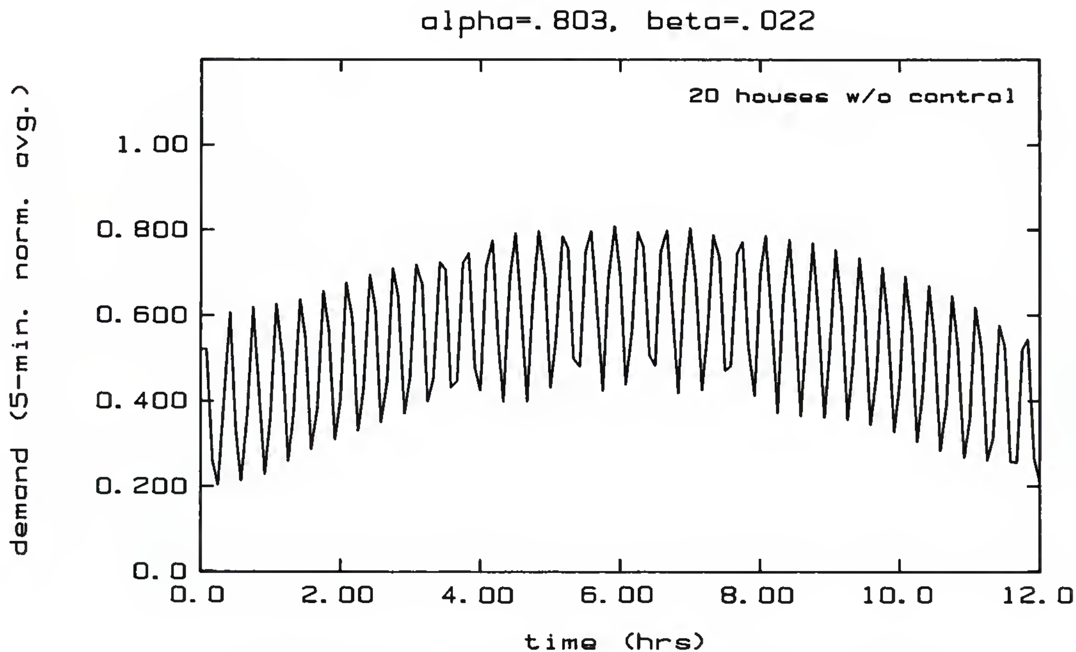


Fig. H-11: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant Witha Peak Value of 95 F.

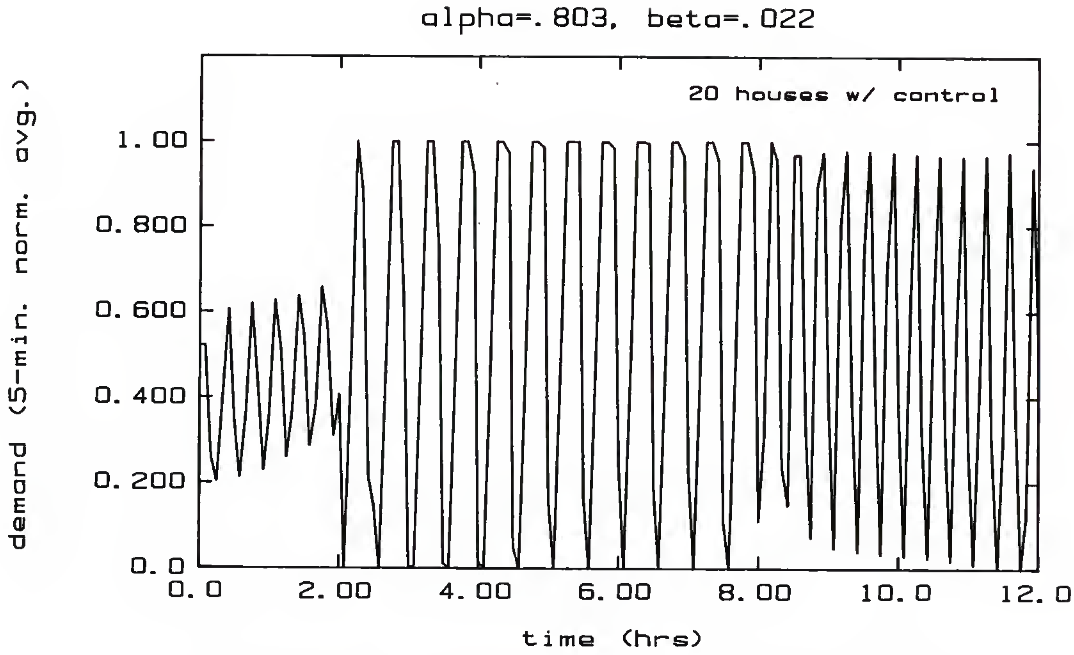


Fig. H-12: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

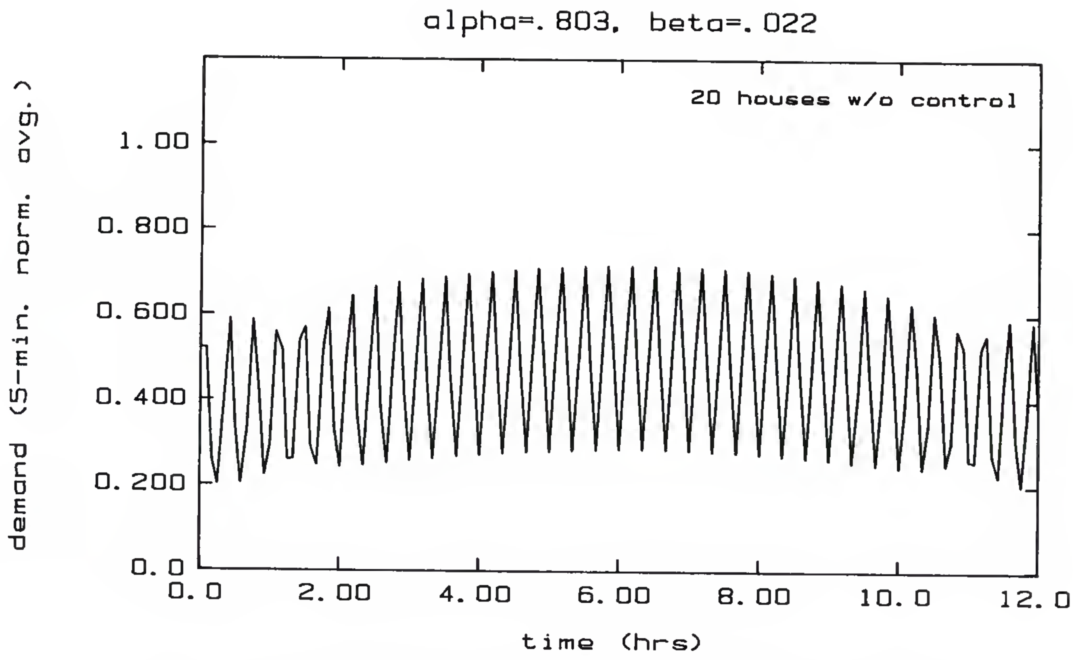


Fig. H-13: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

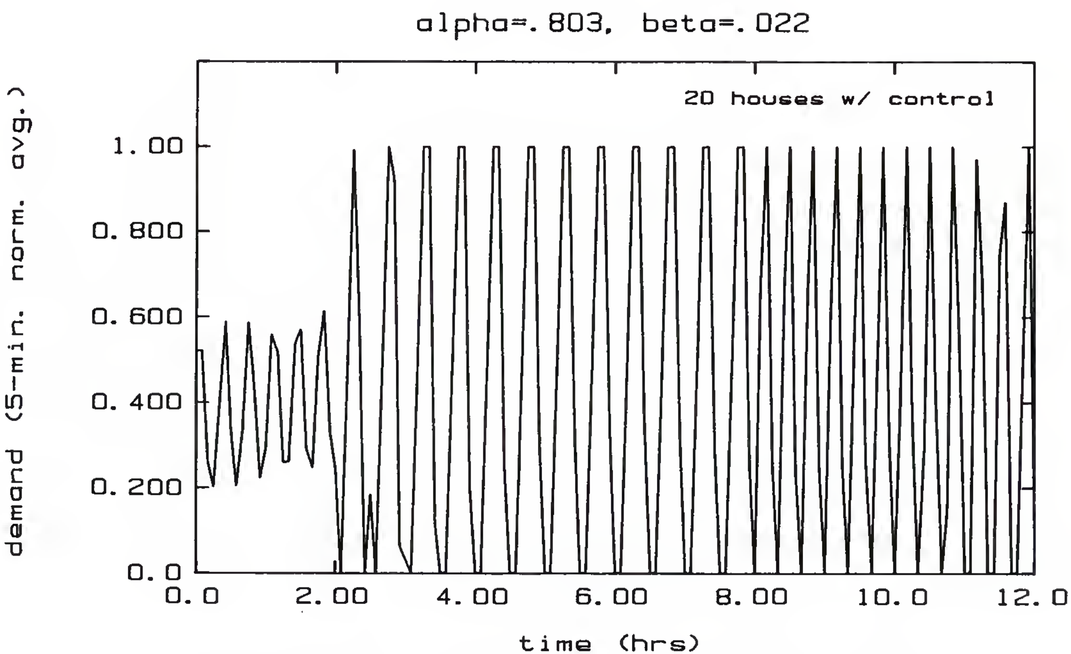


Fig. H-14: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

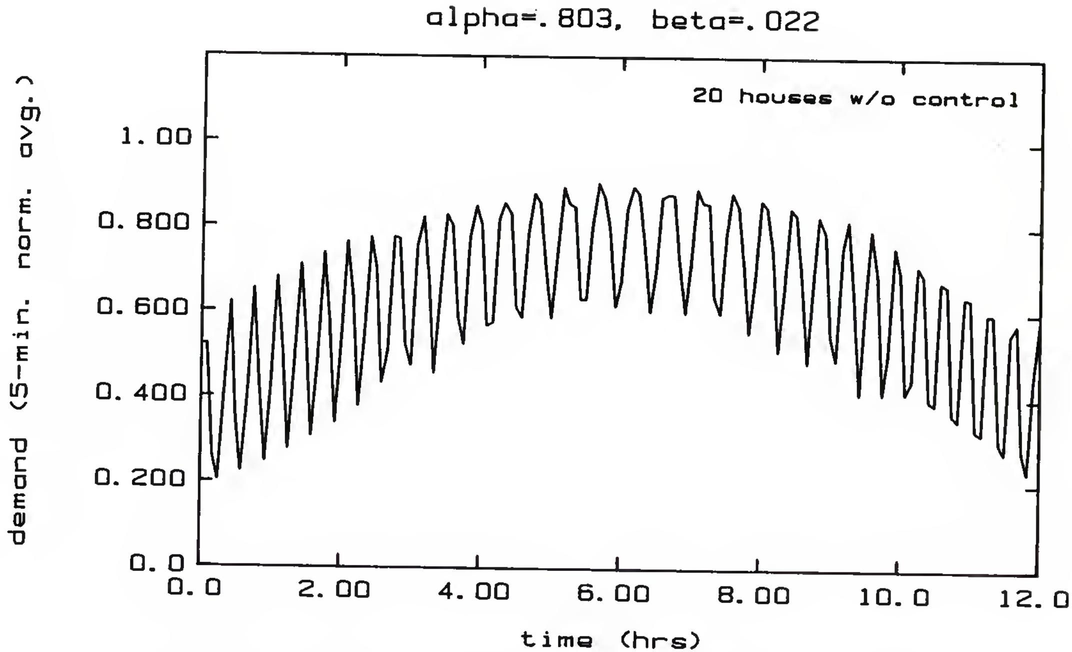


Fig. H-15: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

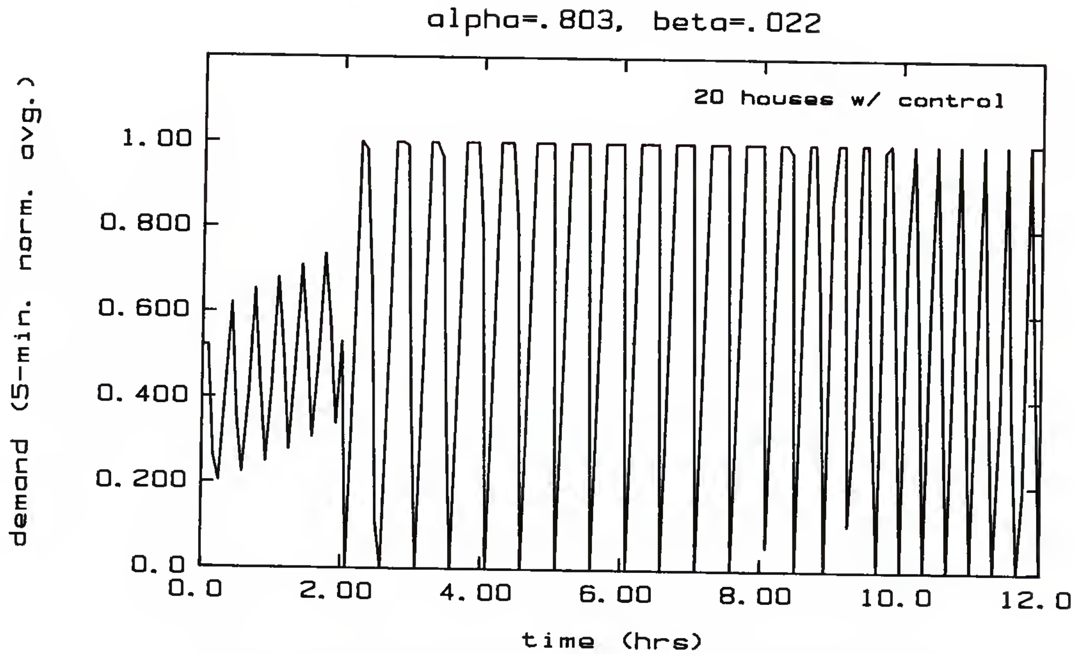


Fig. H-16: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

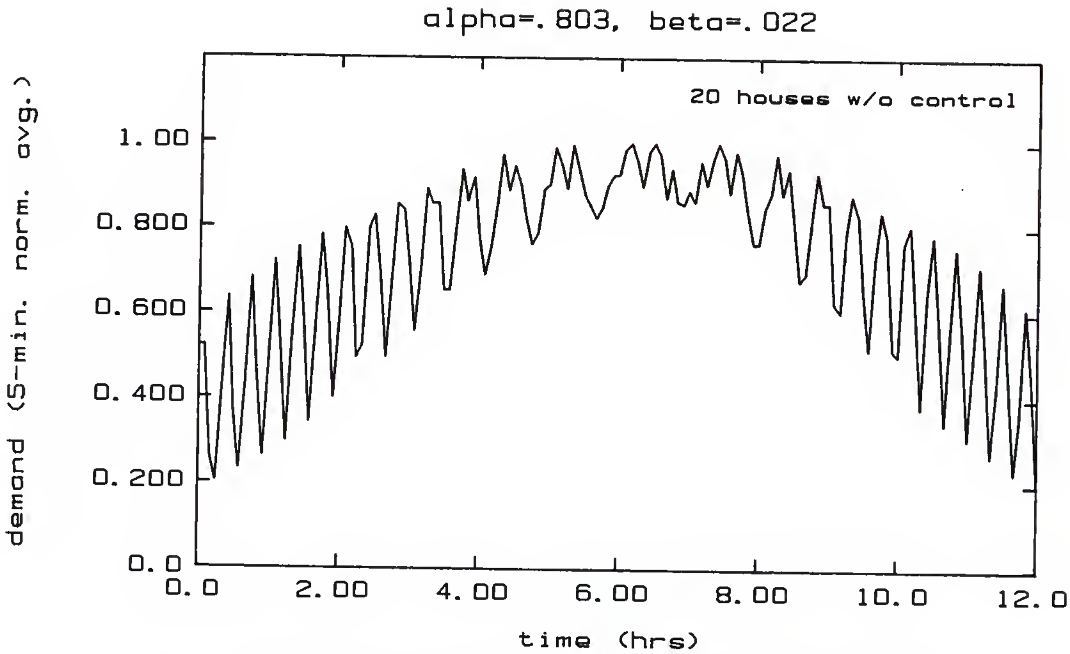


Fig. H-17: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

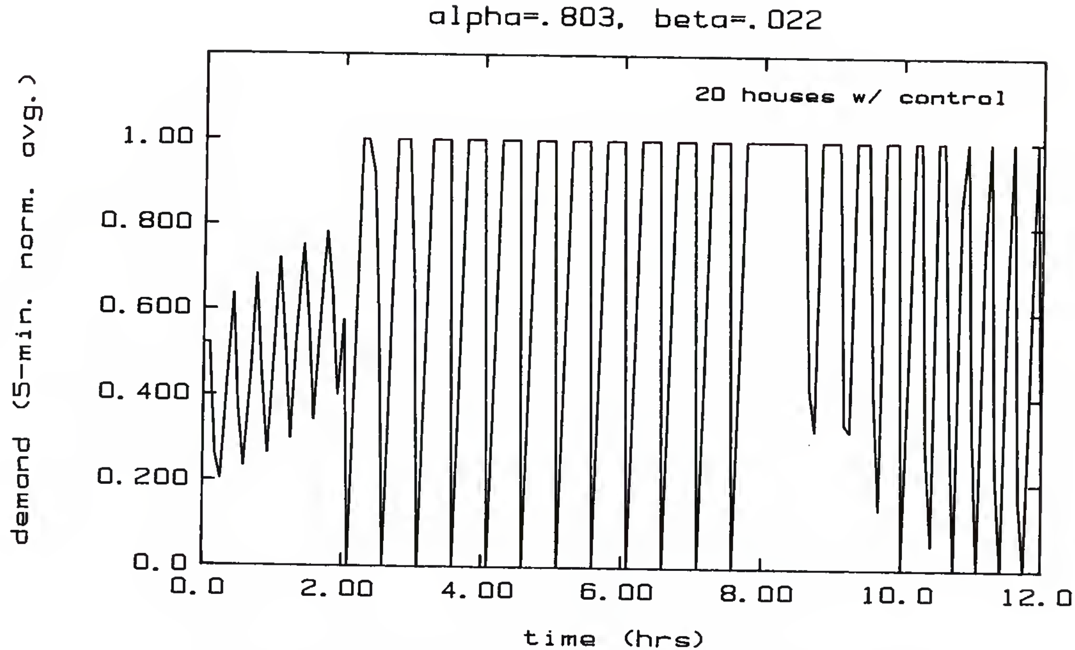


Fig. H-18: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

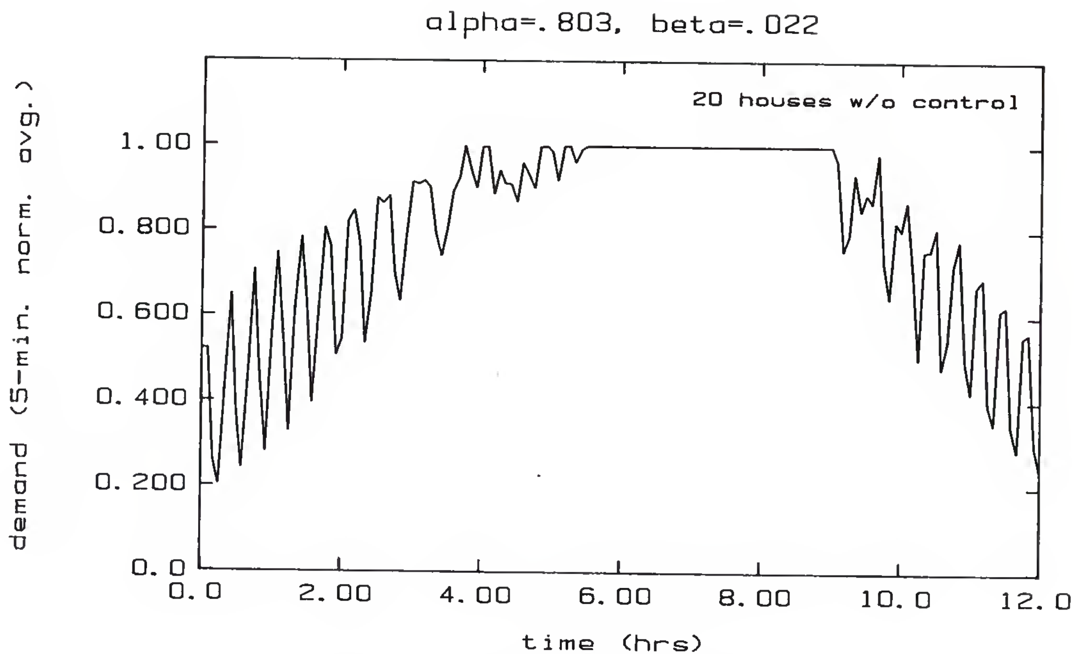


Fig. H-19: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Driving Temperature is Piece-wise Constant With a Peak Vlue of 110 F.

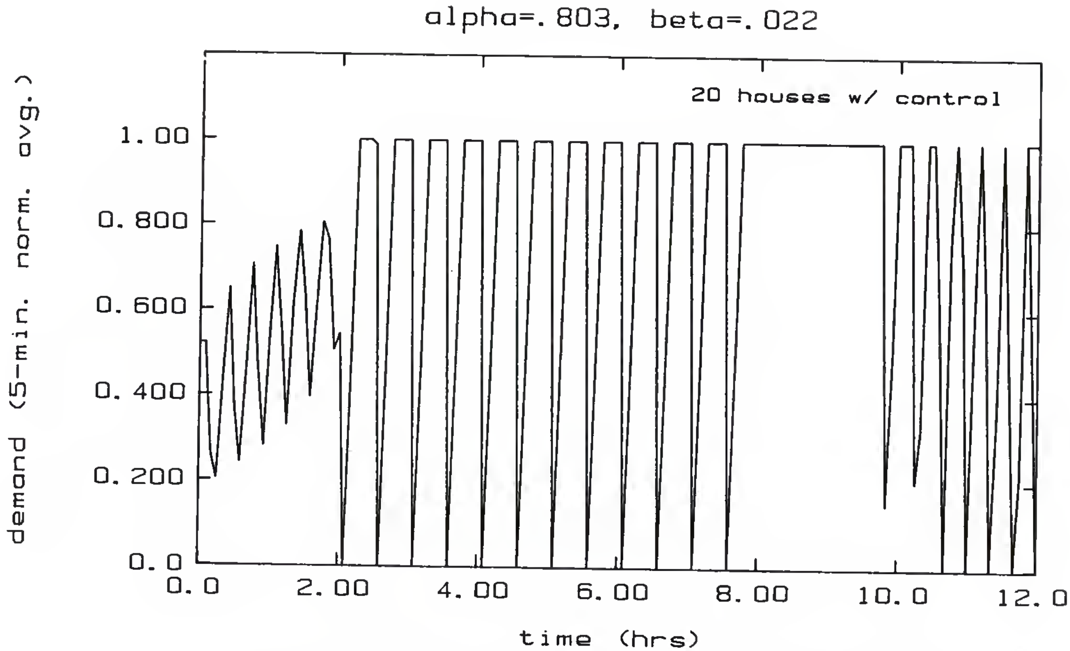


Fig. H-20: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

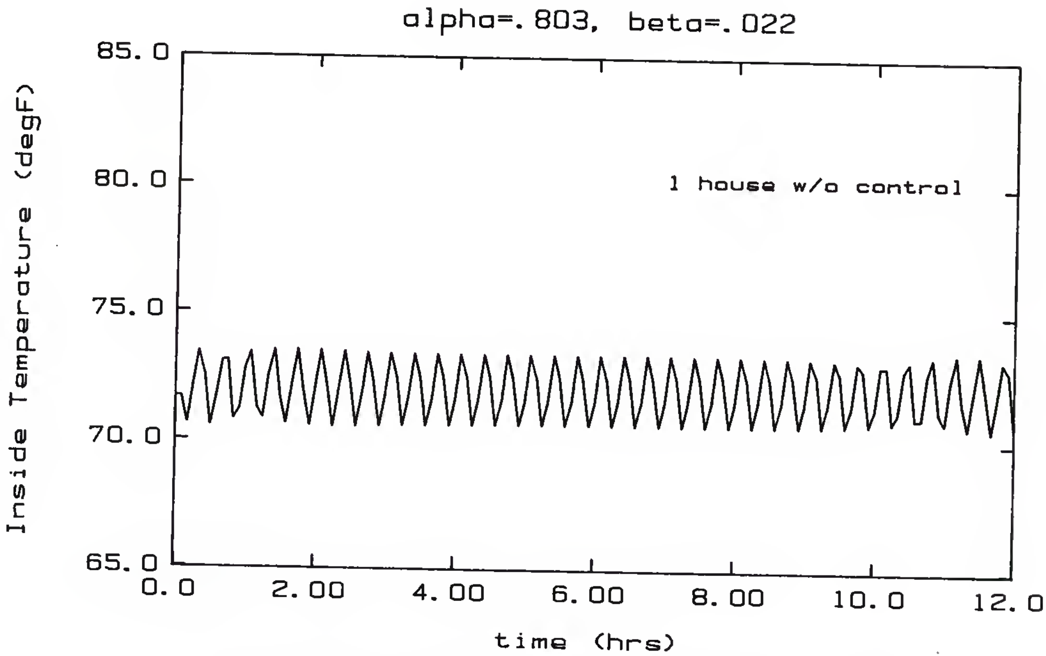


Fig. H-21: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period.

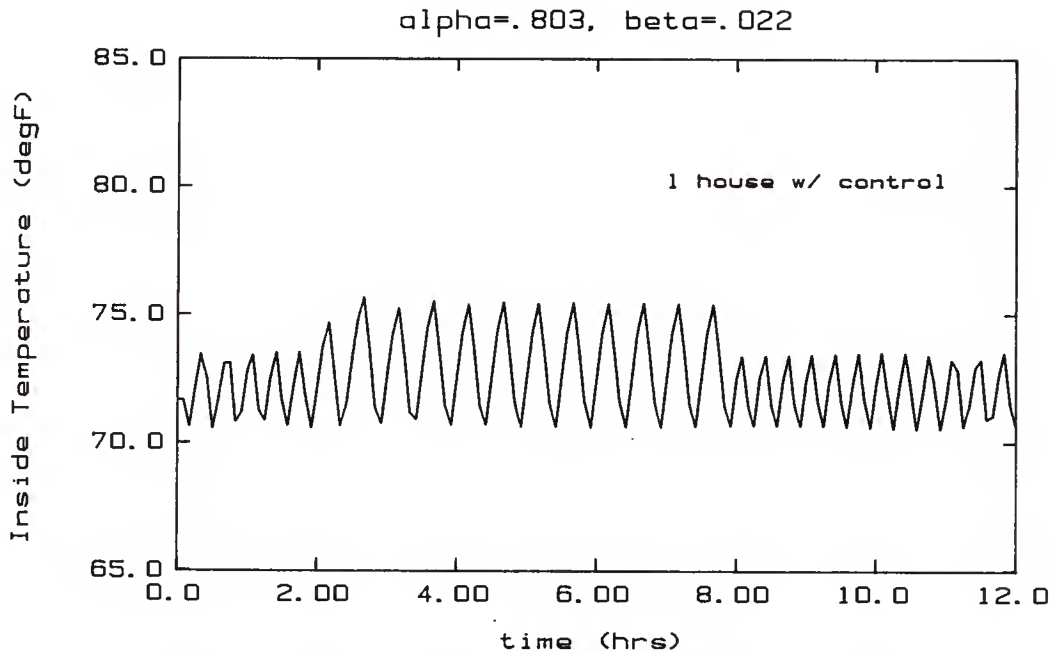


Fig. H-22: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period. Control is Centralized.

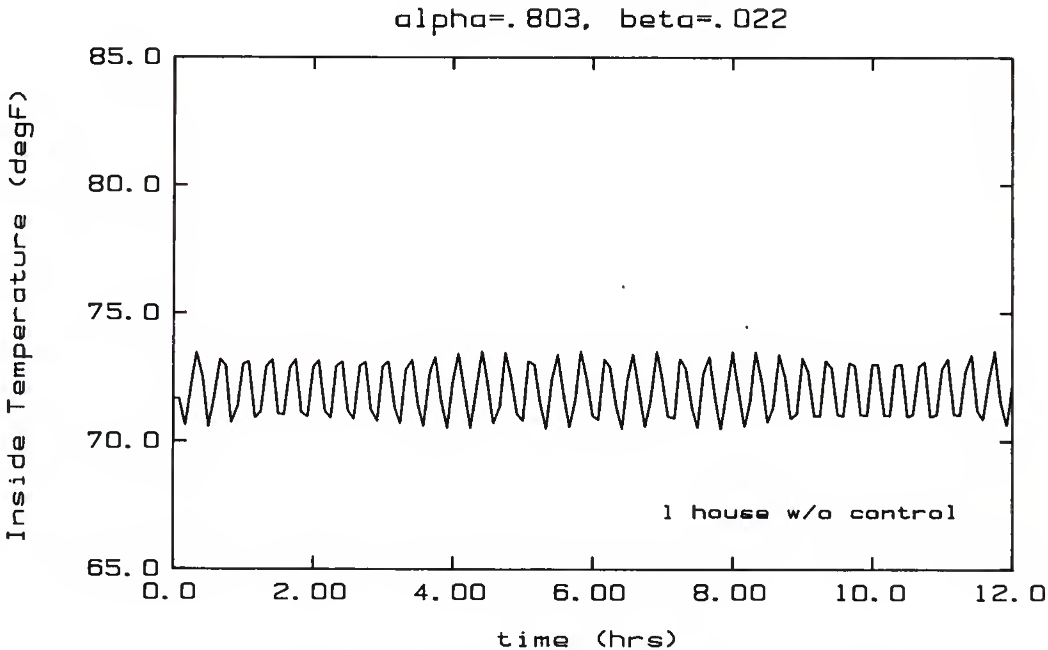


Fig. H-23: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period.

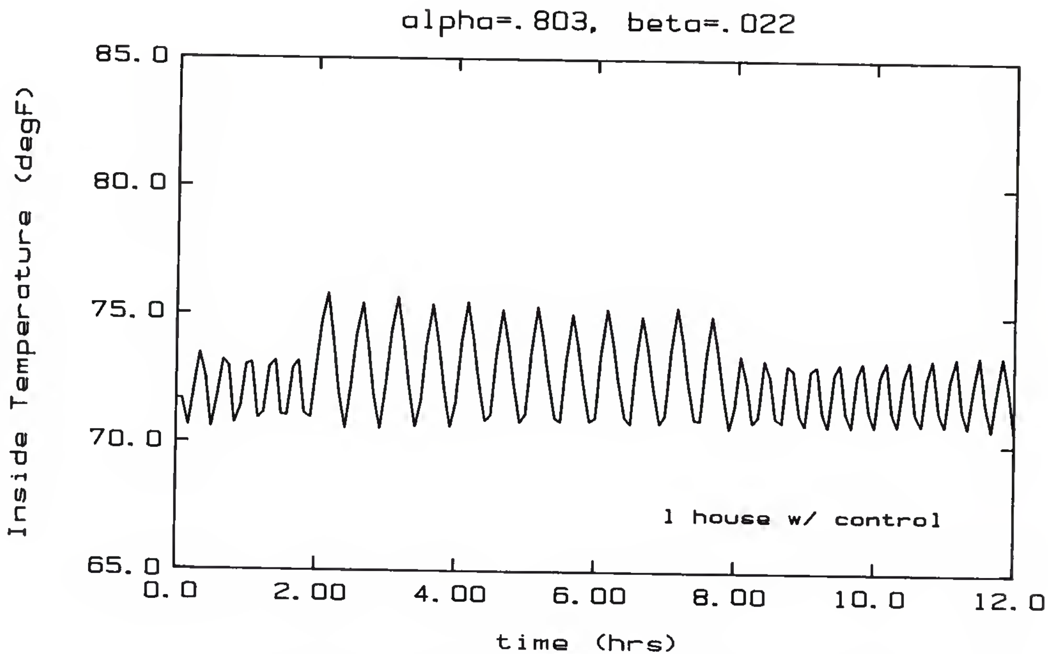


Fig. H-24: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

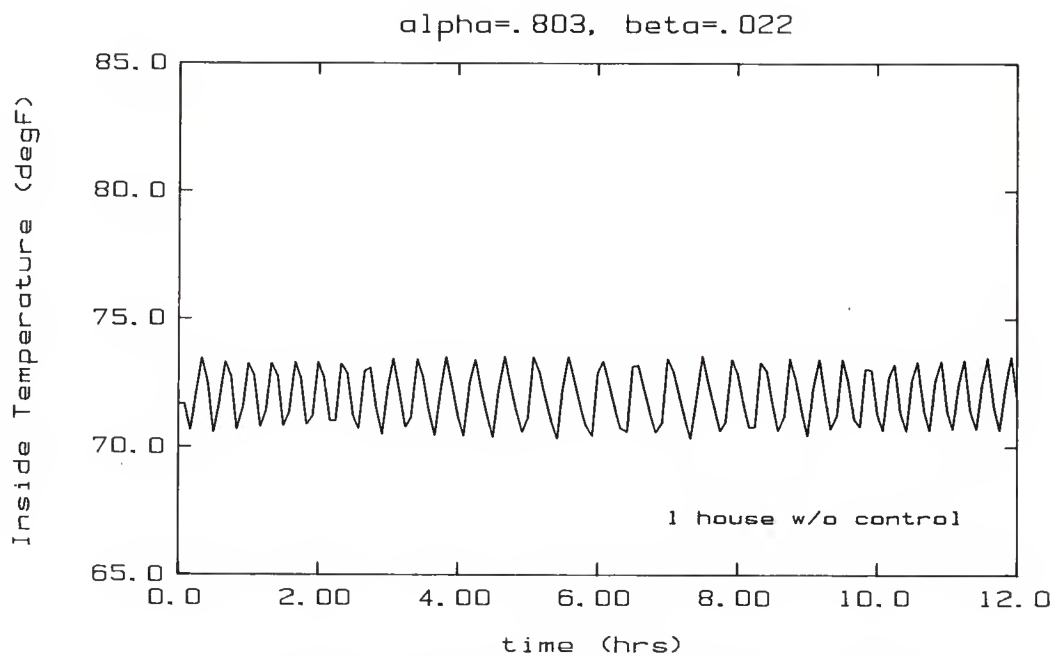


Fig. H-25: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period.

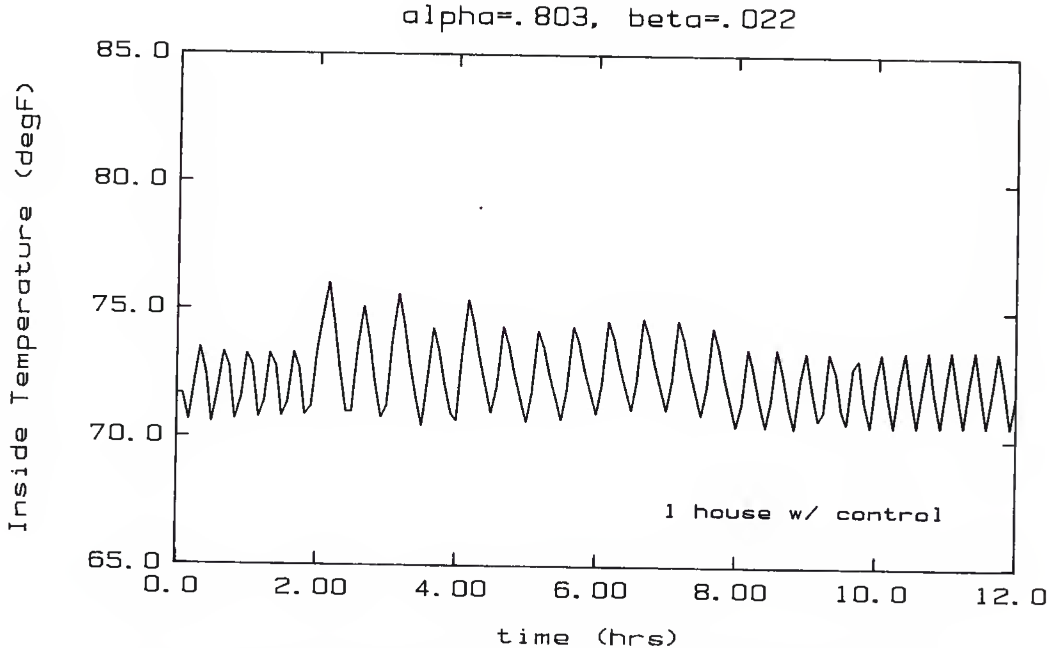


Fig. H-26: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Centralized.

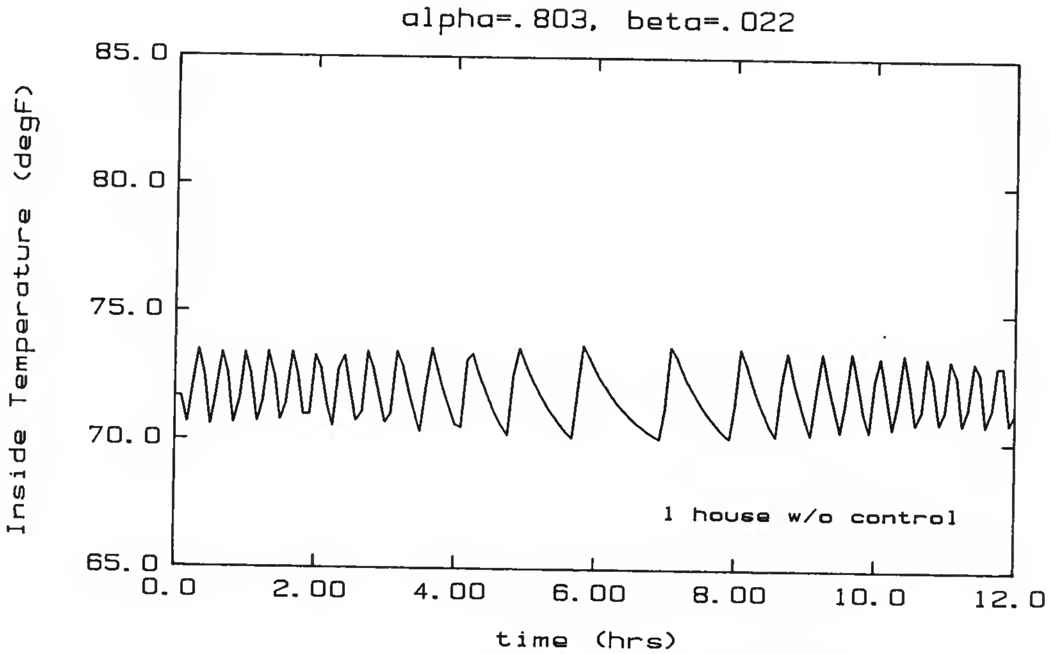


Fig. H-27: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period.

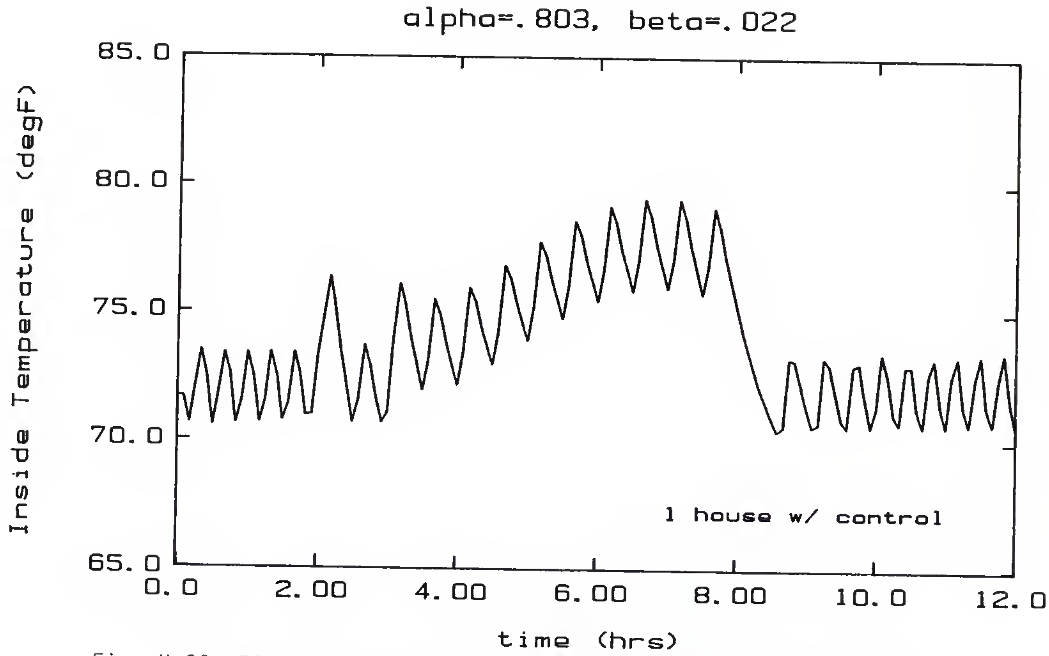


Fig. H-28: Five-Minute Average Inside Temperature for a Typical Case 2 House For Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

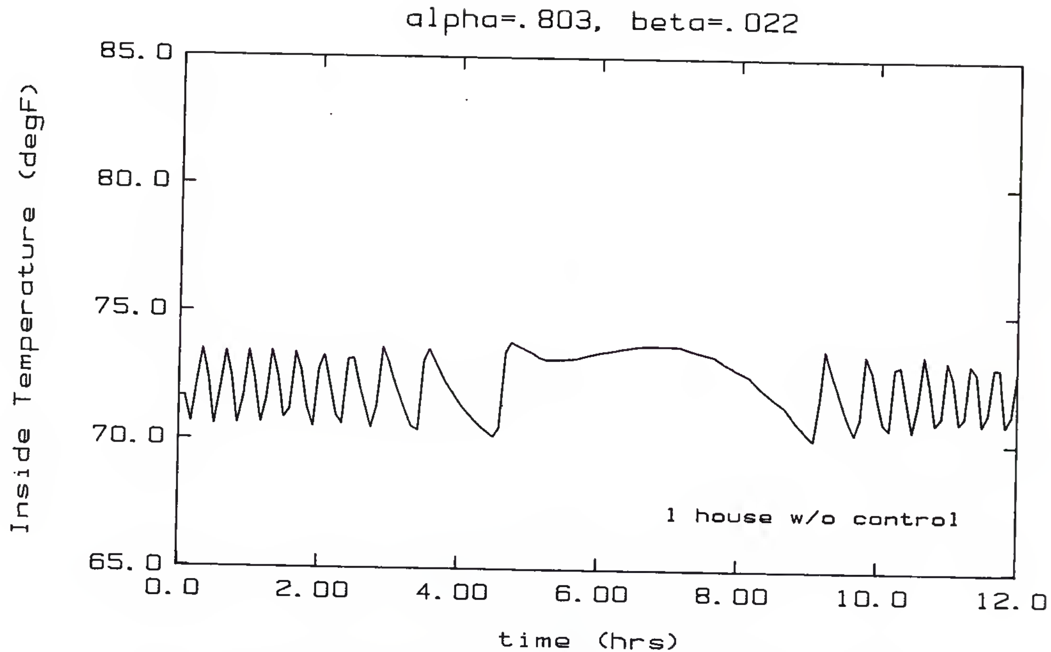


Fig. H-29: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period.

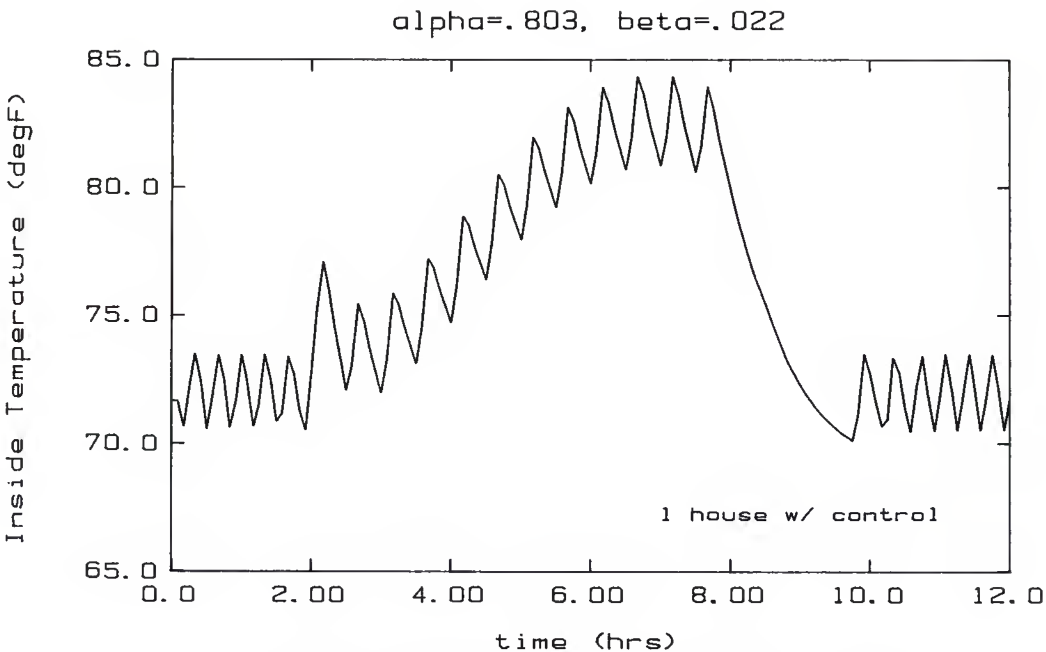


Fig. H-30: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Centralized.

APPENDIX I

PLOTS OF 5 AND 60 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 AND 60 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 3. CONTROL IS CENTRALIZED

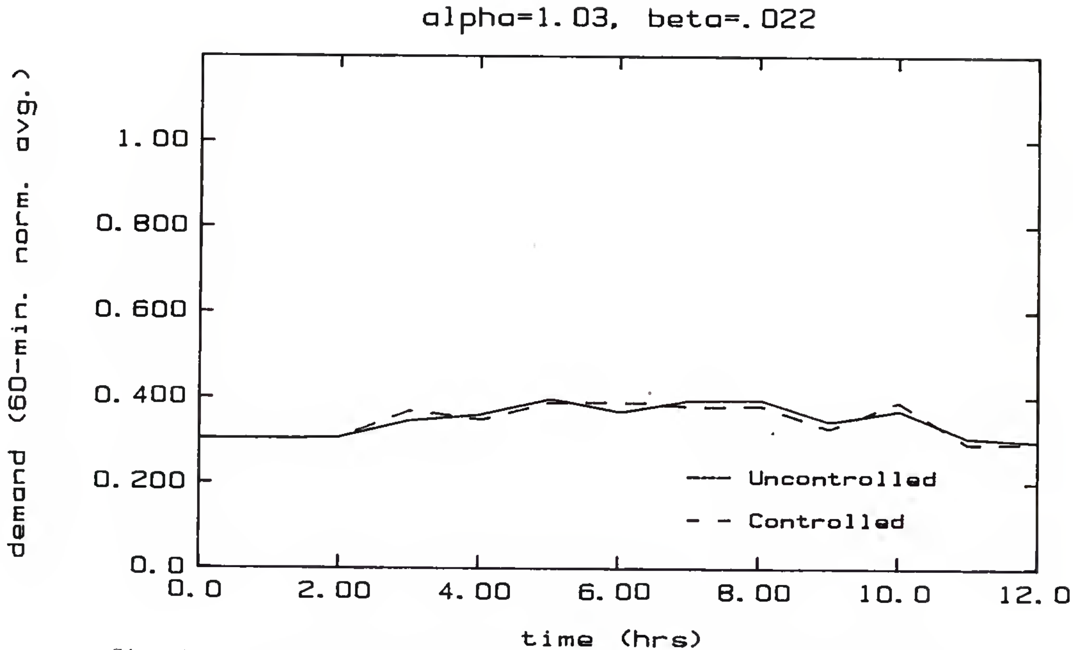


Fig. I-1: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

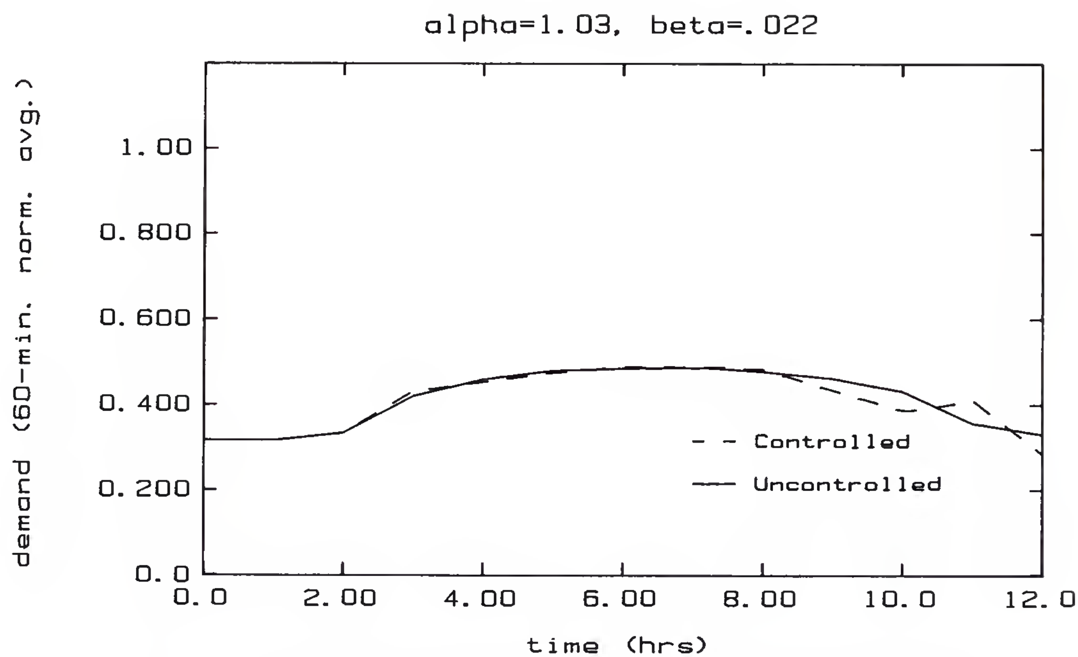


Fig. I-2: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

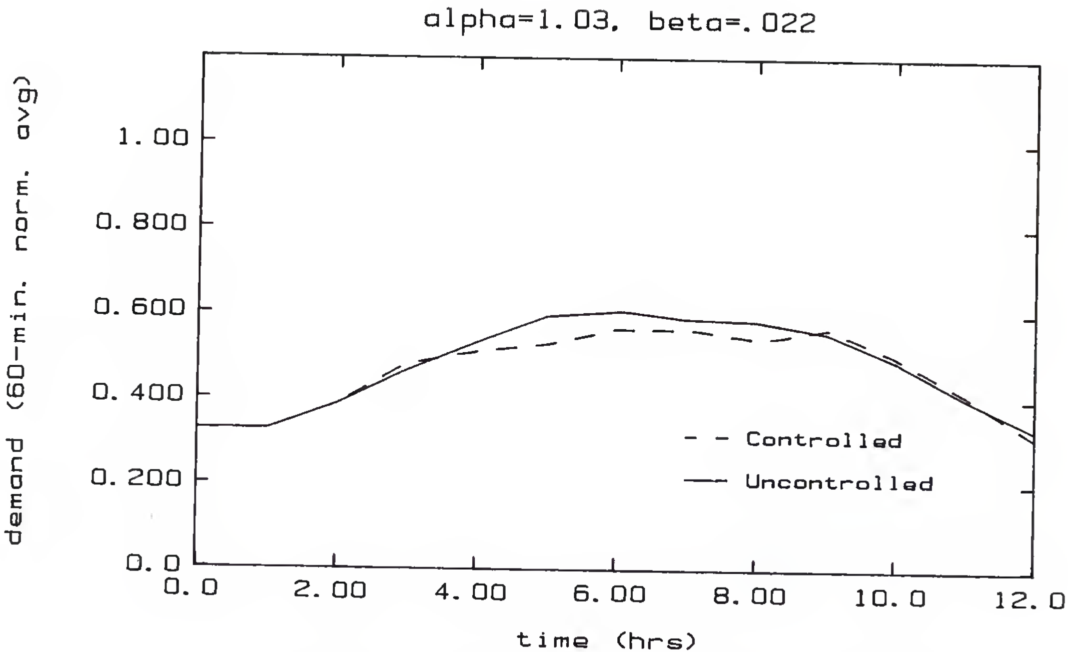


Fig. I-3: Sixty-Minute Average Demand, Normalized for 20 Houses over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

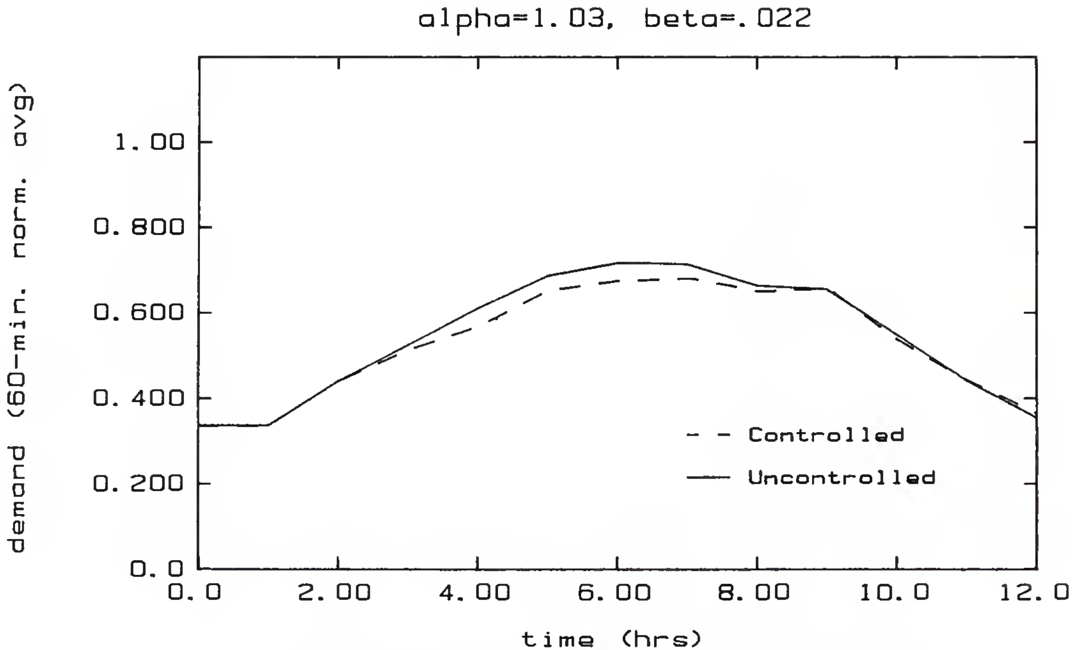


Fig. I-4: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

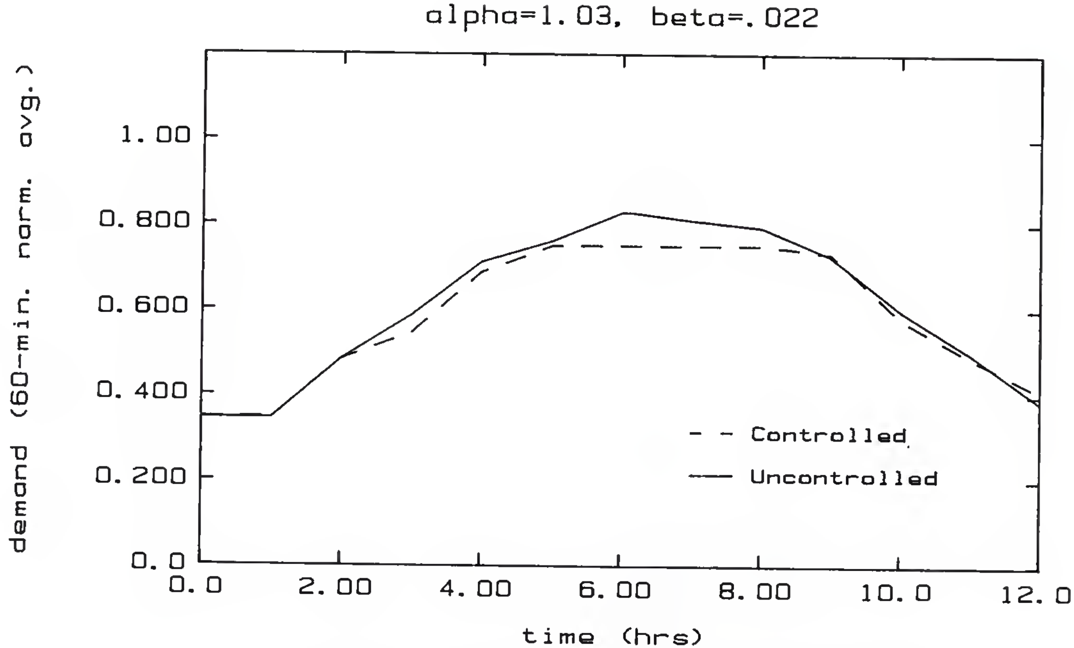


Fig. I-5: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

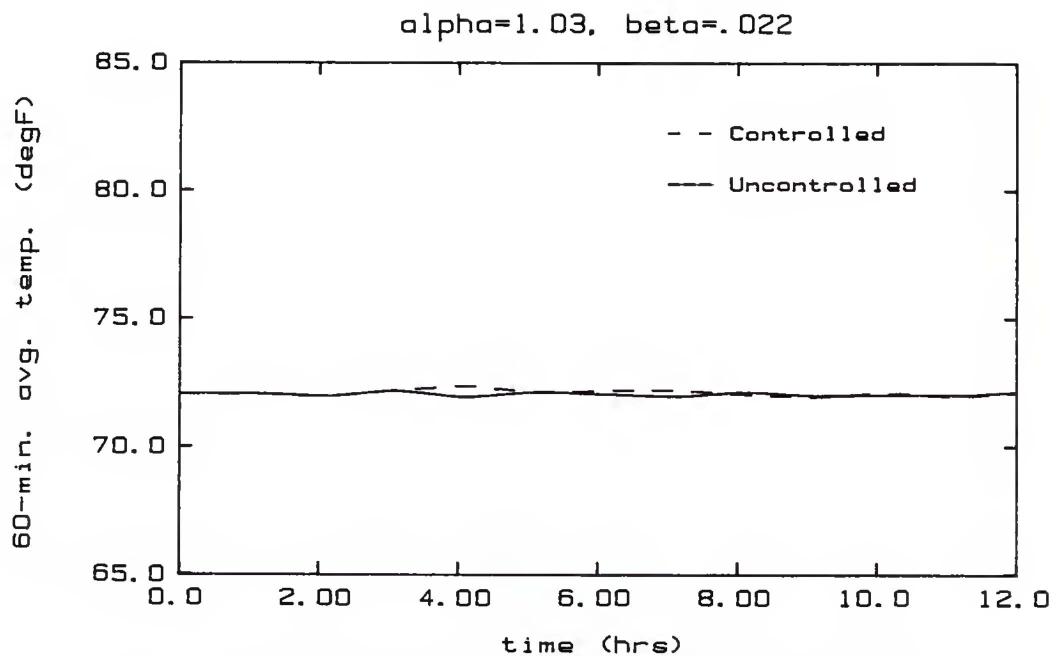


Fig. I-6: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_{peak}=90 F) Over a 12 Hour Period. Control is Centralized.

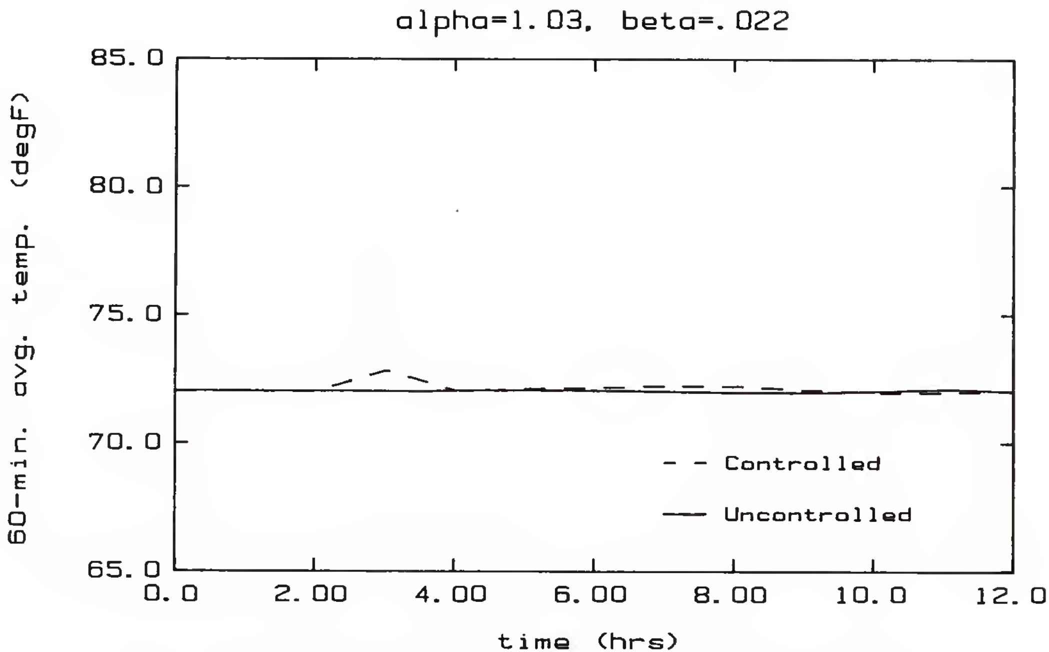


Fig. I-7: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

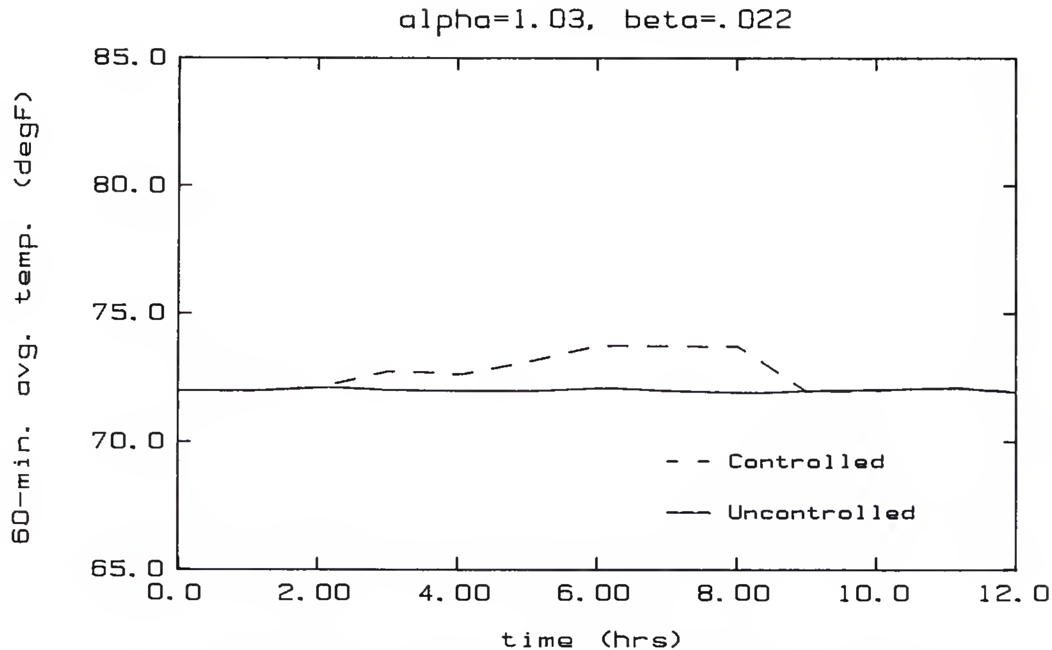


Fig. I-8: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Centralized.

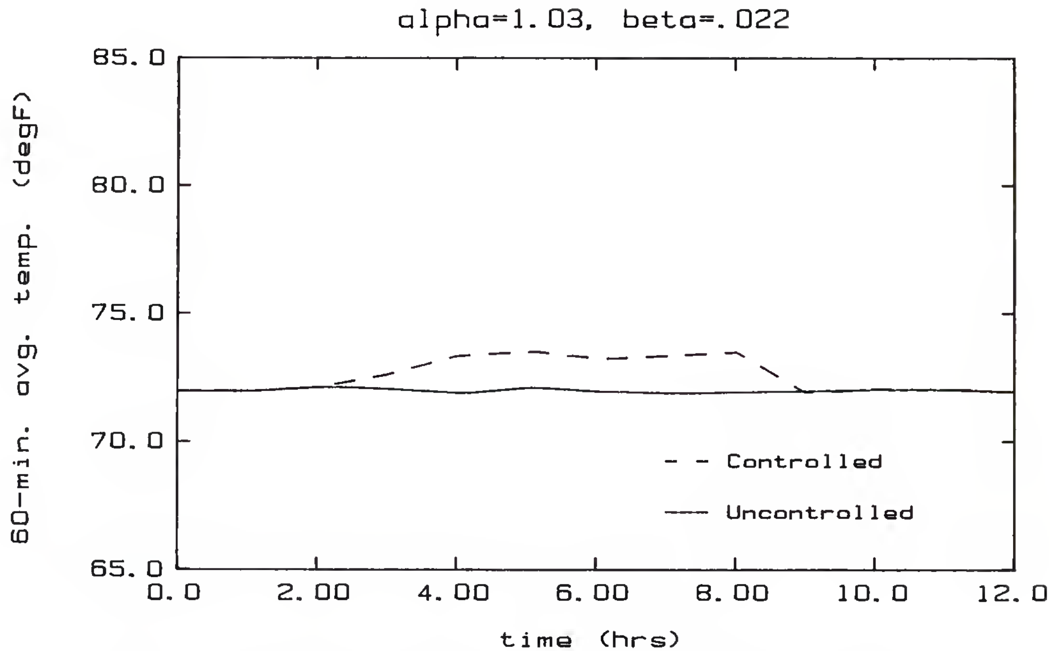


Fig. I-9: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

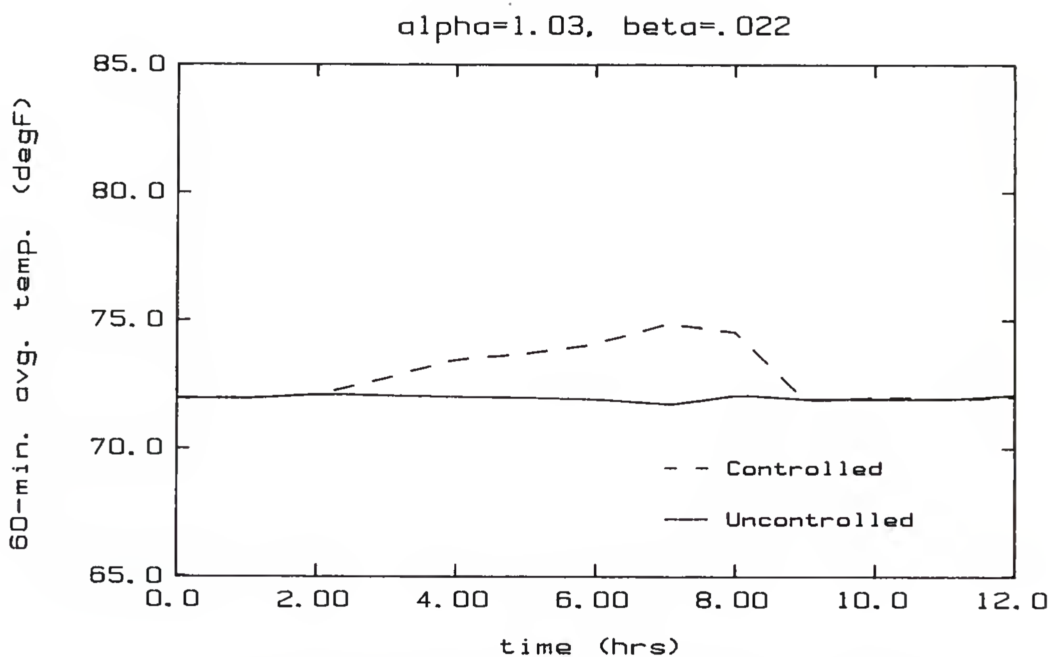


Fig. I-10: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Centralized.

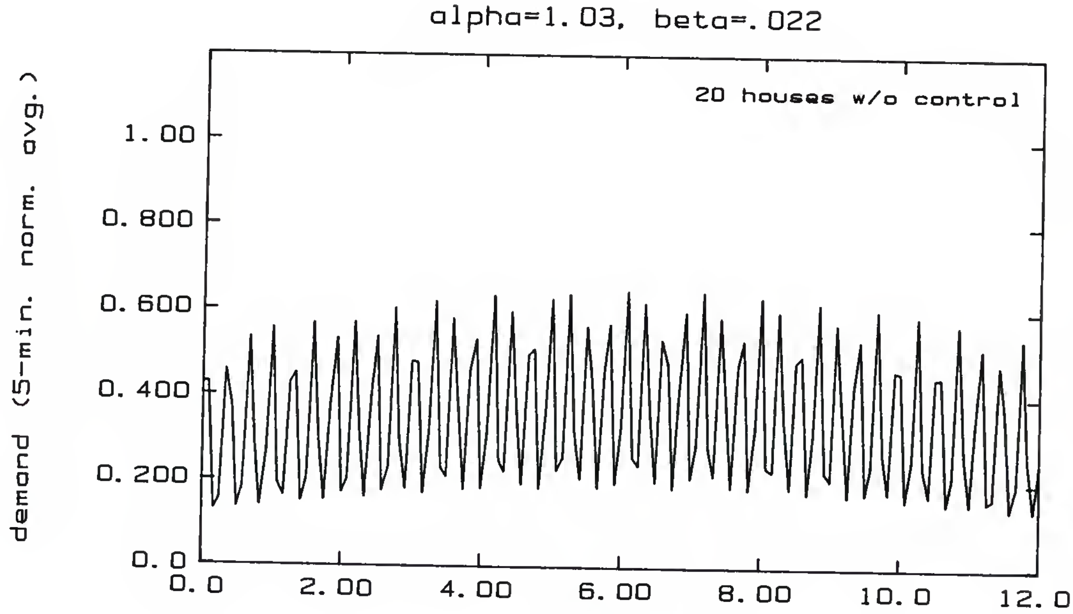


Fig. I-11: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

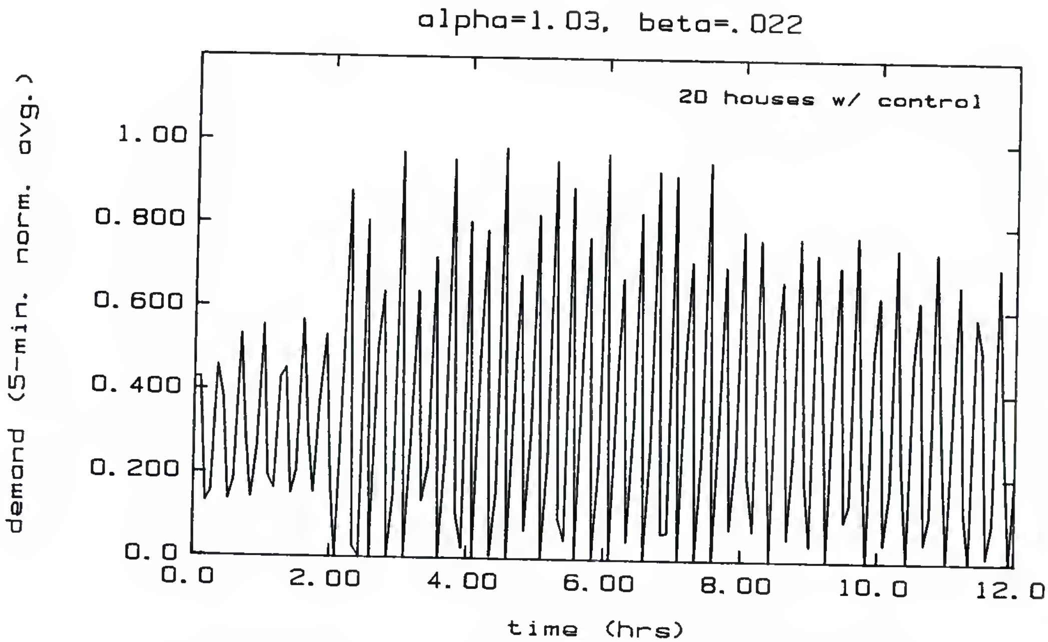


Fig. I-12: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 90 F.

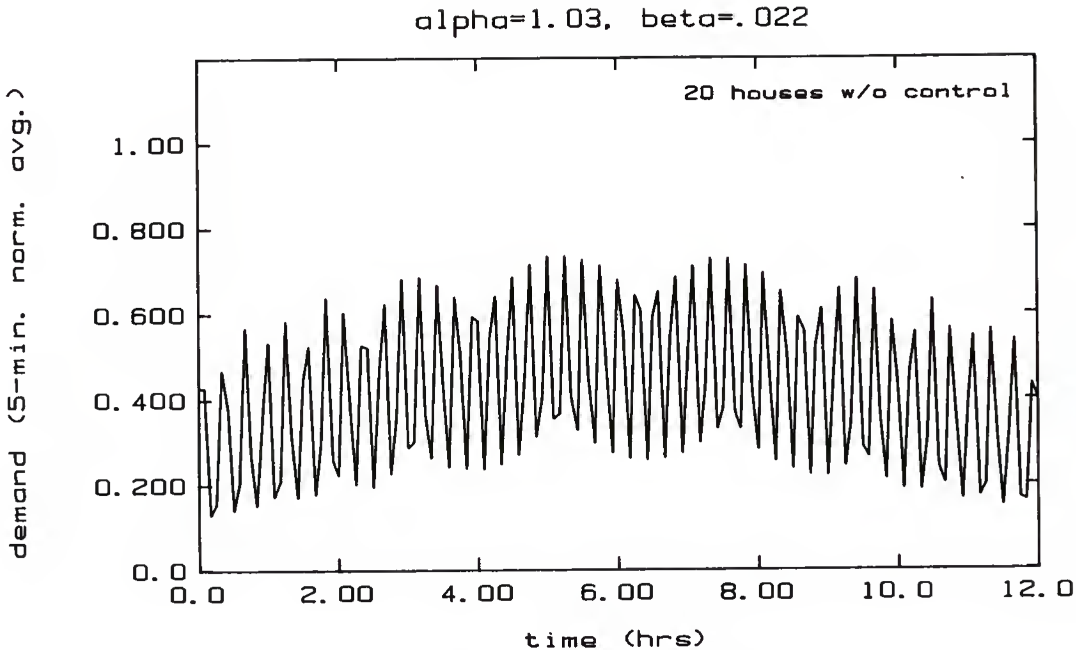


Fig. I-13: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

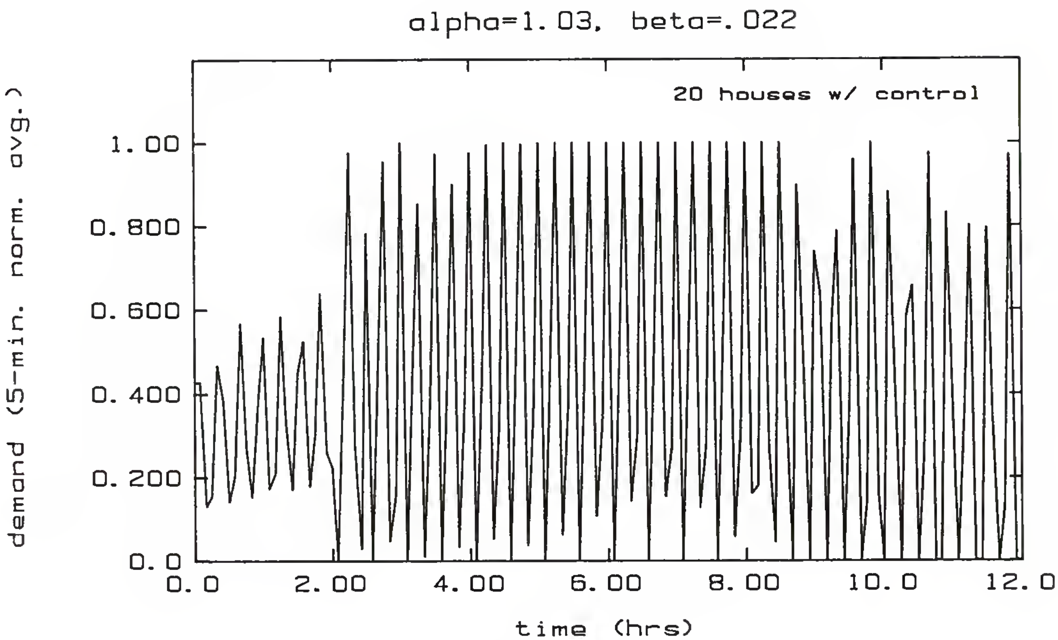


Fig. I-14: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 95 F.

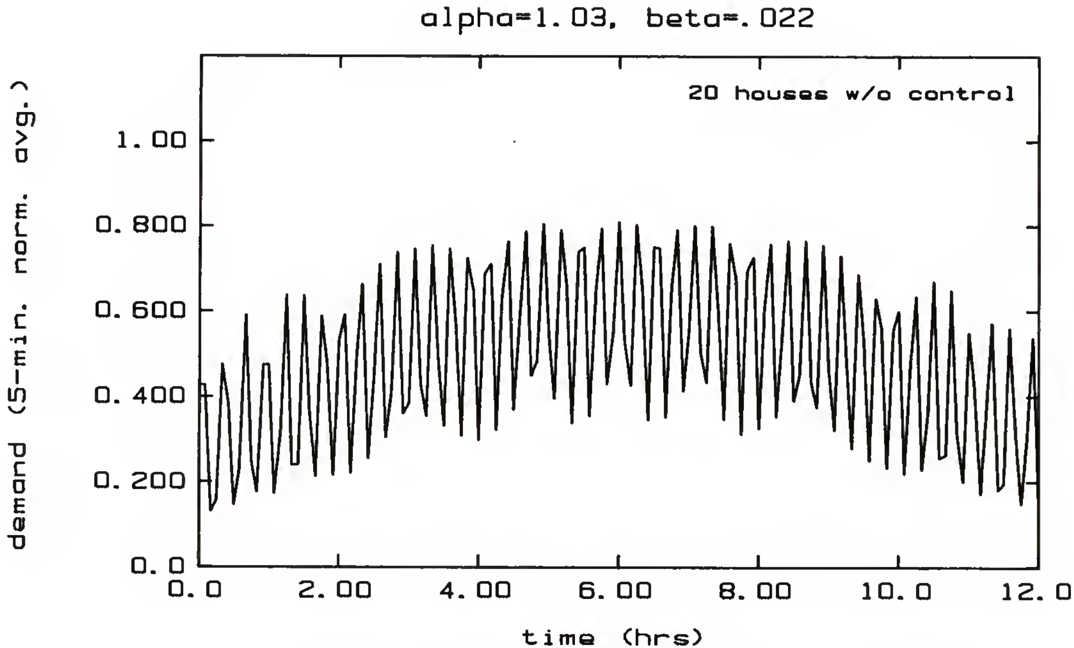


Fig. I-15: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

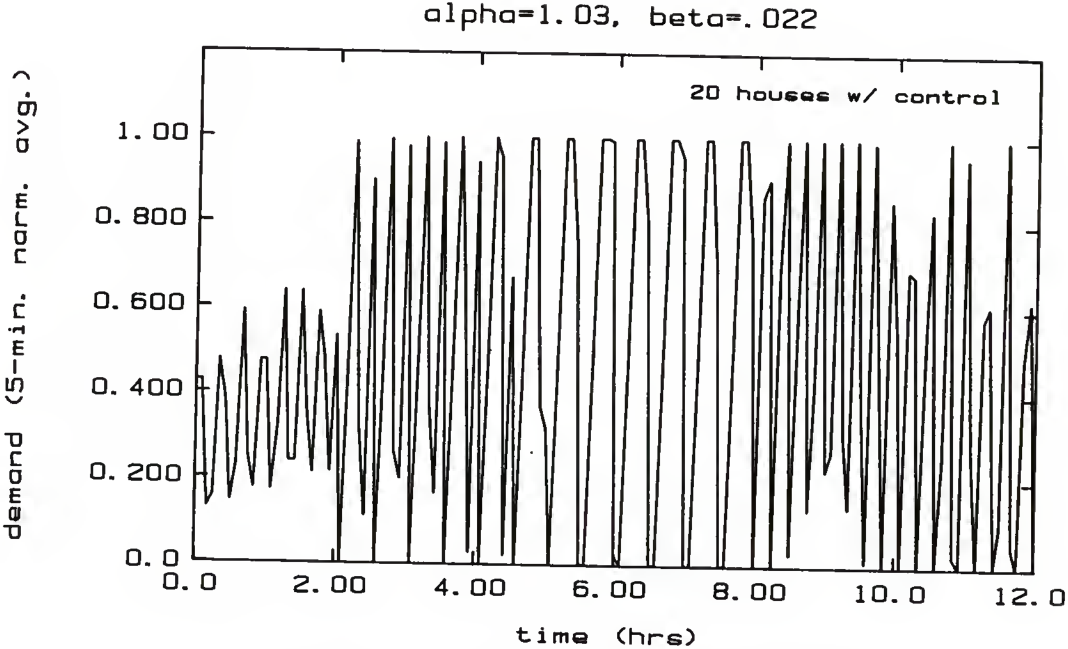


Fig. I-16: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 100 F.

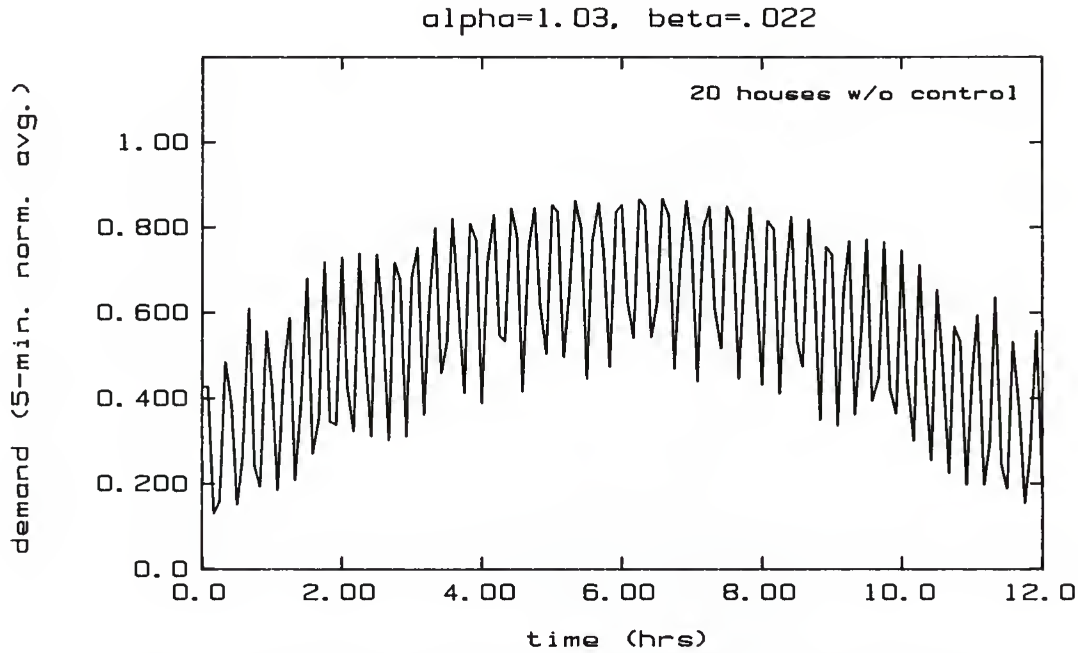


Fig. I-17: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

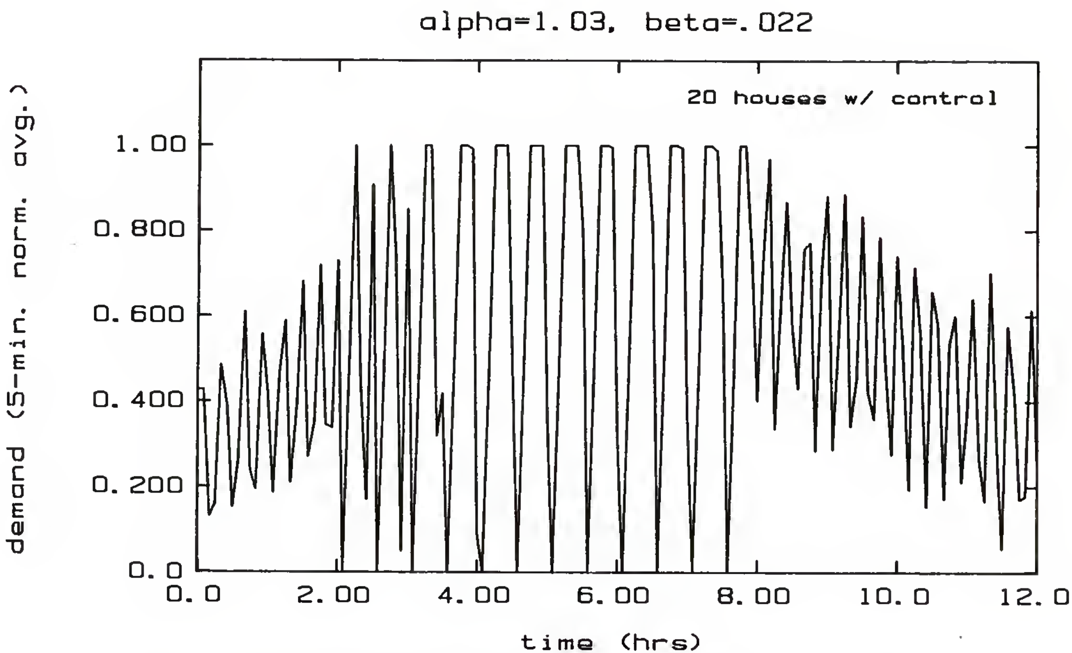


Fig. I-18: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 105 F.

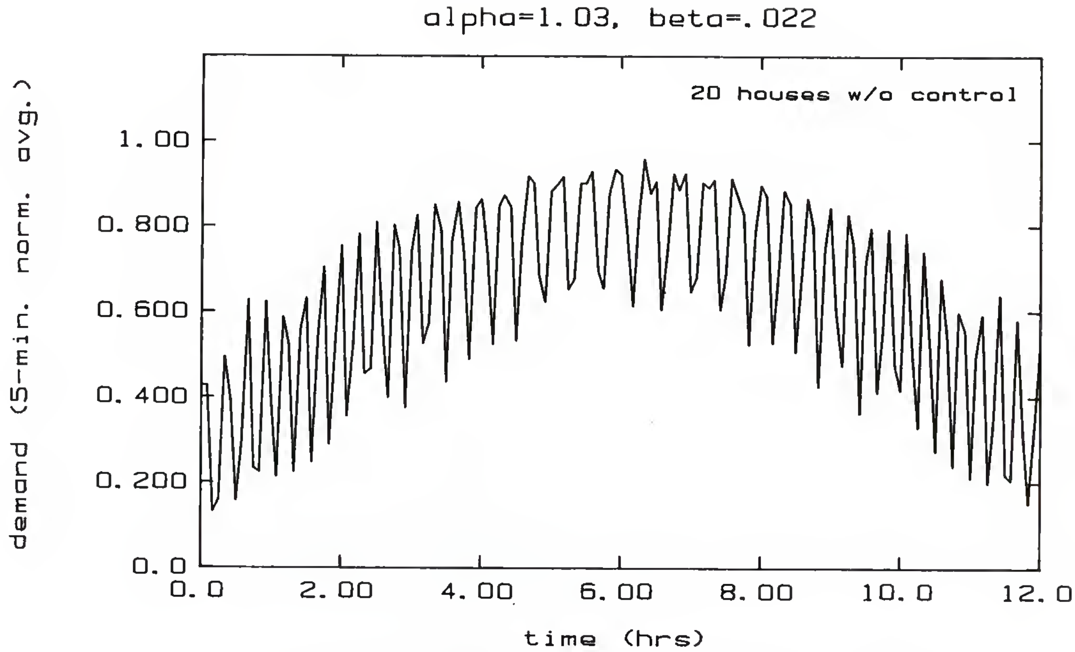


Fig. I-19: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

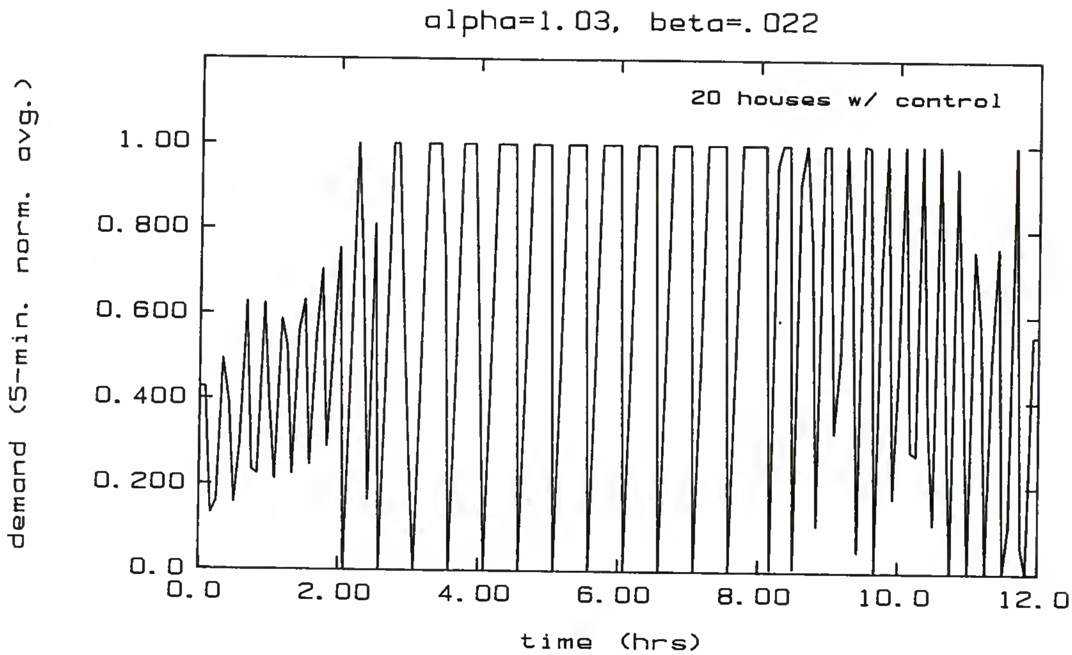


Fig. I-20: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Centralized. Driving Temperature is Piece-wise Constant With a Peak Value of 110 F.

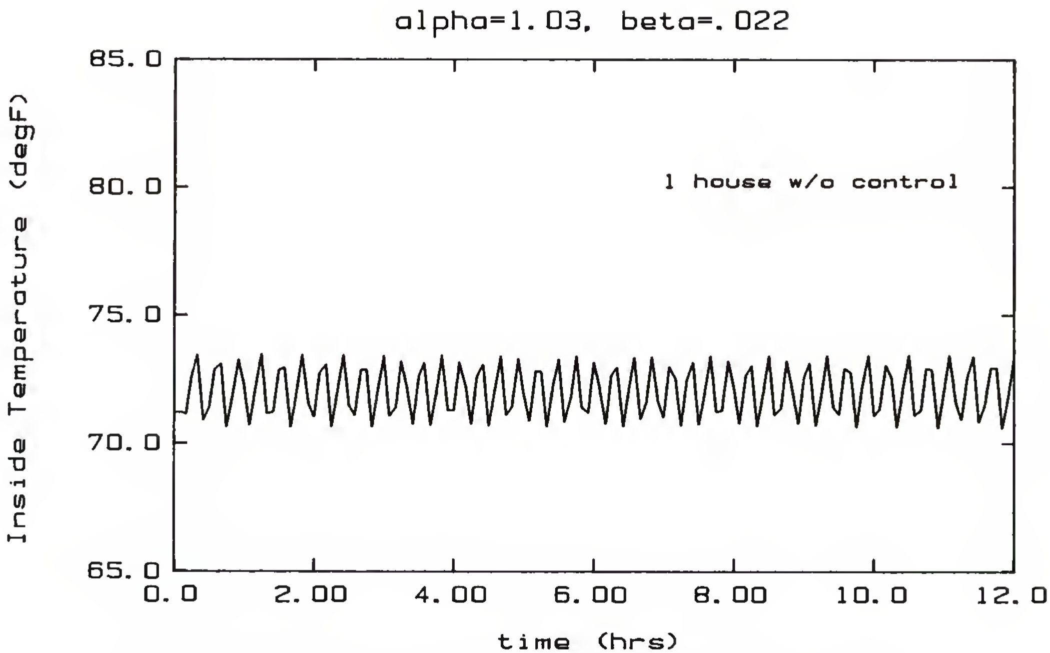


Fig. I-21: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period.

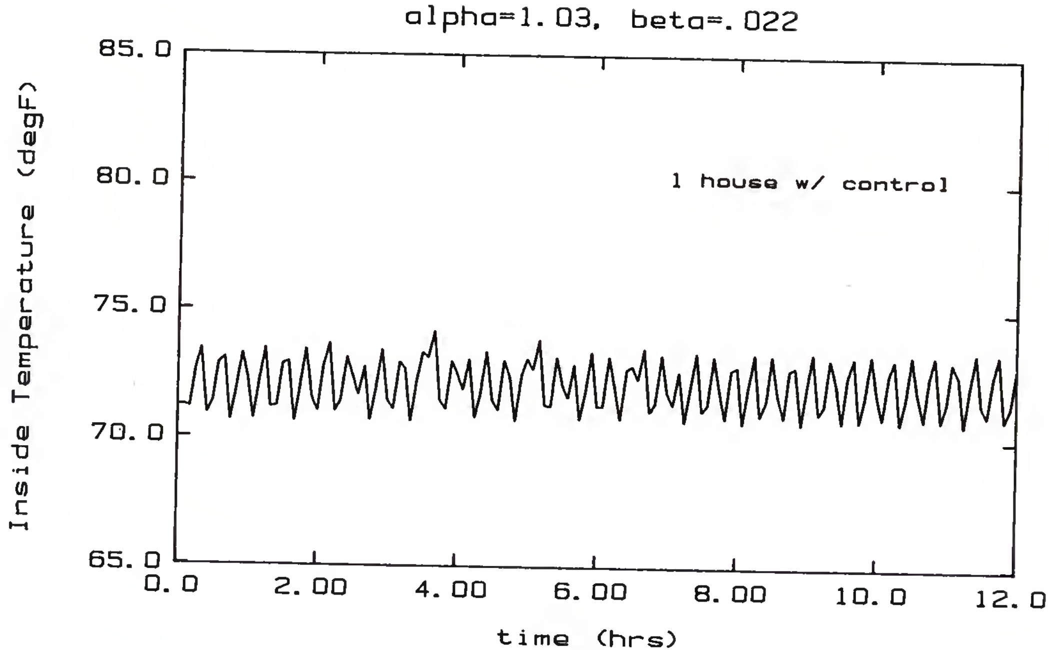


Fig. I-22: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=90 F) Over a 12 Hour Period. Control is Centralized.

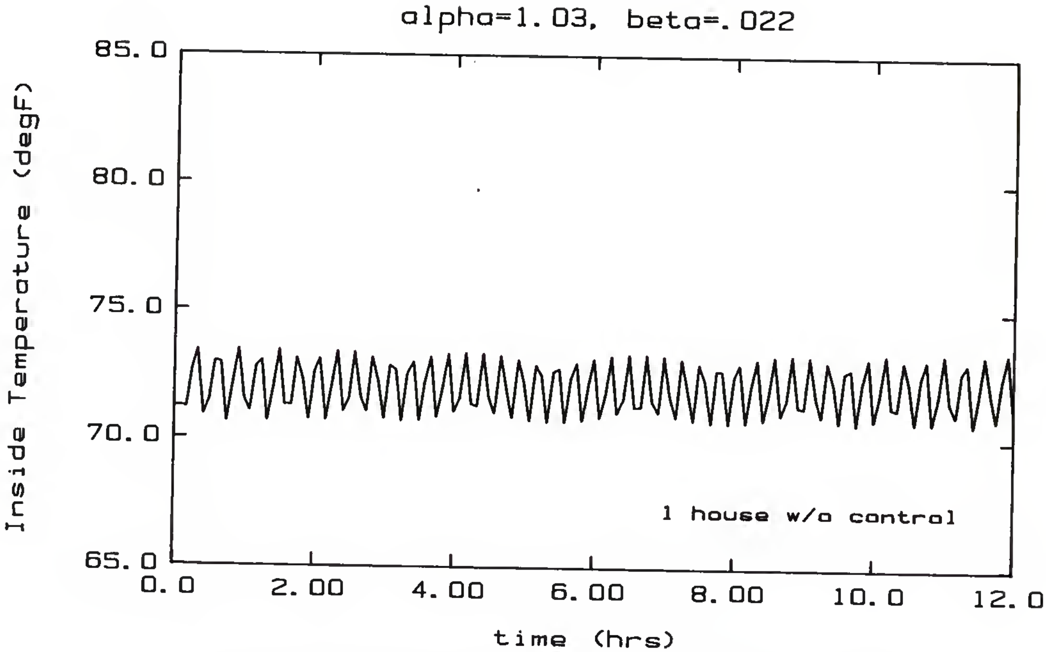


Fig. I-23: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period.

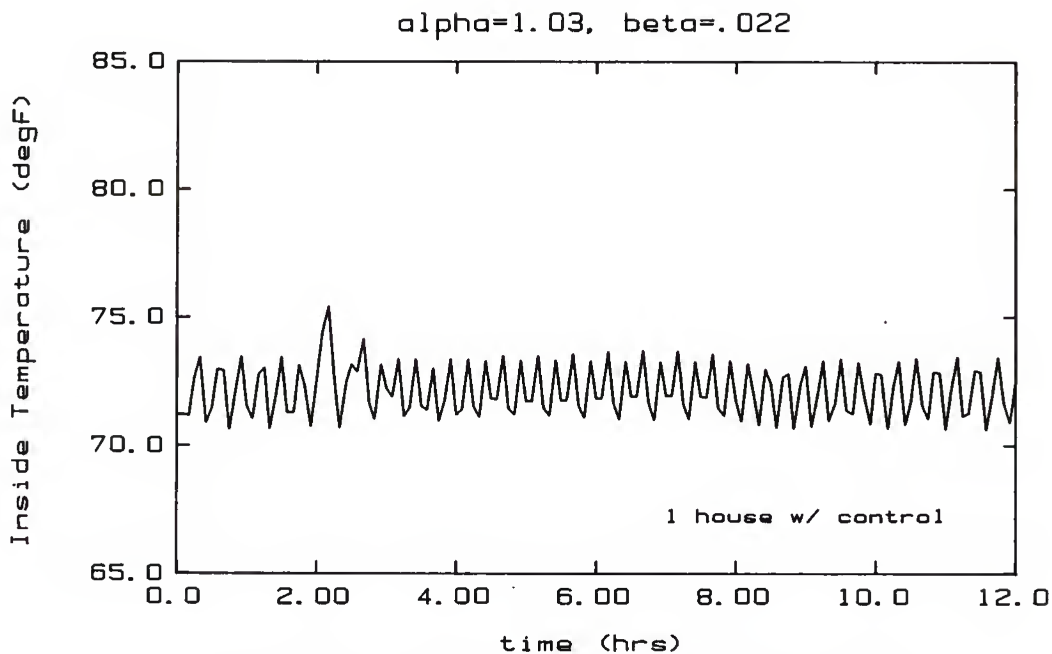


Fig. I-24: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=95 F) Over a 12 Hour Period. Control is Centralized.

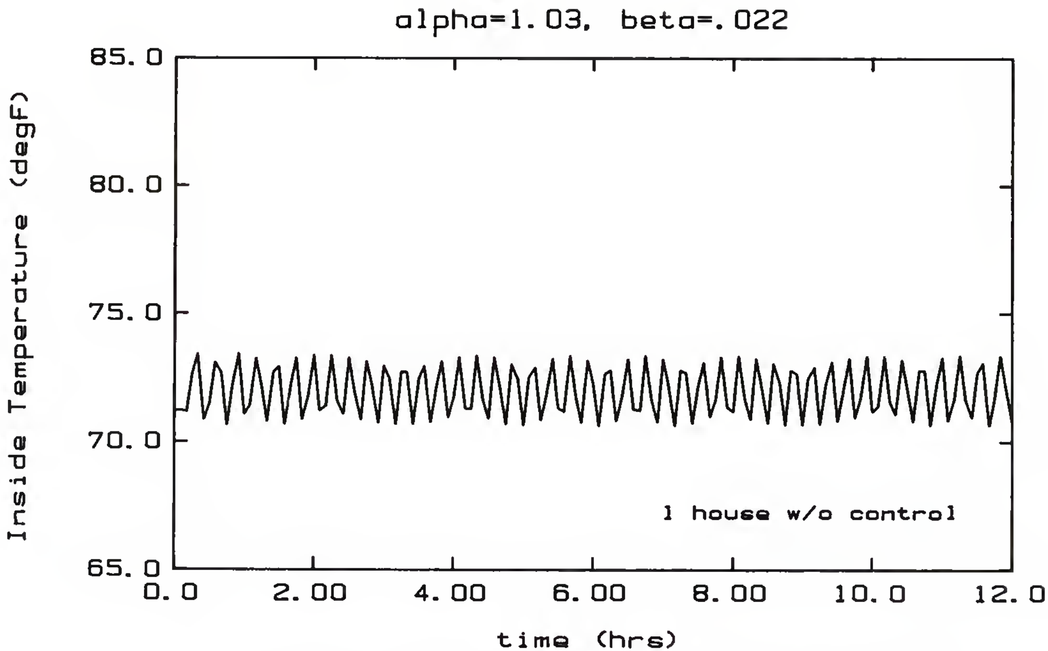


Fig. I-25: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period.

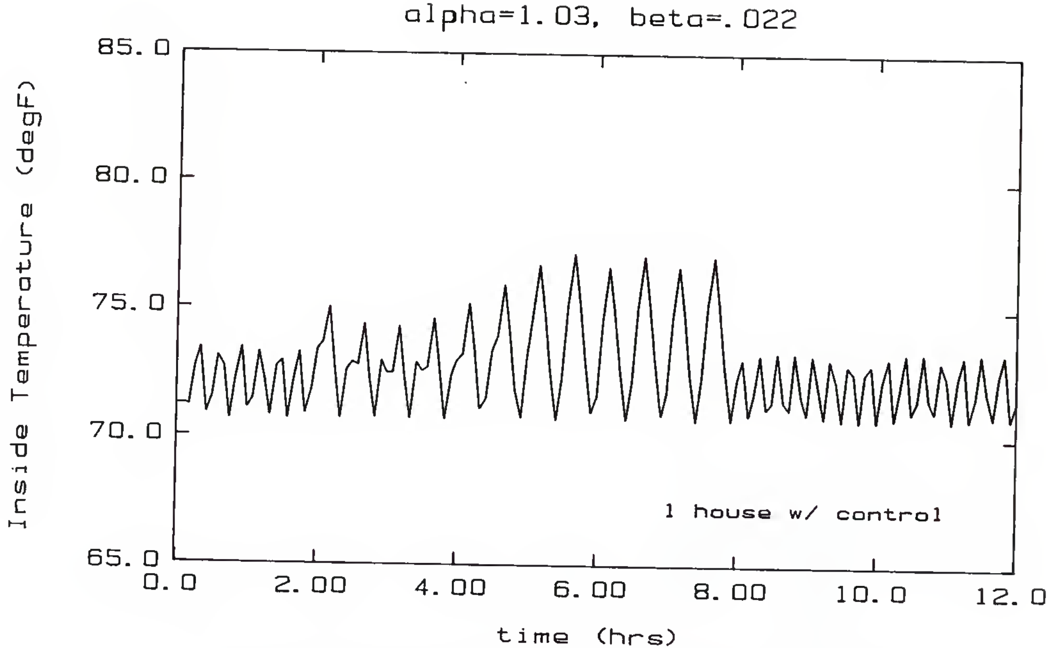


Fig. I-26: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Centralized.

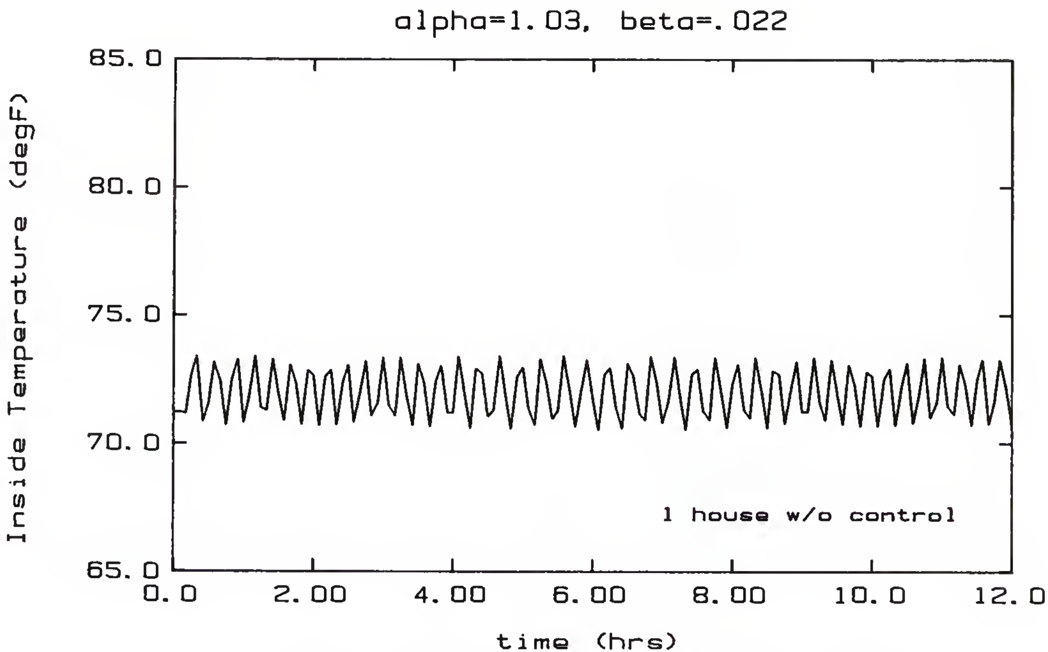


Fig. I-27: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period.

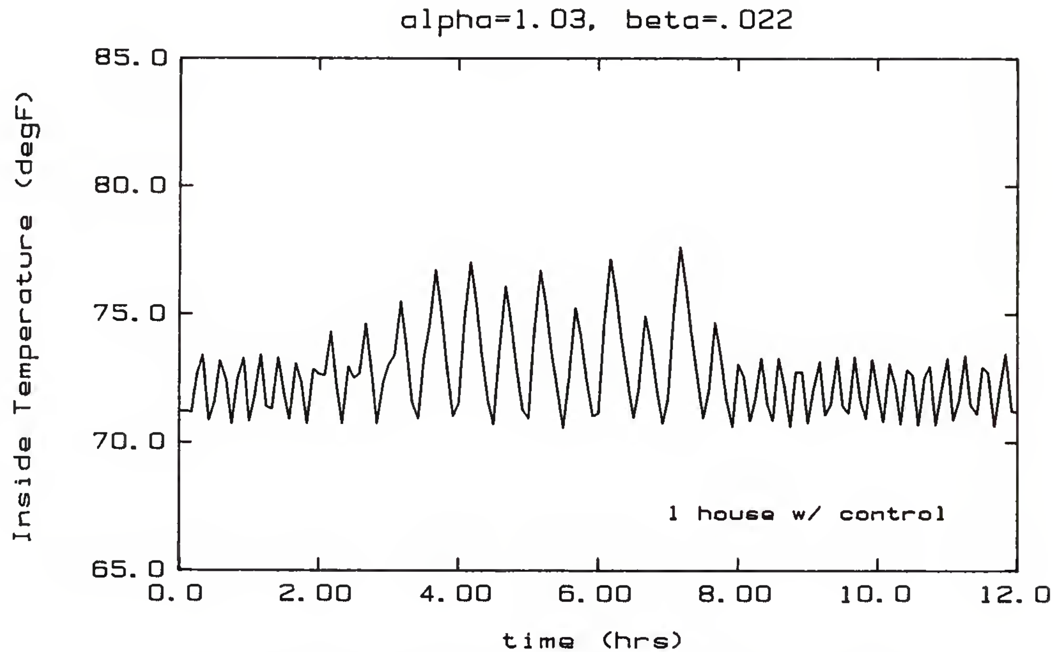


Fig. I-28: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Centralized.

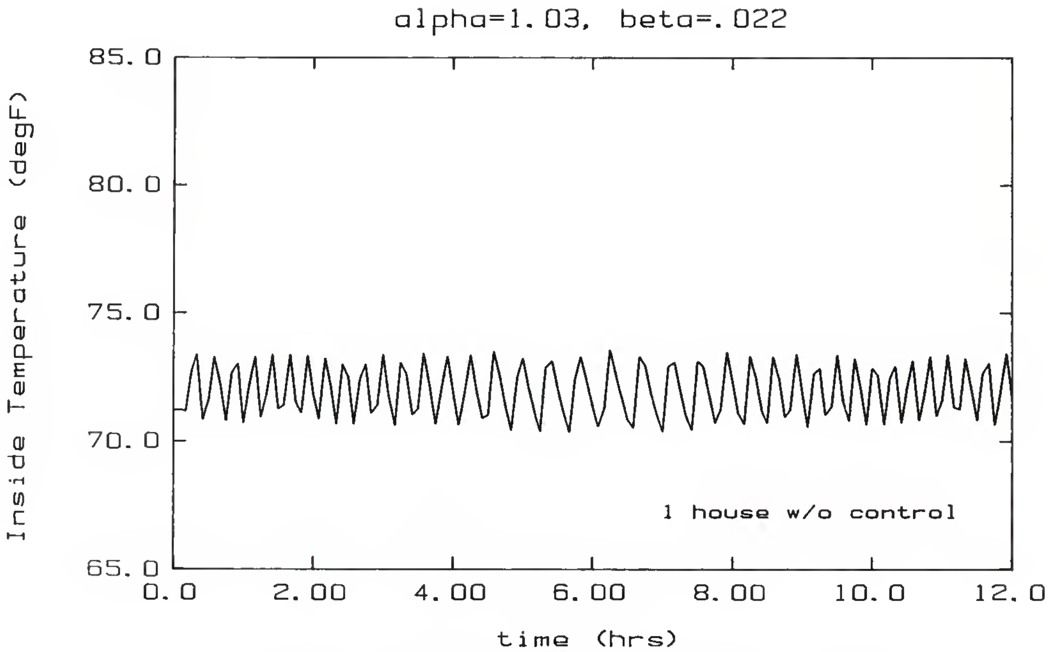


Fig. I-29: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period.

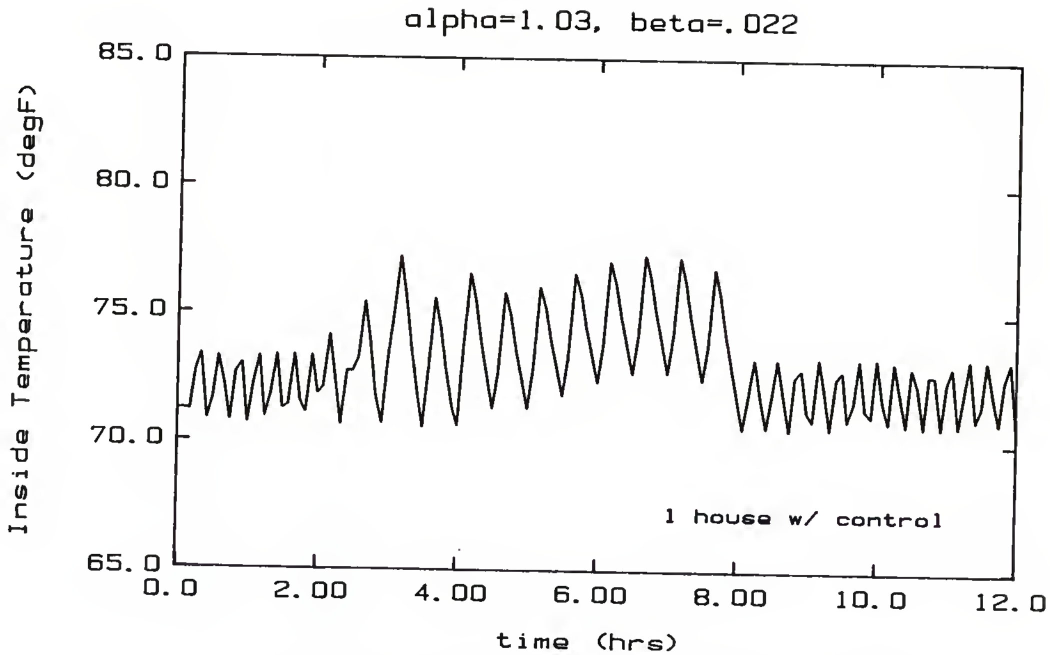


Fig. I-30: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Centralized.

APPENDIX J

PLOTS OF 5 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 1. CONTROL IS LOAD LEVELER TYPE

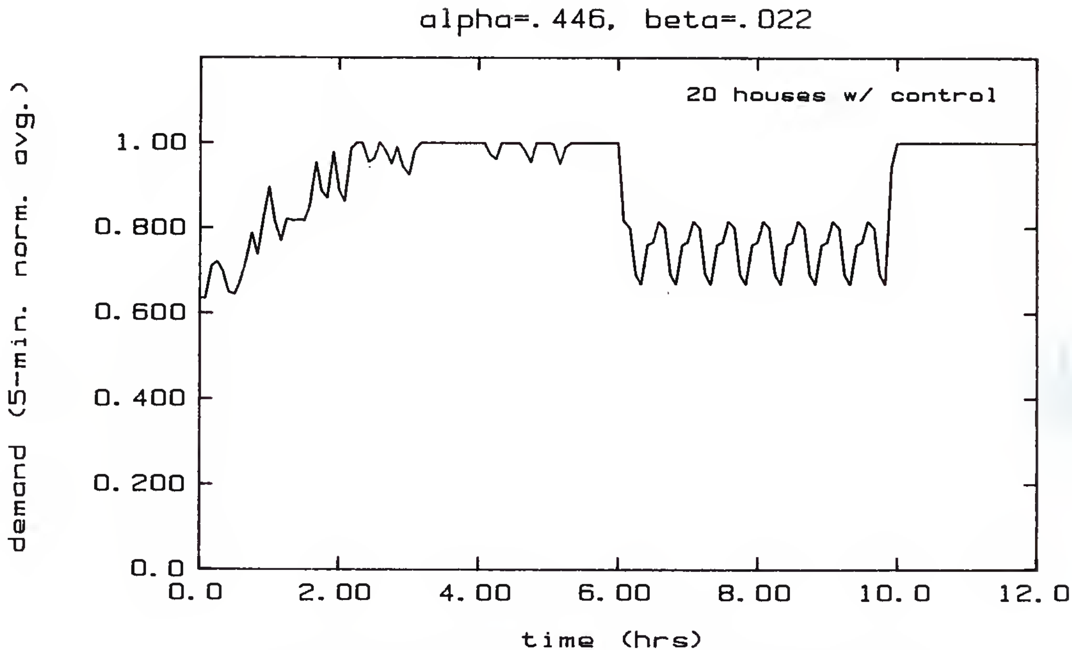


Fig. J-1: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 1 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

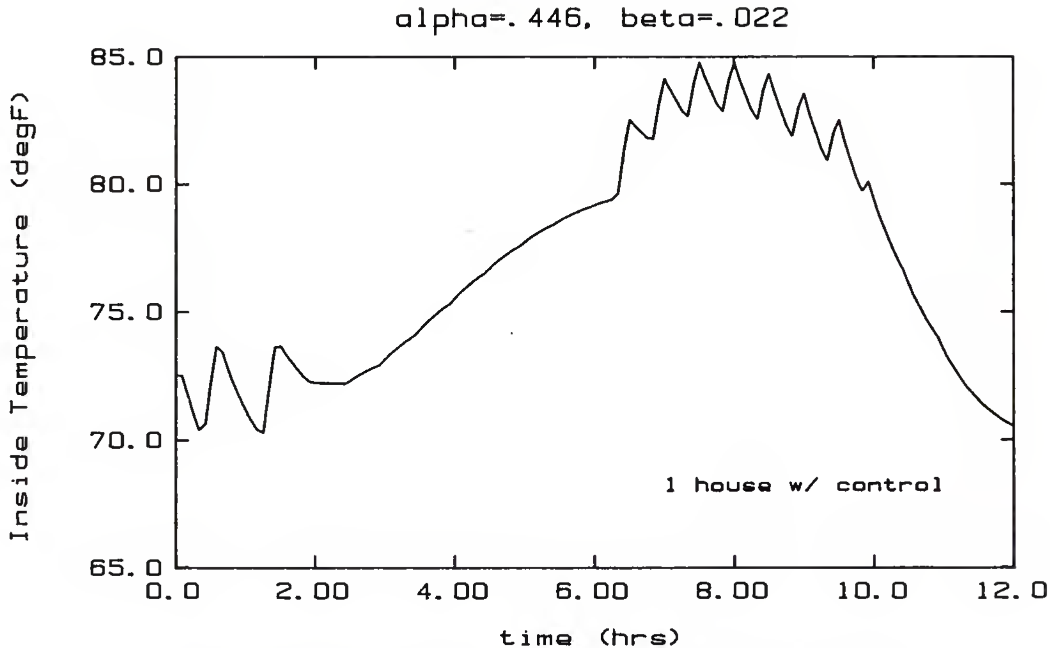


Fig. J-2: Five-Minute Average Inside Temperature for a Typical Case 1 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

APPENDIX K

PLOTS OF 5 AND 60 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 AND 60 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 2. CONTROL IS LOAD LEVELER TYPE

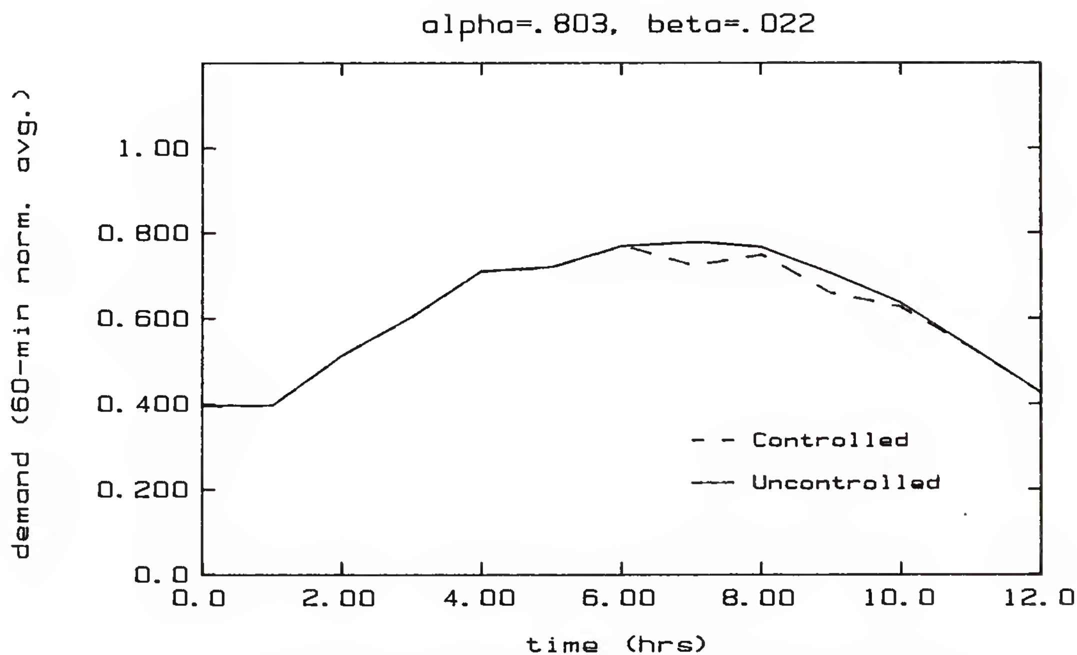


Fig. K-1: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

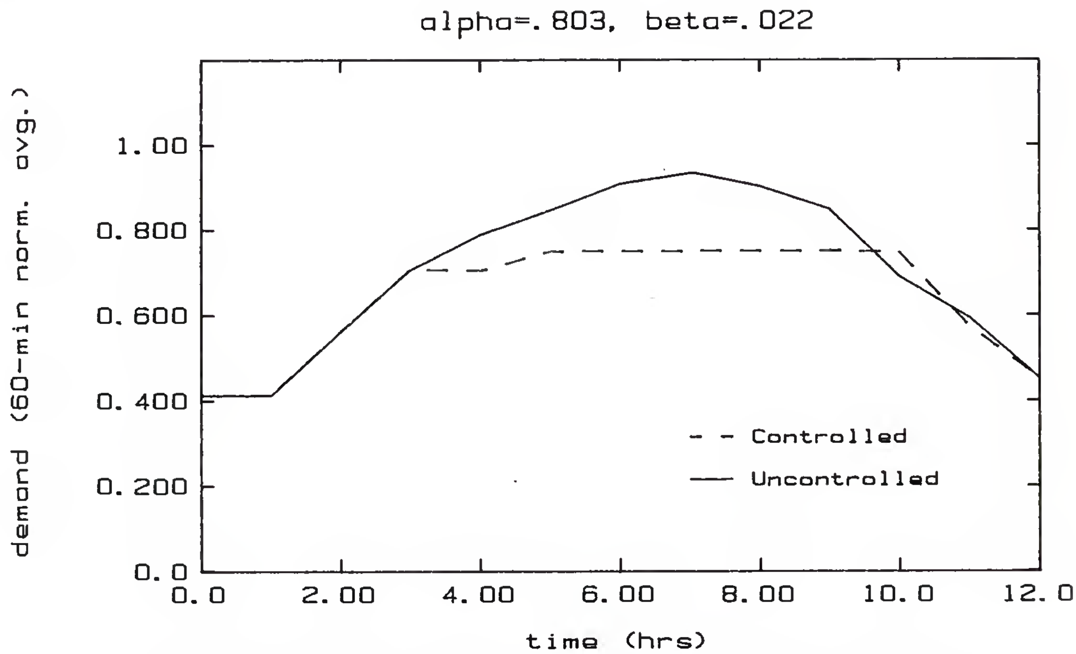


Fig. K-2: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

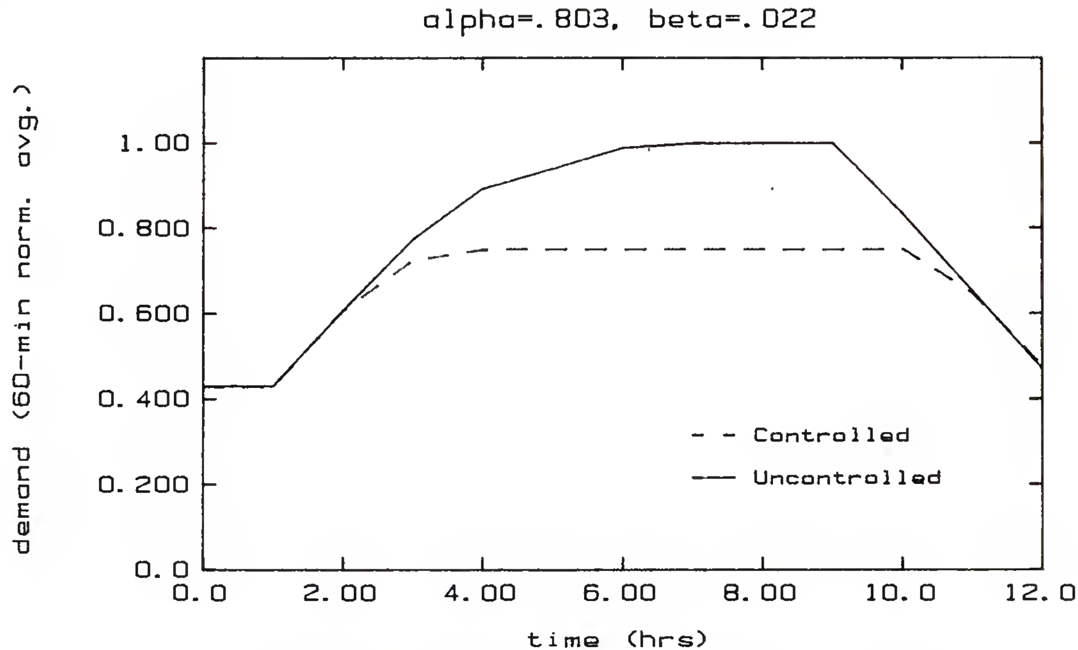


Fig. K-3: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2.Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 110 F.

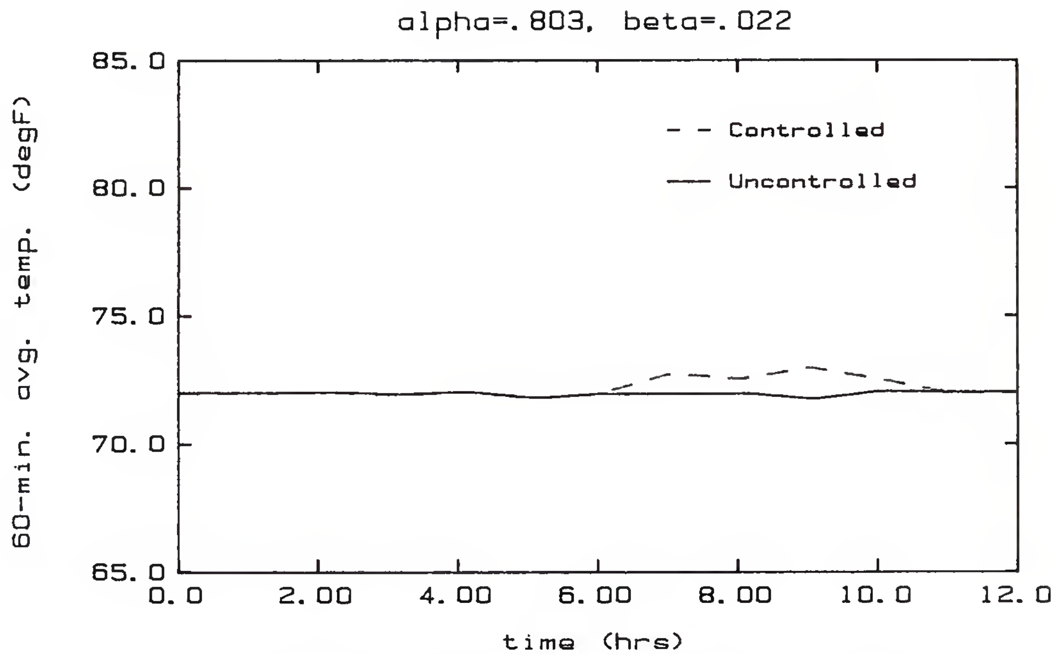


Fig. K-4: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

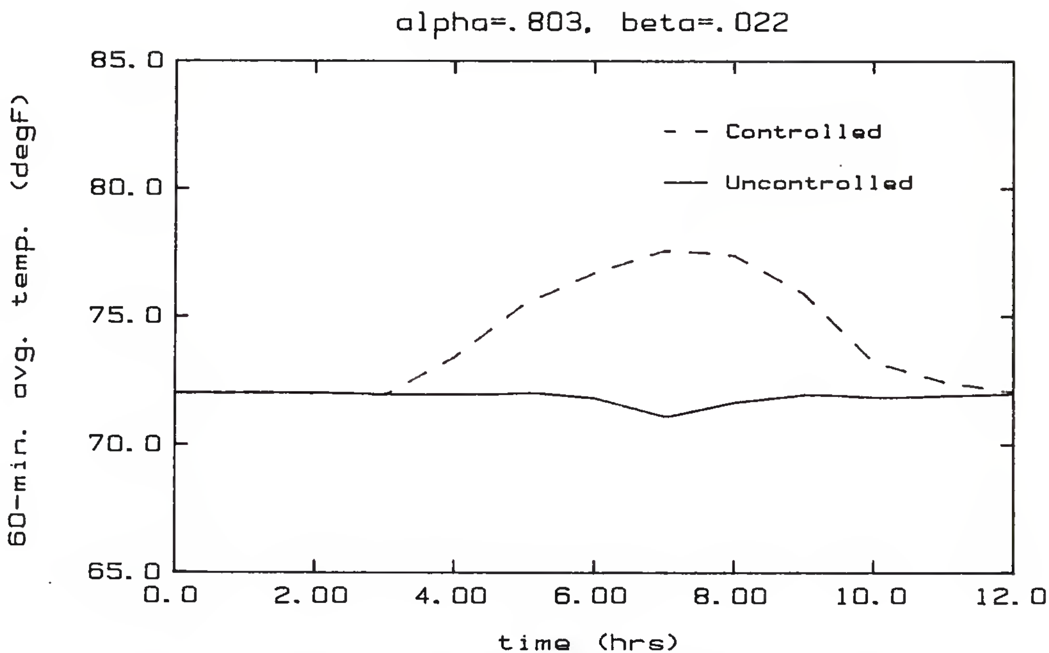


Fig. K-5: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

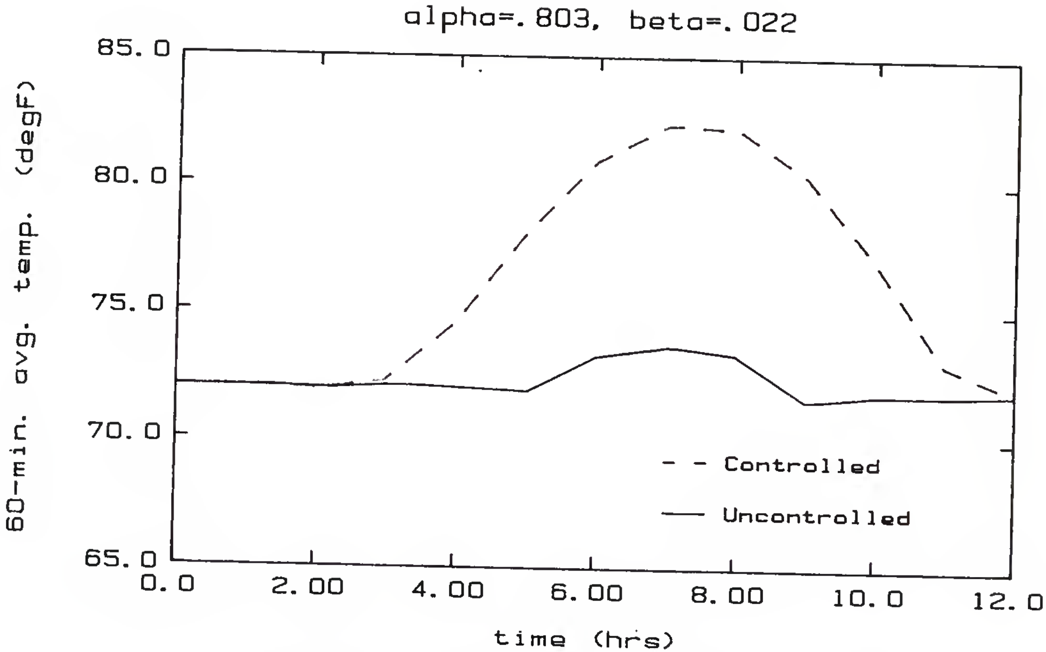


Fig. K-6: Sixty-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Load Leveler Type.

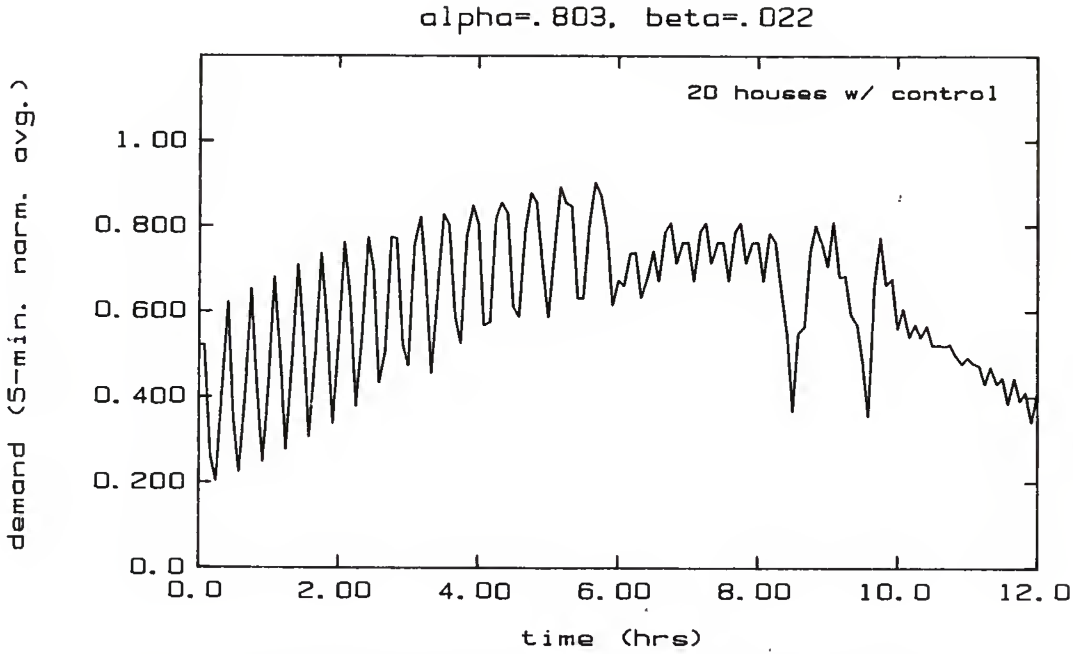


Fig. K-7: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

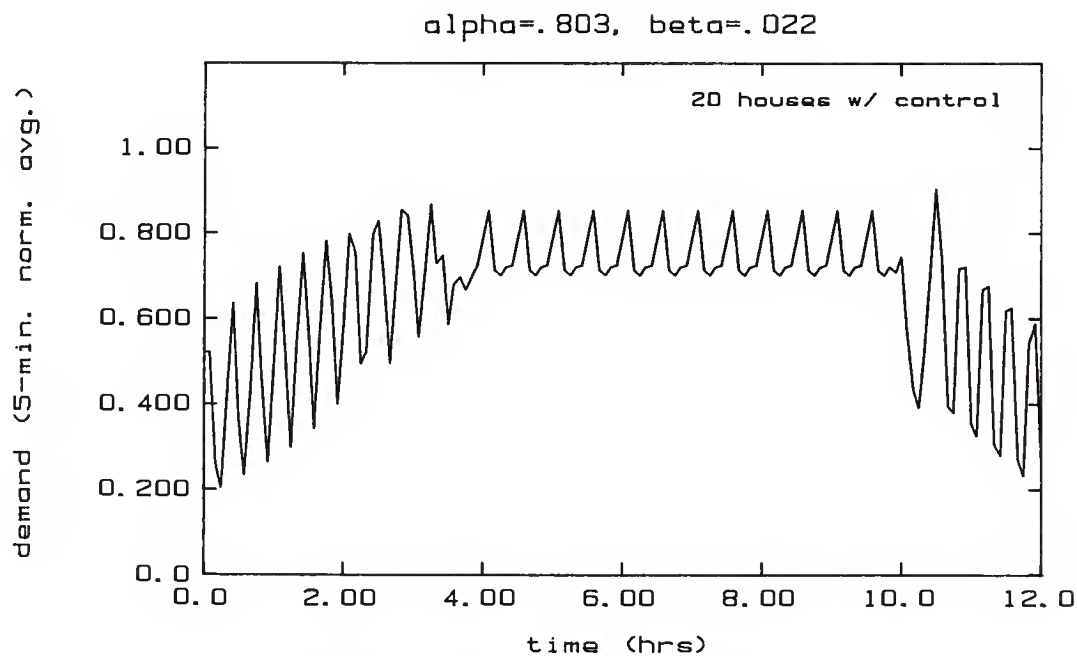


Fig. K-8: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

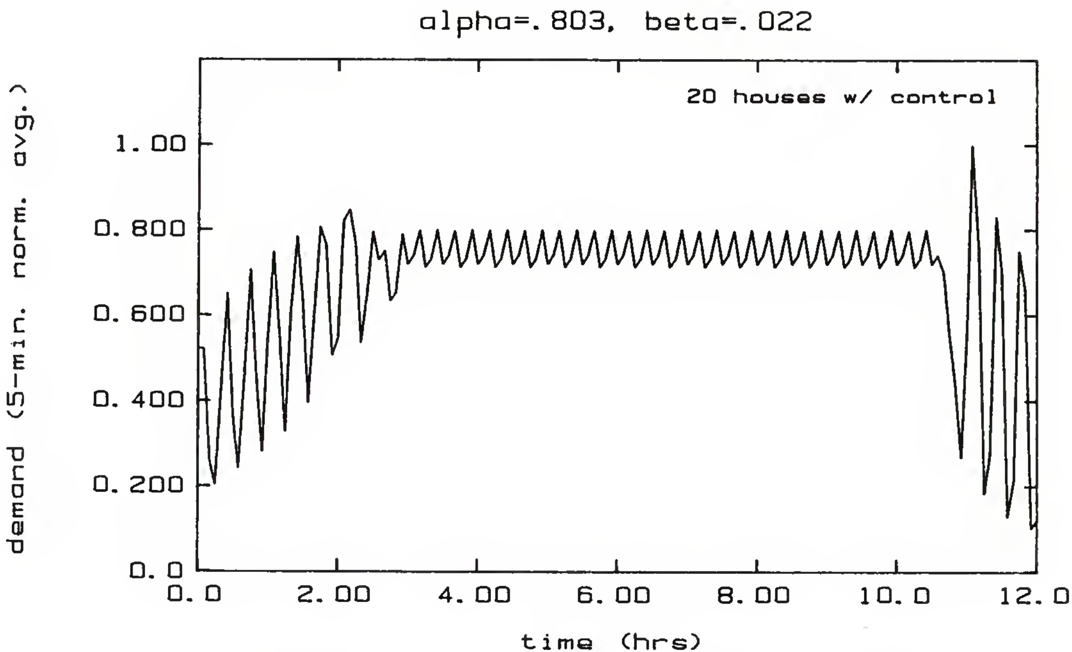


Fig. K-9: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 2 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 110 F.

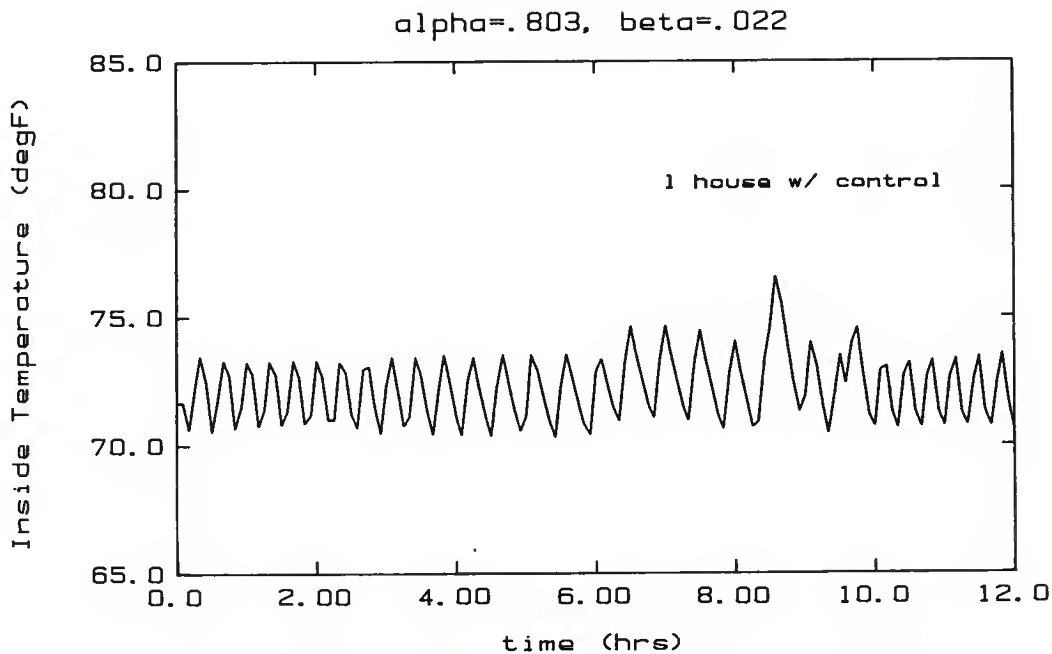


Fig. K-10: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

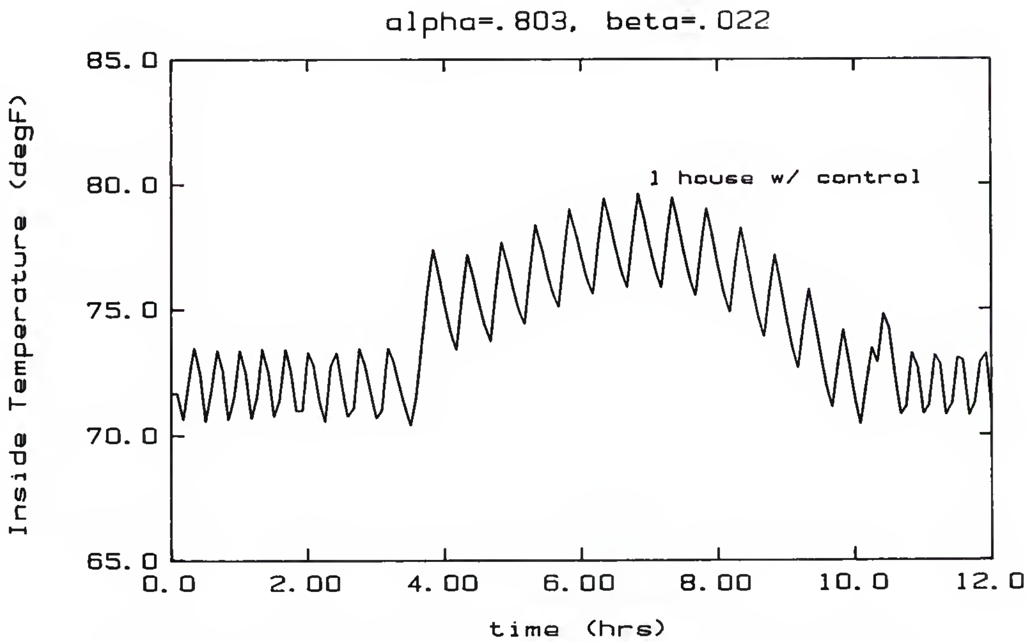


Fig. K-11: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

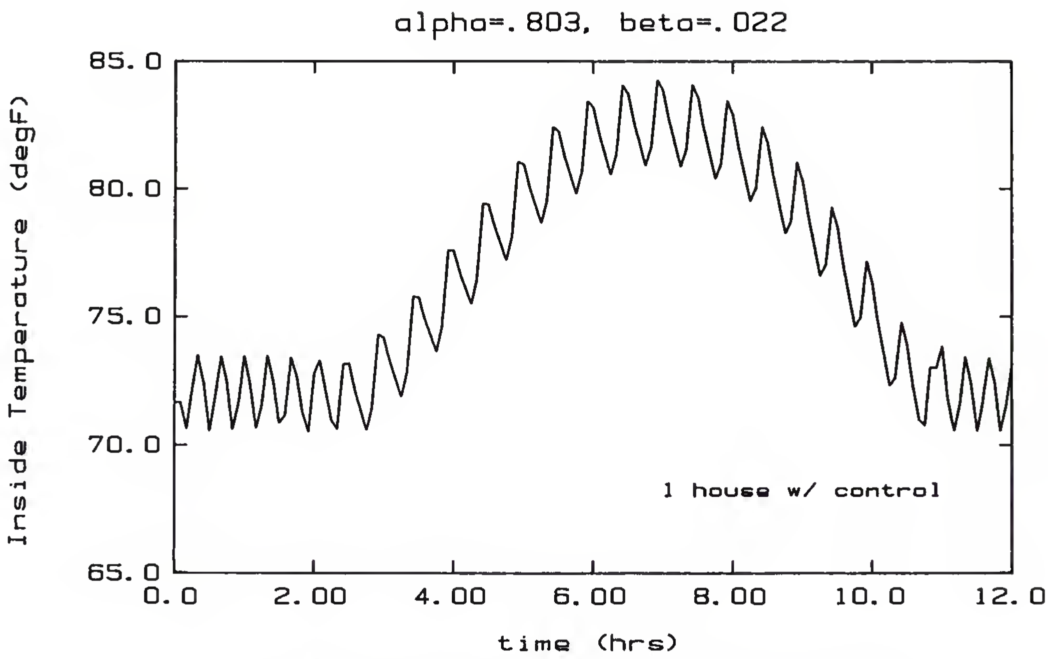


Fig. K-12: Five-Minute Average Inside Temperature for a Typical Case 2 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Load Leveler Type.

APPENDIX L

PLOTS OF 5 AND 60 MINUTE AVERAGE DEMAND (NORMALIZED FOR 20 HOUSES) AND 5 AND 60 MINUTE AVERAGE TEMPERATURE (FOR A TYPICAL HOUSE) OVER A 10 HOUR PERIOD FOR CASE 3. CONTROL IS LOAD LEVELER TYPE

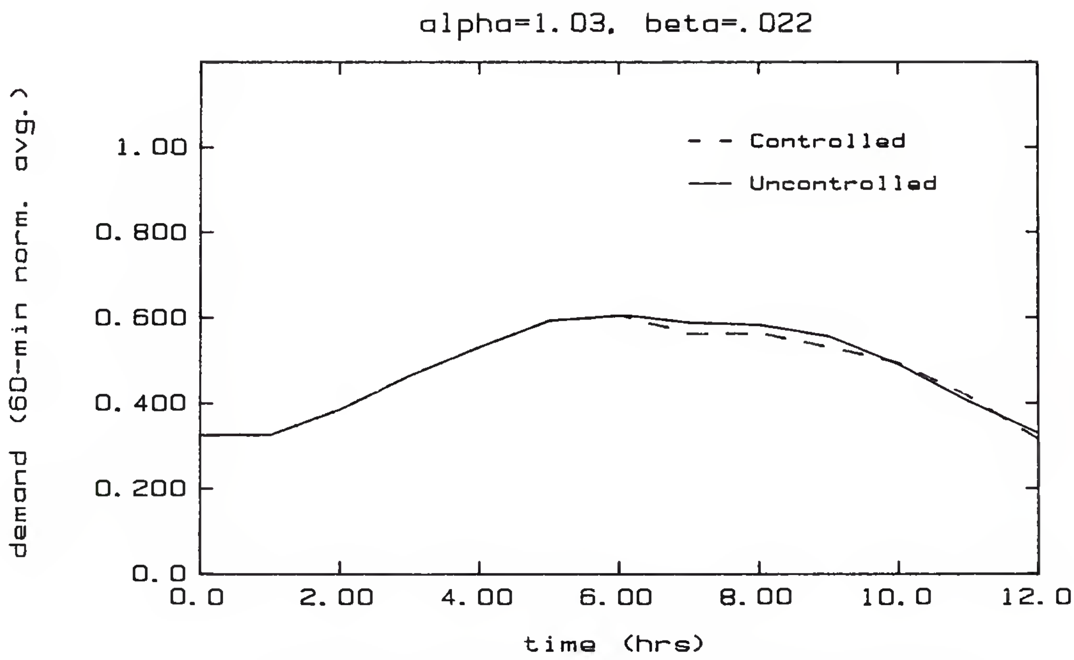


Fig. L-1: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

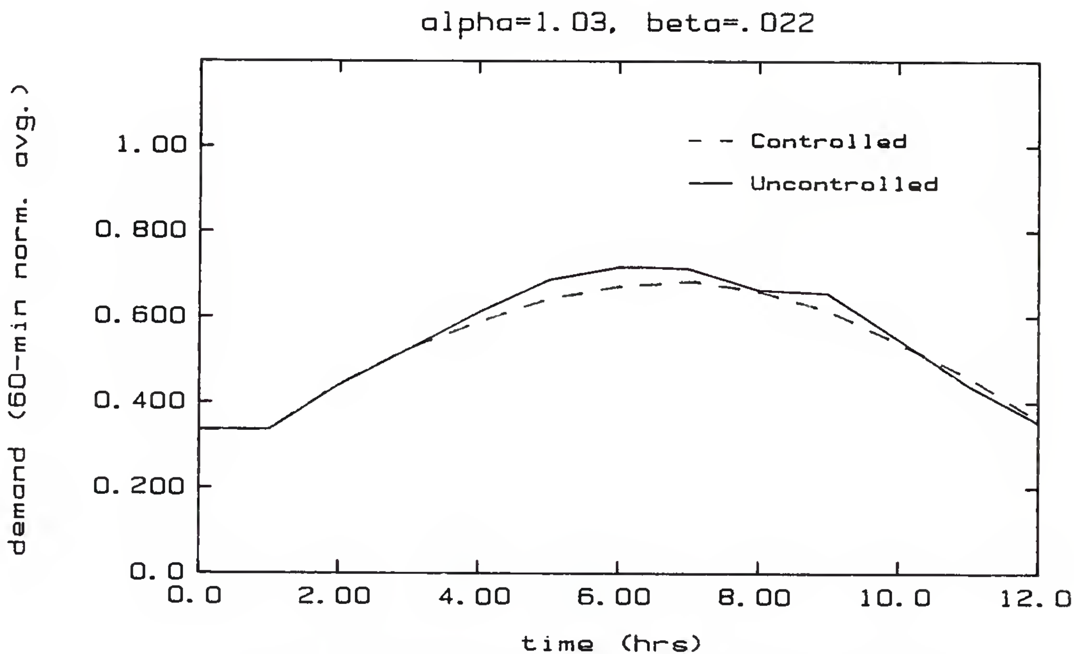


Fig. L-2: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

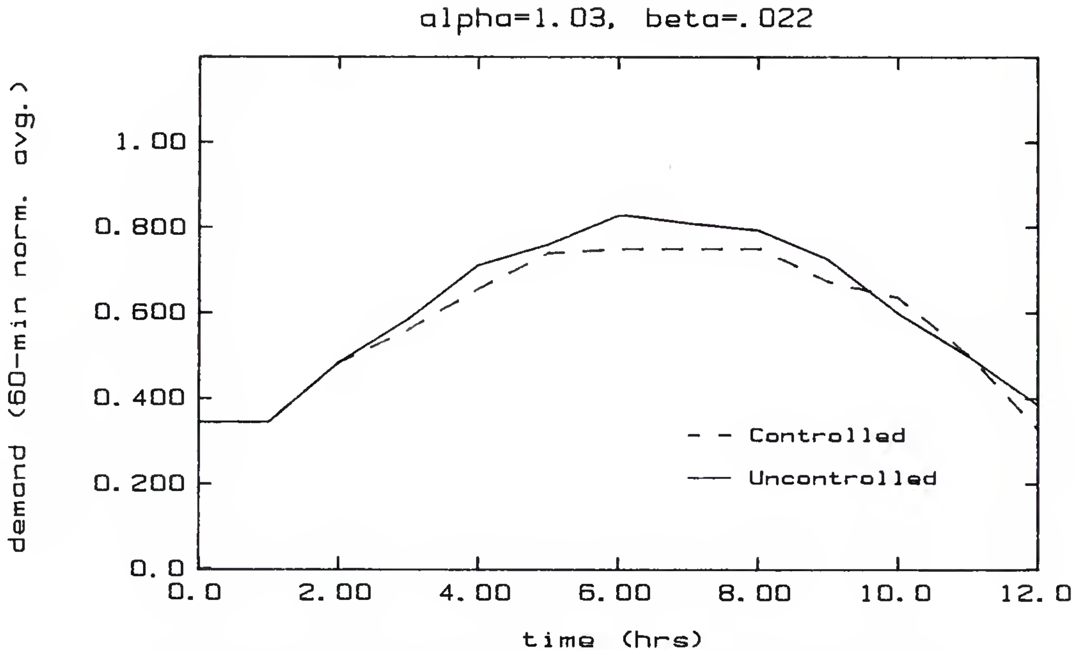


Fig. L-3: Sixty-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 110 F.

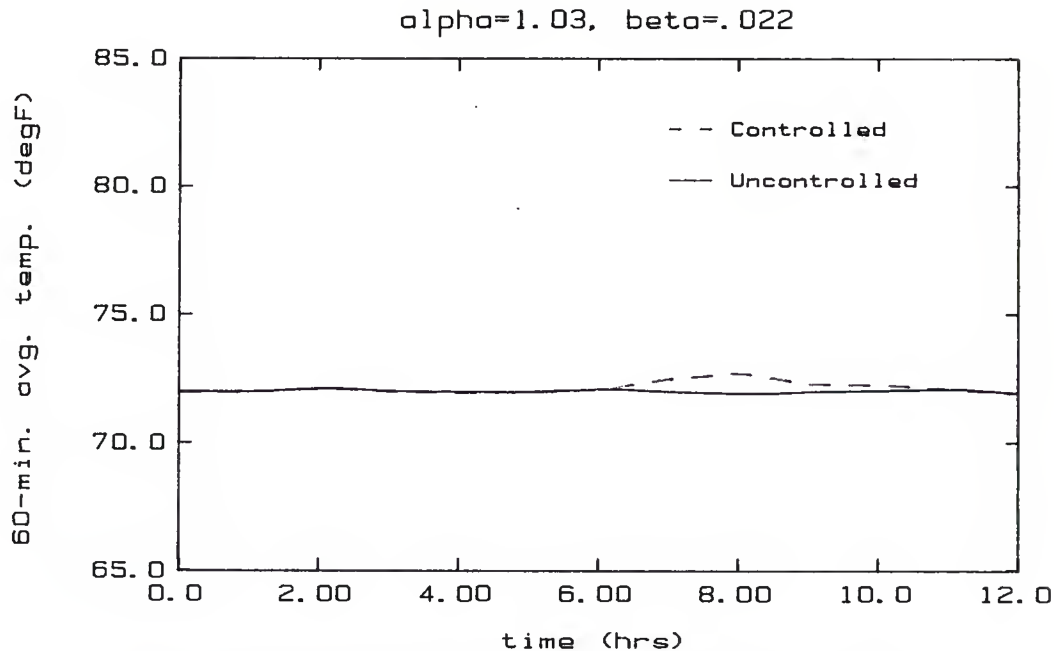


Fig. L-4: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

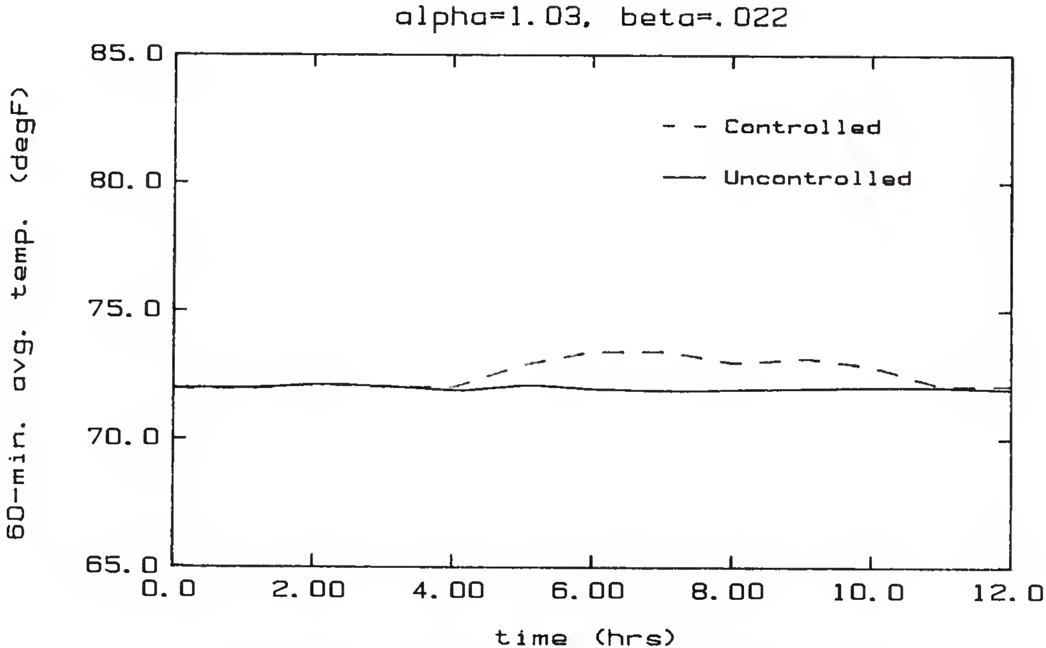


Fig. L-5: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

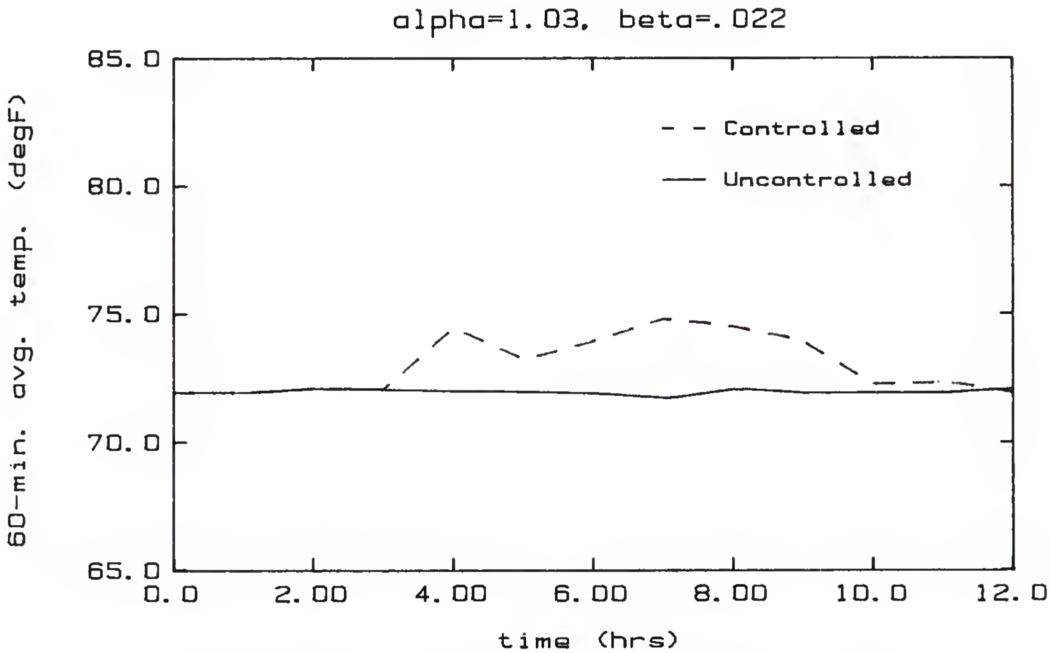


Fig. L-6: Sixty-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Load Leveler Type.

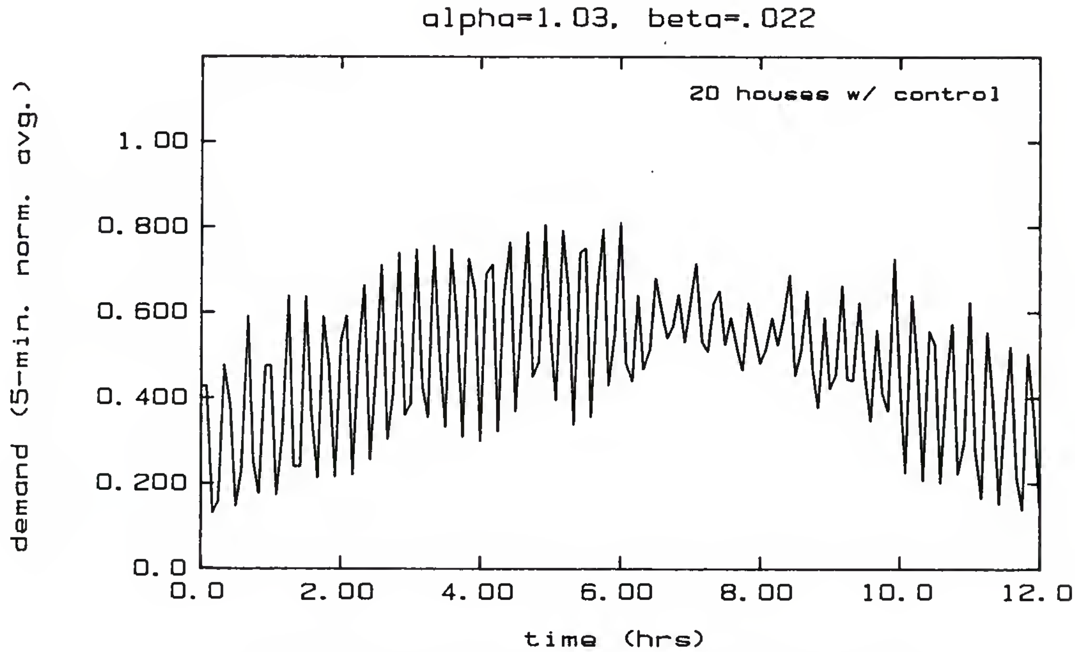


Fig. L-7: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

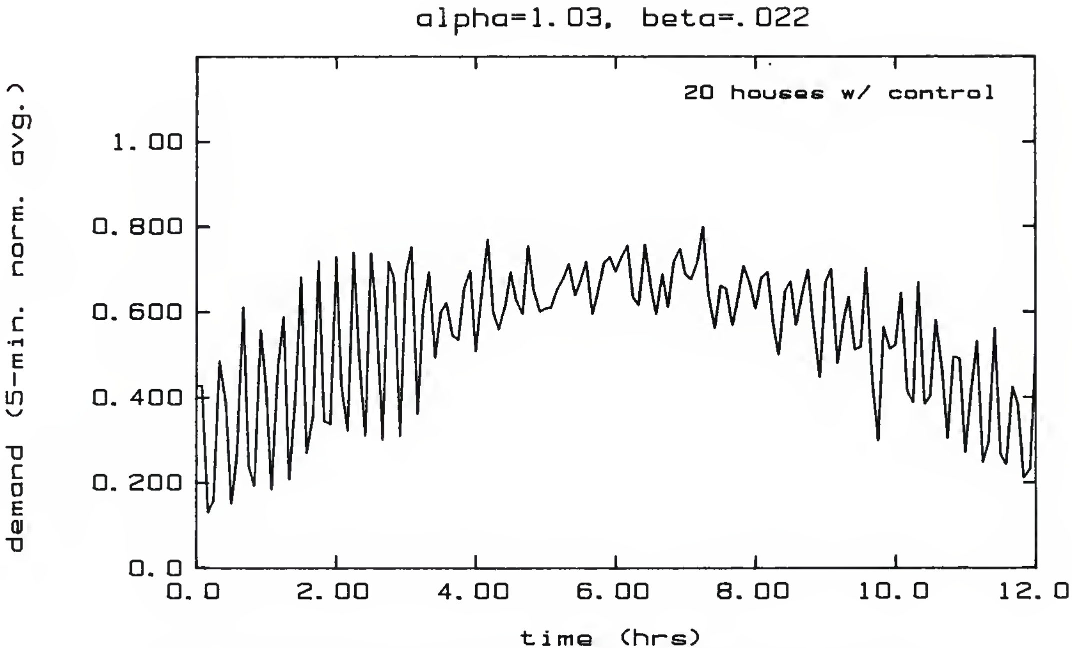


Fig. L-8: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 105 F.

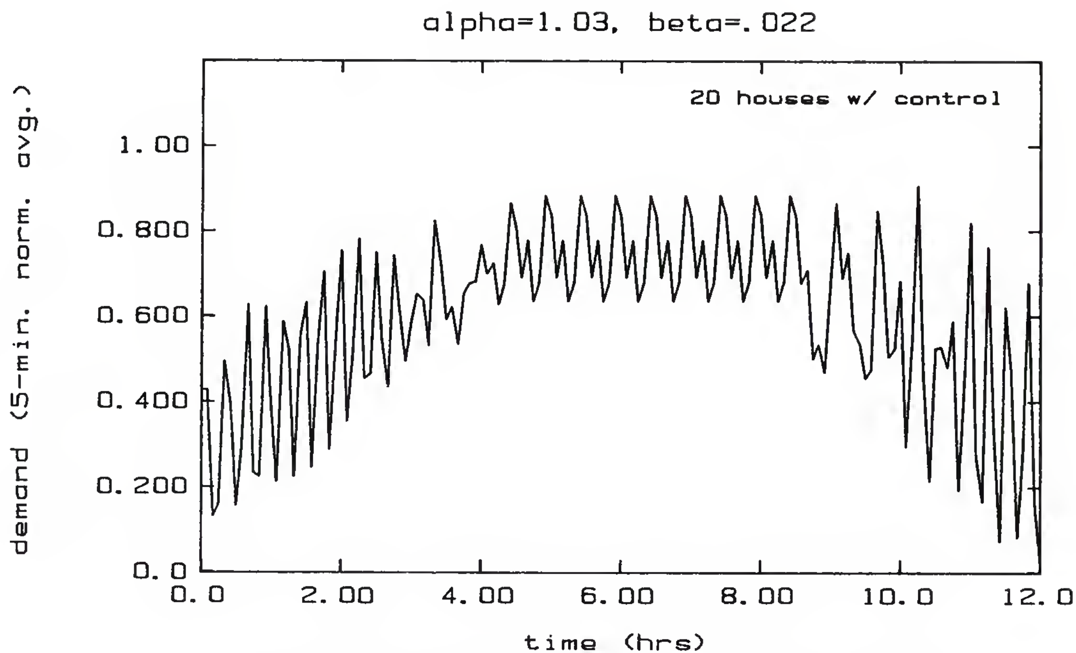


Fig. L-9: Five-Minute Average Demand, Normalized for 20 Houses Over a 12 Hour Period for Case 3 Houses. Control is Load Leveler Type. Driving Temperature Piece-wise Constant With a Peak Value of 100 F.

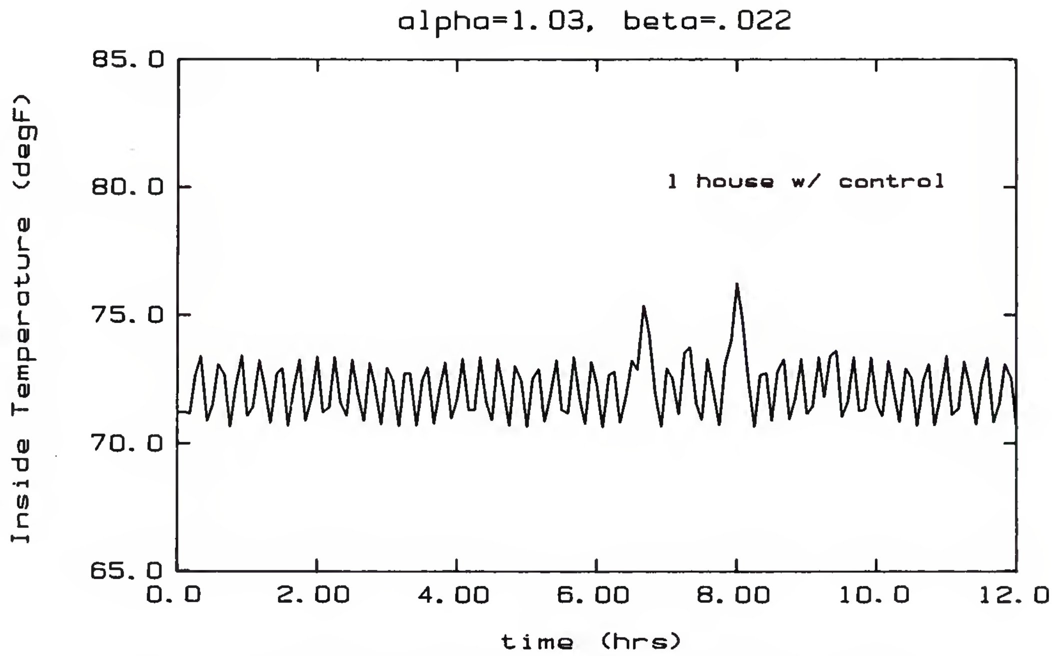


Fig. L-10: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=100 F) Over a 12 Hour Period. Control is Load Leveler Type.

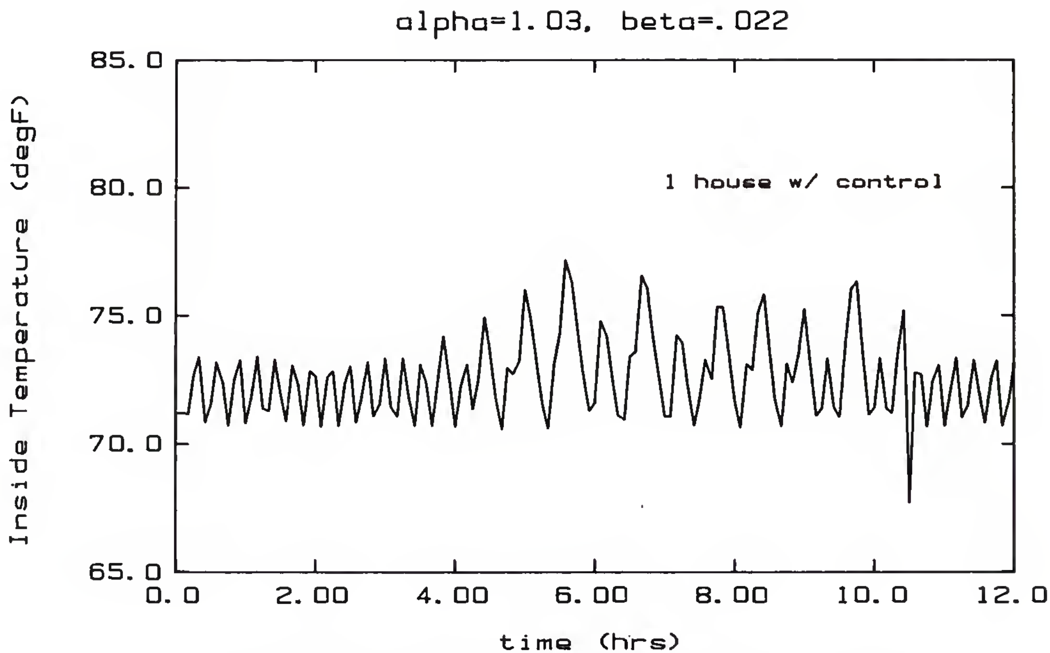


Fig. L-11: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=105 F) Over a 12 Hour Period. Control is Load Leveler Type.

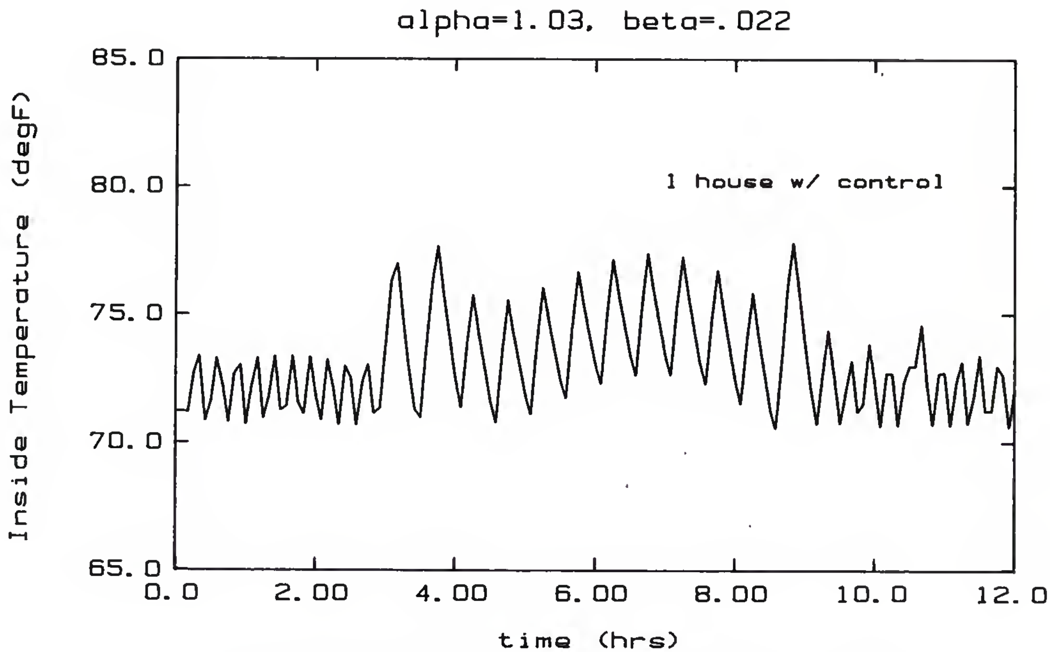


Fig. L-12: Five-Minute Average Inside Temperature for a Typical Case 3 House for Piece-wise Constant Driving Temperature (T_peak=110 F) Over a 12 Hour Period. Control is Load Leveler Type.

APPENDIX M

LISTINGS OF COMPUTER PROGRAMS USED IN SIMULATIONS

APPENDIX M-I

LISTINGS OF COMPUTER PROGRAMS THAT REQUIRE CONSTANT DRIVING TEMPERATURE

```
*
*
*****************************************************************
*   PROGRAM NEWDIST SERVES THE PURPOSE OF OETERMINING THE
*   AVERAGE HOURLY OEMANO REOUCTIONS FOR A 30 HOUR PERIOO.
*   THE NUMBER OF HOUSES USEO VARIES. ONCE THE 30 HOURLY
*   OEMANO REOUCTIONS ARE CALCULATEO, AN AVERAGE ANO STAN-
*   OARO OEVIATION ARE OETERMINEO.
*****************************************************************
*
*
      INTEGER UNIT2,J,K,N,NR,O,HNUM
      REAL ALPHA,BETA,T,TOAY(600),TON,TOFF,PWR(500),
     *   CTOAY(600),PAVG(60),CPWR(500),R(1000),TI(1000),
     *   USYS(500),CSYS(500),EMAX,TEMP(600),CTEMP(600),
     *   STATS(5),Z,CAP(500),UENER(500),CENER(500),TEMPAV
     *   (500),CTEMAV(500),ESAVE(500),EAVG(50,STATMA(10,2)
      OOUBLE PRECISION OSEEO
      CHARACTER STATE*3,START(1000)*3,TRANS(600)*3,
     *   STATUS(600)*3
*
*
*****************************************************************
*   VARIABLE NAMES:
*     ALPHA - COOLING COEFF.FOR THE SYSTEM (OEGF/MIN).
*     BETA - HEATING COEFF. FOR THE SYSTEM (1/MIN).
*     T - VARIABLE USEO TO KEEP TRACK OF TEMPERATURE.
*     TON - TEMPERATURE AT WHICH THE SYSTEM TURNS ON.
*     TOFF - TEMPERATURE AT WHICH THE SYSTEM TURNS OFF.
*     N - VARIABLE SPECIFYING THE LENGTH OF THE PERIOO OF
*        INTEREST FOR POWER ANO ENERGY CONSUMPTION.
*     HNUM - VARIABLE SPECIFYING THE NUMBER OF HOUSES USEO
*        TO PROOUCE A SUMMEO LOAO CURVE.
*     TOAY(600), TRANS(600), TEMP(600) - VECTORS FOR STOR-
*        ING TRANSITION TIMES, STATES (ON/OFF), ANO
*        TEMPERATURES FOR THE UNCONTROLLEO CASE.
*     CTOAY(600), STATUS(600), CTEMP(600) - VECTORS STORING
*        TRANSITION TIMES, STATES (ON/OFF), ANO TEMPERA-
*        TURES FOR THE CONTROLLEO CASE.
*     PWR(500) - VECTOR FOR STORING THE FRACTION OF TIME
*        THE SYSTEM IS ON IN EACH N-MINUTE PERIOO FOR THE
*        UNCONTROLLEO CASE.
*     CPWR(500) - VECTOR FOR STORING THE FRACTION OF TIME
*        THE SYSTEM IS ON IN EACH N-MINUTE PERIOO FOR THE
*        CONTROLLEO CASE.
*     CAP(500) - VECTOR TO STORE THE CAPACITY FACTOR FOR
*        EACH HOUSE.
*     UENER(500) - VECTOR TO STORE THE ENERGY CONSUMPTION
*        FOR N-MINUTE PERIOOS FOR THE UNCONTROLLEO CASE.
*     CENER(500) - VECTOR TO STORE THE ENERGY CONSUMPTION
```

```
*          FOR N-MINUTE PERIOOS FOR THE CONTROLLEO CASE.
*       EMAX - VARIABLE USEO TO OETERMINE THE MAXIMUM N-
*          MINUTE ENERGY CONSUMPTION FOR M HOUSES WITH A
*          GIVEN CAPACITY FACTOR.
*       USYS(500) - VECTOR STORING ENERGY CONSUMPTION FOR N-
*          MINUTE PERIOOS FOR M HOUSES IN THE UNCONTROLLEO
*          CASE (NORMALIZEO FROM 0 TO I).
*       CSYS(500) - VECTOR STORING ENERGY CONSUMPTION FOR N-
*          MINUTE PERIOOS FOR M HOUSES IN THE CONTROLLEO CASE
*          (NORMALIZEO FROM 0 TO I)
*       OSEEO - SEEO NUMBER USED TO GENERATE RANOOM NUMBERS.
*       NR - THE NUMBER OF RANOOM NUMBERS TO BE GENERATEO.
*       R(I000) - VECTOR OF RANOOM NUMBERS.
*       TI(I000), START(I000) - VECTORS THAT STORE THE INIT-
*          IAL TEMP. ANO STATE FOR EACH OF THE M HOUSES.
*       STATS(5) - VECTOR CONTAINING THE STATISTICS FOR THE
*          LOAO CURVE.
*       UNIT2 - VARIABLE USEO TO ESTABLISH AN OUTPUT FILE.
*       J - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          TOAY.
*       K - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          CTDAY.
*       O - VARIABLE CONTAINING THE NUMBER OF N-MINUTE PER-
*          IOOS IN 30 HOURS.
*       ESAVE(500) - VECTOR CONTAINING THE ENERGY SAVINGS FOR
*          EACH N-MINUTE PERIOO.
*       EAVG(50) - VECTOR OF AVERAGE ENERGY SAVINGS OVER
*          LONGER PERIOOS.
*       STATMA(I0,2) - MATRIX OF AVERAGES ANO STANOARO OEV-
*          IATIONS FOR THE OATA IN EAVG.
*****************************************************************
*
*
      UNIT2=10
      OPEN (UNIT=UNIT2,FILE='IOUN2')
C
C    DSEEO IS THE SEEO NUMBER USEO FOR GENERATING RANOOM
C    NUMBERS IN THE RANGE (0,I). ITS VALUE IS DIFFERENT
C    AFTER EACH SET OF RANOOM NUMBERS ARE GENERATEO.
C
      OSEEO=2378465392.D0
C
C    THE FOLLOWING ASSIGNMENT ARE CONSTANTS THROUGHOUT THE
C    PROGRAM.
C
      ALPHA=I.033I7
      BETA=.02231 4
      N=5
      O=1800/N
      TON=74
```

```
      TOFF=70
C
C   OO LOOP 98 VARIES THE NUMBER OF HOUSES THAT ARE SUMMEO
C   INTO A LOAO CURVE.
C
      OO 98 Q=I,2I,IO
      HNUM=Q
      NR=HNUM
C
C   OO LOOP 99 PERFORMS THE NUMBER OF REPETITIONS OF THE
C   SUMMEO LOAO THAT ARE OESIREO. EACH REPITITION HAS OIF-
C   FERENT INITIAL CONOITIONS AS A RESULT OF STARTING WITH
C   OIFFERENT SEEO NUMBERS.
C
      OO 99 L=1,10
C
C   OO LOOP I00 INITIALIZES THE CONTROLLEO AND UNCONTROLLEO
C   ENERGY TO 0.
C
      OO I00 J=1,500
         USYS(J)=0
         CSYS(J)=0
I00   CONTINUE
      EMAX=0
C
C   RANOOM IS CALLEO TO GENERATE THE RANOOM STARTING
C   CONOITIONS.
C
      CALL RANDOM(NR,OSEEO,NR,TOFF,TON,START,TI)
C
C   OO LOOP 220 ASSIGNS THE CAPACITY RATING TO EACH HOUSE
C   ANO MULTIPLIES BY A FACTOR N/60 TO EXPRESS EACH N-MIN-
C   UTE INTERVAL CONSUMPTION IN KWH. IT ALSO TOTALS THE M
C   RATINGS TO OETERMINE HE MAXIMUM AMOUNT OF ENERGY WHICH
C   MAY BE CONSUMEO IN ANY N-MINUTE INTERVAL.
C
      OO 220 I=I,HNUM
         CAP(I)=(4.0*N)/60
         EMAX=EMAX+CAP(I)
220   CONTINUE
C
C   OO LOOP 300 PERFORMS THE CALCULATIONS REQUIREO TO PRO-
C   OUCE A SUMMEO LOAO CURVE MAOE UP OF M HOUSES.
C
      OO 300 I=1,HNUM
         T=TI(I)
         STATE=START(I)
C
C   DUNCON IS USED TO PRODUCE THE TRANSITIONS FOR THE
C   UNCONTROLLEO CASE.
```

```
C
          CALL OUNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                TRANS,TEMP)
          CALL ONAVG(TDAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR,
     *               TEMPAV)
C
C    DCON IS USED TO PRODUCE THE TRANSITIONS FOR THE CON-
C    TROLLED CASE.
C
          CALL OCON(ALPHA,BETA,T,STATE,TON,TOFF,7.5,K,
     *              STATUS,CTDAY,CTEMP)
          CALL ONAVG(CTDAY,STATUS,CTEMP,K,ALPHA,BETA,N,CPWR,
     *               CTEMAV)
C
C    DO LOOP 310 MULTIPLIES EACH TERM IN THE AVERAGE POWER
C    CONSUMPTION VECTOR BY THE CAPACITY FACTOR FOR THE
C    HOUSE. IT ALSO SUMS THE AVERAGE POWER CONSUMPTION OF
C    BOTH CASES FOR EACH N-MINUTE PERIOD FOR THE M HOUSES
C    INTO TWO VECTORS. THE AVERAGE POWER IS NORMALIZED TO A
C    MAXIMUM OF 1.
C
          DO 310 J=1,D
             CENER(J)=CPWR(J)*CAP(I)
             UENER(J)=PWR(J)*CAP(I)
310       CONTINUE
C
C    DO LOOP 350 SUMS THE ENERGY CONSUMPTION FOR EACH N-
C    MINUTE INTERVAL AND NORMALIZES ACCORDING TO THE MAXIMUM
C    POSSIBLE CONSUMPTION FOR M HOUSES.
C
          DO 350 J=1,D
             USYS(J)=USYS(J)+UENER(J)/EMAX
             CSYS(J)=CSYS(J)+CENER(J)/EMAX
350       CONTINUE
300    CONTINUE
C
C    DO LOOP 400 CALCULATES THE ENERGY SAVINGS IN EACH N-
C    MINUTE INTERVAL.
C
       DO 400 I=1,D
          ESAVE(I)=USYS(I)-CSYS(I)
400    CONTINUE
C
C    OVEPWR IS USED TO CALCULATE THE AVERAGE ENERGY SAVINGS
C    ON AN HOURLY BASIS OVER A 30 HOUR PERIOD.
C
       CALL OVEPWR(ESAVE,60,N,EAVG)
C
C    SUBROUTINE CALC IS CALLED TO CALCULATE THE AVERAGE ONE-
C    HOUR ENERGY SAVINGS (STORED IN COLUMN 1 OF MATRIX
```

```
C    STATMA) OVER 30 HOURS AND THE STANDARD DEVIATION OF
C    THAT AVERAGE (STORED IN COLUMN 2 OF STATMA).
C
      CALL CALC(EAVG,30,STATS)
      STATMA(L,1)=STATS(1)
      STATMA(L,2)=STATS(5)
99    CONTINUE
      WRITE (10,*)
      WRITE (10,1000) ' STATISTICS FOR TRIALS OF',HNUM,
     *   'HOUSES'
      WRITE (10,1001) ' TRIAL','AVG','STD'
      WRITE (10,1002) (I,STATMA(I,1),STATMA(I,2), I=1,L-1)
98    CONTINUE
1000  FORMAT (A25,1X,I3,1X,A6)
1001  FORMAT (2X,A6,5X,A3,5X,A3)
1002  FORMAT (4X,I2,6X,F5.3,3X,F5.3)
      STOP
      END
```

```
*
*
************************************************************
*   PROGRAM HOURDIST IS USED TO FIND THE STATISTICS OF THE
*   HOURLY AVERAGE ENERGY SAVINGS FOR A LOAD CURVE MADE OF
*   A VARYING NUMBER OF HOUSES. AVERAGE AND STANDARD DEV-
*   IATION WERE FOUND FOR EACH HOUR OF A 10 HOUR PERIOD.
*   TO DO THIS, 10 INDEPENT TRIALS WERE RUN FOR EACH LOAD
*   CURVE.
************************************************************
*
*
      INTEGER UNIT2,J,K,M,NR,O,NUMREP,INTLEN
      REAL ALPHA,BETA,T,TDAY(600),TON,TOFF,PWR(200),
     *   CTDAY(600),CPWR(200),TI(1000),USYS(200),CSYS(200),
     *   EMAX,STATS(5),CAP(500),UENER(200),CENER(200),
     *   CURVE(10),AVGSAV(10),TEMP(600),CTEMP(600),
     *   AVG(10),SD(10),TMATR(10,10),CTMATR(10,10),
     *   AVGTEM(50),CAGRTE(200),CAVGTE(50),TAVG(10),
     *   CTAVG(10),CTSD(10),TCURVE(10),CTCURV(10),SAVAVG,
     *   TEMPAV(200),CTEMAV(200),CYCLE,N,TSD(10),
     *   ESAVE(200),MATRIX(10,10),AGRTEM(200)
      DOUBLE PRECISION DSEED
      CHARACTER STATE*3,START(500)*3,TRANS(600)*3,
     *   STATUS(600)*3
*
*
************************************************************
*   VARIABLE NAMES:
*     ALPHA - COOLING COEFFICIENT WITH THE A/C ON.
*        (DEGF/MIN)
*     BETA - HEATING COEFFICIENT. (1/MIN)
*     T - VARIABLE USED TO KEEP TRACK OF TEMPERATURE.
*     TON - TEMPERATURE AT WHICH THE SYSTEM TURNS ON.
*        (DEGF)
*     TOFF - TEMPERATURE AT WHICH THE SYSTEM TURNS OFF.
*        (DEGF)
*     N - VARIABLE SPECIFYING THE LENGTH OF THE PERIOD OF
*        INTEREST FOR POWER AND ENERGY CONSUMPTION.
*     M - VARIABLE SPECIFYING THE NUMBER OF HOUSES USED TO
*        PRODUCE A SUMMED LOAD CURVE.
*     TDAY(1800), TRANS(1800), TEMP(1800) - VECTORS FOR
*        STORING TRANSTION TIMES, STATES (ON/OFF), AND
*        TEMPERATURES FOR THE UNCONTROLLED CASE.
*     CTDAY(600), STATUS(600), CTEMP(600) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), AND
*        TEMPERATURES FOR THE CONTROLLED CASE.
*     PWR(200), CPWR(200) - VECTORS STORING THE FRACTION OF
*        EACH N-MINUTE PERIOD IN WHICH THE A/C IS ON FOR
*        BOTH OF THE CASES.
```

```
*       TEMPAV(200), CTEMAV(200) - VECTORS STORING THE N-
*          MINUTE TEMPERATURE AVERAGES FOR BOTH OF THE CASES.
*       CAP(500) - VECTOR TO STORE THE CAPACITY FACTOR FOR
*          EACH HOUSE.
*       UENER(200), CENER(200), SCENER(200) - VECTORS FOR
*          STORING THE N-MINUTE ENERGY CONSUMPTIONS FOR EACH
*          OF THE THREE CASES.
*       EMAX - VARIABLE USED TO DETERMINE THE MAXIMUM N-
*          MINUTE ENERGY CONSUMPTION FOR M HOUSES WITH A
*          GIVEN CAPACITY FACTOR.
*       USYS(200), CSYS(200) - VECTORS STORING THE TOTAL
*          ENERGY CONSUMPTION FOR EACH N-MINUTE INTERVAL FOR
*          HNUM HOUSES FOR BOTH CASES.
*       DSEED - SEED NUMBER USED TO GENERATE RANDOM NUMBERS.
*       NR - THE NUMBER OF RANDOM NUMBERS TO BE GENERATED.
*       R(1000) - VECTOR OF RANDOM NUMBERS.
*       TI(500), START(500) - VECTORS THAT STORE THE INITIAL
*          TEMP. AND STATE FOR EACH OF THE M HOUSES.
*       STATS(5) - VECTOR CONTAINING THE STATISTICS FOR THE
*          LOAD CURVE.
*       UNIT2 - VARIABLE USED TO ESTABLISH AN OUTPUT FILE.
*       J - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          TDAY.
*       K - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          CTDAY.
*       D - VARIABLE CONTAINING THE NUMBER OF N-MINUTE PER-
*          IODS IN 10 HOURS.
*       ESAVE(200) - A VECTOR STORING THE DIFFERENCE BETWEEN
*          THE UNCONTROLLED AND CONTROLLED TOTAL ENERGY CON-
*          SUMPTION FOR EACH N-MINUTE INTERVAL.
*       AVGSAV(10) - A VECTOR STORING THE HOURLY AVERAGE
*          ENERGY SAVINGS.
*       MATRIX(10,10) - MATRIX OF THE HOURLY ENERGY SAVINGS
*          FOR EACH REPITITION.
*       CURVE(10) TCURVE(10), CTCURV(10) - INTERMEDIATE VEC-
*          TORS THAT STORE THE ENERGY SAVINGS AND AVERAGES
*          TEMPERATURES FOR A PARTICULAR HOUR IN ORDER TO
*          CALCULATE THE STATISTICS FOR THAT HOUR.
*       AVG(10), SD(10), TAVG(10), TSD(10), CTAVG(10),
*          CTSD(10) - VECTORS THAT STORE THE ENERGY SAVINGS
*          AND AVERAGE TEMPERATURE STATISTICS.
*       NUMREP - A VARIABLE WHICH CONTAINS THE NUMBER OF
*          REPITITIONS THAT WILL BE PERFORMED FOR EACH SPEC-
*          IFIED CURVE.
*       TMATR(10,10), CTMATR(10,10) - MATRICES TO STORE THE
*          AVERAGE TEMPERATURES FOR THE UNCONTROLLED AND THE
*          CONTROLLED CASES.
*       AGRTEM(200), CAGRTE(200) - VECTORS USED TO CALCULATE
*          THE AVERAGE AGREGATE TEMPERATURE FOR N-MINUTE
*          PERIODS FOR THE CONTROLLED AND UNCONTROLLED CASES.
```

```
*       AVGTEM(50), CAVGTE(50) - VECTORS THAT STORE THE AVER-
*          AGE AGGREGATE TEMPERATURE FOR PERIODS LONGER THAN
*          N MINUTES.
*****************************************************************
*
*
        UNIT2=10
        OPEN (UNIT=UNIT2,FILE='IOUN2')
        ALPHA=1.03317
        BETA=.022314355
        NUMREP=10
        INTLEN=30
        DSEE0=675432834.00
        WRITE (I0,80) ' CASES FOR ALPHA=',ALPHA,' AND BETA=',
     *     BETA
        WRITE (10,*)
C
C     DO LOOP 90 ALTERS THE NUMBER OF HOUSES IN THE LOAD
C     CURVE.
C
        DO 90 Q=1,1
           M=Q
C
C     DO LOOP 101 PERFORMS THE DESIRED NUMBER OF REPITITIONS
C     FOR EACH NUMBER OF HOUSES.
C
        DO 101 L=1,NUMREP
C
C     DO LOOP 100 INITIALIZES ALL OF THE ELEMENTS OF THE
C     TOTAL SYSTEM CURVES TO 0.
C
        DO 100 J=1,200
           USYS(J)=0
           CSYS(J)=0
           AGRTEM(J)=0
           CAGRTE(J)=0
100     CONTINUE
        N=5
        O=600/N
        TON=74
        TOFF=70
        EMAX=0
C
C     RANDOM IS CALLED TO GENERATE THE RANDOM STARTING CONDI-
C     TIONS.
C
        CALL RANDOM(M,DSEE0,M,TOFF,TON,START,TI)
        DO 205 I=1,M
           IF (START(I) .EQ. 'OFF') THEN
              START(I)='ON'
```

```
         ELSE
            START(I)='OFF'
         ENDIF
205   CONTINUE
C
C   DO LOOP 220 ASSIGNS THE CAPACITY RATING TO EACH HOUSE
C   AND MULTIPLIES BY A FACTOR N/60 TO EXPRESS EACH N-MIN-
C   UTE INTERVAL CONSUMPTION IN KWH. IT ALSO TOTALS THE M
C   RATINGS TO DETERMINE THE MAXIMUM AMOUNT OF ENERGY WHICH
C   MAY BE CONSUMED IN ANY N-MINUTE INTERVAL.
C
      DO 220 I=1,M
         CAP(I)=(4.0*N)/60
         EMAX=EMAX+CAP(I)
220   CONTINUE
C
C   DO LOOP 300 PERFORMS THE CALCULATIONS REQUIRED TO PRO-
C   DUCE A SUMMED LOAD CURVE MADE UP OF M HOUSES.
C
      DO 300 I=1,M
         T=TI(I)
         STATE=START(I)
C
C   UNCON IS USED TO PRODUCE THE TRANSITIONS FOR THE UNCON-
C   TROLLED CASE.
C
         CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *              TRANS,TEMP,CYCLE)
         CALL NAVG(TDAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR,
     *             TEMPAV)
C
C   CON IS USED TO PRODUCE THE TRANSITIONS FOR THE CON-
C   TROLLED CASE.
C
         CALL CON(ALPHA,BETA,T,STATE,TON,TOFF,7.5,K,STATUS,
     *            CTDAY,CTEMP,INTLEN)
         CALL NAVG(CTDAY,STATUS,CTEMP,K,ALPHA,BETA,N,CPWR,
     *             CTEMAV)
C
C   DO LOOP 310 MULTIPLIES EACH TERM IN THE AVERAGE POWER
C   CONSUMPTION VECTOR BY THE CAPACITY FACTOR FOR THE
C   HOUSE. THE RESULT IS AVERAGE ENERGY CONSUMPTION FOR THE
C   N-MINUTE PERIOD.
C
         DO 310 J=1,D
            CENER(J)=CPWR(J)*CAP(I)
            UENER(J)=PWR(J)*CAP(I)
310      CONTINUE
C
C   DO LOOP 350 SUMS THE ENERGY CONSUMPTION FOR EACH N-MIN-
```

```
C    UTE INTERVAL AND NORMALIZES ACCORDING TO THE MAXIMUM
C    POSSIBLE CONSUMPTION FOR M HOUSES. IT ALSO COMPUTES THE
C    AVERAGE TEMPERATURE FOR EACH N-MINUTE INTERVAL OVER THE
C    WHOLE LOAD CURVE FOR BOTH THE CONTROLLED AND UNCCN-
C    TROLLED CASES.
C
           DO 350 J=1,O
              USYS(J)=USYS(J)+UENER(J)/EMAX
              CSYS(J)=CSYS(J)+CENER(J)/EMAX
              AGRTEM(J)=AGRTEM(J)+TEMPAV(J)/M
              CAGRTE(J)=CAGRTE(J)+CTEMAV(J)/M
350        CONTINUE
300     CONTINUE
C
C    DO LOOP 400 CALCULATES THE ENERGY SAVINGS IN EACH N-
C    MINUTE INTERVAL.
C
        DO 400 I=1,O
           ESAVE(I)=USYS(I)-CSYS(I)
400     CONTINUE
C
C    AVEPWR IS USED TO CALCULATE THE AVERAGE ENERGY SAVINGS
C    AND AGGREGATE TEMPERATURE FOR EACH HOUR OF THE 10 HOUR
C    PERIOD.
C
        CALL AVEPWR(ESAVE,60,INT(N),AVGSAV)
        CALL AVEPWR(AGRTEM,60,INT(N),AVGTEM)
        CALL AVEPWR(CAGRTE,60,INT(N),CAVGTE)
C
C    DO LOOP 410 STORES THE ONE-HOUR AVERAGE ENERGY SAVINGS
C    AND AGGREGATE TEMPERATURE IN MATRICES.
C
        DO 410 I=1,10
           MATRIX(I,L)=AVGSAV(I)
           TMATR(I,L)=AVGTEM(I)
           CTMATR(I,L)=CAVGTE(I)
410     CONTINUE
101     CONTINUE
C
C    DO LOOP 500 PERFORMS THE REPITITIONS NEEDED TO CALCU-
C    LATE THE STATISTICS FOR THE ENERGY SAVINGS AND AGGRE-
C    GATE TEMPERATURE FOR EACH HOUR OF THE 10 HOUR PERIOD.
C
        DO 500 L=1,10
C
C    DO LOOP 510 STORES THE APPROPRIATE ROW IN AN INTERMED-
C    IATE ARRAY TO CALCULATE THE STATISTICS.
C
           DO 510 I=1,NUMREP
              CURVE(I)=MATRIX(L,I)
```

```
            TCURVE(I)=TMATR(L,I)
            CTCURV(I)=CTMATR(L,I)
510       CONTINUE
C
C    CALC IS CALLED TO CALCULATE THE STATISTICS AND THE
C    STATISTICS ARE STORED IN ARRAYS TO BE WRITTEN INTO A
C    FILE.
C
          CALL CALC(CURVE,NUMREP,STATS)
          AVG(L)=STATS(1)
          SD(L)=STATS(5)
          CALL CALC(TCURVE,NUMREP,STATS)
          TAVG(L)=STATS(1)
          TSD(L)=STATS(5)
          CALL CALC(CTCURV,NUMREP,STATS)
          CTAVG(L)=STATS(1)
          CTSD(L)=STATS(5)
500     CONTINUE
        WRITE (10,600) ' ENERGY SAVINGS STATISTICS FOR',M,
     *     'HOUSES'
        WRITE (10,601) ' HOUR','AVG SAVINGS','AVG + 2*SD',
     *     'AVG - 2*SD'
        WRITE (10,602) (I,100*AVG(I),100*AVG(I)+(200*SD(I)),
     *AVG(I)*100 - (200*SD(I)), I=1,10)
        SAVAVG = 0
        DO 550 I=1,10
           SAVAVG = SAVAVG + AVG(I)
550     CONTINUE
        SAVAVG = (SAVAVG/10)*100
        WRITE (10,610) SAVAVG
610     FORMAT (' AVERAGE HOURLY SAVINGS = ',F6.3,'%')
        WRITE (10,*)
        WRITE (10,603) M
        WRITE (10,604)
        WRITE (10,605) (I,TAVG(I),TAVG(I)+2*TSD(I),TAVG(I)-
     *     2*TSD(I),CTAVG(I),CTAVG(I)+2*CTSD(I),CTAVG(I)-
     *     2*CTSD(I), I=1,10)
        WRITE (10,*)
90      CONTINUE
80      FORMAT (A17,1X,F6.4,A10,1X,F6.4)
600     FORMAT (A30,1X,I3,1X,A6)
601     FORMAT (A5,3X,A11,3X,A10,3X,A10)
602     FORMAT (2X,I2,6X,F7.4,6X,F7.4,6X,F7.4)
603     FORMAT (' TEMPERATURE STATISTICS FOR',1X,I3,1X,
     *     'HOUSES')
604     FORMAT (' HOUR',2X,'UNCON TEMP',2X,'UT + 2*SD',2X,
     *     'UT - 2*SD',2X,'CON TEMP',2X,'CT + 2*SD',2X,
     *     'CT - 2*SD')
605     FORMAT (2X,I2,5X,F6.2,5X,F6.2,5X,F6.2,5X,F6.2,4X,
     *     F6.2,5X,F6.2)
```

```
STOP
END
```

```
*
*
************************************************************
*   PROGRAM CYCLE GENERATES THE AVERAGE HOURLY SAVINGS AS A
*   FUNCTION OF DUTY CYCLE. EACH CASE IS RUN 10 TIMES TO
*   GENERATE A RANGE OF POSSIBLE VALUES.
************************************************************
*
*
      INTEGER UNIT2,J,K,M,NR,D,UNIT7,UNIT8,NUMREP
      REAL ALPHA,BETA,T,TDAY(600),TON,TOFF,PWR(200),
     *   CTDAY(600),CPWR(200),TI(500),USYS(200),CSYS(200),
     *   EMAX,STATS(5),CAP(500),UENER(200),CENER(200),
     *   CURVE(10),AVGSAV(10),TEMP(600),CTEMP(600),
     *   CTEMAV(200),ESAVE(200),AVG,SD,TMATR(10,10),
     *   CTMATR(10,10),AGRTEM(200),AVGTEM(50),CAGRTE(200),
     *   TCURVE(10),CTCURV(10),CYCLE,N,TAMB,LCON,INTLEN,
     *   CAVGTE(50),TAVG,TSD,CTAVG,CTSD,MATRIX(10,10),
     *   TEMPAV(200)
      DOUBLE PRECISION DSEED
      CHARACTER STATE*3,START(500)*3,TRANS(500)*3,
     *   STATUS(500)*3
*
*
************************************************************
*   VARIABLE NAMES:
*     ALPHA - COOLING COEFF. WITH THE A/C ON. (DEGF/MIN)
*     BETA - HEATING COEFFICIENT. (1/MIN)
*     T - VARIABLE USED TO KEEP TRACK OF TEMPERATURE.
*     TON - TEMPERATURE AT WHICH THE SYSTEM TURNS ON.
*        (DEGF)
*     TOFF - TEMPERATURE AT WHICH THE SYSTEM TURNS OFF.
*        (DEGF)
*     N - VARIABLE SPECIFYING THE LENGTH OF THE PERIOD OF
*        INTEREST FOR POWER AND ENERGY CONSUMPTION.
*     M - VARIABLE SPECIFYING THE NUMBER OF HOUSES USED TO
*        PRODUCE A SUMMED LOAD CURVE.
*     TDAY(600), TRANS(600), TEMP(600) - VECTORS FOR STOR-
*        ING TRANSITION TIMES, STATES (ON/OFF), AND TEMP-
*        ERATURES FOR THE UNCONTROLLED CASE.
*     CTDAY(600), STATUS(600), CTEMP(600) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), AND
*        TEMPERATURES FOR THE CONTROLLED CASE.
*     PWR(200), CPWR(200) - VECTORS STORING THE FRACTION OF
*        EACH N-MINUTE PERIOD IN WHICH THE A/C IS ON FOR
*        BOTH OF THE CASES.
*     TEMPAV(200), CTEMAV(200) - VECTORS STORING THE N-MIN-
*        UTE TEMPERATURE AVERAGES FOR BOTH OF THE CASES.
*     CAP(500) - VECTOR TO STORE THE CAPACITY FACTOR FOR
*        EACH HOUSE.
```

```
*     UENER(200), CENER(200) - VECTORS FOR STORING THE
*        N-MINUTE ENERGY CONSUMPTIONS FOR EACH OF THE
*        THREE CASES.
*     EMAX - VARIABLE USED TO DETERMINE THE MAXIMUM N-
*        MINUTE ENERGY CONSUMPTION FOR M HOUSES WITH A
*        GIVEN CAPACITY FACTOR.
*     USYS(200), CSYS(200) - VECTORS STORING THE TOTAL
*        ENERGY CONSUMPTION FOR EACH N-MINUTE INTERVAL FOR
*        HNUM HOUSES FOR BOTH CASES.
*     DSEED - SEED NUMBER USED TO GENERATE RANDOM NUMBERS.
*     NR - THE NUMBER OF RANDOM NUMBERS TO BE GENERATED.
*     R(500) - VECTOR OF RANDOM NUMBERS.
*     TI(500), START(500) - VECTORS THAT STORE THE INITIAL
*        TEMP. AND STATE FOR EACH OF THE M HOUSES.
*     STATS(5) - VECTOR CONTAINING THE STATISTICS FOR
*        THE LOAD CURVE.
*     UNIT2 - VARIABLE USED TO ESTABLISH AN OUTPUT FILE.
*     J - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS
*        IN TDAY.
*     K - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS
*        IN CTDAY.
*     D - VARIABLE CONTAINING THE NUMBER OF N-MINUTE
*        PERIODS IN 10 HOURS.
*     ESAVE(200) - A VECTOR STORING THE DIFFERENCE BETWEEN
*        THE UNCONTROLLED AND CONTROLLED TOTAL ENERGY CON-
*        SUMPTION FOR EACH N-MINUTE INTERVAL.
*     AVGSAV(10) - A VECTOR STORING THE HOURLY AVERAGE
*        ENERGY SAVINGS.
*     MATRIX(10,10) - MATRIX OF THE HOURLY ENERGY SAVINGS
*        FOR EACH REPITITION.
*     CURVE(10) TCURVE(10), CTCURV(10) - INTERMEDIATE VEC-
*        TORS THAT STORE THE ENERGY SAVINGS AND AVERAGES
*        TEMPERATURES FOR A PARTICULAR HOUR IN ORDER TO
*        CALCULATE THE STATISTICS FOR THAT HOUR.
*     AVG(10), SD(10), TAVG(10), TSD(10), CTAVG(10),
*        CTSD(10) - VECTORS THAT STORE THE ENERGY SAVINGS
*        AND AVERAGE TEMPERATURE STATISTICS.
*     NUMREP - A VARIABLE WHICH CONTAINS THE NUMBER OF
*        REPITITIONS THAT WILL BE PERFORMED FOR EACH
*        SPECIFIED CURVE.
*     TMATR(10,10), CTMATR(10,10) - MATRICES TO STORE THE
*        AVERAGE TEMPERATURES FOR THE UNCONTROLLED AND THE
*        CONTROLLED CASES.
*     AGRTEM(200), CAGRTE(200) - VECTORS USED TO CALCULATE
*        THE AVERAGE AGGREGATE TEMPERATURE FOR N-MINUTE
*        PERIODS FOR THE CONTROLLED AND UNCONTROLLED CASES.
*     AVGTEM(50), CAVGTE(50) - VECTORS THAT STORE THE
*        AVERAGE AGGREGATE TEMPERATURE FOR PERIODS LONGER
*        THAN N MINUTES.
*     TAMB - DRIVING TEMPERATURE FOR THE SYSTEM.
```

```
*      LCON - LENGTH OF THE CONTROL PERIOD.
**************************************************************************
*
*
       UNIT2=10
       OPEN (UNIT=UNIT2,FILE='IOUN2')
       ALPHA=.446287103
       BETA=.022314355
       N=5
       D=600/N
       TON=74.0
       TOFF=70.0
       NUMREP=10
       INTLEN=10
       LCON=2.5
       DSEED=789861234.00
       M=20
       WRITE (10,80) ' CASES FOR ALPHA=',ALPHA,
     *    ' AND BETA=',BETA
       WRITE (10,85) LCON,INTLEN
       WRITE (10,*)
       WRITE (10,600)
C
C   DO LOOP 90 LOOPS OVER THE DESIRED RANGE OF TAMB.
C
       DO 90 LOOP=1,4
          TAMB=85.300+LOOP*0.03
C
C   DO LOOP 101 PERFORMS THE DESIRED NUMBER OF REPITI-
C   TIONS FOR EACH SET OF HOUSES.
C
       DO 101 L=1,NUMREP
C
C   DO LOOP 100 INITIALIZES ALL OF THE ELEMENTS OF THE
C   TOTAL SYSTEM CURVES TO 0.
C
       DO 100 J=1,200
          USYS(J)=0
          CSYS(J)=0
          AGRTEM(J)=0
          CAGRTE(J)=0
100    CONTINUE
       EMAX=0
C
C   RANDOM IS CALLED TO GENERATE THE RANDOM STARTING
C   CONDITIONS.
C
       CALL RANDOM(M,DSEED,M,TOFF,TON,START,TI)
       DO 205 I=1,M
          IF (START(I) .EQ. 'OFF') THEN
```

```
            START(I)='ON'
         ELSE
            START(I)='OFF'
         ENDIF
205   CONTINUE
C
C     DO LOOP 220 ASSIGNS THE CAPACITY RATING TO EACH HOUSE
C     AND MULTIPLIES BY A FACTOR N/60 TO EXPRESS EACH N-MIN-
C     UTE INTERVAL CONSUMPTION IN KWH. IT ALSO TOTALS THE M
C     RATINGS TO DETERMINE THE MAXIMUM AMOUNT OF ENERGY
C     WHICH MAY BE CONSUMED IN ANY N-MINUTE INTERVAL.
C
      DO 220 I=1,M
         CAP(I)=(4.0*N)/60
         EMAX=EMAX+CAP(I)
220   CONTINUE
C
C     DO LOOP 300 PERFORMS THE CALCULATIONS REQUIRED TO
C     PRODUCE A SUMMED LOAD CURVE MADE UP OF M HOUSES.
C
      DO 300 I=1,M
         T=TI(I)
         STATE=START(I)
C
C     UNCON IS USED TO PRODUCE THE TRANSITIONS FOR THE
C     UNCONTROLLED CASE.
C
         CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *              TRANS,TEMP,CYCLE,TAMB,10.0)
         CALL NAVG(TDAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR,
     *              TEMPAV,TAMB)
C
C     CON IS USED TO PRODUCE THE TRANSITIONS FOR THE
C     CONTRULLED CASE.
C
         CALL CON(ALPHA,BETA,TI(I),STATE,TON,TOFF,LCON,K,
     *              STATUS,CTDAY,CTEMP,INTLEN,TAMB)
         CALL NAVG(CTDAY,STATUS,CTEMP,K,ALPHA,BETA,N,CPWR,
     *              CTEMAV,TAMB)
C
C     DO LOOP 310 MULTIPLIES EACH TERM IN THE AVERAGE POWER
C     CONSUMPTION VECTOR BY THE CAPACITY FACTOR FOR THE
C     HOUSE. THE RESULT IS AVERAGE ENERGY CONSUMPTION FOR THE
C     N-MINUTE PERIOD.
C
         DO 310 J=1,D
            CENER(J)=CPWR(J)*CAP(I)
            UENER(J)=PWR(J)*CAP(I)
310      CONTINUE
C
```

```
C    DO LOOP 350 SUMS THE ENERGY CONSUMPTION FOR EACH
C    N-MINUTE INTERVAL AND NORMALIZES ACCORDING TO THE
C    MAXIMUM POSSIBLE CONSUMPTION FOR HNUM HOUSES. IT ALSO
C    COMPUTES THE AVERAGE TEMPERATURE FOR EACH N-MINUTE
C    INTERVAL OVER THE WHOLE LOAD CURVE FOR BOTH
C    THE CONTROLLED AND UNCONTROLLED CASES.
C
            DO 350 J=1,D
               USYS(J)=USYS(J)+UENER(J)/EMAX
               CSYS(J)=CSYS(J)+CENER(J)/EMAX
               AGRTEM(J)=AGRTEM(J)+TEMPAV(J)/M
               CAGRTE(J)=CAGRTE(J)+CTEMAV(J)/M
350         CONTINUE
300      CONTINUE
C
C    DO LOOP 400 CALCULATES THE ENERGY SAVINGS IN EACH
C    N-MINUTE INTERVAL.
C
         DO 400 I=1,D
            ESAVE(I)=USYS(I)-CSYS(I)
400      CONTINUE
C
C    AVEPWR IS USED TO CALCULATE THE AVERAGE ENERGY SAVINGS
C    AND AGGREGATE TEMPERATURE FOR EACH HOUR OF THE
C    10 HOUR PERIOD.
C
         CALL AVEPWR(ESAVE,60,INT(N),AVGSAV,10.0)
         CALL AVEPWR(AGRTEM,60,INT(N),AVGTEM,10.0)
         CALL AVEPWR(CAGRTE,60,INT(N),CAVGTE,10.0)
C
C    NEXT, AVERAGE THE SAVINGS FOR THE LAST 9 HOURS OF THE
C    PERIOD AND SAVE IT IN A VECTOR TO CALCULATE STATISTICS.
C
         CURVE(L)=0
         TCURVE(L)=0
         CTCURV(L)=0
         DO 410 I=2,10
            CURVE(L)=CURVE(L)+AVGSAV(I)
            TCURVE(L)=TCURVE(L)+AVGTEM(I)
            CTCURV(L)=CTCURV(L)+CAVGTE(I)
410      CONTINUE
         CURVE(L)=CURVE(L)/9
         TCURVE(L)=TCURVE(L)/9
         CTCURV(L)=CTCURV(L)/9
101      CONTINUE
517      CONTINUE
C
C    CALC IS CALLED TO CALCULATE THE AVERAGE AND STANDARD
C    DEVIATION OF THE DAILY AVERAGE SAVINGS.
C
```

```
      CALL CALC(CURVE,NUMREP,STATS)
      AVG=STATS(1)
      SD=STATS(5)
      CALL CALC(TCURVE,NUMREP,STATS)
      TAVG=STATS(1)
      TSD=STATS(5)
      CALL CALC(CTCURV,NUMREP,STATS)
      CTAVG=STATS(1)
      CTSD=STATS(5)
C
C    PRINT OUT THE DATA FOR THIS VALUE OF TAMB.
C
      WRITE (10,610) CYCLE,TAMB,AVG*100,AVG*100+200*SD,
     *    AVG*100-200*SD,TAVG,TAVG+2*TSD,TAVG-2*TSD,CTAVG,
     *    CTAVG+2*CTSD,CTAVG-2*CTSD
90    CONTINUE
80    FORMAT (' ',A17,1X,F6.4,A10,1X,F6.4)
85    FORMAT (' ','CONTROL STATEGY IS:',1X,F3.1,' MIN. OF',
     *    1X,I2)
600   FORMAT (' CYCLE',2X,'TDRIVE',2X,'SAVG',3X,'+2SD',
     *    3X,'-2SD',2X,'TAVG',3X,'+2SD',3X,'-2SD',3X,
     *    'CTAVG',2X,'+2SD',3X,'-2SD')
610   FORMAT (' ',F5.1,2X,F5.1,1X,F6.2,1X,F6.2,1X,F6.2,
     *    1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
      STOP
      END
```

```
* THIS IS THE FINAL VERSION OF UNCON FOR CONSTANT DRIVING
* TEMPERATURE.
**************************************************************
*    SUBROUTINE UNCON DETERMINES THE TRANSITION TIMES FOR
*    THE UNCONTROLLED CASE. THE RESULTING TRANSITION TIMES
*    ARE RETURNSED IN TDAY WHICH IS A 600 MEMBER ARRAY.
*    TRANS RETURNS THE STATE THAT THE SYSTEM GOES TO WHEN
*    THE TRANSITION IS MADE.
**************************************************************
*
*
      SUBROUTINE UNCON (ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                  TRANS,TEMP,CYCLE,TAMB,NUMHRS)
*
*
**************************************************************
*    ARGUMENT EXPLANATIONS:
*       ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*               (INPUT)
*       BETA - HEATING COEFFICIENT (I/MIN). (INPUT
*       T - INITIAL TEMPERATURE OF THE SYSTEM. (INPUT)
*       STATE - INITIAL STATE (ON/OFF) OF THE A/C. (INPUT)
*       TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*       TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*              (INPUT)
*       J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A SPEC-
*           IFIED PERIOD. (OUTPUT)
*       TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*              TIMES (IN MINUTES) FOR THE II-HOUR PERIOD.
*              (OUTPUT)
*       TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*               (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*               ING TRANSITION IN TDAY. (OUTPUT)
*       TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*              SYSTEM AT EACH TRANSITION. (OUTPUT)
*       CYCLE - % ON FOR THE GIVEN CONSTANTS AND DRIVING
*               TEMPERATURE. (OUTPUT)
**************************************************************
*
*
      REAL ALPHA,BETA,T,TDAY(*),TON,TOFF,TEMP(*),TAMB,CYCLE
     *     ,TION,TIOFF,NUMHRS
      INTEGER J
      CHARACTER*(*) STATE,TRANS(*)
*
*
**************************************************************
*    VARIABLE EXPLANATION:
*       TAMB - DRIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
*       TION, TIOFF - ON AND OFF TIMES FOR THE GIVEN
```

```
*          SITUATION.
*****************************************************************
*
*
      J=1
      TEMP(J)=T
      TRANS(J)=STATE
      TDAY(J)=0
C
C   CALCULATE PERCENT OF THE TIME THAT THE SYSTEM IS ON.
C
      IF (ALPHA/BETA .LE. (TAMB - TOFF)) THEN
         CYCLE = 100
      ELSE
         TION = -(1/BETA) * LOG((TOFF + ALPHA/BETA-TAMB)/
     *         (TON + ALPHA/BETA -TAMB))
         TIOFF = -(1/BETA) * LOG((TON-TAMB)/(TOFF-TAMB))
         CYCLE = TION/(TION + TIOFF) * 100
      ENDIF
C
C   THIS IF STATEMENT STARTS THE LOOP BY CHECKING IF THE
C   TIME HAS EXPIRED.
C
100   IF (TDAY(J) .GT. (60*NUMHRS+30)) GO TO 150
C
C   THE NEXT THREE IF STATEMENTS CHECK IF THE SYSTEM IS IN
C   AN EXTREME SITUATION, AND IF SO, CALLS THE APPROPRIATE
C   SUBROUTINE AND STARTS THE LOOP OVER.
C
      IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB .GT. TON)
     *   THEN
         CALL NOCOOL(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,TEMP)
         GO TO 100
      ENDIF
      IF (TAMB .LE. TON .AND. ALPHA/BETA .GT. (TAMB-TOFF))
     *   THEN
         CALL NOHEAT(ALPHA,BETA,TOFF,TAMB,J,TDAY,TRANS,
     *         TEMP)
         GO TO 100
      ENDIF
      IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB .LE. TON)
     *   THEN
         CALL ABEXT(ALPHA,BETA,TAMB,J,TDAY,TRANS,TEMP)
         GO TO 100
      ENDIF
C
C   THESE STATEMENTS DETERMINE THE TRANSITIONS IF THE
C   SYSTEM IS IN NORMAL OPERATION. IF THE SYSTEM IS ON,
C   NEXT TRANSITION IS DETERMINED USING THE COOLING MODEL.
C   IF THE SYSTEM IS OFF, THE NEXT TRANSITION
```

```
C    IS DETERMINED BY THE HEATING MODEL.
C
        IF (TRANS(J) .EQ. 'ON') THEN
           TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *        TAMB)/(TEMP(J)+ALPHA/BETA-TAMB))
           TRANS(J+1)='OFF'
           TEMP(J+1)=TOFF
           J=J+1
        ELSE
           TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TON-TAMB)/
     *        (TEMP(J)-TAB))
           TRANS(J+1)='ON'
           TEMP(J+1)=TON
           J=J+1
        ENDIF
C
C    THIS STATEMENT STARTS THE LOOP OVER AGAIN
C
        GO TO 100
150     RETURN
        END
```

```
*
* THIS IS THE VERSION OF CON USED WITH CYCLE FORTRAN.
* IT REPRESENTS THE FINAL VERSION UTILIZING CONSTANT
* DRIVING TEMPERATURE.
*************************************************************
*   SUBROUTINE CON DETERMINES THE TRANSITION TIMES  AND
*   STATES OF THE SYSTEM FOR THE CONTROLLED CASE. THE
*   SYSTEM IS AUTOMATICALLY OFF FOR THE FIRST LCON MINUTES
*   OF EACH HALF HOUR. THE SUBROUTINE GENERATES DATA FOR
*   AN 11 HOUR PERIOD. CTDAY RETURNS THE TRANSITION TIMES
*   AND STATUS RETURNS THE CORRESPONDING STATES.
*************************************************************
*
*
      SUBROUTINE CON(ALPHA,BETA,TI,STATE,TON,TOFF,LCON,K,
     *              STATUS,CTDAY,T,INTLEN,TAMB)
*
*
*************************************************************
*   ARGUMENT EXPLANATION:
*      ALPHA - COOLING COEFFICIENT WIHT A/C ON (DEGF/MIN).
*         (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TI - INITIAL TEMPERATURE. (INPUT)
*      STATE - THE INITIAL STATE (ON/OFF) OF THE A/C.
*      TON - TEMPERATURE AT WHICH A/C SHUTS OFF. (INPUT)
*      TOFF - TEMPERATURE AT WHICH A/C SHUTS OFF. (INPUT)
*      LCON - VARIABLE THAT SPECIFIES THE LENGTH OF THE
*         CONTROL PERIOD. (INPUT)
*      K - VARIABLE THAT COUNTS THE NUMBER OF TRANSITIONS
*          IN AN 11-HOUR PERIOD. (OUTPUT)
*      STATUS - A VECTOR OF LENGTH K THAT GIVES THE STATE
*               (ON/OFF) AFTER EACH TRANSITION. (OUTPUT)
*      CTDAY - A VECTOR OF LENGTH K THAT CONTAINS THE
*              TRANSITION TIMES (IN MINUTES) FOR THE GIVEN
*              SITUATION. (OUTPUT)
*      T - A VECTOR CONTAINING THE TEMPERATURES AT THE
*          TRANSITION TIMES.  (OUTPUT)
*      INTLEN - LENGTH OF INTERVAL OF WHICH THE FIRST LCON
*               MINUTES ARE AUTOMATICALLY OFF.
*************************************************************
*
*
      INTEGER K
      REAL ALPHA,BETA,T(*),TON,TOFF,CTDAY(*),TI,LCON,TAMB,
     *   INTLEN
      CHARACTER*(*) STATUS(*),STATE
      CHARACTER*3 PREVST
      DOUBLE PRECISION DSEED
*
```

```
*
*****************************************************************
*   VARIABLE EXPLANATION:
*      TAMB - TEMPERATURE DRIVING FORCE FROM OUTSIDE THE .
*             SYSTEM.
*      PREVST - VARIABLE TO KEEP TRACK OF THE STATE (ON/
*               /OFF) OF THE SYSTEM AT THE TIME OF CONTROL.
*****************************************************************
*
*
      PREVST=STATE
      K=1
      T(K)=TI
C
C   EACH LOOP OF DO LOOP 100 REPRESENTS 1 HALF-HOUR PERIOD.
C
      DO 100 I=1,INT(630/INTLEN)
         STATUS(K)='OFF'
         CTDAY(K)=(I-1) * INTLEN
         T(K+1)=TAMB+(T(K)-TAMB)*EXP(-BETA*LCON)
C
C   THESE THREE IF STATEMENTS DETERMINE IF AN EXTREME
C   CASE IS PRESENT CONTROL TO THE SECTION OF THE SUB-
C   ROUTINE THAT HANDLES THAT PARTICULAR CASE. IF AN EX-
C   TREME CASE DOES NOT EXIST, OPERATION PROCEEDS IN A
C   NORMAL FASHION.
C
         IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB .GT.
     *      TON) GO TO 110
         IF (TAMB .LE. TON .AND. ALPHA/BETA .GT.
     *      (TAMB-TOFF)) GO TO 120
         IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB .LE.
     *      TON) GO TO 130
         STATUS(K+1)='ON'
         K=K+1
C
C   THIS NESTED IF STATEMENT DETERMINES THE FIRST POST-
C   CONTROL TRANSIITION.
C
         IF (T(K) .GE. TON) THEN
            CTDAY(K)=CTDAY(K-1)+LCON
         ELSE
            IF (PREVST .EQ. 'ON') THEN
               CTDAY(K)=CTDAY(K-1)+LCON
            ELSE
               CTDAY(K)=CTDAY(K-1)+LCON-1/BETA*LOG(
     *            (TON-TAMB)/(T(K)-TAMB))
               T(K)=TON
            ENDIF
         ENDIF
```

```
C
C   THIS IF STATEMENT IS TO DETERMINE IF THE FIRST POST-
C   CUNTROL TRANSITION IS PAST THE ENO OF THE HALF HOUR.
C   IF SO, THE TEMPERATURE IS CORRECTED TO THE ENO OF THE
C   HALF HOUR ANO THE NEXT CONTROL PERIOO IS ENTEREO.
C
          IF (CTOAY(K) .GE. I*INTLEN) THEN
             T(K)=TAMB+(T(K-1)-TAMB)*EXP(-BETA*(I*INTLEN-
     *          CTDAY(K-1)))
             GO TO 100
          ENOIF
C
C   THE FOLLOWING STATEMENTS ARE TO OETERMINE THE TRANS-
C   ITIONS IN THE REST OF THE HALF HOUR.
C
200       K=K+1
          IF (STATUS(K-1) .EQ. 'ON') THEN
             CTOAY(K)=CTDAY(K-1)-1/BETA*LOG((TOFF+ALPHA/BETA
     *          -TAMB)/(T(K-1)+ALPHA/BETA-TAMB))
             STATUS(K)='OFF'
             T(K)=TOFF
          ELSE
             CTOAY(K)=CTDAY(K-1)-1/BETA*LOG((TON-TAMB)/
     *          (T(K-1)TAMB))
             STATUS(K)='ON'
             T(K)=TON
          ENDIF
C
C   THIS IF STATEMENT CHECKS IF THE LAST TRANSITION EX-
C   CEEOEO THE ENO OF THE HALF HOUR. IF NOT CONTROL IS
C   RETURNEO TO 200.
C
          IF (CTOAY(K) .LT. I*INTLEN) GO TO 200
C
C   IF THE ENO OF THE HALF HOUR HAS BEEN REACHED, THESE
C   IF STATEMENTS CORRECTS THE TEMPERATURE AND OETER-
C   MINE WHAT STATE THE SYSTEM WAS IN WHEN THE HALF HOUR
C   ENDEO.
C
          IF (STATUS(K) .EQ. 'OFF') THEN
             T(K)=TAMB-ALPHA/BETA+(T(K-1)+ALPHA/BETA-TAMB)*
     *          *EXP(-BETA * (I*INTLEN - CTOAY(K-1)))
             PREVST='ON'
          ELSE
             T(K)=TAMB+(T(K-1)-TAMB)*EXP(-BETA*(I*INTLEN-
     *          CTDAY(K-1)))
             PREVST='OFF'
          ENDIF
          GO TO 100
C
```

```
C    SECTION 110 HANDLES THE CASE WHERE THE A/C DOES NOT
C    PROVIDE ENOUGH COOLING TO FORCE THE SYSTEM DOWN TO TOFF
C    AND THE AMBIENT TEMPERATURE IS HIGH ENOUGH TO CAUSE
C    THE SYSTEM TO HEAT UP.
C
110       IF (PREVST .EQ. 'OFF' .AND. T(K+1) .LT. TON) THEN
             K=K+1
             CTDAY(K)=CTDAY(K-1)-(1/BETA)*LOG((TON-TAMB)/
     *          (T(K-1)-TAMB))
             T(K)=TON
             STATUS(K)='ON'
             IF (CTDAY(K) .GT. I*INTLEN) THEN
                T(K)=TAMB+(T(K-1)-TAMB)*EXP(-BETA*INTLEN)
                PREVST='OFF'
                GO TO 100
             ENDIF
          ELSE
             K=K+1
             CTDAY(K)=(I-1)*INTLEN+LCON
             STATUS(K)='ON'
          ENDIF
          K=K+1
          T(K)=TAMB-ALPHA/BETA+(T(K-1)+ALPHA/BETA-TAMB)*EXP
     *       (-BETA * (I*INTLEN - CTDAY(K-1)))
          PREVST='ON'
C
C    CONTROL IS TRANSFERRED TO THE END OF LOOP 100 TO START
C    THE NEXT HALF-HOUR PERIOD.
C
          GO TO 100
C
C    SECTION 120 HANDLES THE EXTREME CASE WHERE THE AMBIENT
C    TEMPERATURE IS NOT HIGH ENOUGH TO PRODUCE HEATING BUT
C    THE A/C IS SUFFICIENT TO PRODUCE A DROP IN TEMPERATURE.
C
120       IF (PREVST .EQ. 'ON' .AND. T(K+1) .GT. TOFF) THEN
             K=K+1
             CTDAY(K)=(I-1)*INTLEN + LCON
             STATUS(K)='ON'
             K=K+1
             CTDAY(K)=CTDAY(K-1)-(1/BETA)*LOG((TOFF+
     *          ALPHA/BETA-TAMB)/(T(K-1)+ALPHA/BETA-TAMB))
             T(K)=TOFF
             STATUS(K)='OFF'
             IF (CTDAY(K) .GT. I*INTLEN) THEN
                T(K)=TAMB-ALPHA/BETA+(T(K-1)+ALPHA/BETA-
     *             TAMB)*EXP(-BETA*(I*INTLEN - CTDAY(K-1)))
                PREVST='ON'
                GO TO 100
             ENDIF
```

```
      ENDIF
      K=K+1
      T(K)=TAMB+(T(K-1)-TAMB)*EXP(-BETA*(I*INTLEN-
     *   CTDAY(K-1)))
      PREVST='OFF'
C
C   CONTROL IS TRANSFERRED TO THE END OF LOOP 100 TO START
C   THE NEXT HALF-HOUR PERIOD.
C
      GO TO 100
C
C   SECTION 130 HANDLES THE EXTREME CASE WHERE THE AMBIENT
C   TEMPERATURE IS NOT SUFFICIENT TO PRODUCE HEATING AND
C   THE A/C IS NOT SUFFICIENT TO PRODUCE COOLING. IT IS
C   ASSUMED THAT THE A/C STAYS OFF BECAUSE CONDITIONS ARE
C   SUCH THAT THE HOUSE WILL REMAIN BELOW TON.
C
130   K=K+1
      CTDAY(K)=CTDAY(K-1) + INTLEN
      STATUS(K)='OFF'
      T(K)=TAMB+(T(K-1)-TAMB)*EXP(-BETA*INTLEN)
100 CONTINUE
    RETURN
    END
```

```
* THIS IS THE CONSTANT DRIVING TEMPERATURE VERSION OF
* NEOCON.
*****************************************************************
*    SUBROUTINE NEOCON DETERMINES THE TRANSITION TIMES FOR
*    THE CONTROLLED CASE WHERE 7.5 MINUTES OF RUNNING TIME
*    ARE TAKEN AWAY FROM EACH 30 MINUTES OF RUNNING TIME.
*****************************************************************
*
*
      SUBROUTINE NEOCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                  TRANS,TEMP,NUMHRS,TAMB,TIMEO,DSEED)
*
*
*****************************************************************
*    ARGUMENT EXPLANATIONS:
*       ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*           (INPUT)
*       BETA - HEATING COEFFICIENT (1/MIN). (INPUT
*       T - INITIAL TEMPERATURE OF THE SYSTEM. (INPUT)
*       STATE - INITIAL STATE (ON/OFF) OF THE A/C. (INPUT)
*       TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*       TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*           (INPUT)
*       J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A
*           PERIOD OF SPECIFIED LENGTH. (OUTPUT)
*       TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*           TIMES IN MINUTES) FOR THE PERIOD OF SPECIFIED
*           LENGTH. (OUTPUT)
*       TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*          (ON/OFF) OF THE SYSTEM AFTER THE CORRESPONDING
*          TRANSITION IN TDAY. (OUTPUT)
*       TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*          SYSTEM AT EACH TRANSITION. (OUTPUT)
*       NUMHRS - NUMBER OF HOURS FOR WHICH TRANSISTIONS ARE
*          DESIRED. (INPUT)
*       TIMEO - INITIAL TIME FOR TRANSITIONS. (INPUT)
*       TAMB - DRIVING TEMPERATURE. (OUTPUT)
*       DSEED - SEED NUMBER FOR GENERATING RANDOM AMOUNTS OF
*          INITIAL TIME. (INPUT)
*****************************************************************
*
*
      REAL ALPHA,BETA,T,TDAY(*),TON,TOFF,TEMP(*),TAMB,
     *     NUMHRS,TPEAK,TIMEO,TION,R(2)
      DOUBLE PRECISION DSEED
      INTEGER J
      CHARACTER*(*) STATE,TRANS(*)
*
*
*****************************************************************
```

```
*    VARIABLE EXPLANATION:
*      TION - VARIABLE USED TO KEEP TRACK OF ON TIME.
*      R - RANDOM NUMBER BETWEEN 0 AND 1.
*******************************************************************
*
*
      J=1
      TEMP(J)=T
      TRANS(J)=STATE
      TDAY(J)=TIMEO
C
C    GENERATE THE AMOUNT OF ON TIME ALREADY ON THE LOAD
C    LEVELER.
C
      CALL GGUBS(DSEED,1,R)
      TION=R(1)*30.0
C
C    THIS IF STATEMENT STARTS THE LOOP BY CHECKING IF THE
C    TIME HAS EXPIRED.
C
100   IF (TDAY(J) .GE. (60*NUMHRS+30+TIMEO)) GO TO 150
C
C    THE NEXT THREE IF STATEMENTS CHECK IF THE SYSTEM IS IN
C    AN EXTREME SITUATION, AND IF SO, CALLS THE APPROPRIATE
C    SUBROUTINE AND STARTS THE LOOP OVER.
C
      IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB
     *   .GT. TON) THEN
         CALL NEONOC(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,TEMP,
     *      TION)
         GO TO 100
      ENDIF
      IF (TAMB .LE. TON .AND. ALPHA/BETA .GT.
     *   (TAMB-TOFF)) THEN
         CALL NOHEAT(ALPHA,BETA,TOFF,TAMB,J,TDAY,TRANS,
     *               TEMP)
         GO TO 100
      ENDIF
      IF (ALPHA/BETA .LE. (TAMB-TOFF) .AND. TAMB .LE. TON)
     *   THEN
         CALL ABEXT(ALPHA,BETA,TAMB,J,TDAY,TRANS,TEMP)
         GO TO 100
      ENDIF
C
C    THESE STATEMENTS DETERMINE THE TRANSITIONS IF THE
C    SYSTEM IS IN NORMAL OPERATION.
C
      IF (TRANS(J) .EQ. 'ON') THEN
C
C    IF THE SYSTEM IS ON, CHECK TO SEE IF IT IS TIME TO
```

```
C    CONTROL IF SO, TAKE APPROPRIATE ACTION.
C
          IF (TION .LT. 7.5) THEN
             TRANS(J)='OFF'
             TRANS(J+1)='ON'
             TDAY(J+I)=TDAY(J)+7.5-TION
             TEMP(J+1)=TAMB+(TEMP(J)-TAMB)*EXP(-BETA*(7.5-
     *          TION))
             TION=7.5
             J=J+1
             IF (ALPHA/BETA .LE. (TAMB-TOFF)) GO TO 100
          ENDIF
C
C    DETERMINE NORMAL, UNCONTROLLED COOLING TRANSITIONS.
C
          TDAY(J+I)=TDAY(J)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *       TAMB)/(TEMP(J)+ALPHA/BETA-TAMB))
          TRANS(J+1)='OFF'
          TEMP(J+1)=TOFF
          TION=TION+TDAY(J+I)-TDAY(J)
          J=J+I
C
C    CHECK IF THE LAST TRANSITION EXCEEDED THE NEED FOR
C    CONTROL, CORRECT FOR THE START OF CONTROL, AND PROCEED
C    TO CONTROL STATEMENTS.
C
          IF (TION .GE. 30.0) THEN
             TDAY(J)=TDAY(J)-(TION-30.0)
             TRANS(J)='ON'
             TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA
     *          -TAMB)*EXP(-BETA*(TDAY(J)-TDAY(J-1)))
             IF (TDAY(J) .GT. (60*NUMHRS+30+TIMEO))
     *          GO TO 150
             TION=0.0
             GO TO 100
          ENDIF
       ELSE
C
C    DETERMINE NORMAL HEATING PHASE TRANSITIONS.
C
          TDAY(J+I)=TDAY(J)-(1/BETA)*LOG((TON-TAMB)/(TEMP(J)
     *       -TAMB))
          TRANS(J+1)='ON'
          TEMP(J+1)=TON
          J=J+1
       ENDIF
C
C    THIS STATEMENT STARTS THE LOOP OVER AGAIN
C
       GO TO 100
```

```
150     RETURN
        END
```

```
* THIS VERSION IS USEO WITH CONSTANT ORIVING TEMPERATURE.
*
*****************************************************************
*   SUBROUTINE NOCOOL OEALS WITH THE EXTREME CASE WHERE
*   THE AMBIENT TEMPERATURE IS SUFFICIENT TO PROOUCE HEAT-
*   ING AT THE OESIREO INOOOR TEMPERATURE BUT THE A/C IS
*   NOT SUFFICIENT TO PRODUCE COOLING.
*****************************************************************
*
*
      SUBROUTINE NOCOOL(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS
     *                  TEMP)
*
*
*****************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (OEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*      TAMB - ORIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
*             (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MAOE IN A SPEC-
*          IFIED PERIOO. (INPUT/OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE 11-HOUR PERIOO.
*              (INPUT/OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*              ING TRANSITION IN TDAY. (OUTPUT/OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
*****************************************************************
*
*
      REAL ALPHA,BETA,TDAY(*),TON,TEMP(*),TAMB
      INTEGER J
      CHARACTER*(*) TRANS(*)
      WRITE (6,*) 'WEN INTO NOCOOL'
C
C   THIS IF STATEMENT TAKES CARE OF THE CASE WHERE THE A/C
C   IS INITIALLY OFF.
C
      IF (TRANS(J) .EQ. 'OFF') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)-(1/BETA)*LOG((TON-TAMB)/
     *      (TEMP(J-1)-TAMB))
         TEMP(J)=TON
         TRANS(J)='ON'
      ENDIF
```

```
C
C   THE A/C IS ASSUMED TO RUN ALL OF THE TIME. THIS SECTION
C   MAKES THE NECESSARY STATUS UPDATES AT THE END OF EACH
C   HALF HOUR. THEN CONTROL IS RETURNED TO THE MAIN PROGRAM
C   TO SEE IF THE CONDITIONS HAVE CHANGED.
C
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-TAMB)*
     *   EXP(-BETA*30)
      TRANS(J)='ON'
      RETURN
      END
```

```
*  THIS IS THE CONSTANT DRIVING TEMP. VERSION OF NEONOC.
*
****************************************************************
*   SUBROUTINE NEONOC DEALS WITH THE EXTREME CASE WHERE
*   THE AMBIENT TEMPERATURE IS SUFFICIENT TO PRODUCE HEAT-
*   ING AT THE DESIRED INDOOR TEMPERATURE BUT THE A/C IS
*   NOT SUFFICIENT TO PRODUCE COOLING.
****************************************************************
*
*
      SUBROUTINE NEONOC(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,
     *                  TEMP,TION)
*
*
****************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*      TAMB - DRIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
*             (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A SPEC
*          IFIED PERIOD. (INPUT/OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE 11-HOUR PERIOD.
*             (INPUT/OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRES-
*              PONDING TRANSITION IN TDAY. (OUTPUT/OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
*      TION - VARIABLE TO KEEP TRACK OF ON TIME.
*             (INPUT/OUTPUT)
*      TPEAK - PEAK TEMPERATURE OF THE DAY. (INPUT)
****************************************************************
*
*
      REAL ALPHA,BETA,TDAY(*),TON,TEMP(*),TAMB,TION
      INTEGER J
      CHARACTER*(*) TRANS(*)
C
C   THIS IF STATEMENT TAKES CARE OF THE CASE WHERE THE A/C
C   IS INITIALLY OFF.
C
      IF (TRANS(J) .EQ. 'OFF') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)-(1/BETA)*LOG((TON-TAMB)/
     *      (TEMP(J-1)-TAMB))
         TEMP(J)=TON
```

```
          TRANS(J)='ON'
        ENDIF
C
C   THE A/C IS ASSUMED TO RUN ALL OF THE TIME. THIS SECTION
C   MAKES THE NECESSARY STATUS UPDATES AT THE END OF EACH
C   HALF HOUR. THEN CONTROL IS RETURNED TO THE MAIN PROGRAM
C   TO SEE IF THE CONDITIONS HAVE CHANGED.
C
        IF (TION .LT. 7.5) THEN
          TRANS(J)='OFF'
          TRANS(J+1)='ON'
          TDAY(J+1)=TDAY(J)+7.5-TION
          TEMP(J+1)=TAMB+(TEMP(J)-TAMB)*EXP(-BETA*(7.5-TION
     *        ))
          TION=7.5
          J=J+1
        ENDIF
        J=J+1
        TDAY(J)=TDAY(J-1)+30-TION
        TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-
     *    TAMB)*EXP(-BETA*(30-TION))
        TRANS(J)='ON'
        TION=0.0
        RETURN
        END
```

```
*
*
*****************************************************************
*   SUBROUTINE NOCOOL OEALS WITH THE EXTREME CASE WHERE
*   THE AMBIENT TEMPERATURE IS SUFFICIENT TO PROOUCE HEAT-
*   ING AT THE OESIREO INOOOR TEMPERATURE BUT THE A/C IS
*   NOT SUFFICIENT TO PROOUCE COOLING.
*****************************************************************
*
*
      SUBROUTINE NOCOOL(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS
     *                  ,TEMP)
*
*
*****************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON.
*            (INPUT)
*      TAMB - DRIVING TEMPERATURE FROM OUTSIOE THE SYSTEM.
*             (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A SPEC-
*          IFIEO PERIOD. (INPUT/OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE PERIOD.
*             (INPUT/OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*              ING TRANSITION IN TOAY. (INPUT/OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
*****************************************************************
*
*
      REAL ALPHA,BETA,TOAY(*),TON,TEMP(*),TAMB
      INTEGER J
      CHARACTER*(*) TRANS(*)
C
C   THIS IF STATEMENT TAKES CARE OF THE CASE WHERE THE A/C
C   IS INITIALLY OFF.
C
      IF (TRANS(J) .EQ. 'OFF') THEN
         J=J+1
         TOAY(J)=TOAY(J-1)-(1/BETA)*LOG((TON-TAMB)
     *      /(TEMP(J-1)-TAMB))
         TEMP(J)=TON
         TRANS(J)='ON'
      ENDIF
```

```
C
C    THE A/C IS ASSUMED TO RUN ALL OF THE TIME. THIS SECTION
C    MAKES THE NECESSARY STATUS UPDATES AT THE END OF EACH
C    HALF HOUR. THEN CONTROL IS RETURNED TO THE MAIN PROGRAM
C    TO SEE IF THE CONDITIONS HAVE CHANGED.
C
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-
     *   TAMB)*EXP(-BETA*30)
      TRANS(J)='ON'
      RETURN
      END
```

```
*
* THIS IS THE FINAL CONSTANT ORIVING TEMF VERSION OF NAVG.
*********************************************************
*   SUBROUTINE NAVG TAKES THE ARRAYS OF TRANSITION TIMES,
*   STATES, ANO TEMPERATURES ANO RETURNS THE AVERAGE POWER
*   ANO THE AVERAGE TEMPERATURE FOR EACH N-MINUTE PERIOO.
*   THIS IS DONE FOR A TOTAL OF 10 HOURS.
*********************************************************
*
*
      SUBROUTINE NAVG (TDAY,TRANS,TEMP,NUM,ALPHA,BETA,N,
     *                PWR,TEMPAV,TAMB)
*
*
*********************************************************
*   ARGUMENT EXPLANATIONS:
*      TDAY - A VECTOR CONTAINING TRANSITION TIMES (IN
*             MINUTES). IT MUST CONTAIN AT LEAST ONE
*             TRANSITION PAST 10 HOURS. (INPUT)
*      TRANS - A VECTOR OF THE SAME LENGTH AS TDAY WHICH
*              CONTAINS THE STATE (ON/OFF) OF THE SYSTEM
*              AFTER EACH CORRESPONDING TRANSITION. (INPUT)
*      TEMP - A VECTOR CONTAINING THE TRANSITION TEMP-
*             ERATURES. (INPUT)
*      NUM - THE NUMBER OF ENTRIES INTO VECTORS TDAY AND
*            TRANS. (INPUT)
*      ALPHA - COOLING COEFFICIENT (DEGF/MIN). (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      N - THE LENGTH (IN MINUTES) OF THE INTERVAL OF
*          INTEREST. EXAMPLE: N=5 TO DETERMINE AVERAGE
*          POWER FOR EACH N-MINUTE PERIOO. (INPUT)
*      PWR - A VECTOR WHICH CONTAINS THE FRACTIONAL AMOUNT
*            OF TIME DURING EACH N-MINUTE INTERVAL WHICH
*            THE A/C IS ON (1=N MINUTES; 0=0 MINUTES).
*            LENGTH IS 600/N. (OUTPUT)
*      TEMPAV - A VECTOR WHICH CONTAINS THE AVERAGE TEMP-
*               ERATURE FOR EACH N-MINUTE INTERVAL.
*               (OUTPUT)
*********************************************************
*
*
      REAL TDAY(*),PWR(*),PTDAY(600),ALPHA,BETA,TEMP(*),
     *   TEMPAV(*),AVE,TAMB,N,I,T(600)
      CHARACTER*(*) TRANS(*)
      CHARACTER*3 STATE
      INTEGER J,K,NUM,LOOP
*
*
*********************************************************
*   VARIABLE EXPLANATION:
```

```
*      STATE - VARIABLE TO KEEP TRACK OF CURRENT STATE OF
*              THE SYSTEM AS THE SUBROUTINE GOES THRCUGH
*              THE TRANSTIONS IN THE 10-HOUR PERIOD.
*      J - VARIABLE TO COUNT WHICH TRANSITION AND STATE OF
*          TDAY AND ARE OF CURRENT INTEREST TO SUBROUTINE.
*          (INPUT)
*      PTDAY - ARRAY USED TO STORE VALUES FROM TDAY TO
*              DETERMINE THE DESIRED FOR PWR.
*      TAMB - EXTERIOR TEMPERATURE DRIVING FORCE.
*      AVE - INTERMEDIATE VARIABLE FOR DETERMINING THE
*            AVERAGE TEMPERATURE IN EACH N-MINUTE INTERVAL.
*      I - VARIABLE TO KEEP TRACK OF THE CURRENT INTERVAL
*          OF TIME.
***********************************************************
*
*
      DO 100 LOOP=1,600/N
         PWR(LOOP)=0
         TEMPAV(LOOP)=0
100   CONTINUE
      DO 150 LOOP=1,NUM
         PTDAY(LOOP)=TDAY(LOOP)
         T(LOOP)=TEMP(LOOP)
150   CONTINUE
      J=1
      STATE=TRANS(J)
C
C    EACH LOOP OF DO LOOP 200 REPRESENTS ONE N-MINUTE
C    INTERVAL.
C
      I = N
      K = 1
200   IF (I .LE. 600.0) THEN
C
C    IF STATEMENT 500 STARTS THE NEXT N-MINUTE INTERVAL
C    IF THE CURRENT TRANSITION IS ESSENTIALLY AT THE END OF
C    THE CURRENT INTERVAL.
C
500      IF ((I-PTDAY(J)) .LT. 0.1E-70) GO TO 190
C
C    THE FOLLOWING IF STATEMENT SORTS THE TRANSITIONS
C    ACCORDING TO WHETHER THE HEATING OR COOLING MODEL IS
C    APPROPRIATE.
C
         IF (STATE .EQ. 'ON') THEN
C
C    THIS IF STATEMENT DETERMINES THE APPROPRIATE TIME
C    PEERIOD TO CONSIDER DETERMINED BY THE TIME OF THE NEXT
C    TRANSITION. IF THE TRANSITION IS PAST THE END OF THE
C    CURRENT N-MINUTE NTERVAL THEN THE TIMEPERIOD USED IS
```

```
C   TO THE END OF THE CURRENT N-MINUTE INTERVAL.
C
              IF (PTDAY(J+1) .GT. I) THEN
                 PWR(K)=PWR(K)+(I-PTDAY(J))/N
                 AVE=TAMB-ALPHA/BETA-((T(J)+ALPHA/BETA-TAMB)
     *              /(BETA*(I-PTDAY(J))))*(EXP(-BETA*
     *              (I-PTDAY(J)))-1)
                 TEMPAV(K)=TEMPAV(K)+AVE*(I-PTDAY(J))
                 T(J)=TAMB-ALPHA/BETA+(T(J)+ALPHA/BETA-TAMB)
     *              *EXP(-BETA*(I-PTDAY(J)))
                 PTDAY(J)=I
              ELSE
                 PWR(K)=PWR(K)+(PTDAY(J+1)-PTDAY(J))/N
                 AVE=TAMB-ALPHA/BETA-((T(J)+ALPHA/BETA-TAMB)/
     *              (BETA*(PTDAY(J+1)-PTDAY(J))))*(EXP(-BETA*
     *              (PTDAY(J+1)-PTDAY(J)))-1)
                 TEMPAV(K)=TEMPAV(K)+AVE*(PTDAY(J+1)-
     *              PTDAY(J))
                 J=J+1
                 STATE=TRANS(J)
                 GO TO 500
              ENDIF
           ELSE
C
C   THIS IF STATEMENT IS ANALAGOUS TO THE PREVIOUS IF
C   STATEMENT EXCEPT THE A/C IS CURRENTLY OFF.
C
              IF (PTDAY(J+1) .GT. I) THEN
                 AVE=TAMB-((T(J)-TAMB)/(BETA*(I-PTDAY(J))))
     *              *EXP(-BETA*(I-PTDAY(J)))-1)
                 TEMPAV(K)=TEMPAV(K)+AVE*(I-PTDAY(J))
                 T(J)=TAMB+(T(J)-TAMB)*EXP(-BETA*(I-PTDAY(J)
     *              ))
                 PTDAY(J)=I
              ELSE
                 AVE=TAMB-((T(J)-TAMB)/(BETA*(PTDAY(J+1)-
     *              PTDAY(J))))*(EXP(-BETA*(PTDAY(J+1)-
     *              PTDAY(J)))-1)
                 TEMPAV(K)=TEMPAV(K)+AVE*(PTDAY(J+1)-PTDAY(J)
     *              )
                 J=J+1
                 STATE=TRANS(J)
                 GO TO 500
              ENDIF
           ENDIF
190        TEMPAV(K)=TEMPAV(K)/N
           K = K+1
           I = I+N
           GO TO 200
        ENDIF
```

```
RETURN
END
```

Subroutines Duncon, Dnavg, and Dvepwr are versions of Uncon, Navg, and Avepwr to be used when the length of the time period is 30 hours.

```
*  THIS IS A VERSION OF UNCON ALTERED FOR A LENGTH OF 31
*  HOURS.
**************************************************************
*   SUBROUTINE UNCON DETERMINES THE TRANSITION TIMES FOR
*   THE UNCONTROLLED CASE. THE RESULTING TRANSITION TIMES
*   ARE RETURNED IN TDAY WHICH IS A 600 MEMBER ARRAY. TRANS
*   RETURNS THE STATE THAT THE SYSTEM GOES TO WHEN THE
*   TRANSITION IS MADE.
**************************************************************
*
*
      SUBROUTINE DUNCON (ALPHA,BETA,T,STATE,TON,TOFF,J,
     *                   TDAY,TRANS,TEMP)
*
*
**************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - RATE AT WHICH SYSTEM COOLS WITH A/C ON
*              (DEGF/MIN). (INPUT)
*      BETA - RATE AT WHICH SYSTEM HEATS UP WITH A/C OFF
*             (DEGF/MIN). (INPUT)
*      T - INITIAL TEMPERATURE OF THE SYSTEM. (INPUT)
*      STATE - INITIAL STATE (ON/OFF) OF THE A/C. (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*      TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*             (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN THE 30-
*          HOUR PERIOD. (OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE 11-HOUR PERIOD.
*             (OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*              ING TRANSITION IN TDAY. (OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION.
**************************************************************
*
*
      REAL ALPHA,BETA,T,TDAY(*),TON,TOFF,TEMP(*),TAMB
      INTEGER J
      CHARACTER*(*) STATE,TRANS(*)
*
*
**************************************************************
*   VARIABLE EXPLANATION:
*      TAMB - DRIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
**************************************************************
*
*
```

```
      J=1
      TEMP(J)=T
      TRANS(J)=STATE
      TOAY(J)=0
      CALL ORIVE(TAMB)
C
C   THE NEXT THREE STATEMENTS CHECK IF THE SYSTEM IS IN AN
C   EXTREME SITUATION, ANO IF SO, SENOS CONTROL TO THE
C   SECTION THAT OEALS WITH THE PARTICULAR EXTREME.
C
100   IF (ALPHA/BETA .LE. (TAMB-TOFF) .ANO. TAMB .GT. TON)
     *   GO TO 110
      IF (TAMB .LE. TON .ANO. ALPHA/BETA .GT. (TAMB-TOFF))
     *   GO TO 120
      IF (ALPHA/BETA .LE. (TAMB-TOFF) .ANO. TAMB .LE. TON)
     *   GO TO 130
C
C   THESE STATEMENTS OETERMINE THE TRANSITIONS IF THE SYS-
C   TEM IS IN NORMAL OPERATION. IF THE SYSTEM IS ON, THE
C   NEXT TRANSITION IS OETERMINEO USING THE COOLING MOOEL.
C   IF THE SYSTEM IS OFF, THE NEXT TRANSITION IS OETERMINEO
C   BY THE HEATING MOOEL.
C
      IF (TRANS(J) .EQ. 'ON') THEN
         TOAY(J+1)=TOAY(J)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *      TAMB)/(TEMP(J)+ALPHA/BETA-TAMB))
         TRANS(J+1)='OFF'
         TEMP(J+1)=TOFF
         J=J+1
      ELSE
         TOAY(J+1)=TOAY(J)-(1/BETA)*LOG((TON-TAMB)/(TEMP(J)
     *      -TAMB))
         TRANS(J+1)='ON'
         TEMP(J+1)=TON
         J=J+1
      ENOIF
      GO TO 150
C
C   THIS SECTION DEALS WITH THE EXTREME WHERE ALPHA IS NOT
C   SUFFICIENT TO PRODUCE A DROP IN TEMPERATURE ANO THE
C   AMBIENT TEMPERATURE IS SUFFICIENT TO PRODUCE A RISE IN
C   TEMPERATURE.
C
110   IF (TRANS(J) .EQ. 'OFF') THEN
         J=J+1
         TOAY(J)=TOAY(J-1)-(1/BETA)*LOG((TON-TAMB)/
     *      (TEMP(J-1)-TAMB))
         TEMP(J)=TON
         TRANS(J)='ON'
      ENDIF
```

```
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-TAMB)*
     *   EXP(-BETA*30)
      TRANS(J)='ON'
C
C   CONTROL IS TRANSFERRED AT THE END OF 30 MINUTES TO
C   CHECK IF THE 30 HOURS HAVE EXPIRED AND TO CHECK THE
C   CONDITIONS AGAIN.
C
      GO TO 150
C
C   THIS SECTION DEALS WITH THE EXTREME WHERE TAMB IS TOO
C   LOW FOR THE HOUSE TO NEED COOLING AND THE A/C IS SUF-
C   FICIENT TO PRODUCE COOLING.
C
120   IF (TRANS(J) .EQ. 'ON') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *      TAMB)/(TEMP(J-1)+ALPHA/BETA-TAMB))
         TRANS(J)='OFF'
         TEMP(J)=TOFF
      ENDIF
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB+(TEMP(J-1)-TAMB)*EXP(-BETA*30)
      TRANS(J)='OFF'
C
C   CONTROL IS TRANSFERRED AT THE END OF 30 MINUTES TO
C   DETERMINE IF 30 HOURS HAVE EXPIRED AND TO CHECK THE
C   CONDITIONS AGAIN.
C
      GO TO 150
C
C   SECTION 130 HANDLES THE SITUATION WHEN THE AMBIENT
C   TEMPERATURE IS NOT SUFFICIENT TO PRODUCE HEATING AND
C   THE A/C IS NOT SUFFICIENT TO PRODUCE COOLING. IT IS
C   ASSUMED THAT THE A/C WILL BE TURNED OFF BECAUSE THE
C   CONDITIONS ARE SUCH THAT A/C IS NOT NEEDED.
C
130   IF (TRANS(J) .EQ. 'ON') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)+1
         TRANS(J)='OFF'
         TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-
     *      TAMB)*EXP(-BETA)
      ENDIF
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TRANS(J)='OFF'
```

```
      TEMP(J)=TAMB+(TEMP(J-1)-TAMB)*EXP(-BETA*30)
C
C    THIS STATEMENT CHECKS IF 11 HOURS HAVE EXPIRED. IF SO,
C    CONTROL IS RETURNED TO THE MAIN PROGRAM. IF NOT, THE
C    SUBROUTINE CONTINUES TO LOOP THROUGH THE ABOVE STATE-
C    MENTS.
C
150   IF (TOAY(J) .LE. 1980) GO TO 100
      RETURN
      END
```

```
*  (THIS IS A VERSION OF NAVG THAT HAS BEEN ALTERED FOR USE
*   WITH PROGRAM NEWDIST)
****************************************************************
*   SUBROUTINE NAVG TAKES THE ARRAYS OF TRANSITION TIMES,
*   STATES, AND TEMPERATURES AND RETURNS THE AVERAGE POWER
*   AND THE AVERAGE TEMPERATURE FOR EACH N-MINUTE PERIOD.
*   THIS IS DONE FOR A TOTAL OF 10 HOURS.
****************************************************************
*
*
      SUBROUTINE DNAVG (TDAY,TRANS,TEMP,NUM,ALPHA,BETA,N,
     *                  PWR,TEMPAV)
*
*
****************************************************************
*   ARGUMENT EXPLANATIONS:
*      TDAY - A VECTOR CONTAINING TRANSITION TIMES (IN MIN-
*             UTES) IT MUST CONTAIN AT LEAST ONE TRANSITION
*             PAST 10 HOURS. (INPUT)
*      TRANS - A VECTOR OF THE SAME LENGTH AS TDAY WHICH
*              CONTAINS THE STATE (ON/OFF) OF THE SYSTEM
*              AFTER EACH CORRESPONDING TRANSITION. (INPUT)
*      TEMP - A VECTOR CONTAINING THE TRANSITION TEMPERA-
*             TURES. (INPUT)
*      NUM - THE NUMBER OF ENTRIES INTO VECTORS TDAY AND
*            TRANS. (INPUT)
*      ALPHA - COOLING COEFFICIENT (DEGF/MIN). (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      N - THE LENGTH (IN MINUTES) OF THE INTERVAL OF IN-
*          TEREST EXAMPLE: N=5 TO DETERMINE POWER CONSUMP-
*          TION FOR EACH 5-MINUTE PERIOD. (INPUT)
*      PWR - A VECTUR WHICH CONTAINS THE FRACTIONAL AMOUNT
*            OF TIME DURING EACH N-MINUTE INTERVAL WHICH
*            THE A/C IS ON ( 1=N MINUTES; 0=0 MINUTES).
*            LENGTH IS 600/N. (OUTPUT)
*      TEMPAV - A VECTOR WHICH CONTAINS THE AVERAGE TEMPER-
*               ATURE FOR EACH N-MINUTE INTERVAL. (OUTPUT)
****************************************************************
*
*
      REAL TDAY(*),PWR(*),PTDAY(1800),ALPHA,BETA,TEMP(*),
     *   T(1800),TEMPAV(*),AVE,TAMB
      CHARACTER*(*) TRANS(*)
      CHARACTER*3 STATE
      INTEGER J,N,NUM
*
*
****************************************************************
*   VARIABLE EXPLANATION:
*      STATE - VARIABLE TO KEEP TRACK OF CURRENT STATE OF
```

```
*              THE SYSTEM AS THE SUBROUTINE GOES THROUGH
*              THE TRANSITIONS IN THE 10-HOUR PERIOD.
*       J - VARIABLE TO COUNT WHICH TRANSITION AND STATE OF
*           TDAY AND ARE OF CURRENT INTEREST TO SUBROUTINE.
*       PTDAY - ARRAY USED TO STORE VALUES FROM TDAY TO
*              DETERMINE THE DESIRED FOR PWR.
*       TAMB - EXTERIOR TEMPERATURE DRIVING FORCE. OBTAINED
*             FROM SUBROUTINE DRIVE.
*       AVE - INTERMEDIATE VARIABLE FOR DETERMINING THE
*            AVERAGE TEMPERATURE IN EACH N-MINUTE INTERVAL.
*************************************************************
*
*
      DO 100 I=1,1800/N
         PWR(I)=0
         TEMPAV(I)=0
100   CONTINUE
      DO 150 I=1,NUM
         PTDAY(I)=TDAY(I)
         T(I)=TEMP(I)
150   CONTINUE
      J=1
      STATE=TRANS(J)
      CALL DRIVE(TAMB)
C
C    EACH LOOP OF DO LOOP 200 REPRESENTS ONE N-MINUTE
C    INTERVAL.
C
      DO 200 I=N,1800,N
C
C    IF STATEMENT 500 STARTS THE NEXT N-MINUTE INTERVAL IF
C    THE CURRENT TRANSITION IS ESSENTIALLY AT THE END OF THE
C    CURRENT INTERVAL.
C
500      IF ((I-PTDAY(J)) .LT. 0.1E-70) GO TO 190
C
C    THE FOLLOWING IF STATEMENT SORTS THE TRANSITIONS
C    ACCORDING TO WHETHER THE HEATING OR COOLING MODEL IS
C    APPROPRIATE.
C
         IF (STATE .EQ. 'ON') THEN
C
C    THIS IF STATEMENT DETERMINES THE APPROPRIATE TIME
C    PERIOD TO CONSIDER DETERMINED BY THE TIME OF THE NEXT
C    TRANSITION IF THE TRANSITION IS PAST THE END OF THE
C    CURRENT N-MINUTE INTERVAL THEN THE TIME PERIOD USED IS
C    TO THE END OF THE CURRENT N-MINUTE INTERVAL.
C
            IF (PTDAY(J+1) .GT. I) THEN
               PWR(I/N)=PWR(I/N)+(I-PTDAY(J))/N
```

```
                  AVE=TAMB-ALPHA/BETA-((T(J)+ALPHA/BETA-TAMB)/
     *               (BETA*(I-PTDAY(J))))*(EXP(-BETA*(I-
     *               PTDAY(J)))-1)
                  TEMPAV(I/N)=TEMPAV(I/N)+AVE*(I-PTDAY(J))
                  T(J)=TAMB-ALPHA/BETA+(T(J)+ALPHA/BETA-TAMB)*
     *               EXP(-BETA*(I-PTDAY(J)))
                  PTDAY(J)=I
               ELSE
                  PWR(I/N)=PWR(I/N)+(PTDAY(J+1)-PTDAY(J))/N
                  AVE=TAMB-ALPHA/BETA-((T(J)+ALPHA/BETA-TAMB)/
     *               (BETA*(PTDAY(J+1)-PTDAY(J))))*(EXP(-BETA*
     *               (PTDAY(J+1)-PTDAY(J)))-1)
                  TEMPAV(I/N)=TEMPAV(I/N)+AVE*(PTDAY(J+1)-
     *               PTDAY(J))
                  J=J+1
                  STATE=TRANS(J)
                  GO TO 500
               ENDIF
            ELSE
C
C   THIS IF STATEMENT IS ANALAGOUS TO THE PREVIOUS IF
C   STATEMENT EXCEPT THE A/C IS CURRENTLY OFF.
C
               IF (PTDAY(J+1) .GT. I) THEN
                  AVE=TAMB-((T(J)-TAMB)/(BETA*(I-PTDAY(J))))*(
     *               EXP(-BETA*(I-PTDAY(J)))-1)
                  TEMPAV(I/N)=TEMPAV(I/N)+AVE*(I-PTDAY(J))
                  T(J)=TAMB+(T(J)-TAMB)*EXP(-BETA*(I-
     *               PTDAY(J)))
                  PTDAY(J)=I
               ELSE
                  AVE=TAMB-((T(J)-TAMB)/(BETA*(PTDAY(J+1)-
     *               PTDAY(J))))*EXP(-BETA*(PTDAY(J+1)-
     *               PTDAY(J)))-1)
                  TEMPAV(I/N)=TEMPAV(I/N)+AVE*(PTDAY(J+1)-
     *               PTDAY(J))
                  J=J+1
                  STATE=TRANS(J)
                  GO TO 500
               ENDIF
            ENDIF
190         TEMPAV(I/N)=TEMPAV(I/N)/N
200      CONTINUE
         RETURN
         END
```

```
*  THIS IS A VERSION OF AVEPWR ALTEREO FOR USE OVER 30
*  HOURS.
**************************************************************
*   SUBROUTINE AVEPWR CALCULATES THE AVERAGE POWER CONSUMEO
*   IN THE INTERVALS OF OESIRED LENGTH BY TAKING THE POWER
*   CONSUMED IN N-MINUTE INTERVALS ANO AVERAGING THESE
*   FIGURES FOR LONGER PERIOCS OF TIME.
**************************************************************
*
*
      SUBROUTINE OVEPWR(PWR,LENGTH,N,PAVG)
*
*
**************************************************************
*   ARGUMENTS:
*       PWR - VECTOR THAT CONTAINS THE AVERAGE POWER FOR THE
*         N-MINUTE INTERVALS.
*       LENGTH - LENGTH OF INTERVAL THAT AVERAGE POWER IS
*          OESIREO.
*       N - LENGTH OF THE INTERVAL USEO IN PWR.
*       PAVG - VECTOR THAT RETURNS DESIREO AVERAGE POWER FOR
*          THE OESIREO LENGTH INTERVALS.
**************************************************************
*
*
      REAL PWR(*),PAVG(*)
      INTEGER LENGTH,N,NUM,C,COUNT
      NUM=1800/LENGTH
      COUNT=LENGTH/N
      C=0
      00 50 I=1,NUM
         PAVG(I)=0
50    CONTINUE
C
C   DO LOOP 100 CALCULATES THE AVERAGE POWER CONSUMPTION
C   FOR THE NUMBER OF INTERVALS OF OESIREO LENGTH IN THE
C   10-HOUR PERIOD.
C
      00 100 I=1,NUM
C
C   DO LOOP 200 CALCULATES THE AVERAGE POWER IN EACH OF THE
C   INDIVIOUAL INTERVALS.
C
         DO 200 K=1,COUNT
            C=(I-1)*COUNT+K
            PAVG(I)=PAVG(I)+PWR(C)
200      CONTINUE
         PAVG(I)=PAVG(I)/COUNT
100   CONTINUE
      RETURN
```

END

APPENDIX M-II

LISTINGS OF COMPUTER PROGRAMS REQUIRING PIECE-WISE CONSTANT DRIVING TEMPERATURE

```
*
*
************************************************************
*   PROGRAM SINETEMP UTILIZES SUBROUTINES WITH SINUSCIDALLY
*   VARYING ORIVING TEMPERATURE. IT PROOUCES BOTH CON-
*   TROLLEO ANO UNCONTROLLEO LOAO CURVES FOR 12 HOUR OAYS.
*   METHOO OF CONTROL IS CENTRALIZEO.
************************************************************
*
*
      INTEGER UNIT2,J,K,M,COUNT,CCOUNT
      REAL ALPHA,BETA,T,TOAY(1000),TON,TOFF,PWR(200),
     *   CTOAY(1000),CPWR(200),TI(1000),USYS(200),CSYS(200)
     *   ,TEMP(1000),CTEMP(1000),TEMPAV(200),CTEMAV(200),
     *   PWR2(200),TEMPA2(200),N,TAMB(1000),CTAMB(1000),
     *   LCON,INTLEN,NUMHR1,NUMHR2,NUMHR3,PAVG(100),
     *   CPAVG(100),AVGTEM(100),CAVGTE(100),UTEMPA(200)
      DOUBLE PRECISION OSEEO
      CHARACTER STATE*3,START(1000)*3,TRANS(1000)*3,
     *   STATUS(1000)*3
*
*
************************************************************
*   VARIABLE EXPLANATIONS:
*     ALPHA - COOLING COEFFICIENT WITH THE A/C ON.
*        (OEGF/MIN)
*     BETA - HEATING COEFFICIENT. (1/MIN)
*     T - VARIABLE USEO TO KEEP TRACK OF TEMPERATURE.
*     TON - TEMPERATURE AT WHICH THE SYSTEM TURNS ON.
*        (OEGF)
*     TOFF - TEMPERATURE AT WHICH THE SYSTEM TURNS OFF.
*        (OEGF)
*     N - VARIABLE SPECIFYING THE LENGTH OF THE PERIOD OF
*        INTEREST FOR POWER ANO ENERGY CONSUMPTION.
*     M - VARIABLE SPECIFYING THE NUMBER OF HOUSES USEO TO
*        PROOUCE A SUMMEO LOAO CURVE.
*     TOAY(1800), TRANS(1800), TEMP(1800) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), AND
*        TEMPERATURES FOR THE UNCONTROLLEO CASE.
*     CTOAY(1800), STATUS(1800), CTEMP(1800) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), ANO
*        TEMPERATURES FOR THE CONTROLLEO CASE.
*     TAMB(1000), CTAMB(1000) - VECTORS OF THE ORIVING
*        TEMPERATURES AT THE TRANSITION TIMES FOR THE RE-
*        SPECTIVE CASES. (DEGF)
*     PWR(200), CPWR(200) - VECTORS STORING THE FRACTION OF
*        EACH N-MINUTE PERIOC IN WHICH THE A/C IS FOR BOTH
*        OF THE CASES.
*     TEMPAV(200), CTEMAV(200) - VECTORS STORING THE N-MIN-
*        UTE TEMPERATURE AVERAGES FOR BOTH OF THE CASES.
```

```
*      UTEMPA(200) - VECTOR STORING THE N-MINUTE TEMPERATURE
*         AVERAGE FOR THE DAY WITH NO CONTROL PERIOD.
*      USYS(200), CSYS(200) - VECTORS STORING THE TOTAL
*         ENERGY CONSUMPTION FOR EACH N-MINUTE INTERVAL FOR
*         M HOUSES FOR BOTH CASES.
*      LCON - LENGTH OF THE CONTROL PERIOD. (MIN)
*      INTLEN - LENGTH OF THE INTERVAL FOR LCON MINUTES ARE
*         CONTROLLED. (MIN)
*      DSEED - SEED NUMBER USED TO GENERATE RANDOM NUMBERS.
*      TI(1000), START(1000) - VECTORS THAT STORE THE INI-
*         TIAL TEMP. AND STATE FOR EACH OF THE M HOUSES.
*      UNIT2 - VARIABLE USED TO ESTABLISH AN OUTPUT FILE.
*      J - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS
*         IN TDAY.
*      K - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS
*         IN CTDAY.
*      PAVG(100), CPAVG(100) - VECTORS CONTAINING POWER
*         AVERAGES FOR PERIODS OF TIME LONGER THAN N-
*         MINUTES.
*      AVGTEM(100), CAVGTE(100) - VECTORS CONTIAINING TEMP-
*         ERATURE AVERAGES FOR PERIODS OF TIME LONGER THAN
*         N-MINUTES.
*      COUNT, CCOUNT - VARIABLES USED FOR THE MERGING OF
*         CONTROLLED AND UNCONTROLLED PERIODS.
*      STATE - THE STARTING STATE (ON/OFF) FOR THE INDIVID-
*         UAL HOUSE.
*      NUMHR1, NUMHR2, NUMHR3 - THE LENGTH OF THE 3 DIF-
*         FERENT PERIODS OF THE DAY WHERE CONTROL IS USED.
**********************************************************************
*
*
C
C     OPEN A FILE TO PRINT RESULTS TO.
C
      UNIT2=10
      OPEN (UNIT=UNIT2,FILE='IOUN2')
      ALPHA=.446287103
      BETA=.022314355
      INTLEN=30
      LCON=7.5
      DSEED=675432834.D0
      M=20
      TPEAK=100
      N=5.0
      TON=74
      TOFF=70
C
C     DO LOOP 100 INITIALIZES ALL OF THE ELEMENTS OF THE
C     TOTAL SYSTEM CURVES TO 0.
C
```

```
      OO 100 J=1,200
         USYS(J)=0
         CSYS(J)=0
100   CONTINUE
C
C    RANDOM IS CALLEO TO GENERATE THE RANOOM STARTING
C    CONOITIONS.
C
      CALL RANOOM(M,OSEEO,M,TOFF,TON,START,TI)
C
C    OO LOOP 300 LOOPS OVER THE OESIREO NUMBER OF HOUSES TO
C    PROOUCE A CONTROLLEO LOAD CURVE.
C
      OO 300 I=1,M
         T=TI(I)
         STATE=START(I)
C
C    UNCON IS USEO TO PROOUCE THE TRANSITIONS FOR THE UNCON-
C    TROLLEO CASE. NAVG FINDS THE AVERAGE POWER ANO TEMPER-
C    ATURE FOR N-MINUTE INTERVALS.
C
         TIMEO =0.0
         NUMHR1=2.0
         CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *              TRANS,TEMP,NUMHR1,TPEAK,TAMB,TIMEO)
         CALL NAVG(TOAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR,
     *    .         TEMPAV,TAMB,NUMHR1,TIMEO)
C
C    OETERMINE WHAT THE INITIAL TEMPERATURE IS FOR THE
C    CONTROL PERIOO.
C
          TIMEO=120
          NUMHR2=6.0
          COUNT=1
325       IF (TOAY(COUNT) .GE. TIMEO ) GO TO 330
          COUNT=COUNT+1
          GU TO 325
330       IF (TRANS(COUNT-1) .EQ. 'OFF') THEN
             T=TAMB(COUNT-1)+(TEMP(COUNT-1)-TAMB(COUNT-1)
     *          )*EXP(-BETA*(TIMEO-TDAY(COUNT-1)))
             STATE='OFF'
          ELSE
             T=TAMB(COUNT-1)-ALPHA/BETA+(TEMP(COUNT-1)+
     *          ALPHA/BETA-TAMB(COUNT-1))*EXP(-BETA*(TIMEO
     *          -TDAY(COUNT-1)))
             STATE='ON'
          ENOIF
C
C    CON IS USEO TO PRODUCE THE TRANSITIONS FOR THE CON-
C    TROLLEO CASE. NAVG FINOS AVERAGE TEMPERATURE AND POWER
```

```
C    FOR N-MINUTE INTERVALS.
C
           CALL CON(ALPHA,BETA,T,STATE,TON,TOFF,LCON,K,STATUS
     *              ,CTDAY,CTEMP,INTLEN,NUMHR2,TPEAK,CTAMB,
     *              TIMEO)
           CALL NAVG(CTDAY,STATUS,CTEMP,K,ALPHA,BETA,N,CPWR,
     *               CTEMAV,CTAMB,NUMHR2,TIMEO)
C
C    FIND THE INITIAL TEMPERATURE FOR THE NEXT UNCONTROLLED
C    PERIOD.
C
           NUMHR3=4
           TIMEO=480
           CCOUNT=1
335        IF (CTDAY(CCOUNT) .GE. TIMEO) GO TO 340
           CCOUNT=CCOUNT+1
           GO TO 335
340        IF (STATUS(CCOUNT-1) .EQ. 'OFF' ) THEN
              T=CTAMB(CCOUNT-1)+(CTEMP(CCOUNT-1)-CTAMB(CCOUNT
     *           -1))*EXP(-BETA*(TIMEO-CTDAY(CCOUNT-1)))
              STATE='OFF'
           ELSE
              T=CTAMB(CCOUNT-1)-ALPHA/BETA+(CTEMP(CCOUNT-1)+
     *           ALPHA/BETA-CTAMB(CCOUNT-1))*EXP(-BETA*(TIMEO
     *           -CTDAY(CCOUNT-1)))
              STATE='ON'
           ENDIF
C
C    GENERATE THE DATA FOR THE LAST, UNCONTROLLED HOURS OF
C    THE TIME PERIOD.
C
           CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                   TRANS,TEMP,NUMHR3,TPEAK,TAMB,TIMEO)
           CALL   NAVG(TDAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR2,
     *                    TEMPA2,TAMB,NUMHR3,TIMEO)
C
C    MERGE THE DATA FOR THE THREE TIME PERIODS. START BY
C    ADDING THE DATA FOR THE CONTROLLED PERIOD TO THE DATA
C    FOR THE FIRST UNCONTROLLED PERIOD.
C
           COUNT=1
           INT1=NUMHR1*12+1
           INT2=(NUMHR1+NUMHR2)*12
           DO 350 J=INT1,INT2
              PWR(J)=CPWR(COUNT)
              TEMPAV(J)=CTEMAV(COUNT)
              COUNT=COUNT+1
350        CONTINUE
C
C    MERGE THE LAST PERIOD WITH THE FIRST TWO.
```

```
C
          COUNT=1
          INT1=INT2+1
          INT2=(NUMHR1+NUMHR2+NUMHR3)*12
          DO 360 J=INT1,INT2
             PWR(J)=PWR2(COUNT)
             TEMPAV(J)=TEMPA2(COUNT)
             COUNT=COUNT+1
360       CONTINUE
C
C    SUM THE N-MINUTE POWER DATA TO CALCULATE THE AGGREGATE
C    AVERAGE.
C
          DO 370 J=1,144
             CSYS(J)=CSYS(J)+PWR(J)/M
370       CONTINUE
300     CONTINUE
C
C    DO LOOP 400 PRODUCES DATA FOR A SUMMED LOAD CURVE WITH-
C    OUT CONTROL FOR THE DESIRED NUMBER OF HOUSES.
C
        DO 400 LOOP=1,M
          TIME0=0.0
          NUMHR1=12.0
C
C    USE UNCON AND NAVG TO GENERATE N-MINUTE AVERAGES.
C
          CALL UNCON(ALPHA,BETA,TI(LOOP),START(LOOP),TON,
     *              TOFF,J,TDAY,TRANS,TEMP,NUMHR1,TPEAK,
     *              TAMB,TIME0)
          CALL NAVG(TDAY,TRANS,TEMP,J,ALPHA,BETA,N,PWR,
     *             UTEMPA,TAMB,NUMHR1,TIME0)
C
C    CALCULATE THE AGGREGATE POWER AVERAGE.
C
          DO 410 I=1,144
             USYS(I)=USYS(I)+PWR(I)/M
410       CONTINUE
400     CONTINUE
C
C    PRINT OUT N-MINUTE DATA.
C
        WRITE (10,1000) ALPHA,BETA
        WRITE (10,1010) N
        WRITE (10,1020)
        DO 500 I=1,144
          WRITE (10,1030) REAL(I)/12,CSYS(I),TEMPAV(I),
     *       USYS(I),UTEMPA(I)
500     CONTINUE
C
```

```
C     CALCULATE ONE-HOUR AGGREGATE AVERAGES ANO PRINT OUT THE
C     RESULTS.
C
      CALL AVEPWR(CSYS,60,INT(N),CPAVG,NUMHR1)
      CALL AVEPWR(USYS,60,INT(N),PAVG,NUMHR1)
      CALL AVEPWR(TEMPAV,60,INT(N),CAVGTE,NUMHR1)
      CALL AVEPWR(UTEMPA,60,INT(N),AVGTEM,NUMHR1)
      WRITE (10,*)
      WRITE (10,*) ' ONE-HOUR DATA'
      WRITE (10,1040)
      WRITE (10,1045)
      WRITE (10,1050) (I,CPAVG(I),PAVG(I),CAVGTE(I),
     *                 AVGTEM(I), I=1,NUMHR1)
C
C     FORMAT STATEMENTS FOR PRINTING.
C
1000  FORMAT(' OATA FOR ALPHA= ',F5.3,' ANO BETA=',F5.3)
1010  FORMAT(' ',1X,F2.0,'-MINUTE OATA')
1020  FORMAT(' ',' TIME',4X,'W/CONTROL',3X,'W/O CONTROL')
1030  FORMAT('  ',F5.2,2X,F5.3,2X,F5.2,2X,F5.3,2X,F5.2)
1040  FORMAT('  ','TIME',4X,'POWER',6X,'TEMPERATURE')
1045  FORMAT(' ',6X,'CON',3X,'UNCON',3X,'CON',3X,'UNCON')
1050  FORMAT('  ',I2,2X,F5.3,2X,F5.3,2X,F5.2,2X,F5.2)
      STOP
      ENO
```

```
*
*
*****************************************************************
*   PROGRAM NEWSINE IS A VERSION OF SINETEMP THAT USES THE
*   METHOO OF CONTROL USEO IN SUBROUTINE NEOCON. IT PRO-
*   DUCES A CONTROLLED 12 HOUR OAY ANO AN UNCONTROLLEO 12
*   HOUR OAY. THE METHOO OF CONTROL IS LOAO LEVELLER. THE
*   ORIVING TEMPERATURE TEMPERATURE IS PIECEWISE CONSTANT
*   APPROXIMATING A SINUSIOO.
*****************************************************************
*
*
      INTEGER UNIT2,J,K,M,COUNT,CCOUNT,LOOP
      REAL ALPHA,BETA,T,TDAY(1000),TON,TOFF,PWR(200),
     *   CTDAY(1000),CPWR(200),TI(1000),USYS(200),CSYS(200)
     *   ,TEMP(1000),CTEMP(1000),TEMPAV(200),CTEMAV(200),
     *   PWR2(200),TEMPA2(200),N,TAMB(1000),CTAMB(1000),
     *   LCON,INTLEN,NUMHR1,NUMHR2,NUMHR3,PAVG(100),
     *   CPAVG(100),AVGTEM(100),CAVGTE(100),UTEMPA(200),
     *   TDAY2(1000),TEMP2(1000),TAMB2(1000)
      OOUBLE PRECISION OSEEO
      CHARACTER STATE*3,START(1000)*3,TRANS(1000)*3,
     *   STATUS(1000)*3,TRANS2(1000)*3
*
*
*****************************************************************
*   VARIABLE EXPLANATIONS:
*     ALPHA - COOLING COEFFICIENT WITH THE A/C ON.
*        (OEGF/MIN)
*     BETA - HEATING COEFFICIENT. (1/MIN)
*     T - VARIABLE USEO TO KEEP TRACK OF TEMPERATURE.
*     TUN - TEMPERATURE AT WHICH THE SYSTEM TURNS ON.
*        (OEGF)
*     TUFF - TEMPERATURE AT WHICH THE SYSTEM TURNS OFF.
*        (OEGF)
*     N - VARIABLE SPECIFYING THE LENGTH OF THE PERIOO OF
*        INTEREST FOR POWER ANO ENERGY CONSUMPTION.
*     M - VARIABLE SPECIFYING THE NUMBER OF HOUSES USED TO
*        PROOUCE A SUMMEO LOAO CURVE.
*     TDAY(1800), TRANS(1800), TEMP(1800) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), ANO
*        TEMPERATURES FOR THE UNCONTROLLED CASE.
*     CTOAY(1800), STATUS(1800), CTEMP(1800) - VECTORS FOR
*        STORING TRANSITION TIMES, STATES (ON/OFF), AND
*        TEMPERATURES FOR THE CONTROLLEO CASE.
*     TAMB(1000), CTAMB(1000) - VECTORS OF THE DRIVING
*        TEMPERATURES AT THE TRANSITION TIMES FOR THE
*        RESPECTIVE CASES. (OEGF)
*     PWR(200), CPWR(200) - VECTORS STORING THE FRACTION OF
*        EACH N-MINUTE PERIOD IN WHICH THE A/C IS FOR BOTH
```

```
*          OF THE CASES.
*       TEMPAV(200), CTEMAV(200) - VECTORS STORING THE N-
*          MINUTE TEMPERATURE AVERAGES FOR BOTH OF THE CASES.
*       UTEMPA(200) - VECTOR STORING THE N-MINUTE TEMPERATURE
*          AVERAGE FOR THE OAY WITH NO CONTROL PERIOO.
*       USYS(200), CSYS(200) - VECTORS STORING THE TOTAL
*          ENERGY CONSUMPTION FOR EACH N-MINUTE INTERVAL FOR
*          M HOUSES FOR BOTH CASES.
*       LCON - LENGTH OF THE CONTROL PERIOO. (MIN)
*       INTLEN - LENGTH OF THE INTERVAL FOR LCON MINUTES ARE
*          CONTROLLEO. (MIN)
*       OSEEO - SEEO NUMBER USED TO GENERATE RANOOM NUMBERS.
*       TI(I000), START(I000) - VECTORS THAT STORE THE
*          INITIAL TEMP. ANO STATE FOR EACH OF THE M HOUSES.
*       UNIT2 - VARIABLE USEO TO ESTABLISH AN OUTPUT FILE.
*       J - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          TOAY.
*       K - VARIABLE CONTAINING THE NUMBER OF TRANSITIONS IN
*          CTDAY.
*       PAVG(100), CPAVG(I00) - VECTORS CONTAINING POWER AV-
*          ERAGES FOR PERIOOS OF TIME LONGER THAN N-MINUTES.
*       AVGTEM(I00), CAVGTE(100) - VECTORS CONTIAINING TEMP-
*          ERATURE AVERAGES FOR PERIODS OF TIME LONGER THAN
*          N-MINUTES.
*       COUNT, CCOUNT - VARIABLES USEO FOR THE MERGING OF
*          CONTROLLEO ANO UNCONTROLLEO PERIOOS.
*       STATE - THE STARTING STATE (ON/OFF) FOR THE INOIVID-
*          UAL HOUSE.
*       NUMHRI, NUMHR2, NUMHR3 - THE LENGTH OF THE 3 OIF-
*          FERENT PERIOOS OF THE OAY WHERE CONTROL IS USEO.
*************************************************************
*
*
C
C   OPEN A FILE TO PRINT RESULTS TO.
C
      UNIT2=I0
      OPEN (UNIT=UNIT2,FILE='IOUN2')
      ALPHA=I.0331697
      BETA=.022314355
      INTLEN=30
      LCON=7.5
      OSEEO=675432834.00
      M=20
      TPEAK=II0
      N=5.0
      TON=74
      TOFF=70
C
C   DO LOOP 100 INITIALIZES ALL OF THE ELEMENTS OF THE
```

```
C     TOTAL SYSTEM CURVES TO 0.
C
        DO 100 J=1,200
           USYS(J)=0
           CSYS(J)=0
100     CONTINUE
C
C     RANDOM IS CALLED TO GENERATE THE RANDOM STARTING
C     CONDITIONS.
C
        CALL RANDOM(M,DSEED,M,TOFF,TON,START,TI)
C
C     DO LOOP 300 LOOPS OVER THE DESIRED NUMBER OF HOUSES TO
C     PRODUCE A CONTROLLED LOAD CURVE.
C
        DO 300 I=1,M
           T=TI(I)
           STATE=START(I)
C
C     UNCON IS USED TO PRODUCE THE TRANSITIONS FOR THE UNCON-
C     TROLLED CASE.
C
           TIMEO =0.0
           NUMHR1=2.45799494
           CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                TRANS,TEMP,NUMHR1,TPEAK,TAMB,TIMEO)
C
C     DETERMINE WHAT THE INITIAL TEMPERATURE IS FOR THE
C     CONTROL PERIOD.
C
            TIMED=147.4796964
            NUMHR2=11.00809997-NUMHR1
            COUNT=1
325         IF (TDAY(COUNT) .GE. TIMED ) GO TO 330
            COUNT=COUNT+1
            GO TO 325
330         IF (TRANS(COUNT-1) .EQ. 'OFF') THEN
               T=TAMB(COUNT-1)+(TEMP(COUNT-1)-TAMB(COUNT-1)
     *            )*EXP(-BETA*(TIMED-TDAY(COUNT-1)))
               STATE='OFF'
            ELSE
               T=TAMB(COUNT-1)-ALPHA/BETA+(TEMP(COUNT-1)+
     *            ALPHA/BETA-TAMB(COUNT-1))*EXP(-BETA*(TIMED-
     *            TDAY(COUNT-1)))
               STATE='ON'
            ENDIF
C
C     CON IS USED TO PRODUCE THE TRANSITIONS FOR THE CON-
C     TROLLED CASE.
C
```

```
      CALL NEDCON(ALPHA,BETA,T,STATE,TON,TOFF,K,CTDAY,
     *                STATUS,CTEMP,NUMHR2,TPEAK,CTAMB,TIMEO,
     *                DSEED)
C
C   FIND THE INITIAL TEMPERATURE FOR THE NEXT UNCONTROLLED
C   PERIOD.
C
      NUMHR3=12.0-NUMHR2-NUMHR1
      TIMEO=660.4859982
      CCOUNT=1
335   IF (CTDAY(CCOUNT) .GE. TIMEO) GO TO 340
      CCOUNT=CCOUNT+1
      GO TO 335
340   IF (STATUS(CCOUNT-1) .EQ. 'OFF' ) THEN
         T=CTAMB(CCOUNT-1)+(CTEMP(CCOUNT-1)-CTAMB(CCOUNT
     *      -1))*EXP(-BETA*(TIMEO-CTDAY(CCOUNT-1)))
         STATE='OFF'
         IF (CTEMP(CCOUNT-1) .GE. TON) STATE='ON'
      ELSE
         T=CTAMB(CCOUNT-1)-ALPHA/BETA+(CTEMP(CCOUNT-1)+
     *      ALPHA/BETA-CTAMB(CCOUNT-1))*EXP(-BETA*(TIMEO
     *      -CTDAY(CCOUNT-1)))
         STATE='ON'
      ENDIF
C
C   GENERATE THE DATA FOR THE LAST UNCONTROLLED HOURS OF
C   THE TIME PERIOD.
C
      CALL UNCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY2,
     *              TRANS2,TEMP2,NUMHR3,TPEAK,TAMB2,TIMEO)
C
C   MERGE THE DATA FOR THE THREE TIME PERIODS. START BY
C   ADDING THE DATA FOR THE CONTROLLED PERIOD TO THE DATA
C   FOR THE FIRST UNCONTROLLED PERIOD.
C
      LOOP=1
      INT1=COUNT
      INT2=COUNT+CCOUNT-2
      DO 350 Q=INT1,INT2
         TDAY(Q)=CTDAY(LOOP)
         TRANS(Q)=STATUS(LOOP)
         TEMP(Q)=CTEMP(LOOP)
         TAMB(Q)=CTAMB(LOOP)
         LOOP=LOOP+1
350   CONTINUE
C
C   MERGE THE LAST PERIOD WITH THE FIRST TWO.
C
      LOOP=1
      INT1=INT2+1
```

```
         INT2=COUNT+CCOUNT+J-2
         DO 360 Q=INT1,INT2
            TDAY(Q)=TDAY2(LOOP)
            TRANS(Q)=TRANS2(LOOP)
            TEMP(Q)=TEMP2(LOOP)
            TAMB(Q)=TAMB2(LOOP)
            LOOP=LOOP+1
360      CONTINUE
C
C    CALL NAVG TO GENERATE THE N-MINUTE AVERAGES.
C
         CALL NAVG(TDAY,TRANS,TEMP,INT2,ALPHA,BETA,N,PWR,
     *            TEMPAV,TAMB,12.0,0.0)
C
C    SUM THE N-MINUTE POWER DATA TO CALCULATE THE AGGREGATE
C    AVERAGE.
C
         DO 370 J=1,144
            CSYS(J)=CSYS(J)+PWR(J)/M
370      CONTINUE
300   CONTINUE
C
C    PRINT OUT N-MINUTE DATA.
C
      WRITE (10,1000) ALPHA,BETA
      WRITE (10,1010) N
      WRITE (10,1020)
      DO 500 I=1,144
         WRITE (10,1030) REAL(I)/12,CSYS(I),TEMPAV(I)
500   CONTINUE
C
C    CALCULATE ONE-HOUR AGGREGATE AVERAGES AND PRINT OUT
C    THE RESULTS.
C
      CALL AVEPWR(CSYS,60,INT(N),CPAVG,12.0)
      CALL AVEPWR(TEMPAV,60,INT(N),CAVGTE,12.0)
      WRITE (10,*)
      WRITE (10,*) ' ONE-HOUR DATA'
      WRITE (10,1040)
      WRITE (10,1050) (I,CPAVG(I),CAVGTE(I),I=1,12)
C
C    FORMAT STATEMENTS FOR PRINTING.
C
1000  FORMAT(' DATA FOR ALPHA= ',F5.3,' AND BETA=',F5.3)
1010  FORMAT(' ',1X,F2.0,'-MINUTE DATA')
1020  FORMAT(' ','  TIME',2X,'POWER',2X,'TEMP.')
1030  FORMAT('  ',F5.2,2X,F5.3,2X,F5.2)
1040  FORMAT('  ','TIME',4X,'POWER',6X,'TEMPERATURE')
1050  FORMAT('   ',I2,5X,F6.4,7X,F6.3)
      STOP
```

END

```
*  THIS IS UNCON USED WITH DIURNALLY VARYING DRIVING TEMP.
*
*****************************************************************
*   SUBROUTINE UNCON DETERMINES THE TRANSITION TIMES FOR
*   THE UNCONTROLLED CASE. THE RESULTING TRANSITION TIMES
*   ARE RETURNED IN TDAY WHICH IS A 600 MEMBER ARRAY. TRANS
*   RETURNS THE STATE THAT THE SYSTEM GOES TO WHEN THE
*   TRANSITION IS MADE.
*****************************************************************
*
*
      SUBROUTINE UNCON (ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                  TRANS,TEMP,NUMHRS,TPEAK,TAMB,TIMEO)
*
*
*****************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT
*      T - INITIAL TEMPERATURE OF THE SYSTEM. (INPUT)
*      STATE - INITIAL STATE (ON/OFF) OF THE A/C. (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON.
*            (INPUT)
*      TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*              (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A PER-
*          IOD OF SPECIFIED LENGTH. (OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE PERIOD. (OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRES-
*              PONDING TRANSITION IN TDAY. (OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION. (OUTPUT)
*      NUMHRS - NUMBER OF HOURS FOR WHICH TRANSISTIONS ARE
*               DESIRED. (INPUT)
*      TIMEO - INITIAL TIME FOR TRANSITIONS. (INPUT)
*      TPEAK - PEAK DRIVING TEMPERATURE. (INPUT)
*      TAMB - VECTOR OF DRIVING TEMPERATURE. (OUTPUT)
*****************************************************************
*
*
      REAL ALPHA,BETA,T,TDAY(*),TON,TOFF,TEMP(*),TAMB(*),
     *     NUMHRS,TPEAK,TIMEO
      INTEGER J
      CHARACTER*(*) STATE,TRANS(*)
      J=1
      TEMP(J)=T
      TRANS(J)=STATE
```

```
      TDAY(J)=TIMEO
C
C    THIS IF STATEMENT STARTS THE LOOP BY CHECKING IF THE
C    TIME HAS EXPIRED.
C
100   IF (TDAY(J) .GT. (60*NUMHRS+30+TIMEO)) GO TO 150
      TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
C
C    THE NEXT THREE IF STATEMENTS CHECK IF THE SYSTEM IS IN
C    AN EXTREME SITUATION, AND IF SO, CALLS THE APPROPRIATE
C    SUBROUTINE AND STARTS THE LOOP OVER.
C
      IF (ALPHA/BETA .LE. (TAMB(J)-TOFF) .AND. TAMB(J)
     *   .GT. TON) THEN
         CALL NOCOOL(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,TEMP
     *               ,TPEAK)
         GO TO 100
      ENDIF
      IF (TAMB(J) .LE. TON .AND. ALPHA/BETA .GT.
     *   (TAMB(J)-TOFF)) THEN
         CALL NOHEAT(ALPHA,BETA,TOFF,TAMB(J),J,TDAY,TRANS,
     *               TEMP)
         GO TO 100
      ENDIF
      IF (ALPHA/BETA .LE. (TAMB(J)-TOFF) .AND. TAMB(J) .LE.
     *   TON) THEN
         CALL ABEXT(ALPHA,BETA,TAMB(J),J,TDAY,TRANS,TEMP)
         GO TO 100
      ENDIF
C
C    THESE STATEMENTS DETERMINE THE TRANSITIONS IF THE
C    SYSTEM IS IN NORMAL OPERATION. IF THE SYSTEM IS ON,
C    THE NEXT TRANSITION IS DETERMINED USING THE COOLING
C    MODEL. IF THE SYSTEM IS OFF, THE NEXT TRANSITION IS
C    DETERMINED BY THE HEATING MODEL.
C
      IF (TRANS(J) .EQ. 'ON') THEN
         TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *      TAMB(J))/(TEMP(J)+ALPHA/BETA-TAMB(J)))
         TRANS(J+1)='OFF'
         TEMP(J+1)=TOFF
         J=J+1
      ELSE
         TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TON-TAMB(J))/
     *      TEMP(J)-TAMB(J)))
         TRANS(J+1)='ON'
         TEMP(J+1)=TON
         J=J+1
      ENDIF
C
```

```
C   THIS STATEMENT STARTS THE LOOP OVER AGAIN
C
      GO TO 100
150   TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
      RETURN
      END
```

```
* THIS IS CON USEO WITH SINETEMP. IT UTILIZES OIURNALLY
* VARYING ORIVING TEMPERATURE.
*************************************************************
*    SUBROUTINE CON OETERMINES THE TRANSITION TIMES  ANO
*    STATES OF THE SYSTEM FOR THE CONTROLLEO CASE. THE
*    SYSTEM IS AUTOMATICALLY OFF FOR THE FIRST LCON MINUTES
*    OF EACH HALF HOUR. THE SUBROUTINE GENERATES OATA FOR A
*    PERIOO OF SPECIFIED LENGTH. CTOAY RETURNS THE TRANSI-
*    TION TIMES ANO STATUS RETURNS THE CORRESPONOING STATES.
*************************************************************
*
*
      SUBROUTINE CON(ALPHA,BETA,TI,STATE,TON,TOFF,LCON,K,
     *               STATUS,CTOAY,T,INTLEN,NUMHRS,TPEAK,
     *               TAMB,TIMEO)
*
*
*************************************************************
*    ARGUMENT EXPLANATION:
*       ALPHA - COOLING COEFFICIENT WIHT A/C ON (OEGF/MIN).
*              (INPUT)
*       BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*       TI - INITIAL TEMPERATURE. (INPUT)
*       STATE - THE INITIAL STATE (ON/OFF) OF THE A/C.
*       TON - TEMPERATURE AT WHICH A/C SHUTS OFF. (INPUT)
*       TOFF - TEMPERATURE AT WHICH A/C SHUTS OFF. (INPUT)
*       LCON - VARIABLE THAT SPECIFIES THE LENGTH OF THE
*              CONTROL PERIOD.
*       K - VARIABLE THAT COUNTS THE NUMBER OF TRANSITIONS
*           THAT ARE CALCULATEO. (OUTPUT)
*       STATUS - A VECTOR OF LENGTH K THAT GIVES THE STATE
*                (ON/OFF) AFTER EACH TRANSITION. (OUTPUT)
*       CTOAY - A VECTOR OF LENGTH K THAT CONTAINS THE TRAN-
*               SITION TIMES (IN MINUTES) FOR THE GIVEN
*               SITUATION. (OUTPUT)
*       T - A VECTOR CONTAINING THE TEMPERATURES AT THE
*           TRANSITION TIMES. (OUTPUT)
*       INTLEN - LENGTH OF INTERVAL OF WHICH THE FIRST LCON
*                MINUTES ARE AUTOMATICALLY OFF. (INPUT)
*       NUMHRS - NUMBER OF HOURS OVER WHICH TO CALCULATE THE
*                A/C TRANSITIONS. (INPUT)
*       TPEAK - PEAK OF THE OAILY TEMPERATURE. (INPUT)
*       TAMB - A VECTOR OF THE ORIVING TEMPERATURES FOR
*              WHICH TRANSITICNS ARE CALCULATEO. (OUTPUT)
*       TIMEO - TIME WHERE CONTROL BEGINS (REFERENCEO TO
*               BEGINNING OF PERIOO OF INTEREST). (INPUT)
*************************************************************
*
*
      INTEGER K
```

```
      REAL ALPHA,BETA,T(*),TCN,TOFF,CTOAY(*),TI,LCON,
     *   TAMB(*),TIMEO,INTLEN,NUMHRS,TPEAK
      CHARACTER*(*) STATUS(*),STATE
      CHARACTER*3 PREVST
      DOUBLE PRECISION DSEEO
*
*
*****************************************************************
*   VARIABLE EXPLANATION:
*      PREVST - VARIABLE TO KEEP TRACK OF THE STATE (ON/
*               OFF) OF THE SYSTEM AT THE TIME OF CONTROL.
*****************************************************************
*
*
      PREVST=STATE
      K=1
      T(K)=TI
C
C   EACH LOOP OF DO LOOP 100 REPRESENTS 1 HALF-HOUR PERIOD.
C
      LOOP=INT((NUMHRS*60+30)/INTLEN)
      DO 100 I=1,LOOP
         STATUS(K)='OFF'
         CTDAY(K)=(I-1) * INTLEN+TIMEO
         TAMB(K)=85+(TPEAK-85)*SIN(.00436332*CTDAY(K))
         T(K+1)=TAMB(K)+(T(K)-TAMB(K))*EXP(-BETA*LCON)
C
C   THESE THREE IF STATEMENTS DETERMINE IF AN EXTREME CASE
C   IS PRESENT AND SENDS CONTROL TO THE SECTION OF THE SUB-
C   ROUTINE THAT HANDLES THAT PARTICULAR CASE. IF AN EX-
C   TREME CASE DOES NOT EXIST, OPERATION PROCEEDS IN A
C   NORMAL FASHION.
         IF (ALPHA/BETA .LE. (TAMB(K)-TOFF) .AND.
     *      TAMB(K) .GT. TON) GO TO 110
         IF (TAMB(K) .LE. TON .AND. ALPHA/BETA .GT.
     *      (TAMB(K)-TOFF)) GO TO 120
         IF (ALPHA/BETA .LE. (TAMB(K)-TOFF) .AND. TAMB(K)
     *      .LE. TON) GO TO 130
         STATUS(K+1)='ON'
         K=K+1
C
C   THIS NESTED IF STATEMENT DETERMINES THE FIRST POST-
C   CONTROL TRANSITION.
C
         IF (T(K) .GE. TON) THEN
            CTDAY(K)=CTDAY(K-1)+LCON
         ELSE
            IF (PREVST .EQ. 'ON') THEN
               CTDAY(K)=CTDAY(K-1)+LCON
            ELSE
```

```
               CTOAY(K)=CTOAY(K-1)+LCON-1/BETA*LOG((TON-
     *            TAMB(K-1))/(T(K)-TAMB(K-1)))
               T(K)=TON
            ENDIF
         ENDIF
         TAMB(K)=85+(TPEAK-85)*SIN(.00436332*CTOAY(K))
C
C    THIS IF STATEMENT IS TO DETERMINE IF THE FIRST POST-
C    CONTROL TRANSITION IS PAST THE END OF THE HALF HOUR. IF
C    SO, THE TEMPERATURE IS CORRECTED TO THE END OF THE HALF
C    HOUR AND THE NEXT CONTROL PERIOD IS ENTERED.
C
         IF (CTOAY(K) .GE. (I*INTLEN+TIMEO)) THEN
            T(K)=TAMB(K-1)+(T(K-1)-TAMB(K-1))*EXP(-BETA*
     *         INTLEN)
            GO TO 100
         ENDIF
C
C    THE FOLLOWING STATEMENTS ARE TO DETERMINE THE TRANS-
C    SITIONS IN THE REST OF THE HALF HOUR.
C
200      K=K+1
         IF (STATUS(K-1) .EQ. 'ON') THEN
            CTOAY(K)=CTOAY(K-1)-1/BETA*LOG((TOFF+ALPHA/BETA
     *         -TAMB(K-1))/(T(K-1)+ALPHA/BETA-TAMB(K-1)))
            STATUS(K)='OFF'
            T(K)=TOFF
         ELSE
            CTOAY(K)=CTOAY(K-1)-1/BETA*LOG((TON-TAMB(K-1))/
     *         (T(K-1)-TAMB(K-1)))
            STATUS(K)='ON'
            T(K)=TON
         ENDIF
         TAMB(K)=85+(TPEAK-85)*SIN(.00436332*CTOAY(K))
C
C    THIS IF STATEMENT CHECKS IF THE LAST TRANSITION EX-
C    CEEDED THE END OF THE HALF HOUR. IF NOT CONTROL IS
C    RETURNED TO 200.
C
         IF (CTOAY(K) .LT. (I*INTLEN+TIMEO)) GO TO 200
C
C    IF THE END OF THE HALF HOUR HAS BEEN REACHED, THIS IF
C    STATEMENT CORRECTS THE TEMPERATURE AND DETERMINES WHAT
C    STATE THE SYSTEM WAS IN WHEN THE HALF HOUR ENDED.
C
         IF (STATUS(K) .EQ. 'OFF') THEN
            T(K)=TAMB(K-1)-ALPHA/BETA+(T(K-1)+ALPHA/BETA-
     *         TAMB(K-1))*EXP(-BETA * (I*INTLEN+TIMEO-
     *         CTOAY(K-1)))
            PREVST='ON'
```

```
          ELSE
             T(K)=TAMB(K-1)+(T(K-1)-TAMB(K-1))*EXP(-BETA*(
     *          ((I*INTLEN+TIMEO)-CTOAY(K-1)))
             PREVST='OFF'
          ENOIF
          GO TO 100
C
C    SECTION 110 HANOLES THE CASE WHERE THE A/C OOES NOT
C    PROVIDE ENOUGH COOLING TO FORCE THE SYSTEM OOWN TO TOFF
C    ANO THE AMBIENT TEMPERATURE IS HIGH ENOUGH TO CAUSE THE
C    SYSTEM TO HEAT UP.
110       IF (PREVST .EQ. 'OFF' .ANO. T(K+1) .LT. TON) THEN
        WRITE (6,*) 'WENT TO 110'
             K=K+1
             CTOAY(K)=CTOAY(K-1)-(1/BETA)*LOG((TON-TAMB(K-1)
     *          )/(T(K-1)-TAMB(K-1)))
             T(K)=TON
             STATUS(K)='ON'
             IF (CTOAY(K) .GT. (I*INTLEN+TIMEO)) THEN
                T(K)=TAMB(K-1)+(T(K-1)-TAMB(K-1))*EXP(-BETA
     *             *INTLEN)
                PREVST='OFF'
                GO TO 100
             ENOIF
          ELSE
             K=K+1
             CTOAY(K)=(I-1)*INTLEN+LCON+TIMEO
             STATUS(K)='ON'
          ENOIF
          TAMB(K)=85+(TPEAK-85)*SIN(.00436332*CTOAY(K))
          K=K+1
          T(K)=TAMB(K-1)-ALPHA/BETA+(T(K-1)+ALPHA/BETA-TAMB
     *       (K-1))*EXP(-BETA * (I*INTLEN + TIMEO - CTOAY
     *        (K-1)))
          PREVST='ON'
C
C    CONTROL IS TRANSFERRED TO THE ENO OF LOOP 100 TO START
C    THE NEXT HALF-HOUR PERIOO.
C
          GO TO 100
C
C    SECTION 120 HANOLES THE EXTREME CASE WHERE THE AMBIENT
C    TEMPERATURE IS NOT HIGH ENOUGH TO PROOUCE HEATING BUT
C    THE A/C IS SUFFICIENT TO PROOUCE A DROP IN TEMPERATURE.
C
120       IF (PREVST .EQ. 'ON' .ANO. T(K+1) .GT. TOFF) THEN
         WRITE (6,*)'WENT TO 120'
             K=K+1
             CTOAY(K)=(I-1)*INTLEN + TIMEO + LCON
             STATUS(K)='ON'
```

```
            K=K+1
            CTDAY(K)=CTDAY(K-1)-(1/BETA)*LOG((TOFF+ALPHA/
     *         BETA-TAMB(K-1))/(T(K-1)+ALPHA/BETA-
     *         (K-1)))
            T(K)=TOFF
            STATUS(K)='OFF'
            IF (CTDAY(K) .GT. (I*INTLEN+TIMED)) THEN
               T(K)=TAMB(K-1)-ALPHA/BETA+(T(K-1)+ALPHA/BETA
     *            -TAMB(K-1))*EXP(-BETA*(I*INTLEN + TIMED -
     *            CTDAY(K-1)))
               PREVST='ON'
               GO TO 100
            ENDIF
         ENDIF
         TAMB(K)=85+(TPEAK-85)*SIN(.00436332*CTDAY(K))
         K=K+1
         T(K)=TAMB(K-1)+(T(K-1)-TAMB(K-1))*EXP(-BETA*
     *      (I*INTLEN+TIMED-CTDAY(K-1)))
         PREVST='OFF'
C
C   CONTROL IS TRANSFERRED TO THE END OF LOOP 100 TO START
C   THE NEXT HALF-HOUR PERIOD.
C
         GO TO 100
C
C   SECTION 130 HANDLES THE EXTREME CASE WHERE THE AMBIENT
C   TEMPERATURE IS NOT SUFFICIENT TO PRODUCE HEATING AND
C   THE A/C IS NOT SUFFICIENT TO PRODUCE COOLING. IT IS
C   ASSUMED THAT THE A/C STAYS OFF BECAUSE CONDITIONS
C   ARE SUCH THAT THE HOUSE WILL REMAIN BELOW TON.
C
130      K=K+1
       WRITE(6,*) 'WENT TO 130'
         CTDAY(K)=CTDAY(K-1) + INTLEN
         STATUS(K)='OFF'
         T(K)=TAMB(K-1)+(T(K-1)-TAMB(K-1))*EXP(-BETA*
     *      INTLEN)
100    CONTINUE
       RETURN
       END
```

```
* THIS IS NEOCON USED WITH NEWSINE
*
******************************************************************
*   SUBROUTINE NOECON OETERMINES THE TRANSITION TIMES FOR
*   THE CONTROLLEO CASE WHERE 7.5 MINUTES OF RUNNING TIME
*   ARE TAKEN AWAY FROM EACH 30 MINUTES OF RUNNING TIME.
******************************************************************
*
*
      SUBROUTINE NEOCON(ALPHA,BETA,T,STATE,TON,TOFF,J,TDAY,
     *                  TRANS,TEMP,NUMHRS,TPEAK,TAMB,TIMEO,
     *                  DSEEO)
*
*
******************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (OEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT
*      T - INITIAL TEMPERATURE OF THE SYSTEM. (INPUT)
*      STATE - INITIAL STATE (ON/OFF) OF THE A/C. (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*      TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*              (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MAOE IN A PERIOO
*           PERIOO OF SPECIFIEO LENGTH. (OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*           TIMES (IN MINUTES) FOR THE PERIOO OF SPECIFIED
*           LENGTH. (OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*         (ON/OFF) OF THE SYSTEM AFTER THE CORRESPONDING
*         TRANSITION IN TOAY. (OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*         SYSTEM AT EACH TRANSITION. (OUTPUT)
*      NUMHRS - NUMBER OF HOURS FOR WHICH TRANSISTIONS ARE
*         OESIREO. (INPUT)
*      TIMEO - INITIAL TIME FOR TRANSITIONS. (INPUT)
*      TPEAK - PEAK DRIVING TEMPERATURE. (INPUT)
*      TAMB - VECTOR OF ORIVING TEMPERATURE. (OUTPUT)
*      DSEED - SEEO NUMBER FOR GENERATING RANOOM AMOUNTS OF
*         INITIAL TIME. (INPUT)
******************************************************************
*
*
      REAL ALPHA,BETA,T,TDAY(*),TON,TOFF,TEMP(*),TAMB(*),
     *     NUMHRS,TPEAK,TIMEO,TION,R
      DOUBLE PRECISION DSEED
      INTEGER J
      CHARACTER*(*) STATE,TRANS(*)
*
```

```
*
*****************************************************************
*    VARIABLE EXPLANATION:
*      TION - VARIABLE USED TO KEEP TRACK OF ON TIME.
*      R - RANDOM NUMBER BETWEEN 0 AND 1.
*****************************************************************
*
*
      J=1
      TEMP(J)=T
      TRANS(J)=STATE
      TDAY(J)=TIMEO
C
C    GENERATE THE AMOUNT OF ON TIME ALREADY ON THE LOAD
C    LEVELER.
C
      CALL GGUBS(DSEED,1,R)
      TION=R*30.0
C
C    THIS IF STATEMENT STARTS THE LOOP BY CHECKING IF THE
C    TIME HAS EXPIRED.
C
100   IF (TDAY(J) .GE. (60*NUMHRS+30+TIMEO)) GO TO 150
      TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
C
C    THE NEXT THREE IF STATEMENTS CHECK IF THE SYSTEM IS IN
C    AN EXTREME SITUATION, AND IF SO, CALLS THE APPROPRIATE
C    SUBROUTINE AND STARTS THE LOOP OVER.
C
      IF (ALPHA/BETA .LE. (TAMB(J)-TOFF) .AND. TAMB(J)
     *   .GT. TON) THEN
         CALL NEONOC(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,TEMP,
     *      TION,TPEAK)
         GO TO 100
      ENDIF
      IF (TAMB(J) .LE. TON .AND. ALPHA/BETA .GT.
     *   (TAMB(J)-TOFF)) THEN
         CALL NOHEAT(ALPHA,BETA,TOFF,TAMB(J),J,TDAY,TRANS,
     *               ,TEMP)
         GO TO 100
      ENDIF
      IF (ALPHA/BETA .LE. (TAMB(J)-TOFF) .AND. TAMB(J) .LE.
     *   TON) THEN
         CALL ABEXT(ALPHA,BETA,TAMB(J),J,TDAY,TRANS,TEMP)
         GO TO 100
      ENDIF
C
C    THESE STATEMENTS DETERMINE THE TRANSITIONS IF THE
C    SYSTEM IS IN NORMAL OPERATION.
C
```

```
      IF (TRANS(J) .EQ. 'ON') THEN
C
C   IF THE SYSTEM IS ON, CHECK TO SEE IF IT IS TIME TO
C   CONTROL. IF SO, TAKE APPROPRIATE ACTION.
C
         IF (TION .LT. 7.5) THEN
            TRANS(J)='OFF'
            TRANS(J+1)='ON'
            TDAY(J+1)=TDAY(J)+7.5-TION
            TEMP(J+1)=TAMB(J)+(TEMP(J)-TAMB(J))*EXP(-BETA*
     *         (7.5-TION))
            TION=7.5
            TAMB(J+1)=85+(TPEAK-85)*SIN(.00436332*
     *         TDAY(J+1))
            J=J+1
            IF (ALPHA/BETA .LE. (TAMB(J)-TOFF)) GO TO 100
         ENDIF
C
C   DETERMINE NORMAL, UNCONTROLLED COOLING TRANSITIONS.
C
         TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *      TAMB(J))/(TEMP(J)+ALPHA/BETA-TAMB(J)))
         TRANS(J+1)='OFF'
         TEMP(J+1)=TOFF
         TION=TION+TDAY(J+1)-TDAY(J)
         J=J+1
C
C   CHECK IF THE LAST TRANSITION EXCEEDED THE NEED FOR
C   CONTROL, CORRECT FOR THE START OF CONTROL, AND PROCEED
C   TO CONTROL STATEMENTS.
C
         IF (TION .GE. 30.0) THEN
            TDAY(J)=TDAY(J)-(TION-30.0)
            TRANS(J)='ON'
            TEMP(J)=TAMB(J-1)-ALPHA/BETA+(TEMP(J-1)+ALPHA/
     *         BETA-TAMB(J-1))*EXP(-BETA*(TDAY(J)-TDAY(J-1
     *         )))
            TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
            IF (TDAY(J) .GT. (60*NUMHRS+30+TIME0))
     *         GO TO 150
            TION=0.0
            GO TO 100
         ENDIF
      ELSE
C
C   DETERMINE NORMAL HEATING PHASE TRANSITIONS.
C
         TDAY(J+1)=TDAY(J)-(1/BETA)*LOG((TON-TAMB(J))/
     *      (TEMP(J)-TAMB(J)))
         TRANS(J+1)='ON'
```

```
          TEMP(J+1)=TON
          J=J+1
       ENDIF
C
C    THIS STATEMENT STARTS THE LOOP OVER AGAIN
C
       GO TO 100
150    TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
       RETURN
       END
```

```
* THIS IS NAVG USED DIURNALLY VARYING DRIVING TEMPERATURE.
*
****************************************************************
*   SUBROUTINE NAVG TAKES THE ARRAYS OF TRANSITION TIMES,
*   STATES AND TEMPERATURES AND RETURNS THE AVERAGE POWER
*   AND THE AVERAGE TEMPERATURE FOR EACH N-MINUTE PERIOD.
*   THIS IS DONE FOR A SPECIFIED NUMBER OF HOURS.
****************************************************************
*
*
      SUBROUTINE NAVG (TDAY,TRANS,TEMP,NUM,ALPHA,BETA,N,PWR
     *                 ,TEMPAV,TAMB,NUMHRS,TIMEO)
*
*
****************************************************************
*   ARGUMENT EXPLANATIONS:
*      TDAY - A VECTOR CONTAINING TRANSITION TIMES (IN MIN-
*             UTES) IT MUST CONTAIN AT LEAST ONE TRANSITION
*             PAST THE SPECIFED LENGTH OF THE PERIOD.
*             (INPUT)
*      TRANS - A VECTOR OF THE SAME LENGTH AS TDAY WHICH
*              CONTAINS THE STATE (ON/OFF) OF THE SYSTEM
*              AFTER EACH CORRESPONDING TRANSITION. (INPUT)
*      TEMP - A VECTOR CONTAINING THE TRANSITION TEMPERA-
*             TURES (INPUT)
*      NUM - THE NUMBER OF ENTRIES INTO VECTORS TDAY AND
            TRANS. (INPUT)
*      ALPHA - COOLING COEFFICIENT (DEGF/MIN). (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      N - THE LENGTH (IN MINUTES) OF THE INTERVAL OF IN-
*          TEREST EXAMPLE: N=5 TO DETERMINE AVERAGE POWER
*          FOR EACH 5-MINUTE PERIOD. (INPUT)
*      PWR - A VECTOR WHICH CONTAINS THE FRACTIONAL AMOUNT
*            OF TIME DURING EACH N-MINUTE INTERVAL WHICH
*            THE A/C IS ON (1=N MINUTES; 0=0 MINUTES).
*            LENGTH IS 600/N. (OUTPUT)
*      TEMPAV - A VECTOR WHICH CONTAINS THE AVERAGE TEMP-
*               ERATURE FOR EACH N-MINUTE INTERVAL.
*               (OUTPUT)
*      TAMB - VECTOR OF THE DRIVING TEMPERATURE AT EACH
*             TRANSITION. (INPUT)
*      NUMHRS - NUMBER OF HOURS FOR WHICH AVERAGES ARE
*               DESIRED. (INPUT)
*      TIMEO - INITIAL TIME FOR DATA. (INPUT)
****************************************************************
*
*
      REAL TDAY(*),PWR(*),PTDAY(600),ALPHA,BETA,TEMP(*),
     *   T(600),TEMPAV(*),AVE,TAMB(*),N,I,NUMHRS,TIMEO
      CHARACTER*(*) TRANS(*)
```

```
      CHARACTER*3 STATE
      INTEGER J,K,NUM,LOOP
*
*
******************************************************************
*   VARIABLE EXPLANATION:
*      STATE - VARIABLE TO KEEP TRACK OF CURRENT STATE OF
*              THE SYSTEM AS THE SUBROUTINE GOES THROUGH
*              THE TRANSITIONS IN THE SPECIFIED PERIOD.
*      J - VARIABLE TO COUNT WHICH TRANSITION AND STATE OF
*          TDAY AND ARE OF CURRENT INTEREST TO SUBROUTINE.
*      PTDAY - ARRAY USED TO STORE VALUES FROM TDAY TO
*              DETERMINE THE DESIRED VALUE FOR PWR.
*      AVE - INTERMEDIATE VARIABLE FOR DETERMINING THE
*            AVERAGE TEMPERATURE IN EACH N-MINUTE INTERVAL.
*      I - VARIABLE TO KEEP TRACK OF THE CURRENT INTERVAL
*          OF TIME.
*      LOOP - GENERAL PURPOSE LOOP COUNTER.
******************************************************************
*
*
      INT1=INT(NUMHRS*60/N)
      DO 100 LOOP=1,INT1
         PWR(LOOP)=0
         TEMPAV(LOOP)=0
100   CONTINUE
      DO 150 LOOP=I,NUM
         PTDAY(LOOP)=TDAY(LOOP)
         T(LOOP)=TEMP(LOOP)
150   CONTINUE
      J=I
      STATE=TRANS(J)
C
C   EACH LOOP OF DO LOOP 200 REPRESENTS ONE N-MINUTE
C   INTERVAL.
C
      I = N + TIMEO
      K = 1
200   IF (I .LE. (NUMHRS*60+TIMEO)) THEN
C
C   STATEMENT 500 STARTS THE NEXT N-MINUTE INTERVAL IF THE
C   THE CURRENT TRANSITION IS ESSENTIALLY AT THE END OF THE
C   CURRENT INTERVAL.
C
500      IF ((I-PTDAY(J)) .LT. 0.1E-70) GO TO 190
C
C   THE FOLLOWING IF STATEMENT SORTS THE TRANSITIONS AC-
C   CORDING TO WHETHER THE HEATING OR COOLING MODEL IS AP-
C   PROPRIATE.
C
```

```
         IF (STATE .EQ. 'ON') THEN
C
C   THIS IF STATEMENT OETERMINES THE APPROPRIATE TIME PER-
C   IOO TOCONSIOER OETERMINEO BY THE TIME OF THE NEXT
C   TRANSITION. IF THE TRANSITION IS PAST THE ENO OF THE
C   CURRENTN-MINUTE INTERVAL THEN THE TIME PERIOO USEO IS
C   TO THE END OF THE CURRENT N-MINUTE INTERVAL.
C
            IF (PTOAY(J+1) .GT. I) THEN
               PWR(K)=PWR(K)+(I-PTDAY(J))/N
               AVE=TAMB(J)-ALPHA/BETA-((T(J)+ALPHA/BETA-
     *            TAMB(J))/(BETA*(I-PTOAY(J))))*(EXP(-BETA*
     *            (I-PTOAY(J)))-1)
               TEMPAV(K)=TEMPAV(K)+AVE*(I-PTOAY(J))
               T(J)=TAMB(J)-ALPHA/BETA+(T(J)+ALPHA/BETA-
     *            TAMB(J))*EXP(-BETA*(I-PTOAY(J)))
               PTDAY(J)=I
            ELSE
               PWR(K)=PWR(K)+(PTDAY(J+1)-PTDAY(J))/N
               AVE=TAMB(J)-ALPHA/BETA-((T(J)+ALPHA/BETA-
     *            TAMB(J))/(BETA*(PTDAY(J+1)-PTDAY(J))))*
     *            (EXP(-BETA*(PTDAY(J+1)-PTOAY(J)))-1)
               TEMPAV(K)=TEMPAV(K)+AVE*(PTDAY(J+1)-PTDAY(J)
     *            )
               J=J+1
               STATE=TRANS(J)
               GO TO 500
            ENDIF
         ELSE
C
C   THIS IF STATEMENT IS ANALAGOUS TO THE PREVIOUS IF
C   STATEMENT EXCEPT THE A/C IS CURRENTLY OFF.
C
            IF (PTDAY(J+1) .GT. I) THEN
               AVE=TAMB(J)-((T(J)-TAMB(J))/(BETA*(I-PTOAY
     *            (J))))*(EXP(-BETA*(I-PTOAY(J)))-1)
               TEMPAV(K)=TEMPAV(K)+AVE*(I-PTDAY(J))
               T(J)=TAMB(J)+(T(J)-TAMB(J))*EXP(-BETA*
     *            (I-PTDAY(J)))
               PTOAY(J)=I
            ELSE
               AVE=TAMB(J)-((T(J)-TAMB(J))/(BETA*(PTDAY
     *           (J+1)-PTDAY(J))))*(EXP(-BETA*(PTDAY(J+1)
     *           -PTDAY(J)))-1)
               TEMPAV(K)=TEMPAV(K)+AVE*(PTDAY(J+1)-PTOAY(J)
     *            )
               J=J+1
               STATE=TRANS(J)
               GO TO 500
            ENDIF
```

```
          ENDIF
190       TEMPAV(K)=TEMPAV(K)/N
          K = K+1
          I = I+N
          GO TO 200
        ENDIF
        RETURN
        END
```

```
*  THIS IS THE VERSION OF NOCOOL USED WITH DIURNALLY
*  VARYING DRIVING TEMP.
**********************************************************************
*   SUBROUTINE NOCOOL DEALS WITH THE EXTREME CASE WHERE
*   THE AMBIENT TEMPERATURE IS SUFFICIENT TO PRODUCE HEAT-
*   ING THE DESIRED INDOOR TEMPERATURE BUT THE A/C IS
*   NOT SUFFICIENT TO PRODUCE COOLING.
**********************************************************************
*
*
      SUBROUTINE NOCOOL(ALPHA,BETA,TON,TAMB,J,TDAY,TRANS,
     *                  TEMP,TPEAK)
*
*
**********************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*              (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TON - TEMPERATURE AT WHICH THE A/C TURNS ON. (INPUT)
*      TAMB - DRIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
*             (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A SPEC-
*          IFIED PERIOD. (INPUT/OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*             TIMES (IN MINUTES) FOR THE 11-HOUR PERIOD.
*             (INPUT/OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*              (ON/OFF) OF THE SYSTEM AFTER THE CORRES-
*              PONDING TRANSITION IN TDAY. (OUTPUT/OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*             SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
**********************************************************************
*
*
      REAL ALPHA,BETA,TDAY(*),TON,TEMP(*),TAMB(*),TPEAK
      INTEGER J
      CHARACTER*(*) TRANS(*)
C
C   THIS IF STATEMENT TAKES CARE OF THE CASE WHERE THE A/C
C   IS INITIALLY OFF.
C
      IF (TRANS(J) .EQ. 'OFF') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)-(1/BETA)*LOG((TON-TAMB(J-1))
     *      /(TEMP(J-1)-TAMB(J-1)))
         TEMP(J)=TON
         TRANS(J)='ON'
         TAMB(J)=85+(TPEAK-85)*SIN(.00436332*TDAY(J))
      ENDIF
```

```
C
C   THE A/C IS ASSUMED TO RUN ALL OF THE TIME. THIS SECTION
C   MAKES THE NECESSARY STATUS UPDATES AT THE END OF EACH
C   HALF HOUR. THEN CONTROL IS RETURNED TO THE MAIN PROGRAM
C   TO SEE IF THE CONDITIONS HAVE CHANGED.
C
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB(J-1)-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-
     *   TAMB(J-1))*EXP(-BETA*30)
      TRANS(J)='ON'
      RETURN
      END
```

APPENDIX M-III

LISTINGS OF COMPUTER PROGRAMS THAT CAN BE USED WITH EITHER TYPE OF DRIVING TEMPERATURE

```
*
*
***********************************************************************
*    SUBROUTINE NOHEAT TAKES CARE OF THE EXTREME CASE WHERE
*    CONDITIONS ARE INSUFFICIENT TO PRODUCE HEATING BUT THE
*    A/C IS SUFFICIENT TO PROCUCE COOLING.
***********************************************************************
*
*
      SUBROUTINE NOHEAT(ALPHA,BETA,TOFF,TAMB,J,TDAY,TRANS,
     *                  TEMP)
*
*
***********************************************************************
*    ARGUMENT EXPLANATIONS:
*       ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*               (INPUT)
*       BETA - HEATING COEFFICIENT (I/MIN). (INPUT)
*       TOFF - TEMPERATURE AT WHICH THE A/C TURNS OFF.
*              (INPUT)
*       TAMB - DRIVING TEMPERATURE FROM OUTSIDE THE SYSTEM.
*              (INPUT)
*       J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN A SPEC-
*           IFIED PERIOD. (INPUT/OUTPUT)
*       TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*              TIMES (IN MINUTES) FOR THE 11-HOUR PERIOD.
*              (INPUT/OUTPUT)
*       TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*               (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*               ING TRANSITION IN TDAY. (INPUT/OUTPUT)
*       TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*              SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
***********************************************************************
*
*
      REAL ALPHA,BETA,TDAY(*),TOFF,TEMP(*),TAMB
      INTEGER J
      CHARACTER*(*) TRANS(*)
C
C    THIS IF STATEMENT TAKES CARE OF THE SITUATION WHERE THE
C    A/C IS INITIALLY ON.
C
      IF (TRANS(J) .EQ. 'ON') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)-(1/BETA)*LOG((TOFF+ALPHA/BETA-
     *      TAMB)/(TEMP(J-I)+ALPHA/BETA-TAMB))
         TRANS(J)='OFF'
         TEMP(J)=TOFF
      ENDIF
C
```

```
C   THE A/C IS ASSUMED TO STAY OFF. STATUS UPDATES ARE MADE
C   AT THE END OF EACH HALF HOUR AND CONTROL IS RETURNED
C   TO THE MAIN PROGRAM TO SEE IF CONDITIONS HAVE CHANGED.
C
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TEMP(J)=TAMB+(TEMP(J-1)-TAMB)*EXP(-BETA*30)
      TRANS(J)='OFF'
      RETURN
      END
```

```
*
*
****************************************************************
*   SUBROUTINE ABEXT HANDLES THE EXTREME CASE WHERE CONDI-
*   TIONS ARE NOT SUFFICIENT TO PRODUCE HEATING AND THE A/C
*   IS NOT SUFFICIENT TO PRODUCE COOLING.
****************************************************************
*
*
      SUBROUTINE ABEXT(ALPHA,BETA,TAMB,J,TDAY,TRANS,TEMP)
*
*
****************************************************************
*   ARGUMENT EXPLANATIONS:
*      ALPHA - COOLING COEFFICIENT WITH A/C ON (DEGF/MIN).
*               (INPUT)
*      BETA - HEATING COEFFICIENT (1/MIN). (INPUT)
*      TAMB - TEMPERATURE DRIVING FORCE FROM OUTSIDE THE
*              SYSTEM. (INPUT)
*      J - THE NUMBER OF ON/OFF TRANSITIONS MADE IN THE
*           SPECIFIED PERIOD. (INPUT/OUTPUT)
*      TDAY - VECTOR OF LENGTH J WHICH CONTAINS TRANSITION
*              TIMES (IN MINUTES) FOR THE 11-HOUR PERIOD.
*              (INPUT/OUTPUT)
*      TRANS - VECTOR OF LENGTH J WHICH CONTAINS THE STATE
*               (ON/OFF) OF THE SYSTEM AFTER THE CORRESPOND-
*               ING TRANSITION IN TDAY. (INPUT/OUTPUT)
*      TEMP - A VECTOR THAT GIVES THE TEMPERATURE OF THE
*              SYSTEM AT EACH TRANSITION. (INPUT/OUTPUT)
****************************************************************
*
*
      REAL ALPHA,BETA,TDAY(*),TEMP(*),TAMB
      INTEGER J
      CHARACTER*(*) TRANS(*)
C
C   THIS IF STATEMENT TAKES CARE OF THE CASE WHERE THE A/C
C   IS INITIALLY ON.
C
      IF (TRANS(J) .EQ. 'ON') THEN
         J=J+1
         TDAY(J)=TDAY(J-1)+1
         TRANS(J)='OFF'
         TEMP(J)=TAMB-ALPHA/BETA+(TEMP(J-1)+ALPHA/BETA-
     *      TAMB)*EXP(-BETA)
      ENDIF
C
C   THE A/C IS ASSUMED TO BE OFF FOR A PERIOD OF 30 MIN-
C   UTES. THEN THE STATUS IS UPDATED AND CONTROL IS RE-
C   TURNED TO THE CALLING PROGRAM.
```

```
C
      J=J+1
      TDAY(J)=TDAY(J-1)+30
      TRANS(J)='OFF'
      TEMP(J)=TAMB+(TEMP(J-1)-TAMB)*EXP(-BETA*30)
      RETURN
      END
```

```
*
*
*****************************************************************
*   SUBROUTINE CALC CALCULATES THE FOLLOWING STATISTICS FOR
*   A GIVEN LOAD CURVE: SIMPLE AVERAGE; MINIMUM; MAXIMUM;
*   VARIANCE; AND STANDARD DEVIATION. THE RESULTS ARE
*   RETURNED IN THE 5 MEMBER VECTOR, STATS.
*****************************************************************
*
*
      SUBROUTINE CALC(CURVE,NUM,STATS)
*
*
*****************************************************************
*   ARGUMENT EXPLANATION:
*      CURVE - THE VECTOR THAT IS COMPRISED OF THE POINTS
*              THAT MAKE UP THE FUNCTION OF INTEREST.
*              (INPUT)
*      NUM - THE NUMBER OF ELEMENTS IN CURVE. (INPUT)
*      STATS - THE VECTOR THAT RETURNS THE RESULTING STAT-
*              ISTICS. (OUTPUT)
*****************************************************************
*
*
      REAL STATS(*),CURVE(*),SUM,MIN,MAX,AVG,VAR,SD,D
      INTEGER NUM
      SUM=0
      D=0
      MIN=CURVE(1)
      MAX=CURVE(1)
C
C   DO LOOP 10 DETERMINES THE MAXIMUM AND MINIMUM OF THE
C   CURVE AND SUMS UP THE ELEMENTS IN THE CURVE TO LATER
C   DETERMINE THE AVERAGE.
C
      DO 10 I=1,NUM
         SUM=CURVE(I)+SUM
         IF(CURVE(I) .GT. MAX) MAX=CURVE(I)
         IF(CURVE(I) .LT. MIN) MIN=CURVE(I)
10    CONTINUE
      AVG=SUM/NUM
C
C   DO LOOP 20 SUMS UP THE TERMS FOR DETERMINING SAMPLE
C   VARIANCE.
C
      DO 20 I=1,NUM
         D=D+(CURVE(I)-AVG)**2
20    CONTINUE
      VAR=D/(NUM-1)
      SD=SQRT(VAR)
```

```
C
C   THE NEXT FIVE STATEMENTS ASSIGN THE APPROPRIATE STAT-
C   ISTIC TO THE APPROPRIATE POSITION IN STATS.
C
      STATS(1)=AVG
      STATS(2)=MIN
      STATS(3)=MAX
      STATS(4)=VAR
      STATS(5)=SD
      RETURN
      END
```

```
*
*
*******************************************************************
*    SUBROUTINE AVEPWR CALCULATES THE AVERAGE POWER CCNSUMED
*    IN THE INTERVALS OF DESIRED LENGTH BY TAKING THE POWER
*    CONSUMED IN N-MINUTE INTERVALS AND AVERAGING THESE
*    FIGURES FOR LONGER PERIODS OF TIME.
*******************************************************************
*
*
      SUBROUTINE AVEPWR(PWR,LENGTH,N,PAVG,NUMHRS)
*
*
*******************************************************************
*    ARGUMENTS:
*       PWR - VECTOR THAT CONTAINS THE AVERAGE POWER FOR THE
*          N-MINUTE INTERVALS. (INPUT)
*       LENGTH - LENGTH OF INTERVAL THAT AVERAGE POWER IS
*          DESIRED (INPUT)
*       N - LENGTH OF THE INTERVAL USED IN PWR. (INPUT)
*       PAVG - VECTOR THAT RETURNS DESIRED AVERAGE POWER FOR
*          THE DESIRED LENGTH INTERVALS. (INPUT)
*       NUMHRS - NUMBER OF HOURS FOR WHICH DATA IS SUPPLIED.
*          (INPUT)
*******************************************************************
*
*
      REAL PWR(*),PAVG(*),NUMHRS
      INTEGER LENGTH,N,NUM,C,COUNT
      NUM=NUMHRS*60/LENGTH
      COUNT=LENGTH/N
      C=0
      DO 50 I=1,NUM
         PAVG(I)=0
50    CONTINUE
C
C    DO LOOP 100 CALCULATES THE AVERAGE POWER CONSUMPTION
C    FOR THE NUMBER OF INTERVALS OF DESIRED LENGTH IN THE
C    SPECIFIED TIME PERIOD.
C
      DO 100 I=1,NUM
C
C    DO LOOP 200 CALCULATES THE AVERAGE POWER IN EACH OF THE
C    INDIVIDUAL INTERVALS.
C
         DO 200 K=1,COUNT
            C=(I-1)*COUNT+K
            PAVG(I)=PAVG(I)+PWR(C)
200      CONTINUE
         PAVG(I)=PAVG(I)/COUNT
```

```
100   CONTINUE
      RETURN
      END
```

```
*
*
****************************************************************
*    THE FUNCTION OF SUBROUTINE RANDOM IS TO GENERATE THE
*    RANDOM STARTING CONDITIONS FOR M HOUSES.
****************************************************************
*
*
      SUBROUTINE RANDOM(M,DSEED,NR,TOFF,TON,START,TI)
*
*
****************************************************************
*    ARGUMENT EXPLANATIONS:
*        M - NUMBER OF HOUSES. (INPUT)
*        DSEED - SEED NUMBER FOR GENERATING RANDOM NUMBERS.
*                (INPUT)
*        NR - NUMBER OF RANDOM NUMBERS TO BE GENERATED AT A
*             TIME. (INPUT)
*        TOFF - TEMPERATURE AT WHICH A/C TURNS OFF. (INPUT)
*        TON - TEMPERATURE AT WHICH A/C TURNS ON. (INPUT)
*        START(*) - VECTOR OF STARTING STATES (ON/OFF) FOR
*                   THE M HOUSES. (OUTPUT)
*        TI(*) - VECTOR OF STARTING TEMPERATURES FOR THE M
*                HOUSES. (OUTPUT)
****************************************************************
*
*
      DOUBLE PRECISION DSEED
      CHARACTER START(*)*3
      INTEGER NR
      REAL R(1000),TI(*),TOFF,TON
C
C    SUBROUTINE GGUBS IS CALLED TO GENERATE RANDOM NUMBERS.
C
      CALL GGUBS(DSEED,NR,R)
C
C    DO LOOP 100 USES THE PREVIOUSLY GENERATED RANDOM NUM-
C    BERS TO ASSIGN THE STARTING STATE (ON/OFF) TO EACH OF
C    THE M HOUSES.
C
      DO 100 I=1,M
         IF(R(I) .GE. .50) THEN
            START(I)='ON'
         ELSE
            START(I)='OFF'
         ENDIF
100   CONTINUE
C
C    CALL GGUBS ONCE AGAIN.
C
```

```
      CALL GGUBS(DSEED,NR,R)
C
C   DO LOOP 200 USED RANDOM NUMBERS TO ASSIGN STARTING
C   TEMPERATURES TO EACH OF THE M HOUSES
C
      DO 200 I=1,M
         TI(I)=TOFF+R(I)*(TON-TOFF)
200   CONTINUE
      RETURN
      END
```

SIMULATION BASED INVESTIGATION OF DIRECT LOAD CONTROL OF RESIDENTIAL AIR-CONDITIONERS

by

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AN ABSTRACT OF A THESIS

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ABSTRACT

In the last two decades, electric utilities have experienced enormous growth in the size of seasonal peak demand. This presents a problem for utilities given the cost of building new generation facilities. One alternate method of approaching this problem is to try to regulate the size of the peak demand. A method for doing this is direct load control, where the loads are shed for a part of a specified period of time (for example, 7.5 minutes out of every 30 minutes). This research sought to examine direct load control of residential air-conditioners (a/c's) using computer modelling and simulation. A model is developed that represents an a/c system at the thermostat level. The model is then used to simulate the behavior of a group of a/c's under load control conditions. Simulations were done using a constant driving temperature (adapted from an outside temperature) to determine steady-state effects of direct load control. Simulations were also performed using a diurnally varying driving temperature to more closely approximate a real life situation. Two different methods of control were used and compared with respect to demand reduction and temperature inside the house. The first is a centralized control where all a/c's are controlled from one central location. In this case, control is excercised simultaneously for all houses. The second method is load leveler control. A load leveler is a device which controls air conditioners depending on the outside temperature. Houses are controlled independently and remotely using load leveler control.