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An Optimum Start/Stop Control Algorithm for Heating and Cooling Systems in Buildings

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

May 1983

Sponsored by:
Office of Building and Community Systems
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Cheol Park

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

When a building structure is occupied intermittently, energy savings can be realized from the optimal start-up and shut-down of the heating or cooling system. This strategy, known as optimum start/stop control, reduces energy consumption by delaying the start-up of the space conditioning system until the last moment and then initiating shut-down as early as possible, while maintaining a preset level of comfort during the period of building occupancy.

Based on the bang-bang control theory, a simple optimum start/stop control algorithm is developed for computerized control systems in buildings. The optimum start time is obtained by finding the intersection of cool-down and heat-up curves that are approximated by exponential fitting of the previous and current day's data.

Information is presented in this report on the input and output variables, logic flow, and methodology employed in developing the algorithm. A computer program listing of the optimum start/stop control algorithm written in FORTRAN 77 and sample input and output data are included in the appendices.

Key words: digital control systems; energy conservation; energy management and control systems; heating and cooling systems; optimum start/stop time; preheat time.

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1. INTRODUCTION

When a building is occupied intermittently, energy savings can be realized by minimizing the time the heating or cooling system is operated. The interior building temperature is maintained at a comfortable level only during occupancy. For example, during the heating season, the heating system is turned off shortly before the end of an occupied period and the space temperature decays until the heating equipment is reactivated. This reactivation occurs either because a new occupied period is approaching or because the indoor temperature has reached a predetermined minimum temperature which must be maintained to prevent freezing and condensation problems. Building control algorithms that try to determine the start and stop times for the heating and cooling equipment such that start-up is delayed until the last moment and shut-down takes place as early as possible before the end of occupancy, are commonly referred to as "optimum start/stop" algorithms [1,2]. One such algorithm is the subject of this report.

Due to thermal inertia of both the building structure and its heating and cooling equipment, a preheat or precool time is almost always required to raise or lower the space temperature to the desired level before the beginning of occupancy. This start-up time depends on the outdoor environment, the thermal response of the building envelope, and the thermal performance of space conditioning equipment [3-5]. The starting time of the equipment is the main value to be determined in optimum start control. Optimum stop control makes use of the dead time after the heating or cooling equipment is turned off when thermal inertia prevents the indoor temperature from dropping below

or rising above comfort levels. This allows the system to be turned off before the end of an occupied period.

Practical use of optimum start control was accomplished by Jackson [3,4] on a heating system using an analog control device. With an intuitively derived relationship between indoor and outdoor air temperatures, the start time of preheat period was determined. Jackson claimed substantial energy savings from the use of optimum start control. He also indicated that a nighttime setback technique was not economically justified in control of intermittently occupied buildings. A field study was made by Henderson [5] comparing optimum start control with nighttime setback. Bloomfield and Fisk [6] described the optimization of intermittent heating with a detailed mathematical presentation and made simulations using prior knowledge of the thermal response factors of building structures.

Using recursive least squares estimation, a self-tuning optimum start control algorithm for a heating plant was developed by Dexter [7]. The preheat start time is expressed in terms of bulk structure temperature and unknown parameters that are to be determined adaptively using daily data. Both analog and digital simulations were made. The estimate of bulk temperature was calculated using a first order difference equation with a bulk time constant representing the thermal behavior of the structure.

As microprocessors became available, the HVAC industry began to implement microcomputers to control building equipment. Although software developed by industry exists on the market, details of the algorithms are not generally available in the public domain. The purpose of this report is to introduce a

simple optimum start/stop algorithm which has been developed for digital control of heating systems. With minimal changes, the same algorithm can be used to optimally start and stop building cooling systems.

In the algorithm presented, the starting time for the heating system is determined by using both the temperature rise characteristics during the preheat period of the previous day and the temperature decay behavior during the current cool-down period. The stop time is determined from the delay in the temperature cool-down cycle. A provision for prevention of freezing and condensation problems is also incorporated. The nature of the algorithm used is adaptive, but the approach is much simpler than that used by Dexter [7]. Neither a time series analysis nor recursive least squares estimation is involved.

2. OPTIMUM START/STOP ALGORITHM

2.1 OVERVIEW

According to optimum control theory, minimization of energy use can be achieved if the control is of the "bang-bang" type [8]. This means that, in the heating mode, the heating system operates at full power during the preheat period and at zero power during the cool-down period. Similar operating procedures are applied in the cooling mode, but for simplicity only heating operation will be described in detail. In addition, it will be assumed that the minimum temperature reached during the off-period is greater than the space temperature which would result in freezing or condensation problem.

The bang-bang control scheme is applied only during the unoccupied period. If the outdoor environmental conditions remain constant during the unoccupied period, an ideal situation is illustrated as shown in figure 1. Room air temperature, T_{RA} , responds immediately on the starting or stopping of the heating equipment. Thermal inertia of the building structure or of the heating system is not accounted for. This kind of ideal response is impossible in the real world. Figure 2 represents a more realistic response. The outdoor environment and thermal response characteristics of the building structure determine the length of the preheat period.

In the optimum start/stop algorithm presented in this report, the start time for heating is determined by using the temperature rise characteristics during the heat-up period of the previous day and the temperature decay characteristics during the current cool-down period. The stop time is determined from the delay in the temperature decay.

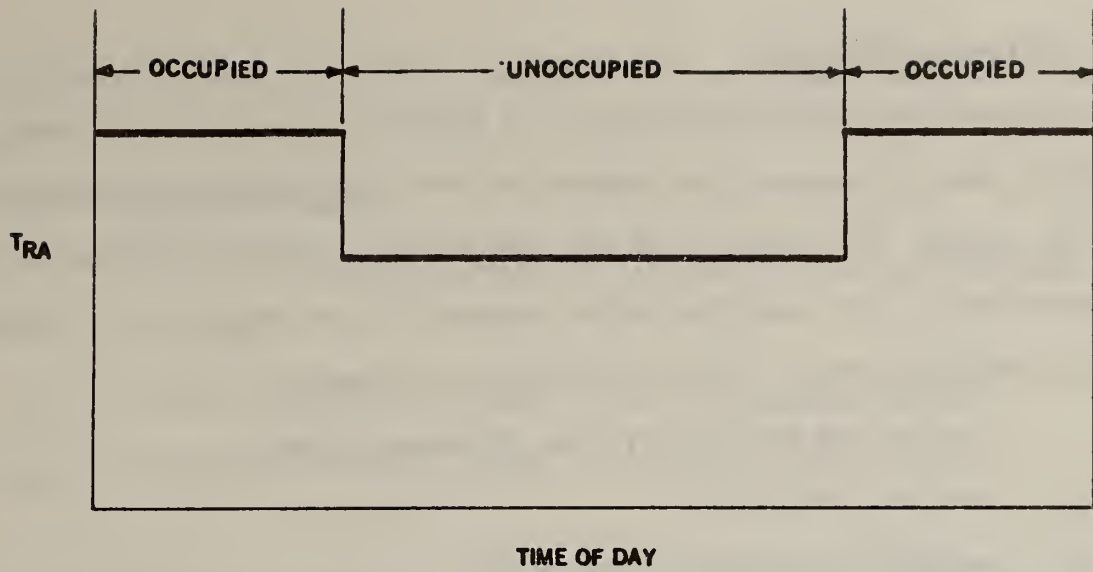


Figure 1. Room air temperature with respect to time of day under an ideal situation

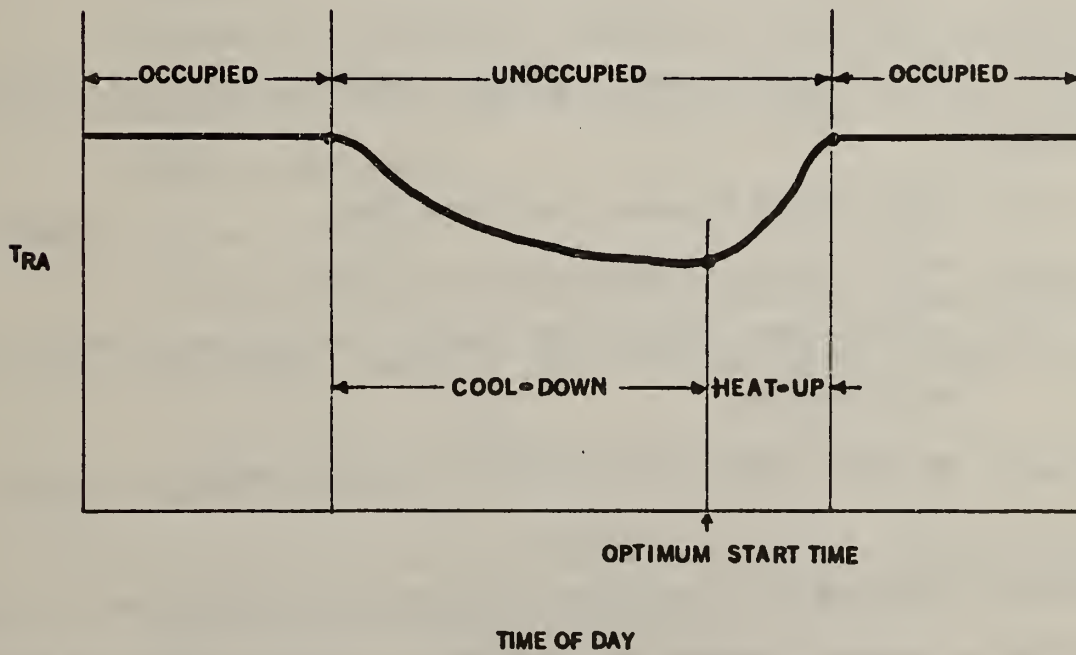


Figure 2. Room air temperature with respect to time of day under a realistic situation

2.2 INPUT AND OUTPUT DATA

It is assumed that the optimum start/stop algorithm is not executed continuously, but at discrete time intervals. The time interval is called the sampling period. The sampling period used depends upon the building response characteristics. The sampling period assigned in this report is 15 minutes. At each sampling instant, the following data are sampled:

- t: time of day in military time expressed in hours
- T_{RA} : room air temperature
- T_{OA} : outdoor air dry-bulb temperature

Units for temperature data can be either metric or English units. Instead of room air and outdoor air temperatures, interior and exterior surface temperatures of a building structure may be used. Surface temperature measurements usually contain less noisy and more stable signals.

As initial input data, the main algorithm (OPTSS) requires the following information:

- t_{occ} : start time of occupancy (military time)
- t_{unoc} : ending time of occupancy (military time)
- t_s : initial guess of starting time for use in the learning cycle (military time)
- y_{set} : set point temperature during the occupied period

In addition, the room air temperature must be maintained above a minimum temperature to prevent freezing and condensation problems during the heating season, and it should not be higher than a maximum temperature during the

cooling season. Because of this, the following additional input data are also needed:

HEAT: logical variable

For the heating mode, HEAT is true and for the cooling mode, HEAT is false.

y_{\min} : minimum temperature allowed during the heating season

y_{\max} : maximum temperature allowed during the cooling season

While the most important output is the start time, t_s , the following logical outputs are also provided for the purpose of system control via supporting software and hardware:

DAYCNT: logical variable

If DAYCNT is true, the daytime controller is to be called, otherwise the daytime controller is not called. The daytime controller is referred as a controller to be used in maintaining y_{set} during the occupied period assuming that the occupied period is at daytime.

FSYSON: logical variable

If FSYSON is true, the heating (or cooling) system operates at full output. Otherwise the heating (or cooling) system operates at less than full output.

MAINTN: logical variable

If MAINTN is true, a controller is called to maintain a minimum requirement in heating (or cooling).

When a simple on-off controller is used to maintain the minimum unoccupied temperature during the heating mode (or the maximum permissible temperature level during the cooling mode). Information on the on-off temperature differential, Δy , will also be required.

2.3 ASSUMPTIONS AND LIMITATION

The following assumptions were made in the development of the optimum start/stop algorithm:

- (a) Full output operation is carried out only by the heating equipment during the preheating period and by the cooling equipment during the precooling period.
- (b) A daytime controller (e.g., PI-controller) is available during the occupied period and both the daytime control and the optimum start/stop control do not interfere with each other in their operations. If the occupancy period is at nighttime, the daytime controller should be considered as a nighttime controller.
- (c) Execution of the algorithm is performed once every sampling period of 15 minutes (i.e., four samples per hour).
- (d) Maintaining a minimum (maximum) temperature load in the heating (cooling) mode during the off-period is done by an on-off controller.

The use of the algorithm in an actual implementation is not limited as long as the computer used in the controls associated with the system to be controlled has enough capacity to store sampled data and the program.

2.4 METHODOLOGY

The optimum start time for heating is determined by using a measured temperature rise curve from the preheat period of the previous day and a measured temperature decay curve from the current cool-down period, and finding the intersecting point of the two curves before occupancy. Equations of the two curves are approximated by simple exponential fits based on actual data. Each equation contains a single time constant (τ), and one predetermined time (x_i) with its corresponding measured temperature (y_i). Each time constant is determined from the exponential fitted equation using two data points. The intersection of two curves are obtained using a method for finding a root of the function which is expressed as a difference of two fitted equations.

An x-y coordinate system is employed to express these equations for convenience. Time and temperature are denoted by x and y, respectively, and the origin of the x-axis is chosen as a midpoint of the occupied period. When the occupancy schedule for the next cycle (e.g., next day) is changed (i.e., t_{occ} and t_{unoc} are varied) before the beginning of the occupied period, the origin of the x-axis is translated by the amount of the change made.

Although it is desirable that the space temperature reaches the target temperature (set point) at the beginning of occupancy, the desired temperature may not be reached on time due to approximation errors in curve fitting and/or changes in characteristics of heating (cooling) equipment and building thermal response from the previous day's state. The temperature will reach the set point a little earlier or later than the optimum time. The fitted temperature rise curve is thus corrected by the amount of time offset, x_0 .

When the building thermal response is slow and the heating or cooling system has a transport delay (dead time), then the space temperature does not rise immediately, but responds after a certain time period is passed. The time period without the response of temperature rise may be called the "flat response" period or simply system dead time, d_{on} . Under these circumstances, the start time obtained by finding two curves should be advanced by the amount of the system dead time. Details on how the start time, x_s , for heating mode is determined can be found in Appendix A, where mathematical expressions are provided.

At the beginning of the unoccupied period, the heating system is usually turned off. However, when the decay of indoor temperature is slowed by the thermal characteristics of the building structure, energy savings can be realized by advancing the turning-off of the heating system so that the "flat response" period is included in the occupied period. This advanced stop time will be referred to as the optimum stop time, even though its determination is not based on optimum control theory. This approach is simple, compared with the method developed by Bloomfield and Fisk [6].

When the outdoor air temperature is low enough, the indoor air temperature may fall below the desired minimum temperature, y_{min} , during the off-period. The indoor temperature must be maintained above the minimum temperature to prevent freezing and condensation problems. A simple on-off control may be utilized to maintain the minimum level of temperature. The heating system is turned on when $y \leq y_{min}$, and turned off when $y \geq y_{min} + \Delta y$. In this case, the full capacity operation of the heating system may not be necessary, and partial

load operation may be adequate. This is illustrated in figure 3, where the dead time is assumed to be zero.

A typical temperature history during the initial cycle (learning cycle) is illustrated in figure 4. Possible time delays and offset are included.

Assuming the program run starts at near a midpoint time of the occupied period of a typical weekday in the heating season, the following is a simplified description of the sequence of operations performed by the program:

- (1) Get initial input data and set initial conditions.
- (2) Start to take data of t , T_{RA} ($=y_4$), and T_{OA} every 15 minutes.
- (3) Turn off the system at the beginning of the unoccupied period.
- (4) Determine dead time during the off-period.
- (5) Check if on-off control is necessary to maintain a minimum space temperature ($y \leq y_{\min}$ any time during the off-period).
- (6) Turn on the system at the given initial guess of the start time.
- (7) Determine dead time during the on-period.
- (8) Turn off the system at the beginning of occupancy and let a daytime controller take over.
- (9) Update constant values, x_1 , x_2 , x_3 , y_1 , y_2 , and y_3 (see Appendix A for definition).
- (10) Determine the minimum outdoor temperature.
- (11) Update the heat-up curve.
- (12) Determine the interval where an intersecting point of the heat-up and cool-down curves locates.
- (13) Begin a new cycle at the midpoint of the following day's occupied period.

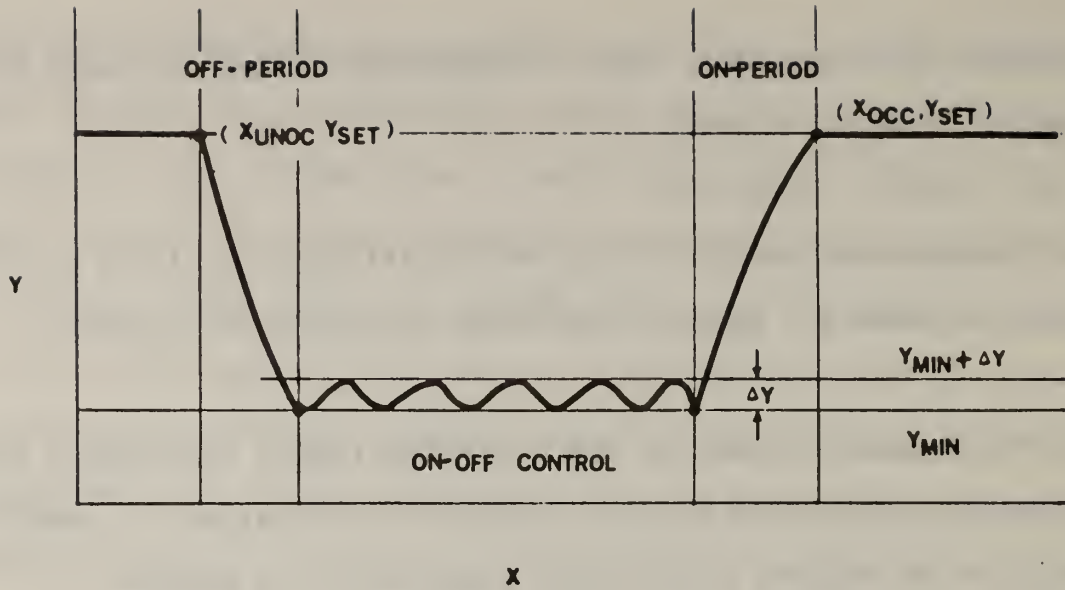


Figure 3. A case with the on-off control operation

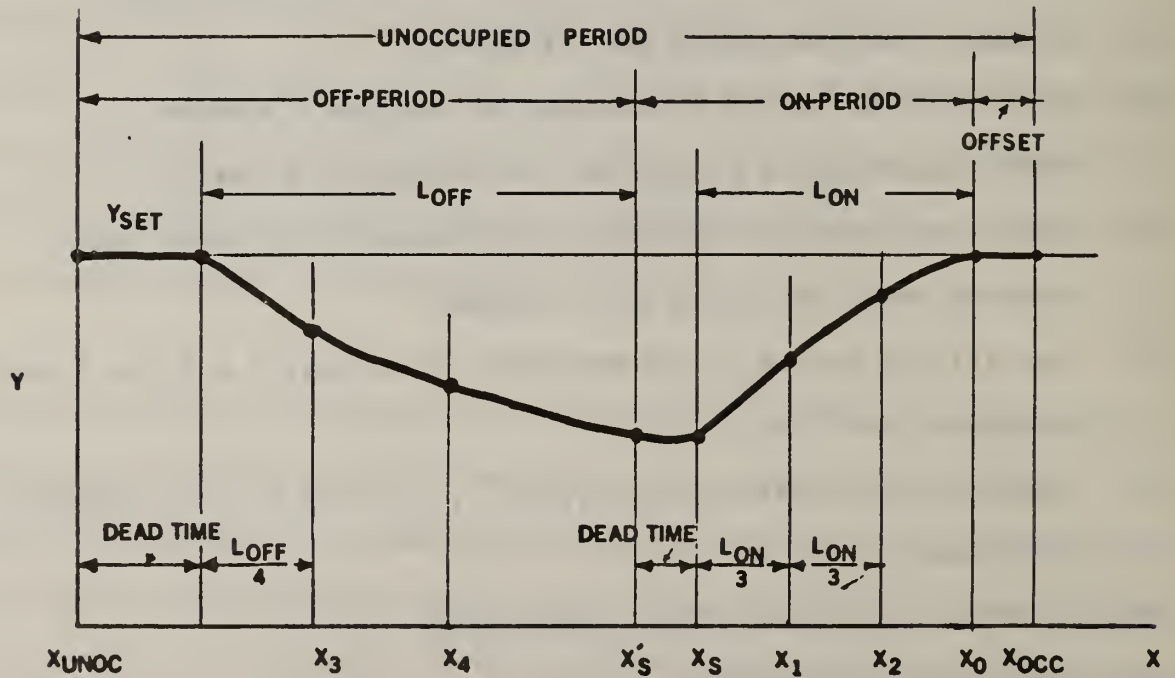


Figure 4. A typical temperature history during the initial cycle

- (14) Turn off the system before the beginning of the unoccupied period by the amount equal to the off-period dead time.
- (15) Repeat steps (4) through (5).
- (16) Find the intersection of the heat-up and cool-down temperature curves by using the regula falsi method (false position method) [9].
- (17) Predict the new start time incorporating the on-period dead time determined previously.
- (18) Turn on the system at the newly calculated start time.
- (19) Go to step (7).

It is possible to generalize the optimum start/stop control algorithm from the heating mode to the cooling mode by relaxing some of the assumptions made in Appendix A. The same equations used for heating given in Appendix A can be used for cooling except that y is taken to be the highest outdoor dry-bulb temperature during the unoccupied period, the value of y_{SS} is approximated as $0.5 y_{set}$ and the maximum allowable space temperature, y_{max} , replaces y_{min} whenever it appears.

Figure 5 shows a block diagram of the relationships between procedures in the main algorithm. The following are brief descriptions of each routine shown in this figure:

OPTSS: Primary routine for optimum start/stop control. Each event is controlled sequentially. Both heating and cooling season operations are included.

XLTRT: Left-most and right-most values of the time coordinate (x) are computed to be used as upper and lower limits of the interval in

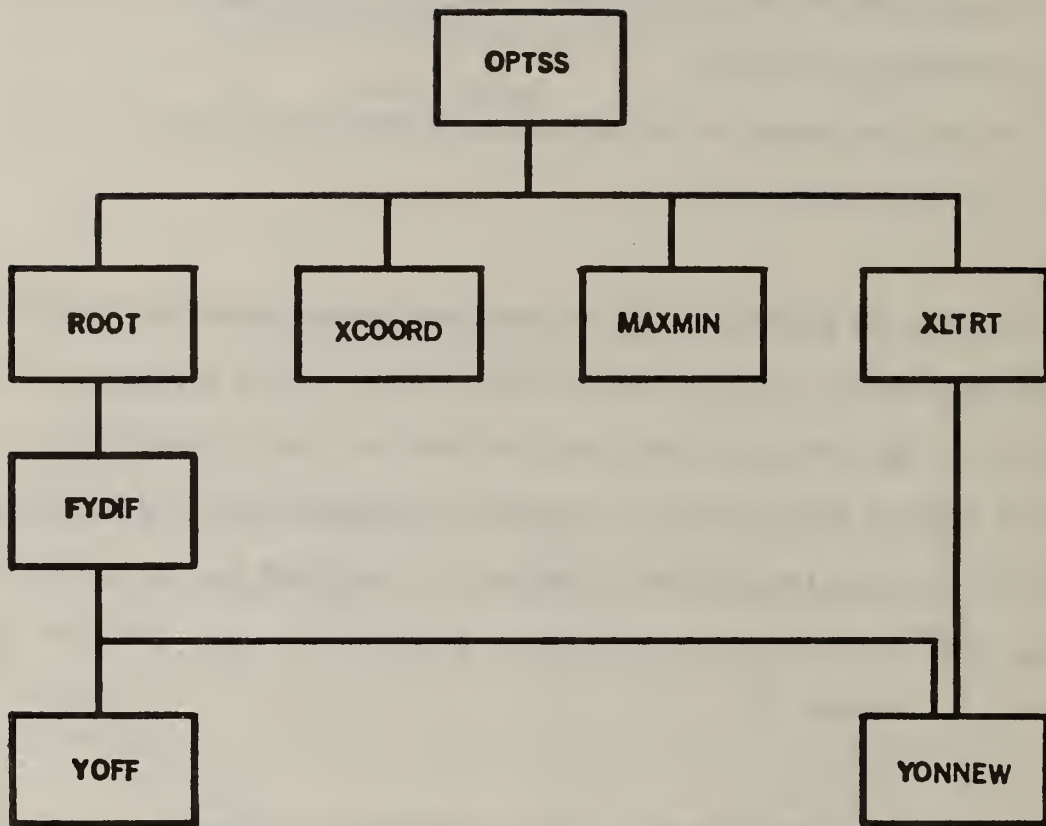


Figure 5. Relationships of subprograms

ROOT subroutine.

ROOT: This subroutine finds the real root of a function in a given interval.

MAXMIN: A subroutine to obtain the maximum and minimum values of a given array.

XCOORD: This subroutine converts military time into the modified time coordinate, x , and vice versa.

FYDIF: A function that obtains the difference of two functional values.

YONNEW: A function to update the heat-up profile, $y_{ON}(x)$.
(See Appendix A.)

YOFF: A function to describe the building cool-down profile, $y_{OFF}(x)$.
(See Appendix A.)

The flow chart of the main algorithm, the subroutine OPTSS, is shown in figure 6. Further detailed flow charts of the OPTSS and the associate subprograms are given in Appendix B. Table 1 is a cross reference of the notation used in the computer program, flow charts, main text, and Appendix A. A complete listing of the computer program appears in Appendix C. The computer program was written in FORTRAN 77 for the UNIVAC 1100/82 computer.

2.5 APPLICATION NOTES

The subroutine OPTSS contains four COMMON blocks of shared storage space with other subroutines and the main program. The DATA statements in the OPTSS contain the following pre-assigned numerical data:

EPS: small positive real number specifying the accuracy required of the ROOT routine (=0.005).

OPTSS

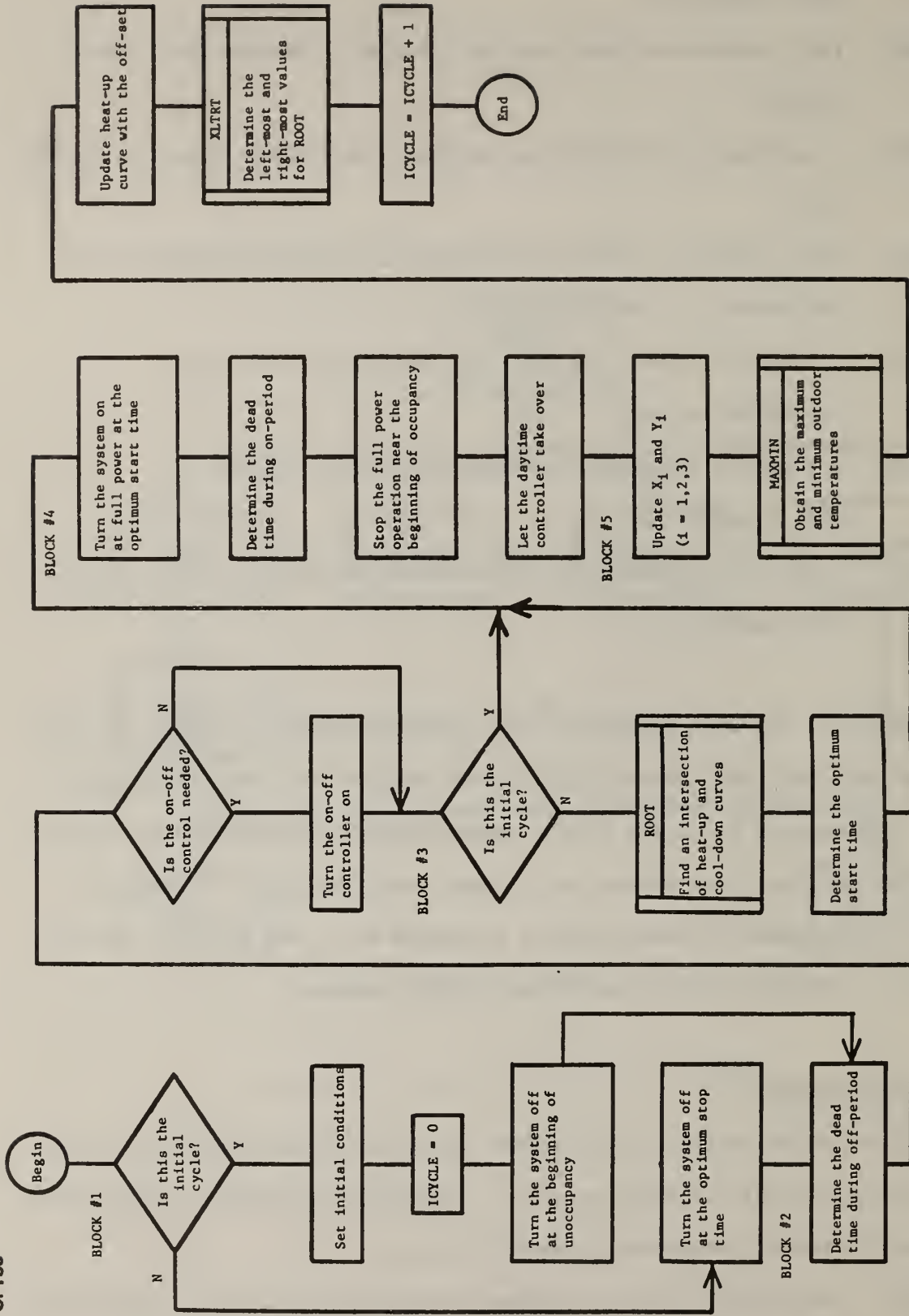


Figure 6. Flow chart of the main algorithm, OPTSS

Table 1. Cross reference table of notation

<u>Notation in Programs</u>	<u>Descriptions</u>	<u>Notation in Flow Charts</u>	<u>Notation in the Text</u>
A(I)	array values	A(I)	
AMAX	maximum value of array values	A_{MAX}	
AMIN	minimum value of array values	A_{MIN}	
DATE	date	DATE	
DAY	0 for non-working day 1 for working day	DAY	
DAYCNT	true if the daytime controller operates false if the daytime controller does not operate	DAYCNT	DAYCNT
DELY	temperature difference	ΔY	Δy
DX	time increment used in XLTRT	ΔX	
EPS	positive small number for accuracy used in ROOT	ϵ	
EPSOFF	positive small number		
EPSON	positive small number		ϵ
EPSSET	positive small number		
EPSX	positive small number determined by sampling frequency		
FSYSON	true if the system operates at full power false if the system is off	FSYSON	FSYSON
FX	scalar function values		$f(x)$
FXL	functional value of FX with the argument of XL	f_L	
FXR	functional value of FX with the argument of XR	f_R	
FX2	intermediate value of FX	f'	

Table 1 (cont.)

<u>Notation in Programs</u>	<u>Description</u>	<u>Notation in Flow Charts</u>	<u>Notation in the Text</u>
HEAT	true if heating mode false if cooling mode	HEAT	HEAT
ICYCLE	number of cycles (e.g., one cycle per day)	ICYCLE	
IEND	index number of ending of search	IEND	
IFLAG	0 if finding a root is successful 1 if finding a root is not successful	IFLAG	
ISTART	index number of beginning of search	ISTART	
ITDOWN	index number where temperature decay begins	ITDOQN	
ITER	number of iteration		
ITIME	index number of modified time of day	I	
ITMAX	maximum number of iteration to obtain a root	IMAX	
ITOFF	index number where $X = XOFF$	ITOFF	
ITON	index number where $X = XSTART$	ITON	
ITSET	index number where temperature reaches at set point	ITSET	
ITUNOC	index number where $X = XUNOC$	ITUNOC	
ITUP	index number where temperature rise begins	ITUP	
IW	index to control printing out		
MAINTN	true if the on-off control is needed false if the on-off control is not needed	MAINTN	MAINTN

Table 1 (cont.)

<u>Notation in Programs</u>	<u>Description</u>	<u>Notation in Flow Charts</u>	<u>Notation in the Text</u>
N	number of intervals used in XLTRT	N	
NMAX	total number of samples a day		
NPTHR	number of samples in one hour		
NSKIP	number of records to be skipped		
PARTON	true if the system operates with a partial capacity false if the system is off	PARTON	
RSCHDL	time when the schedule file is read (military time)		
SWI	event control switches (I = 0, ..., 7)	SWI	
TAUOFF	system time constant during off-period	τ_{OFF}	τ_{OFF}
TAUON	system time constant during on-period	τ_{ON}	τ_{ON}
TBEGIN	origin of x-axis (military time)	t_B	
TDEDOF	dead time during off-period	d_{OFF}	
TDEDON	dead time during on-period	d_{ON}	d_{ON}
TEMP	indoor or internal surface temperature		T_{RA}
TIME	time of day (military time)	TIME	t
TIMEX	modified time of day in scalar		
TITLE	title of input data set in two rows		
TOA(I)	outdoor temperature	$T_{OA}(I)$	T_{OA}

Table 1 (cont.)

<u>Notation in Programs</u>	<u>Description</u>	<u>Notation in Flow Charts</u>	<u>Notation in the Text</u>
TOCC	beginning time of occupancy (military time)		t_{occ}
TOFF	optimum stop time (military time)		
TOUT	dry-bulb outdoor temperature		
TSTART	optimum start time (military time)		t_s
TUNOC	beginning time of unoccupancy (military time)		t_{unoc}
XD	X-value where Y-value is equal to YSET	X_o	x_o
XDATA(I)	modified time of day (X-value)	$X(I)$	x
XL	left-most value of X	X_L	x_L
XOCC	beginning of occupancy	X_{OCC}	x_{occ}
XOCC1	past value of XOCC		
XOFF	optimum off time	X_{OFF}	
XR	right-most value of X	X_R	
XROOT	root	X_{ROOT}	
XSTART	optimum start time	X_S	x_S
XUNOC	beginning of unoccupancy	X_{UNOC}	x_{unoc}
XUNOC1	past value of XUNOC		
XX	intermediate value of X	XX	
X(I)	specific time of day with its origin TBEGIN (I = 1,2,3,4)	X_i	x_i

Table 1 (cont.)

<u>Notation in Programs</u>	<u>Descriptions</u>	<u>Notation in Flow Charts</u>	<u>Notation in the Text</u>
X2	intermediate value used in ROOT	X'	
YDATA(I)	temperature (Y-value)	Y(I)	y
YINF	steady-state temperature as X goes to infinity during off-period	Y_{∞}	y_{∞}
YMAX	maximum temperature	Y_{MAX}	y_{max}
YMIN	minimum temperature	Y_{MIN} *	y_{min}
YOFF	temperature curve during cool-down period	Y_{OFF}	$y_{OFF}(X)$
YONNEW	updated temperature curve during on-period	Y_{ON}	$y_{ON}(X)$
YSET	set point temperature (target temperature)	Y_{SET}	y_{set}
YSS	steady-state temperature as X goes to infinity during on-period	Y_{SS}	y_{SS}
Y(I)	temperature (I = 1,2,3,4)	Y_i	y_i

ITMAX: maximum number of iterations permitted in ROOT to obtain a root within the specified accuracy (=20)

EPSOFF: small positive real number for the temperature tolerance used in determining the dead time during the off-period (=0.25 °C)

EPSON: small positive real number for the temperature tolerance used in determining the dead time during the on-period (=0.25 °C)

EPSSET: small positive real number for the temperature tolerance used in reaching the daytime set point temperature (=0.25 °C)

The above numerical values were assigned to be appropriate for the simulated system under control. Depending upon the characteristics of the building and the heating/cooling system, the values in the DATA statements may be changed accordingly.

For testing purposes, the main program, OPMAIN, can be used. This program, which is listed at the end of Appendix C, calls the main routine, OPTSS, and the on-off control routine, ONOFF. In the OPMAIN program, the on-off control routine is the only routine called during non-working days. The on-off controller may be replaced with another type controller if desired. If occupancy schedule changes are needed, new values of t_{occ} and t_{unoc} for the next cycle must be provided before the ending of the current cycle.

A simulation run of the program has been made using a predetermined temperature history of the outdoor air and the room air to demonstrate input-output operation. Input data and resulting output data of this run are presented in Appendix D, and may be used for test purposes.

If the sampling frequency is to be changed, the integer number NPTHR in the PARAMETER statement of the OPTSS and OPMAIN routines must be changed. For example, if the sampling interval is 10 minutes, the sampling frequency (NPTHR) will be 6 (samples per hour).

Implementation of the optimum start/stop control algorithm on an actual building control computer requires that the main program, OPMAIN, is to be converted into a subroutine which serves as an interface routine between the main routine, OPTSS, and a supervisory program. The supervisory program may govern data collection and transmission activity and perform high level operations; for example, choosing a proper algorithm for a given situation based on the level of priority.

8. CONCLUSIONS

An optimum start/stop control algorithm is described for use in on-line digital control of HVAC systems. The start time for a heating system is determined using the temperature rise profile from the previous day's heat-up period and the temperature decay profile from the current cool-down period, and finding the point (time before occupancy) at which they intersect. The profiles are approximated from actual data using a simple exponential fit. With minor modifications, the algorithm is also capable of finding the optimum start and stop times for a building cooling system. If this algorithm is applied to lightweight, intermittently occupied buildings with low thermal inertia, energy savings should be realized, although the exact magnitude of these savings has not yet been determined. Future research involves implementation, testing, and verification of this algorithm on an energy management and control system in an actual building.

ACKNOWLEDGEMENTS

The author is indebted to Dr. George E. Kelly and Mr. William B. May for their helpful suggestions.

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APPENDIX A. DETERMINATION OF OPTIMUM START TIME FOR HEATING

If measured data are available on the building interior space temperature with respect to time, approximate equations can be constructed to fit both the temperature decay and rise curves that result from turning the heating equipment off and on. Assuming that the structure is very light (fast thermal response) and that the heating equipment has no dead time (immediate response), a temperature history similar to the one shown in figure A-1 may be assumed. The off- and on-periods are defined as the period when heating equipment is off and full on, respectively. For convenience, an x-y coordinate system described in section 2.4 is used. Time and temperature are denoted by x and y, respectively. Military time at the origin of the x-y coordinate system is taken as a midpoint time of the occupied period.

During the on-period, an approximate equation yields:

$$y_{ON}(x) = y_{SS} - (y_{SS} - y_1) e^{-\left(\frac{x-x_1}{\tau_{ON}}\right)} \quad (1)$$

where

x_1 = an arbitrary point of x in the on-period (the chosen value of x_1 is one-third of the on-period plus x-value at the intersection),

y_1 = measured temperature at x_1 ,

y_{SS} = steady-state temperature as $x \rightarrow \infty$, and

τ_{ON} = time constant during the on-period.

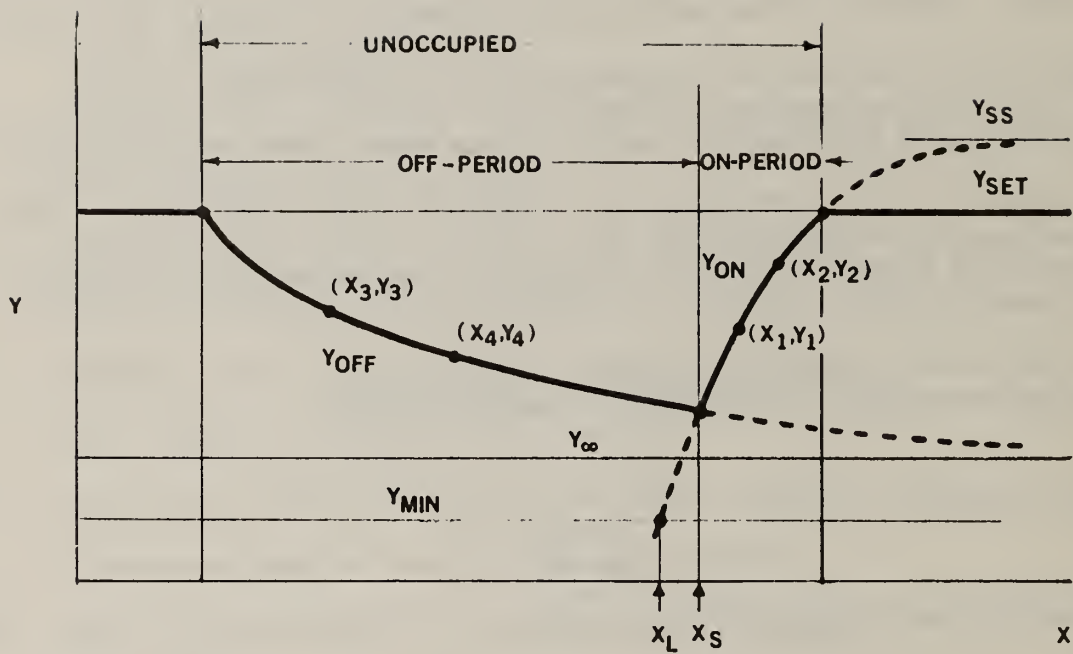


Figure A-1. Temperature history of a lightweight structure with immediate response of heating equipment

Using two data points, (x_1, y_1) and (x_2, y_2) , the time constant can be obtained from:

$$ON = \frac{x_2 - x_1}{\ln\left(\frac{y_{SS} - y_1}{y_{SS} - y_2}\right)} \quad (2)$$

where

x_2 = an arbitrary point of x in the on-period which is greater than x_1 (the chosen value of x_2 is two-thirds of the on-period plus x -value at the intersection), and

y_2 = measured temperature at x_2 .

An expression for the off-period is:

$$y_{OFF}(x) = y_{\infty} + (Y_3 - y_{\infty}) e^{-\left(\frac{x-x_3}{\tau_{OFF}}\right)} \quad (3)$$

where

x_3 = an arbitrary point of x in the off-period (the chosen value of x_3 is one-fourth of the off-period plus x -value at the beginning of the unoccupied period.),

y_3 = measured temperature at x_3 ,

y_{∞} = steady-state temperature as $x \rightarrow \infty$, and

τ_{OFF} = time constant during off-period.

The off-period time constant is given by

$$\tau_{OFF} = \frac{x_4 - x_3}{\ln\left(\frac{y_3 - y_{\infty}}{y_4 - y_{\infty}}\right)} \quad (4)$$

If y_{∞} and y_{SS} are predetermined, the decay and rise temperature curves can be determined using the given data points (x_1, y_1) , (x_2, y_2) , (x_3, y_3) , and (x_4, y_4) . The value of y_{∞} is taken to be the lowest allowable indoor dry-bulb temperature during the unoccupied period (heating mode) and y_{SS} is approximated as $1.5 y_{set}$, where y_{set} is the set point temperature for occupancy. Since the time domain of interest is finite, the effect on $y_{ON}(x)$ and $y_{OFF}(x)$ of errors in the estimated asymptotic values y_{∞} and y_{SS} is small.

After the functions $y_{ON}(x)$ and $y_{OFF}(x)$ are determined, the point of their intersection can be obtained using a method for finding a root of a function $f(x)$, where $f(x) = y_{ON}(x) - y_{OFF}(x)$. The method used was the regula falsi method (false position method [9]). For this method, if a function is bounded and has only one root in a given interval, the solution converges within a given tolerance after a number of iterations. The time corresponding to their intersection is then considered to be the optimum start time.

Difficulties can arise in using the regula falsi method with $y_{ON}(x)$ if the whole unoccupied period is taken as the interval of interest. As seen in figure A-1, $y_{ON}(x)$ is not, in general, bounded in that interval. Thus, the left-most value, x_L , of the interval should be selected so that $y_{ON}(x)$ is bounded in that interval. The approach used in this algorithm for choosing x_L is to set x_L equal to the value of x which satisfies the condition:

$y_{ON}(x) = y_{min}$, where y_{min} is the minimum temperature to maintain.

The optimum start time is determined by finding an intersection of the current temperature decay curve and the temperature rise curve of the previous day. Any changes in the heating system characteristics and environment in the

current day could result in a change in the temperature rise curve during the current on-period.

It is desirable that the temperature rise curve reaches the target temperature (set point) at the beginning of occupancy. If the temperature rise curve changes during the on-period and there are errors due to approximation, the space temperature will reach the set point a little earlier or later than the optimum time. In order to correct this offset, the fitted temperature rise equation should be corrected by the amount of time offset.

Figure A-2 shows both the fitted curve (solid line) based on measurement and the updated curve (dotted line) during the on-period. The x-coordinate is shifted by the difference, $x_{occ} - x_o$. x_{occ} is the beginning of occupancy and x_o is the point where y is equal to the set point, y_{set} . The updated equation is then

$$y_{on}(x) = y_{SS} - (y_{SS} - y_1)e^{-\left(\frac{x-x'_1}{ON}\right)} \quad (5)$$

where

x'_1 = the updated x_1 , given by

$$x'_1 = x_1 + (x_{occ} - x_o), \quad (6)$$

and

$$x_o = x_1 - \tau_{ON} \ln \left(\frac{y_{SS} - y_{set}}{y_{SS} - y_1} \right) \quad (7)$$

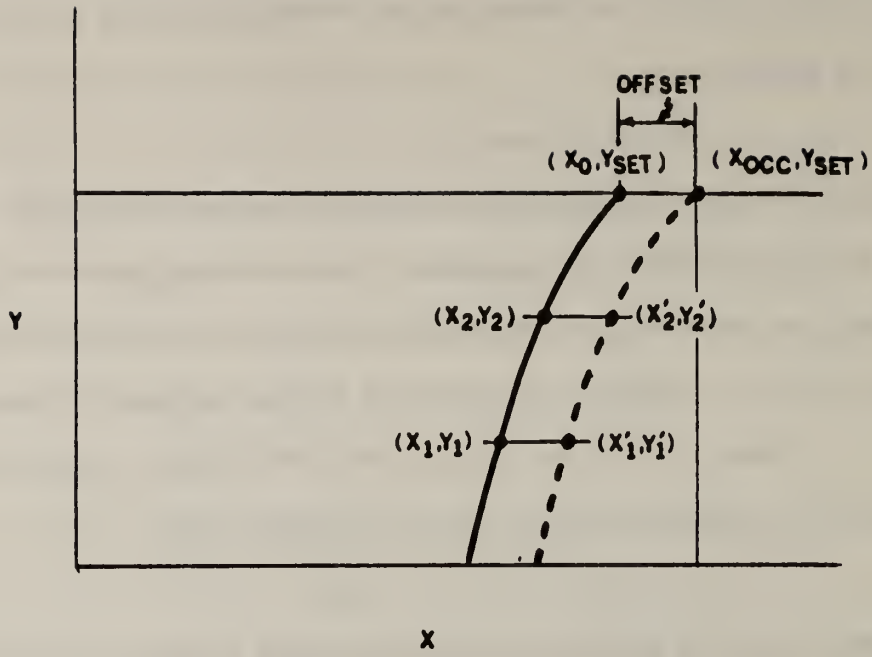


Figure A-2. The fitted curve (solid line) based on measurement and the updated curve (dotted line) during the on-period

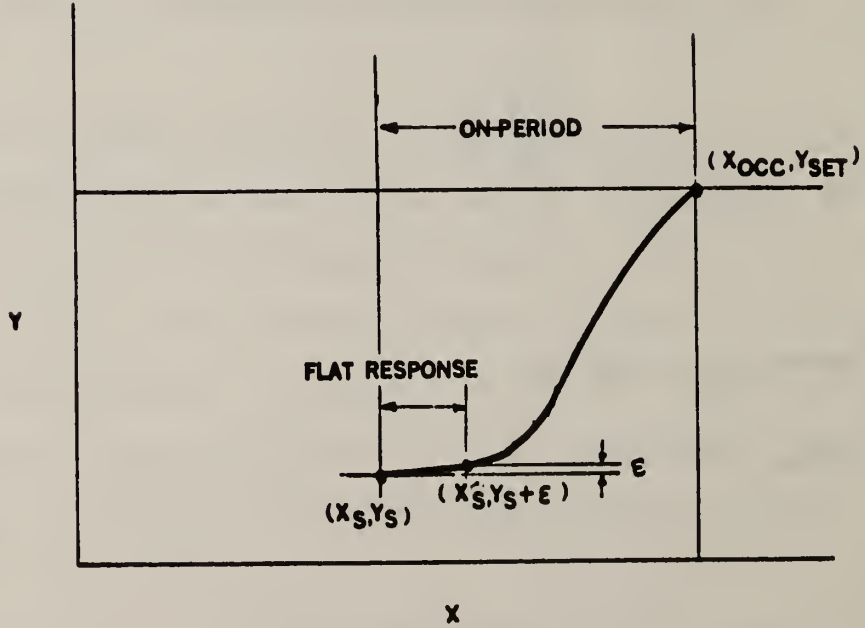


Figure A-3. The dead time during the on-period

Consequently, equation 5 should be used instead of equation 1 to determine the optimum start time in conjunction with equation 3.

When the building structure has slow thermal response and the heating system has a transport delay time (dead time), the assumption made earlier about dead time is not correct. Therefore, it is necessary to take account of the duration of any "flat response" during the on-period. This "flat response" period can be defined as the time period that $|y - y_S| < \epsilon$, where y_S is the temperature at the beginning of the on-period and ϵ is a small positive number. The dead time is then defined as the duration of the "flat response" period (see figure A-3). The calculated start time must then be adjusted by the amount of dead time, d_{ON} . For example, if the calculated start time is x_S under the assumptions of light structure and no dead time, the correct start time for a system with high thermal mass and a heating system with transport delay will be

$$x'_S = x_S - d_{ON}.$$

Since the magnitude of ϵ strongly affects the dead time, the better the selection of ϵ , the better the estimate of the optimum start time. A value for ϵ of 0.25°C was used in the computer program presented in Appendix C.

APPENDIX B. FLOW CHARTS OF THE COMPUTER PROGRAMS

Flow charts of the optimum start/stop control algorithm are shown in figures B-1 through B-9. The most important subroutine is the OPTSS subroutine. For detailed information, this subroutine is divided into five blocks, which are given in subsequent figures (figures B-1 through B-3). Descriptions of principal variables can be found in table 1.

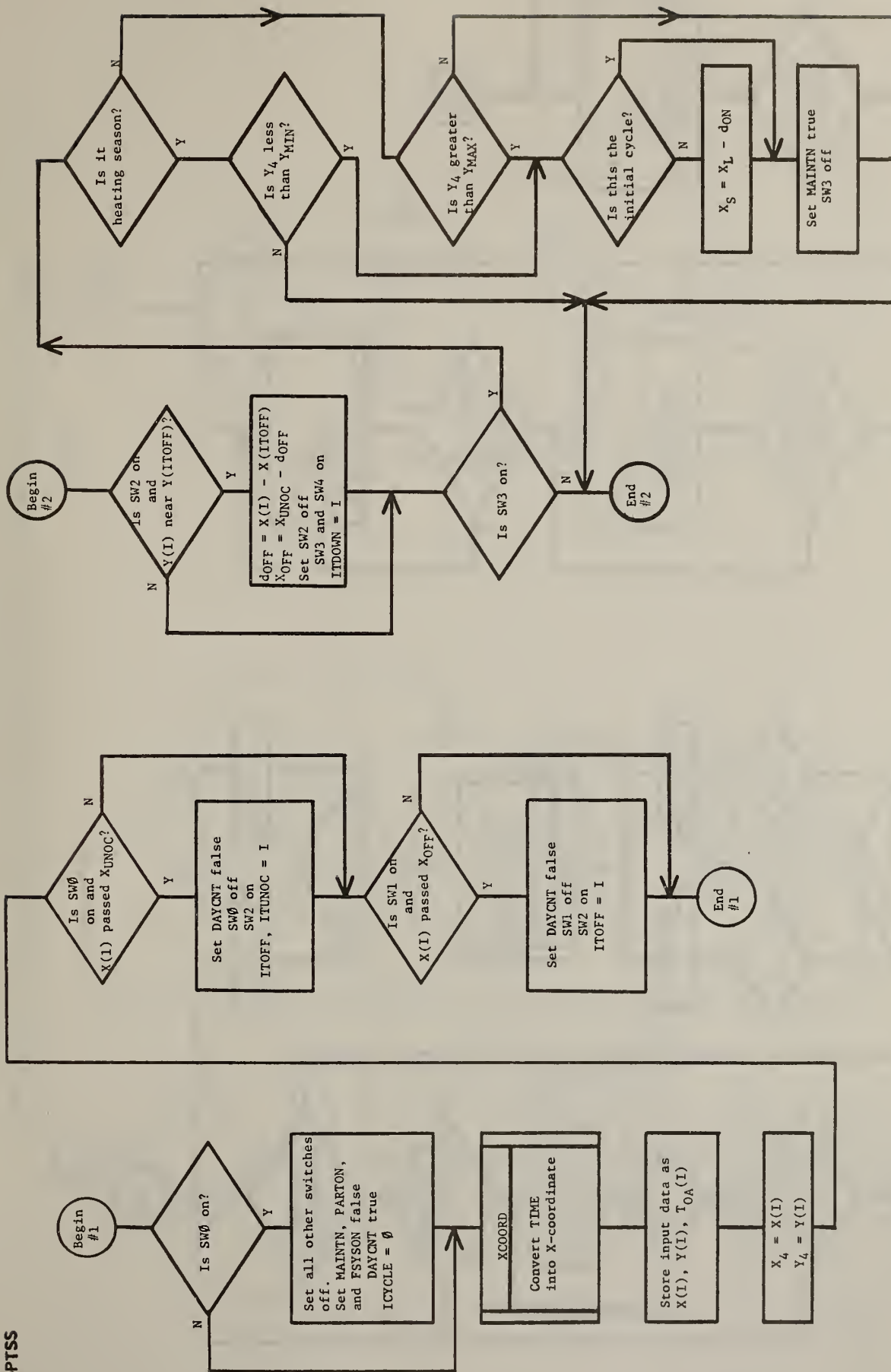


Figure B-1. Flow charts of the block 1 and 2 of the subroutine, OPTSS

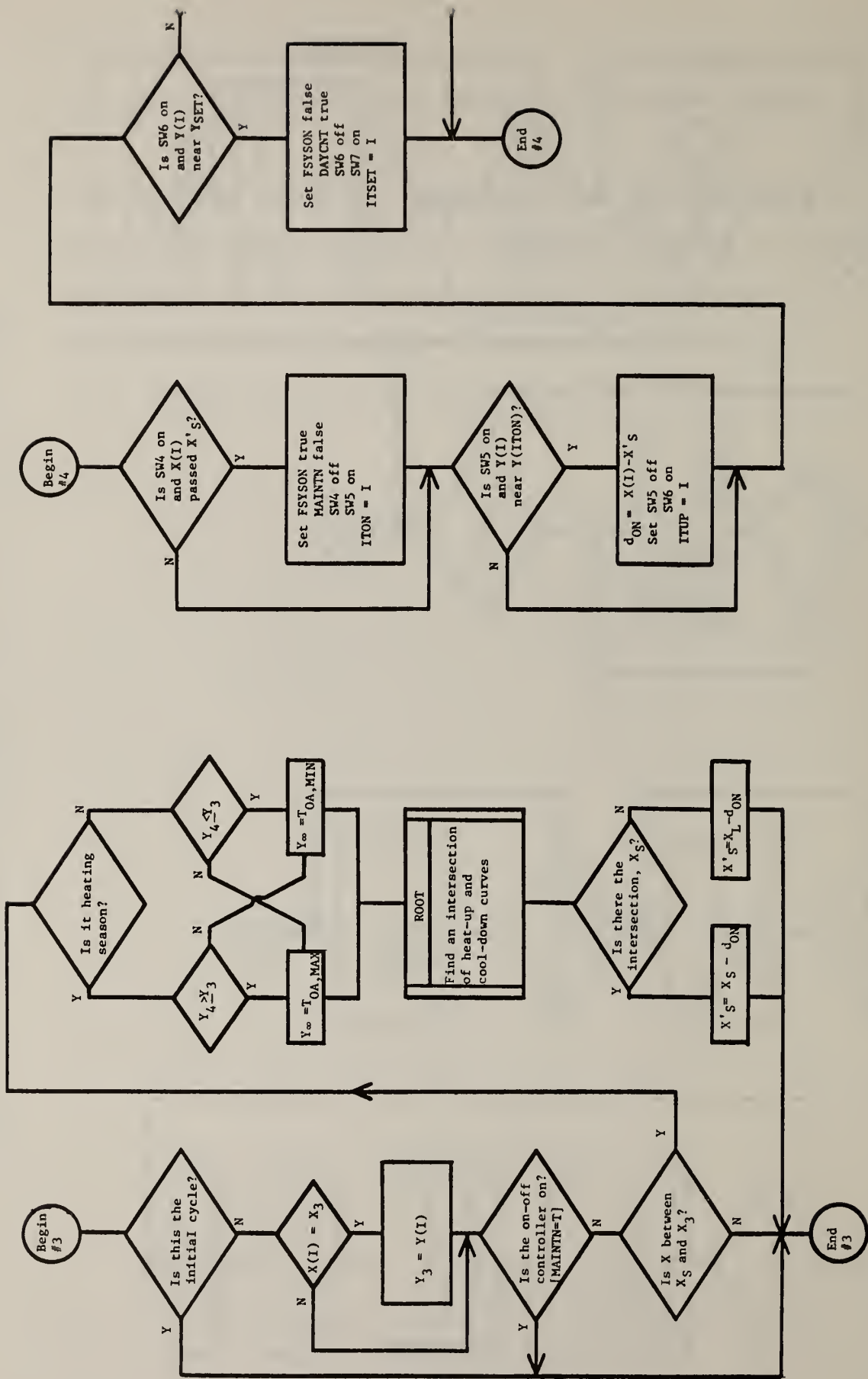


Figure B-2. Flow charts of the block 3 and 4 of the subroutine, OPTSS

XCOORD

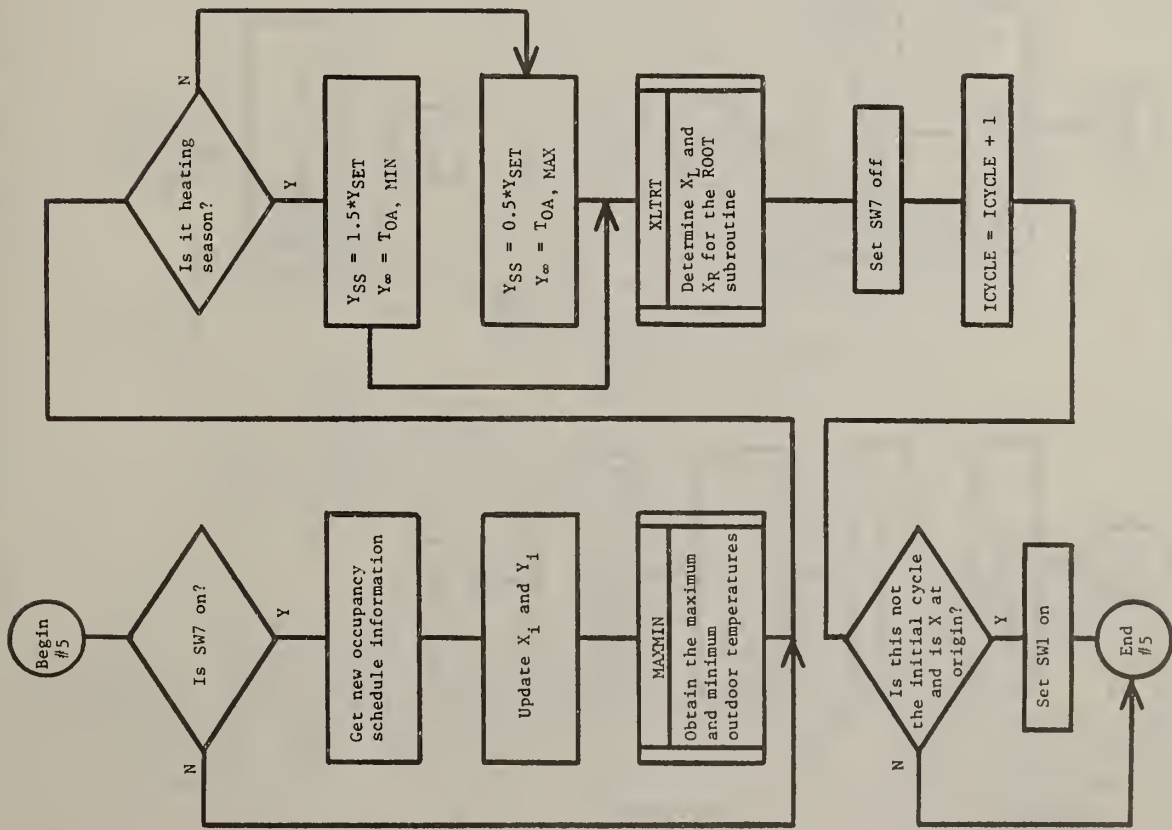


Figure B-3. Flow chart of the block 5 of the OPTSS subroutine, OPTSS

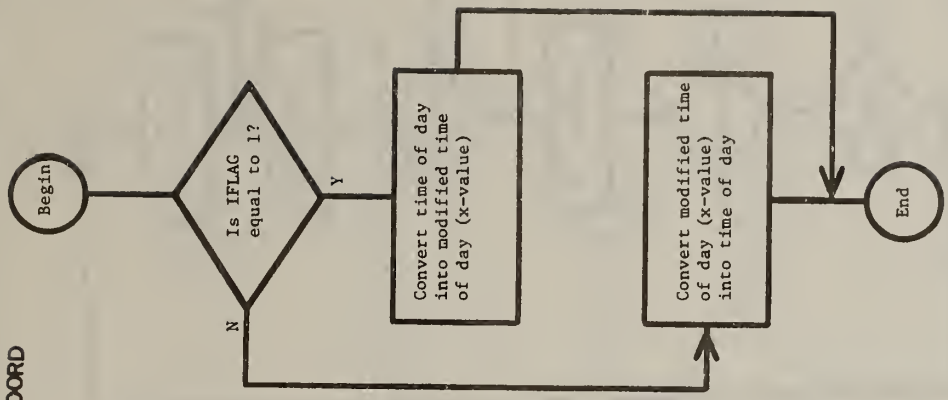


Figure B-4. Flow chart of the XCOORD subroutine, XCOORD

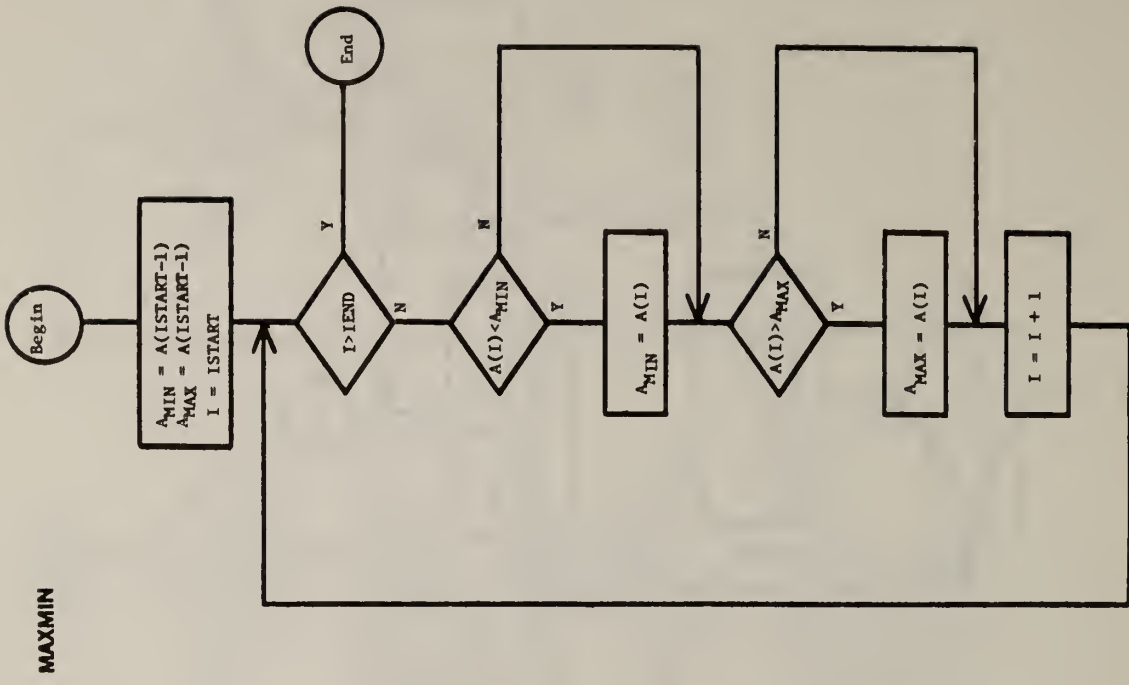


Figure B-6. Flow charts of the MAXMIN subroutine;

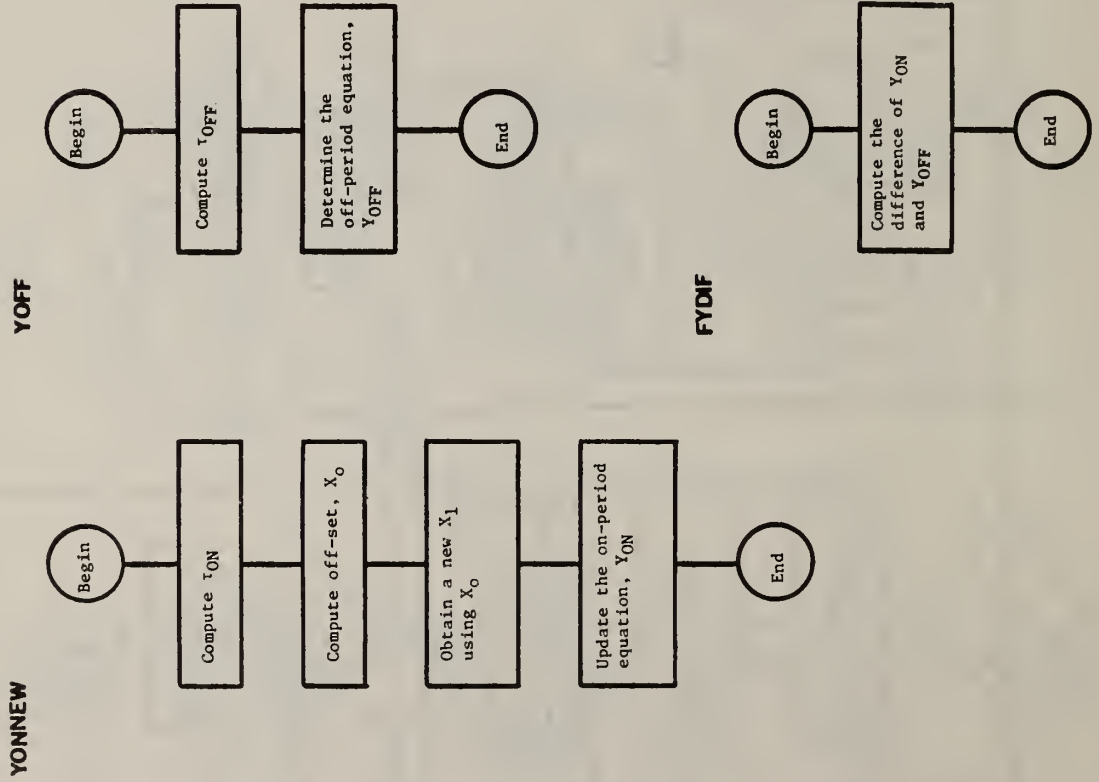


Figure B-5. Flow charts of the functions; YONNEW, YOFF, and FYDIF

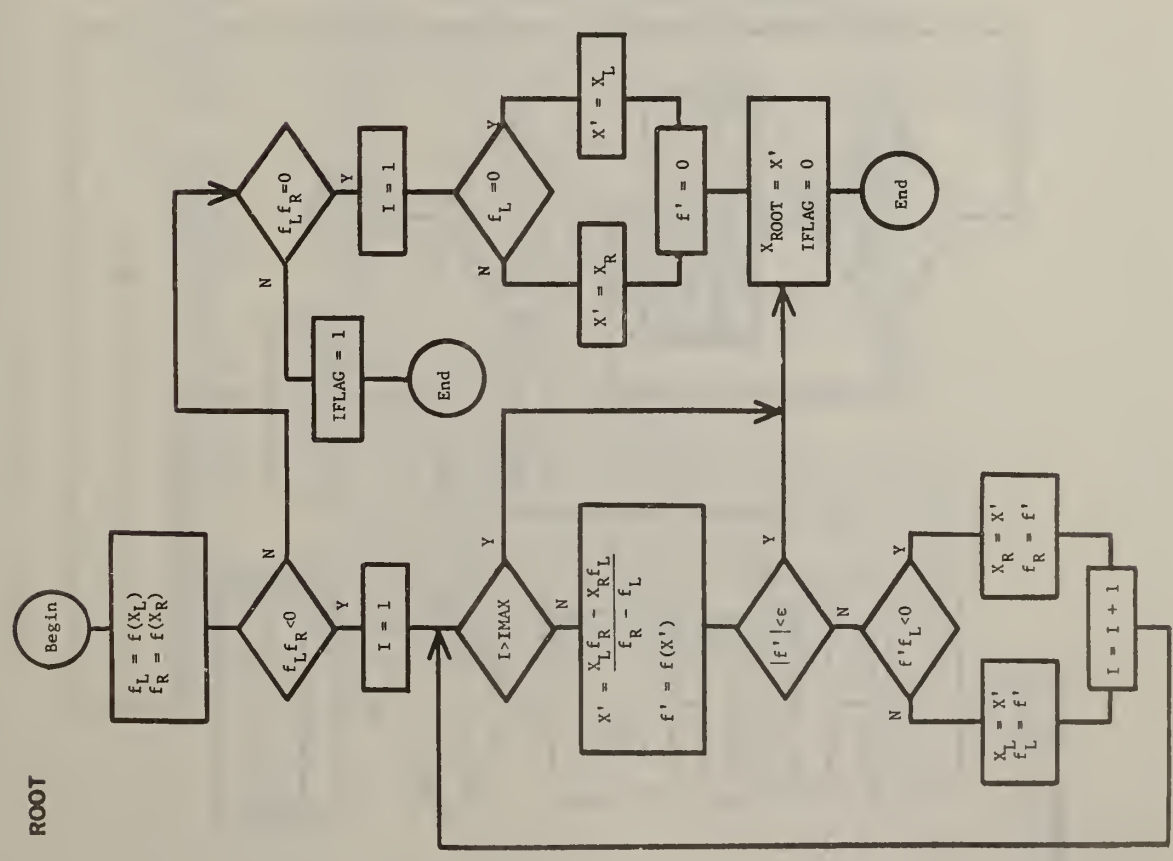
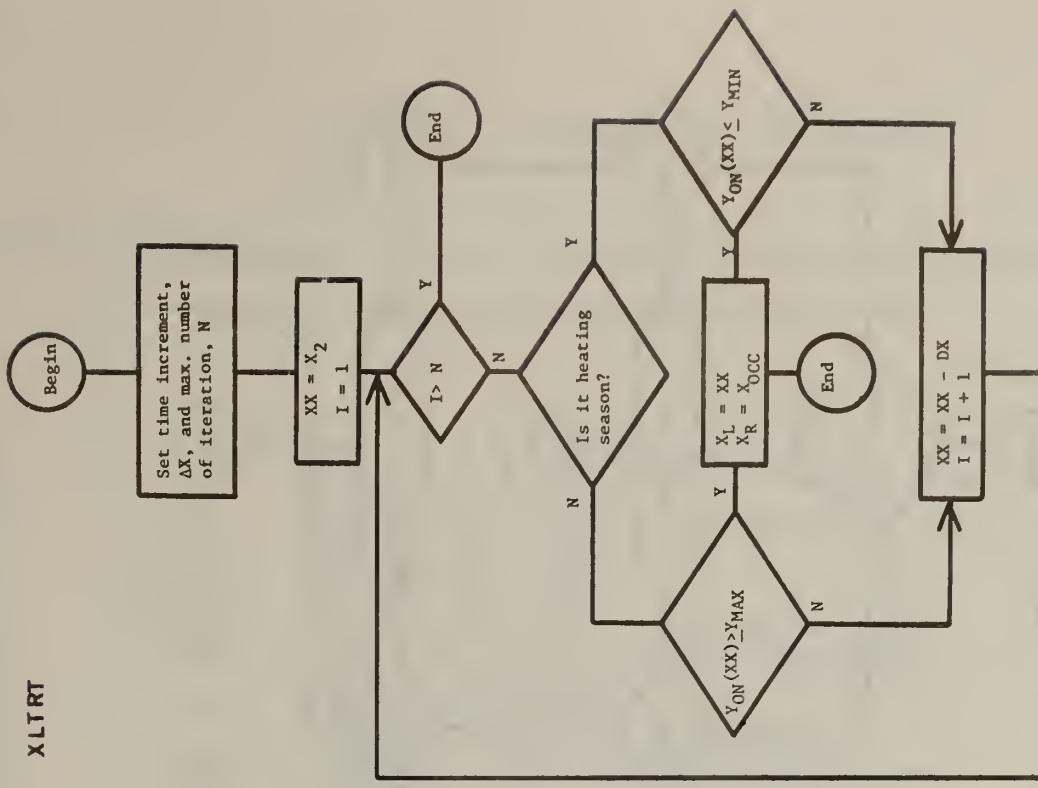


Figure B-7. Flow charts of the subroutines, ROOT and XLTRT

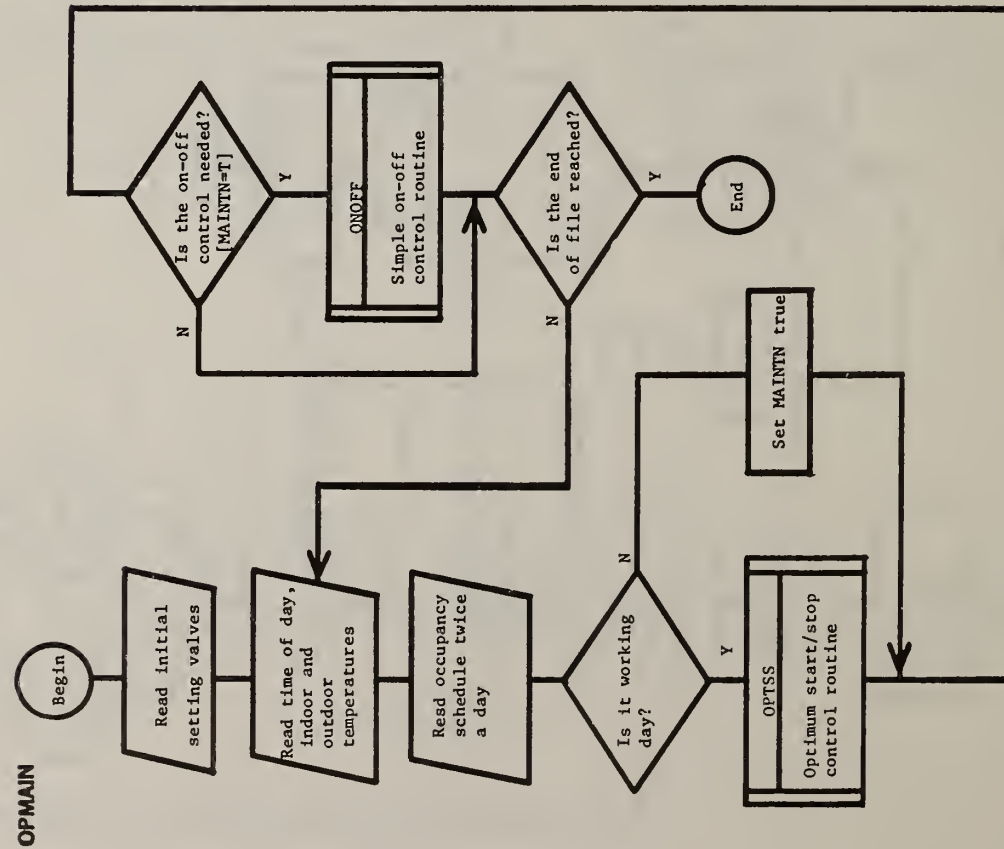


Figure B-8. Flow chart of the main program, OPMAIN

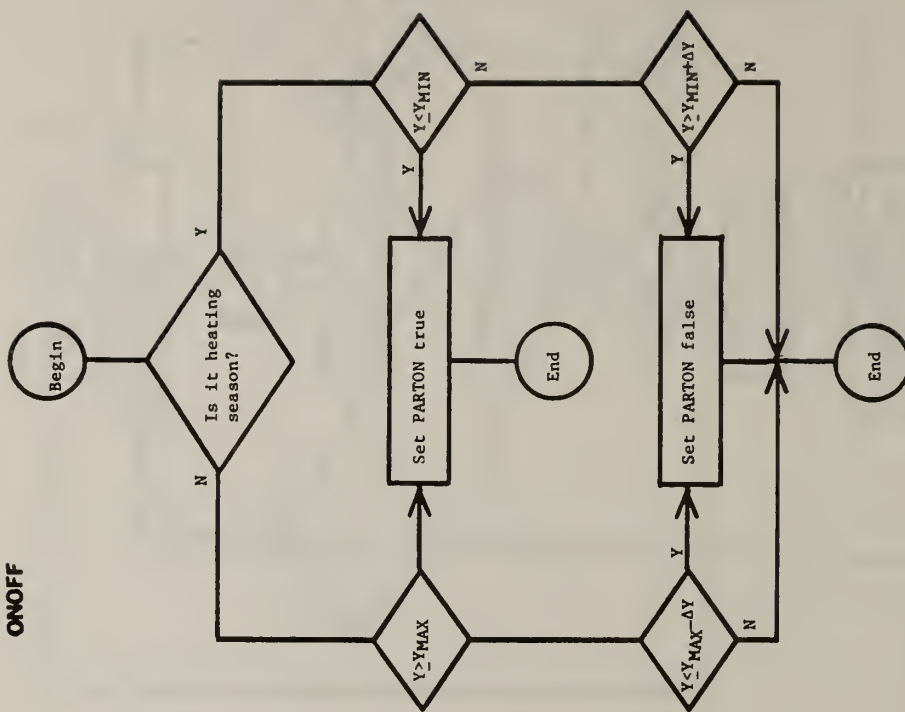


Figure B-9. Flow chart of the on-off subroutine, ONOFF

APPENDIX C. COMPUTER PROGRAM LISTING

```

OSQS*OPT(1).OPTALL(0)
1 C *****
2 C
3 C OPTSS : OPTIMUM START AND STOP CONTROL ALGORITHM
4 C
5 C MAR. 3, 1983 C.P.
6 C
7 C -----
8 C
9 C DAYCNT TRUE IF THE DAYTIME CONTROLLER OPERATES
10 C FALSE IF THE DAYTIME CONTROLLER DOES NOT OPERATE
11 C DELY TEMPERATURE DIFFERENCE
12 C EPS POSITIVE SMALL NUMBER FOR ACCURACY USED IN ROOT
13 C EPSOFF POSITIVE SMALL NUMBER
14 C EPSON POSITIVE SMALL NUMBER
15 C EPSSET POSITIVE SMALL NUMBER
16 C EPSX TOLERANCE DETERMINED BY SAMPLING FREQUENCY
17 C FSYSON TRUE IF THE SYSTEM OPERATES AT FULL POWER
18 C FALSE IF THE SYSTEM IS OFF
19 C HEAT TRUE FOR HEATING MODE
20 C FALSE FOR COOLING MODE
21 C ICYCLE NUMBER OF CYCLES (ONE CYLCE PER DAY)
22 C ITDOWN INDEX NUMBER WHERE TEMPERATURE DECAY BEGINS
23 C ITIME INDEX NUMBER OF MODIFIED TIME OF DAY
24 C ITMAX MAXIMUM NUMBER OF ITERATION TO OBTAIN A ROOT USED IN ROOT
25 C ITOFF INDEX NUMBER WHERE X=XOFF
26 C ITON INDEX NUMBER WHERE X=XSTART
27 C ITSET INDEX NUMBER WHERE TEMPERATURE REACHES AT THE SET POINT
28 C ITUNOC INDEX NUMBER WHERE X=XUNOC
29 C ITUP INDEX NUMBER WHERE TEMPERATURE RISE BEGINS
30 C MAINTN TRUE IF THE ON-OFF CONTROL IS NEEDED
31 C FALSE IF THE ON-OFF CONTROL IS NOT NEEDED
32 C NMAX TOTAL NUMBER OF SAMPLES A DAY
33 C NPTHR NUMBER OF SAMPLES IN ONE HOUR
34 C PARTON TRUE IF THE SYSTEM OPERATES WITH A PARTIAL CAPACITY
35 C FALSE IF THE SYSTEM IS OFF
36 C SWI EVENT CONTROL SWITCHES (I=0....7)
37 C TAUOFF SYSTEM TIME CONSTANT DURING THE OFF-PERIOD
38 C TAUON SYSTEM TIME CONSTANT DURING THE ON-PERIOD
39 C TBEGIN ORIGIN OF X-COORDINATE (MILITARY TIME)
40 C TDEDOF DEAD TIME DURING THE OFF-PERIOD
41 C TDEDON DEAD TIME DURING THE ON-PERIOD
42 C TEMP INDOOR OR INTERIOR SURFACE TEMPERATURE
43 C TIME TIME OF DAY (MILITARY TIME)
44 C TIMEX MODIFIED TIME OF DAY IN SCALAR
45 C TOA(*) OUTDOOR TEMPERATURE
46 C TOCC BEGINNING TIME OF OCCUPANCY (MILITARY TIME)
47 C TOFF OPTIMUM STOP TIME (MILITARY TIME)
48 C TOUT DRY-BULB OUTDOOR TEMPERATURE
49 C TSTART OPTIMUM START TIME (MILITARY TIME)
50 C TUNOC BEGINNING TIME OF UNOCCUPANCY (MILITARY TIME)
51 C X(I) MODIFIED TIME OF DAY WITH ITS ORIGIN AT TBEGIN
52 C XD X-VALUE WHERE Y-VALUE IS EQUAL TO YSET
53 C XDATA(*) MODIFIED TIME OF DAY (X-VALUE)
54 C XOCC BEGINNING TIME OF OCCUPANCY IN X-COORDINATE
55 C XOCC1 PAST VALUE OF XOCC
56 C XOCC1 OPTIMUM STOP TIME IN X-COORDINATE
57 C XSTART OPTIMUM START TIME IN X-COORDINATE

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58 C XUNOC BEGINNING TIME OF UNOCCUPANCY IN X-COORDINATE
59 C XUNOC1 PAST VALUE OF XOCC
60 C Y(I) TEMPERATURE
61 C YDATA(*) TEMPERATURE (Y-VALUE)
62 C YINF STEADY-STATE TEMPERATURE AS X GOES TO INFINITY DURING
63 C THE OFF-PERIOD
64 C YMAX MAXIMUM TEMPERATURE
65 C YMIN MINIMUM TEMPERATURE
66 C YSET SET POINT TEMPERATURE (TARGET TEMPERATURE)
67 C YSS STEADY-STATE TEMPERATURE AS X GOES TO INFINITY DURING
68 C THE ON-PERIOD
69 C
70 C *****
71 C
72 C SUBROUTINE OPTSS(TIME,TEMP,TOUT)
73 C LOGICAL SWO,SW1,SW2,SW3,SW4,SW5,SW6,SW7,HEAT,MAINTN,PARTON,
74 C & FSYSON,DAYCNT
75 C EXTERNAL FYDIF
76 C PARAMETER (NPTHR=4,NMAX=NPTHR*24)
77 C DIMENSION XDATA(O:NMAX),YDATA(O:NMAX),TOA(O:NMAX)
78 C COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
79 C & /CNST/ TAUON,TAUOFF,YINF,YSS,XD
80 C & /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
81 C & /TSET/ TSTART,TOFF,TOCC,TUNOC,TBEGIN
82 C NAMELIST /RESULT/X,Y,XOFF,XSTART,TAUON,TAUOFF,TDEDON,TDEDOF,
83 C & YSS,YINF,ICYCLE,ITIME,ITOFF,ITUNOC,ITDOWN,ITON,ITUP,ITSET,
84 C & TBEGIN,TOFF,TUNOC,TSTART,TOCC
85 C DATA EPS,ITMAX/O.005,20/
86 C DATA SWO/.TRUE./,EPSOFF,EPSON,EPSSSET/3*0.25/
87 C
88 C INITIAL CONDITIONS
89 C
90 C EPSX=0.5/NPTHR
91 C IF(SWO) THEN
92 C ICTYPE=0
93 C SW1=.FALSE.
94 C SW2=.FALSE.
95 C SW3=.FALSE.
96 C SW4=.FALSE.
97 C SW5=.FALSE.
98 C SW6=.FALSE.
99 C SW7=.FALSE.
100 C MAINTN=.FALSE.
101 C PARTON=.FALSE.
102 C FSYSON=.FALSE.
103 C DAYCNT=.TRUE.
104 C
105 C CHANGE TIME COORDINATES
106 C
107 C CALL XCOORD(XSTART,TSTART,TBEGIN,1)
108 C CALL XCOORD(XOCC,TOCC,TBEGIN,1)
109 C CALL XCOORD(XUNOC,TUNOC,TBEGIN,1)
110 C ENDIF
111 C
112 C STORE INPUT DATA AS ARRAYS IN TERMS OF INDEX TIME
113 C
114 C CALL XCOORD(TIMEX,TIME,TBEGIN,1)
115 C ITIME=TIMEX*NPTHR

```

```

116      TOA(ITIME)=TOUT
117      XDATA(ITIME)=TIMEX
118      YDATA(ITIME)=TEMP
119      X(4)=XDATA(ITIME)
120      Y(4)=YDATA(ITIME)
121      C
122      C      TURN OFF THE SYSTEM AT THE BEGINNING OF UNOCCUPANCY OF INITIAL
123      C      CYCLE
124      C
125      IF(SWO.AND.ABS(XDATA(ITIME)-XUNOC).LT.EPSX) THEN
126          DAYCNT=.FALSE.
127          ITOFF=ITIME
128          ITUNOC=ITIME
129          SWO=.FALSE.
130          SW2=.TRUE.
131          PRINT 100
132      ENDIF
133      C
134      C      TURN OFF THE SYSTEM AT THE BEGINNING OF UNOCCUPANCY AFTER INITIAL
135      C      CYCLE
136      C
137      IF(SW1.AND.XDATA(ITIME).GE.XOFF) THEN
138          DAYCNT=.FALSE.
139          ITOFF=ITIME
140          SW1=.FALSE.
141          SW2=.TRUE.
142          PRINT 200
143      ENDIF
144      C
145      C      DETERMINE DEAD TIME DURING THE OFF-PERIOD
146      C
147      IF(SW2.AND.ABS(YDATA(ITIME)-YDATA(ITOFF)).GE.EPSOFF) THEN
148          TDEDOF=XDATA(ITIME)-XDATA(ITOFF)
149          XOFF=XUNOC-TDEDOF
150          ITDOWN=ITIME
151          SW2=.FALSE.
152          SW3=.TRUE.
153          SW4=.TRUE.
154          PRINT 300
155      ENDIF
156      C
157      C      MAINTAIN MINIMUM LEVEL OF OPREATION
158      C
159      IF(SW3) THEN
160          IF((HEAT.AND.(Y(4).LE.YMIN)).OR.(.NOT.(HEAT).AND.
161      & Y(4).GT.YMAX)) THEN
162              IF(ICYCLE.GE.1) XSTART=XLEFT-TDEDON
163              MAINTN=.TRUE.
164              SW3=.FALSE.
165              PRINT 400
166          ENDIF
167      ENDIF
168      C
169      C      FIND THE INTERSECTION OF ON- AND OFF-TEMPERATURE CURVES
170      C
171      IF(ICYCLE.GE.1) THEN
172          IF(ABS(XDATA(ITIME)-X(3)).LT.EPSX) THEN
173              Y(3)=YDATA(ITIME)

```

```

174         ENDIF
175     C
176     IF((.NOT.MAINTN).AND.(XDATA(ITIME).GT.X(3).AND.XDATA(ITIME)
177 & .LT.XSTART).AND.(ABS(Y(3)-Y(4)).GT.EPSSET)) THEN
178     C
179         IF(HEAT) THEN
180             IF(Y(4).GE.Y(3)) THEN
181                 YINF=TOAMAX
182             ELSE
183                 YINF=TOAMIN
184             ENDIF
185         ELSE
186             IF(Y(4).LE.Y(3)) THEN
187                 YINF=TOAMIN
188             ELSE
189                 YINF=TOAMAX
190             ENDIF
191         ENDIF
192     C
193         XL=XLEFT
194         XR=XRIGHT
195         CALL ROOT(XL,XR,EPS,ITMAX,FYDIF,XROOT,IFLAG)
196         IF(IFLAG.EQ.O) THEN
197             XSTART=XROOT-TDEDON
198         ELSE
199             XSTART=XLEFT-TDEDON
200         ENDIF
201     ENDIF
202     CALL XCOORD(XSTART,TSTART,TBEGIN,2)
203 ENDIF
204 C
205 C     TRUN ON THE SYSTEM AT OPTIMUM START TIME
206 C
207     IF(SW4.AND.XDATA(ITIME).GE.XSTART) THEN
208         FSYSON=.TRUE.
209         ITON=ITIME
210         MAINTN=.FALSE.
211         SW4=.FALSE.
212         SW5=.TRUE.
213         PRINT 500
214     ENDIF
215 C
216 C     DETERMINE DEAD TIME DURING THE ON-PERIOD
217 C
218     IF(SW5.AND.ABS(YDATA(ITIME)-YDATA(ITON)).GE.EPSON) THEN
219         TDEDON=XDATA(ITIME)-XSTART
220         ITUP=ITIME
221         SW5=.FALSE.
222         SW6=.TRUE.
223         PRINT 600
224     ENDIF
225 C
226 C     TURN OFF THE SYSTEM NEAR THE BEGINNING OF OCCUPANCY AND CALL
227 C     THE DAYTIME CONTROLLER
228 C
229     IF(SW6.AND.((ABS(YDATA(ITIME)-YSET).LE.EPSSET)
230 & .OR.(HEAT.AND.YDATA(ITIME).GE.YSET)
231 & .OR.(.NOT.HEAT.AND.YDATA(ITIME).LE.YSET))) THEN

```

```

232         FSYSON=.FALSE.
233         DAYCNT=.TRUE.
234         ITSET=ITIME
235         SW6=.FALSE.
236         SW7=.TRUE.
237         PRINT 700
238     ENDIF
239
240     C
241     C   COMPUTE X- AND Y-VALUES BASED ON PREVIOUS OBSERVATION
242     C   AND UPDATE THEM USING NEW TOCC AND TUNOC
243
244     IF(SW7) THEN
245         CALL XCOORD(XOFF,TOFF,TBEGIN,2)
246         PRINT 900
247         PRINT RESULT
248         PRINT 900
249         XOCC1=XOCC
250         XUNOC1=XUNOC
251         IF(TUNOC.GT.TOCC) THEN
252             TBEGIN=0.5*(TUNOC+TOCC)
253         ELSE
254             TBEGIN=0.5*(TUNOC+24.+TOCC)
255             IF(TBEGIN.GE.24.) TBEGIN=TBEGIN-24.
256         ENDIF
257         CALL XCOORD(XOCC,TOCC,TBEGIN,1)
258         CALL XCOORD(XUNOC,TUNOC,TBEGIN,1)
259         K1=(ITSET-ITUP)/3+ITUP
260         K2=(ITSET-ITUP)*2/3+ITUP
261         IF(ICYCLE.EQ.0) THEN
262             K3=(ITON-ITUNOC)/4+ITUNOC
263         ELSE
264             K3=(ITON-ITDOWN)/4+ITDOWN
265         ENDIF
266         X(1)=XDATA(K1)+XOCC-XOCC1
267         X(2)=XDATA(K2)+XOCC-XOCC1
268         X(3)=XDATA(K3)+XUNOC-XUNOC1
269         Y(1)=YDATA(K1)
270         Y(2)=YDATA(K2)
271         Y(3)=YDATA(K3)
272         XSTART=XSTART+XOCC-XOCC1
273         XOFF=XOFF+XUNOC-XUNOC1
274         CALL XCOORD(XSTART,TSTART,TBEGIN,2)
275         CALL XCOORD(XOFF,TOFF,TBEGIN,2)
276
277     C
278     C   DETERMINE MAXIMUM AND MINIMUM OUTDOOR TEMPERATURES
279     C
280     CALL MAXMIN(TOA,TOAMIN,TOAMAX,NMAX)
281
282     C
283     C   COMPUTE CONSTANTS FOR ON- AND OFF-PERIOD TEMPERATURE EQUATIONS
284     C
285     IF(HEAT) THEN
286         YSS=1.5*YSET
287         YINF=TOAMIN
288     ELSE
289         YSS=0.5*YSET
290         YINF=TOAMAX
291     ENDIF

```

```

290 C DETERMINE XLEFT AND XRIGHT
291 C
292 CALL XLTRT(XLEFT,XRIGHT)
293 ICYCLE=ICYCLE+1
294 SW7=.FALSE.
295 PRINT 800
296 PRINT 900
297 PRINT RESULT
298 PRINT 900
299 ENDIF
300 C
301 C RESET SWITCH SW1 AT THE BEGINNING OF NEXT CYCLE
302 C
303 IF(ICYCLE.GE.1.AND.ABS(TIME-TBEGIN).LT.EPSX) SW1=.TRUE.
304 C
305 C FORMAT STATEMENTS
306 C
307 100 FORMAT(5X,'---SW0---SYSTEM OFF AT THE FIRST CYCLE')
308 200 FORMAT(5X,'---SW1---SYSTEM OFF')
309 300 FORMAT(5X,'---SW2---DECAY/RISE RESPONSE OCCURS')
310 400 FORMAT(5X,'---SW3---ON-OFF CONTROLLER TAKES OVER')
311 500 FORMAT(5X,'---SW4---SYSTEM ON AT FULL POWER')
312 600 FORMAT(5X,'---SW5---UPRISE/DECAY RESPONSE OCCURS')
313 700 FORMAT(5X,'---SW6---DAYTIME CONTROLLER TAKES OVER')
314 800 FORMAT(5X,'---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE')
315 900 FORMAT(80(' ')/)
316 C
317 C
318 RETURN
319 END
320 C *****
321 C
322 C FYDIF : TEMPERATURE DIFFERENCE
323 C
324 C -----
325 C
326 C YONNEW UPDATED TEMPERATURE DURING THE HEAT-UP PERIOD
327 C YOFF TEMPERATURE DURING THE COOL-DOWN PERIOD
328 C
329 C *****
330 C
331 C FUNCTION FYDIF(XX)
332 C
333 C TEMPERATURE DIFFERENCE BETWEEN YONNEW AND YOFF
334 C TO BE USED IN DETERMINATION OF INTERSECTION, XROOT
335 C
336 C FYDIF=YONNEW(XX)-YOFF(XX)
337 C RETURN
338 C END
339 C *****
340 C
341 C YONNEW, YOFF : THE ON- AND OFF-PERIOD TEMPERATURES
342 C
343 C *****
344 C
345 C FUNCTION YONNEW(XX)
346 C COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
347 C & /CNST/ TAUON,TAUOFF,YINF,YSS,XD

```

```

348 C
349 C THE ON-PERIOD TEMPERATURE WITH ADJUSTMENT
350 C
351 TAUNON=(X(2)-X(1))/ALOG((YSS-Y(1))/(YSS-Y(2)))
352 XD=X(1)-TAUNON*ALOG((YSS-YSET)/(YSS-Y(1)))
353 X1P=X(1)+XOCC-XD
354 YONNEW=YSS-(YSS-Y(1))*EXP((X1P-XX)/TAUNON)
355 RETURN
356 C
357 ENTRY YOFF(XX)
358 C
359 C THE OFF-PERIOD TEMPERATURE
360 C
361 TAUOFF=(X(4)-X(3))/ALOG((Y(3)-YINF)/(Y(4)-YINF))
362 YOFF=(Y(3)-YINF)*EXP((X(3)-XX)/TAUOFF)+YINF
363 RETURN
364 END
365 C *****
366 C
367 C ROOT : FIND A ROOT OF A FUNCTION F(X)=O IN A GIVEN INTERVAL
368 C BY THE REGULA-FALSI METHOD
369 C
370 C REFERENCE :
371 C CARNAHAN, LUTHER, AND WILKES
372 C " APPLIED NUMERICAL METHODS ", JOHN WILEY, 1969, P.193
373 C
374 C THE ORIGINAL PROGRAM WAS MODIFIED IN FORTRAN77.
375 C
376 C -----
377 C
378 C EPS A POSITIVE SMALL NUMBER FOR ACCURACY
379 C FX SCALAR FUNCTION VALUE
380 C IFLAG 0 IF FINDING A ROOT IS SUCCESSFUL
381 C 1 IF FINDING A ROOT IS NOT SUCCESSFUL
382 C ITMAX MAXIMUM NUMBER OF ITERATIONS
383 C XL LEFT-MOST X-VALUE
384 C XR RIGHT-MOST X-VALUE
385 C XROOT A REAL ROOT
386 C
387 C *****
388 C
389 C SUBROUTINE ROOT(XL,XR,EPS,ITMAX,FX,XROOT,IFLAG)
390 C
391 C* PRINT 100,XL,XR,EPS,ITMAX
392 100 FORMAT(3F10.5,I5)
393 C
394 C SET LEFTMOST AND RIGHTMOST FUNCTION VALUES
395 C
396 C FXL=FX(XL)
397 C FXR=FX(XR)
398 C
399 C CHECK FOR PRESENCE OF A ROOT
400 C
401 C IF(FXL*FXR.LT.O.) THEN
402 C
403 C BEGIN REGULA FALSI ITERATION
404 C
405 C DO 10 ITER=1,ITMAX

```

```

406          X2=(XL*FXR-XR*FXL)/(FXR-FXL)
407          FX2=FX(X2)
408      C
409      C      CHECK FOR CONVERGENCE
410      C
411          IF(ABS(FX2).LE.EPS) GOTO 20
412      C
413      C      KEEP RIGHT OR LEFT SUBINTERVAL
414      C
415          IF(FX2*FXL.LT.O.) THEN
416              XR=X2
417              FXR=FX2
418          ELSE
419              XL=X2
420              FXL=FX2
421          ENDIF
422      10      CONTINUE
423              PRINT 200,ITMAX
424      200      FORMAT(5X,'NO CONVERGENCE AFTER' ,I5,2X,'ITERATIONS')
425      ELSEIF (FXL*FXR.EQ.O.) THEN
426          ITER=1
427          IF(FXL.EQ.O.) THEN
428              X2=XL
429              FX2=O.
430          ELSE
431              X2=XR
432              FX2=O.
433          ENDIF
434      ELSE
435          IFLAG=1
436          PRINT 300
437      300      FORMAT(5X,'POSSIBLY NO ROOT ')
438          RETURN
439      ENDIF
440      20      XROOT=X2
441          IFLAG=0
442      C*      PRINT 400,ITER,XROOT,FX2
443      400      FORMAT(5X,'ITER = ',I5/5X,'XROOT = ',F10.6/5X,'FX2 = ',F10.6/)
444      C
445          RETURN
446          END
447      C *****
448      C
449      C      XLTRT : LEFTMOST AND RIGHTMOST X-VALUES FOR THE SUBROUTINE, ROOT
450      C
451      C -----
452      C
453      C      DX      TIME INCREMENT
454      C      N      NUMBER OF INTERVALS
455      C      XL      LEFT-MOST VALUE OF X
456      C      XR      RIGHT-MOST VALUE OF X
457      C
458      C *****
459      C
460          SUBROUTINE XLTRT(XL,XR)
461          LOGICAL HEAT
462          COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
463          &      /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART

```



```

464 C
465 C TIME BASIS IS HOUR, AND TIME INCREMENT IS 5 MIN.
466 C
467 DX=5./60.
468 N=(XOCC-XUNOC)/DX
469 XX=X(2)
470 DO 10 I=1,N
471 IF(HEAT) THEN
472 IF(YONNEW(XX).LE.YMIN) GOTO 20
473 ELSEIF(YONNEW(XX).GE.YMAX) THEN
474 GOTO 20
475 ENDIF
476 XX=XX-DX
477 10 CONTINUE
478 20 XL=XX
479 XR=XOCC
480 PRINT 100,XL,XR
481 100 FORMAT(5X,'XLEFT=',F10.4,5X,'XRIGHT=',F10.4/)
482 C
483 RETURN
484 END
485 C *****
486 C
487 C MAXMIN : EVALUATION OF MAXIMUM AND MINIMUM VALUES
488 C
489 C -----
490 C
491 C A ARRAY VALUES
492 C AMAX MAXIMUM VALUE OF ARRAY VALUES
493 C AMIN MIMINUM VALUE OF ARRAY VALUES
494 C IEND INDEX NUMBER OF ENDING OF SEARCH
495 C ISTART INDEX NUMBER OF START OF SEARCH
496 C NMAX NUMBER OF SAMPLES A DAY
497 C NPTHR SAMPLEING FREQUENCY ( SAMPLES PER HOUR )
498 C
499 C *****
500 C
501 SUBROUTINE MAXMIN(A,AMIN,AMAX,NMAX)
502 DIMENSION A(0:NMAX)
503 COMMON /XY/X(4),Y(4),XOCC,XUNOC,YSET
504 NPTHR=NMAX/24
505 ISTART=XUNOC*NPTHR
506 IEND=XOCC*NPTHR
507 AMIN=A(ISTART-1)
508 AMAX=A(ISTART-1)
509 DO 10 I=ISTART,IEND
510 IF(A(I).LT.AMIN) AMIN=A(I)
511 IF(A(I).GT.AMAX) AMAX=A(I)
512 10 CONTINUE
513 C
514 RETURN
515 END
516 C *****
517 C
518 C XCOORD : X-COORDINATE TRANSFORM
519 C
520 C IFLAG =1 FOR TRANSFORM OF TIME OF DAY INTO X-VALUE
521 C =2 FOR TRANSFORM OF X-VALUE INTO TIME OF DAY

```

```

522 C
523 C *****
524 C
525 SUBROUTINE XCOORD(X,TIME,TBEGIN,IFLAG)
526 IF(IFLAG.EQ.1) THEN
527 IF(TIME.GE.TBEGIN.AND.TIME.LE.24.) THEN
528 X=TIME-TBEGIN
529 ELSE
530 X=TIME+(24.-TBEGIN)
531 ENDIF
532 ELSE
533 TIME=X+TBEGIN
534 IF(TIME.GE.24.0) TIME=TIME-24.0
535 ENDIF
536 C
537 RETURN
538 END
539 C *****
540 C
541 C ONOFF : THE ON-OFF CONTROL ALGORITHM
542 C
543 C *****
544 C
545 SUBROUTINE ONOFF(TEMP)
546 LOGICAL HEAT,MAINTN,FSYSON,DAYCNT,PARTON
547 COMMON /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
548 & /ONOFFC/ PARTON,DELY
549 C
550 IF(HEAT) THEN
551 IF(TEMP.LE.YMIN) PARTON=.TRUE.
552 IF(TEMP.GE.YMIN+DELY) PARTON=.FALSE.
553 ELSEIF(TEMP.GE.YMAX) THEN
554 PARTON=.TRUE.
555 ELSEIF(TEMP.LE.YMAX-DELY) THEN
556 PARTON=.FALSE.
557 ENDIF
558 C
559 RETURN
560 END
561 C *****
562 C
563 C OPMAIN : MAIN PROGRAM OF OPTIMUM START/STOP CONTROL
564 C FOR BOTH HEATING AND COOLING SEASONS
565 C
566 C -----
567 C
568 C DATE DATE OF YEAR
569 C DAY =0 FOR NON-WORKING DAY
570 C =1 FOR WORKING DAY
571 C NSKIP NUMBER OF RECORDS TO BE SKIPPED IN PRINTING OUT
572 C RSCHDL TIMES WHEN THE SCHEDULE FILE IS READ (MILITARY TIME)
573 C TITLE TITLE OF INPUT DATA SET IN TWO ROWS
574 C
575 C *****
576 C
577 PROGRAM OPMAIN
578 LOGICAL HEAT,MAINTN,FSYSON,DAYCNT,PARTON
579 INTEGER DATE,DAY

```

```

580 CHARACTER TITLE(2)*80
581 PARAMETER (NPTHR=4)
582 DIMENSION RSCHDL(2)
583 COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
584 & /CNST/ TAUON,TAUOFF,YINF,YSS,XD
585 & /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
586 & /ONOFFC/ PARTON,DELY
587 & /TSET/ TSTART,TOFF,TOCC,TUNOC,TBEGIN
588 NAMELIST /INIT/ DATE,DAY,TOCC,TUNOC,TSTART,
589 & YSET,YMIN,YMAX,DELY,HEAT,NSKIP
590 & /DAYOCC/ DATE,DAY,TOCC,TUNOC
591 & /OUTPUT/ TIME,MAINTN,PARTON,FSYSON,DAYCNT,
592 & TSTART,TOFF,TOCC,TUNOC,TBEGIN
593 DATA RSCHDL/6.0,18.0/
594 C
595 C OPEN FILE 7 FOR INITIAL AND SCHEDULE INFORMATION
596 C OPEN FILE 8 FOR SIMULATED DATA OF MEASURED VALUES
597 C
598 OPEN (7,FILE='OPTIN')
599 OPEN (8,FILE='OPTDATA')
600 REWIND 7
601 REWIND 8
602 C
603 C READ INITIAL INPUT DATA
604 C
605 READ(7,1000) TITLE
606 READ(7,INIT)
607 PRINT 1000, TITLE
608 PRINT INIT
609 IW=0
610 I=0
611 C
612 C READ SIMULATED MEASURED DATA AND SCHEDULE INFORMATION
613 C
614 10 READ(8,*,END=999) TIME,TEMP,TOUT
615 IF(I.EQ.0) TBEGIN=TIME
616 IF((ABS(TIME-RSCHDL(1)).LT.0.5/NPTHR).OR.
617 & (ABS(TIME-RSCHDL(2)).LT.0.5/NPTHR)) THEN
618 READ(7,DAYOCC)
619 PRINT DAYOCC
620 ENDIF
621 C
622 C MAINTAIN MINIMUM REQUIREMENT DURING NOT-WORKING DAYS
623 C
624 IF(DAY.EQ.0) THEN
625 MAINTN=.TRUE.
626 ELSE
627 CALL OPTSS(TIME,TEMP,TOUT)
628 ENDIF
629 C
630 IF(MAINTN) CALL ONOFF(TEMP)
631 IF(IW.EQ.NSKIP+1) THEN
632 PRINT *,TIME,TEMP,TOUT
633 PRINT OUTPUT
634 IW=0
635 ENDIF
636 IW=IW+1
637 I=1

```

```
638      GOTO 10
639      C
640      C   FORMAT STATEMENTS
641      C
642      1000  FORMAT(A80/A80)
643      C
644      999   STOP
645      END
```

APPENDIX D. SAMPLE INPUT AND OUTPUT OF THE PROGRAM

INPUT DATA

OPTDATA

	TIME	TEMP	TOUT		TIME	TEMP	TOUT
1	12.0000	18.3000	3.5000	58	2.2500	9.1000	-3.3000
2	12.2500	18.3000	3.7500	59	2.5000	9.0000	-2.4000
3	12.5000	18.3000	4.0000	60	2.7500	8.9000	-3.5000
4	12.7500	18.3000	4.2500	61	3.0000	8.8000	-3.6000
5	13.0000	18.3000	4.5000	62	3.2500	8.7500	-3.6750
6	13.2500	18.3000	4.6250	63	3.5000	8.7000	-3.7500
7	13.5000	18.3000	4.7500	64	3.7500	8.6500	-3.8250
8	13.7500	18.3000	4.8750	65	4.0000	8.6000	-3.9000
9	14.0000	18.3000	5.0000	66	4.2500	8.7000	-3.9250
10	14.2500	18.3000	4.9250	67	4.5000	8.8000	-3.9500
11	14.5000	18.3000	4.8500	68	4.7500	8.9000	-3.9750
12	14.7500	18.3000	4.7750	69	5.0000	9.0000	-4.0000
13	15.0000	18.3000	4.7000	70	5.2500	9.3750	-3.9750
14	15.2500	18.3000	4.5250	71	5.5000	9.7500	-3.9500
15	15.5000	18.3000	4.3500	72	5.7500	10.1250	-3.9250
16	15.7500	18.3000	4.1750	73	6.0000	10.5000	-3.9000
17	16.0000	18.3000	4.0000	74	6.2500	11.2500	-3.7750
18	16.2500	18.3000	3.8000	75	6.5000	12.0000	-3.6500
19	16.5000	18.3000	3.6000	76	6.7500	12.7500	-3.5250
20	16.7500	18.3000	3.4000	77	7.0000	13.5000	-3.4000
21	17.0000	18.3000	3.2000	78	7.2500	14.3000	-3.2000
22	17.2500	18.3000	2.9750	79	7.5000	15.1000	-3.0000
23	17.5000	18.3000	2.7500	80	7.7500	15.9000	-2.8000
24	17.7500	18.3000	2.5250	81	8.0000	16.7000	-2.6000
25	18.0000	18.3000	2.3000	82	8.2500	17.1000	-2.3750
26	18.2500	18.1000	2.0250	83	8.5000	17.5000	-2.1500
27	18.5000	17.9000	1.7500	84	8.7500	17.9000	-1.9250
28	18.7500	17.7000	1.4750	85	9.0000	18.3000	-1.7000
29	19.0000	17.5000	1.2000	86	9.2500	18.3000	-1.2250
30	19.2500	17.1000	1.0000	87	9.5000	18.3000	-.7500
31	19.5000	16.7000	.8000	88	9.7500	18.3000	-.2750
32	19.7500	16.3000	.6000	89	10.0000	18.3000	.2000
33	20.0000	15.9000	.4000	90	10.2500	18.3000	.6000
34	20.2500	15.5000	.2250	91	10.5000	18.3000	1.0000
35	20.5000	15.1000	.0500	92	10.7500	18.3000	1.4000
36	20.7500	14.7000	-.1250	93	11.0000	18.3000	1.8000
37	21.0000	14.3000	-.3000	94	11.2500	18.3000	2.2250
38	21.2500	13.9500	-.4750	95	11.5000	18.3000	2.6500
39	21.5000	13.6000	-.6500	96	11.7500	18.3000	3.0750
40	21.7500	13.2500	-.8250	97	12.0000	18.3000	3.5000
41	22.0000	12.9000	-1.0000	98	12.2500	18.3000	3.7500
42	22.2500	12.6000	-1.1500	99	12.5000	18.3000	4.0000
43	22.5000	12.3000	-1.3000	100	12.7500	18.3000	4.2500
44	22.7500	12.0000	-1.4500	101	13.0000	18.3000	4.5000
45	23.0000	11.7000	-1.6000	102	13.2500	18.3000	4.6250
46	23.2500	11.4000	-1.7250	103	13.5000	18.3000	4.7500
47	23.5000	11.1000	-1.8500	104	13.7500	18.3000	4.8750
48	23.7500	10.8000	-1.9750	105	14.0000	18.3000	5.0000
49	0.0000	10.5000	-2.1000	106	14.2500	18.3000	4.9250
50	-.2500	10.3000	-2.2500	107	14.5000	18.3000	4.8500
51	-.5000	10.1000	-2.4000	108	14.7500	18.3000	4.7750
52	-.7500	9.9000	-2.5500	109	15.0000	18.3000	4.7000
53	1.0000	9.7000	-2.7000	110	15.2500	18.3000	4.5250
54	1.2500	9.5750	-2.8250	111	15.5000	18.3000	4.3500
55	1.5000	9.4500	-2.9500	112	15.7500	18.3000	4.1750
56	1.7500	9.3250	-3.0750	113	16.0000	18.3000	4.0000
57	2.0000	9.2000	-3.2000	114	16.2500	18.3000	3.8000
				115	16.5000	18.3000	3.6000

	TIME	TEMP	TOUT		TIME	TEMP	TOUT
116	16.7500	18.3000	3.4000	174	7.2500	14.3000	-3.2000
117	17.0000	18.3000	3.2000	175	7.5000	15.1000	-3.0000
118	17.2500	18.3000	2.9750	176	7.7500	15.9000	-2.8000
119	17.5000	18.3000	2.7500	177	8.0000	16.7000	-2.6000
120	17.7500	18.3000	2.5250	178	8.2500	17.1000	-2.3750
121	18.0000	18.3000	2.3000	179	8.5000	17.5000	-2.1500
122	18.2500	18.1000	2.0250	180	8.7500	17.9000	-1.9250
123	18.5000	17.9000	1.7500	181	9.0000	18.3000	-1.7000
124	18.7500	17.7000	1.4750	182	9.2500	18.3000	-1.2250
125	19.0000	17.5000	1.2000	183	9.5000	18.3000	-.7500
126	19.2500	17.1000	1.0000	184	9.7500	18.3000	-.2750
127	19.5000	16.7000	.8000	185	10.0000	18.3000	.2000
128	19.7500	16.3000	.6000	186	10.2500	18.3000	.6000
129	20.0000	15.9000	.4000	187	10.5000	18.3000	1.0000
130	20.2500	15.5000	.2250	188	10.7500	18.3000	1.4000
131	20.5000	15.1000	.0500	189	11.0000	18.3000	1.8000
132	20.7500	14.7000	-.1250	190	11.2500	18.3000	2.2250
133	21.0000	14.3000	-.3000	191	11.5000	18.3000	2.6500
134	21.2500	13.9500	-.4750	192	11.7500	18.3000	3.0750
135	21.5000	13.6000	-.6500	193	12.0000	18.3000	3.5000
136	21.7500	13.2500	-.8250	194	12.2500	18.3000	3.7500
137	22.0000	12.9000	-1.0000	195	12.5000	18.3000	4.0000
138	22.2500	12.6000	-1.1500	196	12.7500	18.3000	4.2500
139	22.5000	12.3000	-1.3000	197	13.0000	18.3000	4.5000
140	22.7500	12.0000	-1.4500	198	13.2500	18.3000	4.6250
141	23.0000	11.7000	-1.6000				
142	23.2500	11.4000	-1.7250				
143	23.5000	11.1000	-1.8500				
144	23.7500	10.8000	-1.9750				
145	0.0000	10.5000	-2.1000				
146	.2500	10.3000	-2.2500				
147	.5000	10.1000	-2.4000				
148	.7500	9.9000	-2.5500				
149	1.0000	9.7000	-2.7000				
150	1.2500	9.5750	-2.8250				
151	1.5000	9.4500	-2.9500				
152	1.7500	9.3250	-3.0750				
153	2.0000	9.2000	-3.2000				
154	2.2500	9.1000	-3.3000				
155	2.5000	9.0000	-3.4000				
156	2.7500	8.9000	-3.5000				
157	3.0000	8.8000	-3.6000				
158	3.2500	8.7500	-3.6750				
159	3.5000	8.7000	-3.7500				
160	3.7500	8.6500	-3.8250				
161	4.0000	8.6000	-3.9000				
162	4.2500	8.7000	-3.9250				
163	4.5000	8.8000	-3.9500				
164	4.7500	8.9000	-3.9750				
165	5.0000	9.0000	-4.0000				
166	5.2500	9.3750	-3.9750				
167	5.5000	9.7500	-3.9500				
168	5.7500	10.1250	-3.9250				
169	6.0000	10.5000	-3.9000				
170	6.2500	11.2500	-3.7750				
171	6.5000	12.0000	-3.6500				
172	6.7500	12.7500	-3.5250				
173	7.0000	13.5000	-3.4000				

INPUT DATA

OPTIN

```

1 OPTIN: INPUT DATA FOR OPMAIN
2 HEATING MODE
3 $INIT DATE=61, DAY=1, TOCC=9.0, TUNOC=17.0, TSTART=4.0,
4 YSET=18.3, YMIN=1.0, YMAX=27.0, DELY=1.0, HEAT=T, NSKIP=5, $END
5 $DAYOCC DATE=61, DAY=1, TOCC=9.0, TUNOC=17.0, $END
6 $DAYOCC DATE=62, DAY=1, TOCC=9.0, TUNOC=17.0, $END
7 $DAYOCC DATE=62, DAY=1, TOCC=9.0, TUNOC=17.0, $END
8 $DAYOCC DATE=63, DAY=1, TOCC=9.0, TUNOC=17.0, $END
END PRT OUTPUT

```

EXOT OBJ. NAMES

```

OPTIN: INPUT DATA FOR OPMAIN
HEATING MODE
$INIT
DATE = 61, DAY = 1, TOCC = 9.0000000+001, TUNOC = .17000000+002, TSTART = .40000000+001, YSET = .18300000+002,
YMIN = .10000000+001, YMAX = .27000000+002, DELY = .10000000+001, HEAT = T, NSKIP = 5
$END

```

```

13.500000 18.300000 4.7500000
$OUTPUT
TIME = .13500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

15.000000 18.300000 4.7000000
$OUTPUT
TIME = .15000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

16.500000 18.300000 3.6000000
$OUTPUT
TIME = .16500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

---SWD---SYSTEM OFF AT THE FIRST CYCLE

```

$DAYOCC
DATE = 61, DAY = 1, TOCC = .90000000+001, TUNOC = .17000000+002
$END
18.000000 18.300000 2.3000000
$OUTPUT
TIME = .18000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

---SW2---DECAY/RISE RESPONSE OCCURS
19.500000 16.700000 .8000000
$OUTPUT
TIME = .19500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

21.000000 14.300000 -.30000000
$OUTPUT
TIME = .21000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

22.500000 12.300000 -1.30000000
$OUTPUT
TIME = .22500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

25.000000 12.300000 -1.30000000
$OUTPUT
TIME = .25000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

.00000000 10.500000 -2.10000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .00000000 .MAINTN = F.PARTON = F.FSYSON = F.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
1.50000000 9.45000000 -2.95000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .15000000+001.MAINTN = F.PARTON = F.FSYSON = F.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
3.00000000 8.80000000 -3.60000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .30000000+001.MAINTN = F.PARTON = F.FSYSON = F.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
---SW4---SYSTEM ON AT FULL POWER
4.50000000 8.80000000 -3.95000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .45000000+001.MAINTN = F.PARTON = F.FSYSON = T.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
---SW5---UPRISE/DECAY RESPONSE OCCURS
$DAYOCC
DATE = 62.DAY = 1.TOCC = .90000000+001.TUNOC = .17000000+002
$END
6.00000000 10.500000 -3.90000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .60000000+001.MAINTN = F.PARTON = F.FSYSON = T.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
7.50000000 15.100000 -3.00000000 .TOCC = .900000000+001.
$OUTPUT
TIME = .75000000+001.MAINTN = F.PARTON = F.FSYSON = T.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
---SW6---DAYTIME CONTROLLER TAKES OVER
*****
$RESULT
X = .00000000 .00000000 .00000000 .21000000+002.
Y = .00000000 .00000000 .00000000 .18300000+002.XOFF = .35000000+001.XSTART = .16000000+002.TAUN = .00000000
TAUOFF = .00000000 .TDEDON = .75000000+000.TDEDOF = .15000000+001.YSS = .00000000 .YINF = .00000000 .ICYCLE =
ITIME = 84.ITOFF = 20.ITUNOC = 20.ITDOWN = 26.ITON = 64.ITUP = 67.
ITSET = 84.TBEGIN = .12000000+002.TOFF = .15500000+002.TUNOC = .17000000+002.TSTART = .40000000+001.TOCC = .90000000+001
$END
*****
XLEFT= 14.9167 XRIGHT= 20.0000
---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE
*****
$RESULT
X = .17000000+002. .18500000+002. .67500000+001. .21000000+002.
Y = .10500000+002. .15100000+002. .16300000+002. .18300000+002.XOFF = .25000000+001.XSTART = .15000000+002.TAUN = .47376636+001.
TAUOFF = .00000000 .TDEDON = .75000000+000.TDEDOF = .15000000+001.YSS = .27450000+002.YINF = .40000000+001.ICYCLE =
ITIME = 84.ITOFF = 20.ITUNOC = 20.ITDOWN = 26.ITON = 64.ITUP = 67.
ITSET = 84.TBEGIN = .13000000+002.TOFF = .15500000+002.TUNOC = .17000000+002.TSTART = .40000000+001.TOCC = .90000000+001

```



```

SEND
*****
9.000000 18.300000 -1.700000
$OUTPUT
TIME = .90000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

10.500000 18.300000 1.000000
$OUTPUT
TIME = .10500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

12.000000 18.300000 3.500000
$OUTPUT
TIME = .12000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

13.500000 18.300000 4.750000
$OUTPUT
TIME = .13500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

15.000000 18.300000 4.700000
$OUTPUT
TIME = .15000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

---SW1---SYSTEM OFF

16.500000 18.300000 3.600000
$OUTPUT
TIME = .16500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

$DAYOCC
DATE = 62.DAY = 1.TOCC = .90000000+001,TUNOC = .17000000+002
$END

18.000000 18.300000 2.300000
$OUTPUT
TIME = .18000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

---SW2---DECAY/RISE RESPONSE OCCURS

19.500000 16.700000 .80000000
$OUTPUT
TIME = .19500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

21.000000 14.300000 -.30000000
$OUTPUT
TIME = .21000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .41115713+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

22.500000 12.300000 -1.30000000
$OUTPUT
TIME = .22500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .41635842+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

```

```

.00000000      10.500000      -2.1000000
$OUTPUT
TIME = .00000000 ,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TTOFF = .41742094+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
1.50000000      9.45000000      -2.95000000
$OUTPUT
TIME = .15000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TTOFF = .43090498+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
3.00000000      8.80000000      -3.60000000
$OUTPUT
TIME = .30000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TTOFF = .44677372+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
4.50000000      8.80000000      -3.95000000
$OUTPUT
TIME = .45000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TTOFF = .47176206+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

```

```

---SW4---SYSTEM ON AT FULL POWER
---SW5---UPRISE/DECAY RESPONSE OCCURS
$DAYOFF      63.DAY = .1.TOCC = .90000000+001,TUNOC = .17000000+002
DATE =
$END
6.00000000      10.500000      -3.90000000
$OUTPUT
TIME = .60000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = F,TTOFF = .47176206+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
7.50000000      15.100000      -3.00000000
$OUTPUT
TIME = .75000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = F,TTOFF = .47176206+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END

```

```

---SW6---DAYTIME CONTROLLER TAKES OVER
*****
$RESULT
X = .17000000+002, .18500000+002, .67500000+001, .20000000+002,
Y = .10500000+002, .15100000+002, .16300000+002, .18300000+002, .XOFF = .10000000+001, XSTART = .15717621+002, TAUON = .47376636+001,
TAUOFF = .18973245+002, TDEDON = .53237939+000, TDEDOF = .30000000+001, YSS = .27450000+002, YINF = -.40000000+001, ICYCLE = .
ITIME = 80, ITOFF = 10, ITUNOC = 20, ITDOWN = 22, ITON = 63, ITUP = 65,
ITSET = 80, TBEGIN = .13000000+002, TOFF = .14000000+002, TUNOC = .17000000+002, TSTART = .47176206+001, TOCC = .90000000+001
$END
*****

```

```

XLEFT= 15.4167      XRIGHT= 20.0000
---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE
*****

```

```

$RESULT
X = .17500000+002, .18750000+002, .80000000+001, .20000000+002,
Y = .12000000+002, .15900000+002, .14300000+002, .18300000+002, .XOFF = .10000000+001, XSTART = .15717620+002, TAUON = .42966613+001,
TAUOFF = .18973245+002, TDEDON = .53237939+000, TDEDOF = .30000000+001, YSS = .27450000+002, YINF = -.40000000+001, ICYCLE = .
ITIME = 80, ITOFF = 10, ITUNOC = 20, ITDOWN = 22, ITON = 63, ITUP = 65,
ITSET = 80, TBEGIN = .13000000+002, TOFF = .14000000+002, TUNOC = .17000000+002, TSTART = .47176204+001, TOCC = .90000000+001

```

\$SEND

9.000000 18.300000 -1.7000000
\$OUTPUT
TIME = .90000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .47176204+001,TOFF = .14000000+002,TOCC = .90000000+001
TUNOC = .17000000+002,TBEGIN = .13000000+002

\$SEND
10.500000 18.300000 1.0000000
\$OUTPUT
TIME = .10500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .47176204+001,TOFF = .14000000+002,TOCC = .90000000+001
TUNOC = .17000000+002,TBEGIN = .13000000+002

\$SEND
12.000000 18.300000 3.5000000
\$OUTPUT
TIME = .12000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .47176204+001,TOFF = .14000000+002,TOCC = .90000000+001
TUNOC = .17000000+002,TBEGIN = .13000000+002

\$SEND

'OPTIN(1)
 1 OPTIN: INPUT DATA FOR OPMAIN
 2 HEATING MODE
 3 \$INIT DATE=61, DAY=1, TOCC=9.0, TUNOC=17.0, TSTART=4.0,
 4 YSET=18.3, YMIN=1.0, YMAX=27.0, DELY=1.0, HEAT=T, NSKIP=5, \$SEND
 5 \$DAYOCC DATE=61, DAY=1, TOCC=9.0, TUNOC=17.0, \$SEND
 6 \$DAYOCC DATE=62, DAY=1, TOCC=8.0, TUNOC=16.0, \$SEND
 7 \$DAYOCC DATE=62, DAY=1, TOCC=8.0, TUNOC=16.0, \$SEND
 8 \$DAYOCC DATE=63, DAY=1, TOCC=7.0, TUNOC=16.0, \$SEND
 END PRT

OXOT OBJ.NAMES
 OPTIN: INPUT DATA FOR OPMAIN
 HEATING MODE

\$INIT
 DATE = 61, DAY = 1, TOCC = .90000000+001, TUNOC = .17000000+002, TSTART = .40000000+001, YSET = .18300000+002,
 YMIN = .10000000+001, YMAX = .27000000+002, DELY = .10000000+001, HEAT = T, NSKIP = 5
 \$SEND

13.500000 18.300000 4.7500000
 \$OUTPUT
 TIME = .13500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

15.000000 18.300000 4.7000000
 \$OUTPUT
 TIME = .15000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

16.500000 18.300000 3.6000000
 \$OUTPUT
 TIME = .16500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = T, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

---SWO---SYSTEM OFF AT THE FIRST CYCLE

\$DAYOCC
 DATE = 61, DAY = 1, TOCC = .90000000+001, TUNOC = .17000000+002
 \$SEND

18.000000 18.300000 2.3000000
 \$OUTPUT
 TIME = .18000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

---SW2---DECAY/RISE RESPONSE OCCURS

19.500000 16.700000 .80000000
 \$OUTPUT
 TIME = .19500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

21.000000 14.300000 -.30000000
 \$OUTPUT
 TIME = .21000000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

22.500000 12.300000 -1.30000000
 \$OUTPUT
 TIME = .22500000+002, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000, TOCC = .90000000+001,
 TUNOC = .17000000+002, TBEGIN = .12000000+002
 \$SEND

```

.00000000    10.500000    -2.10000000
$OUTPUT
TIME = .00000000    .MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .90000000+001
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

1.50000000    9.45000000    -2.95000000
$OUTPUT
TIME = .15000000+001, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .90000000+001
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

3.00000000    8.80000000    -3.60000000
$OUTPUT
TIME = .30000000+001, MAINTN = F, PARTON = F, FSYSON = F, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .90000000+001
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

---SW4---SYSTEM ON AT FULL POWER
4.50000000    8.80000000    -3.95000000
$OUTPUT
TIME = .45000000+001, MAINTN = F, PARTON = F, FSYSON = T, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .90000000+001
TUNOC = .17000000+002, TBEGIN = .12000000+002
$END

```

```

---SW5---UPRISE/DECAY RESPONSE OCCURS
$DAYOCC
OATE = 62, DAY = 1, TOCC = .80000000+001, TUNOC = .16000000+002
$END

6.00000000    10.500000    -3.90000000
$OUTPUT
TIME = .60000000+001, MAINTN = F, PARTON = F, FSYSON = T, DAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .80000000+001
TUNOC = .16000000+002, TBEGIN = .12000000+002
$END

7.50000000    15.100000    -3.00000000
$OUTPUT
TIME = .75000000+001, MAINTN = F, PARTON = F, FSYSON = T, OAYCNT = F, TSTART = .40000000+001, TOFF = .00000000    , TOCC = .80000000+001
TUNOC = .16000000+002, TBEGIN = .12000000+002
$END

```

```

---SW6---DAYTIME CONTROLLER TAKES OVER
*****
$RESULT
X = .00000000    , .00000000    , .00000000    , .21000000+002,
Y = .00000000    , .00000000    , .00000000    , .18300000+002, XOFF = .35000000+001, XSTART = .16000000+002, TAUON = .00000000
TAUOFF = .00000000    , TDEDON = .75000000+000, TOEDOF = .15000000+001, YSS = .00000000    , YINF = .00000000    , ICYCLE =
ITIME = 84, ITOFF = 20, ITUNOC = 20, ITDOWN = 26, ITON = 64, ITUP = 67,
ITSET = 84, TBEGIN = .12000000+002, TOFF = .15500000+002, TUNOC = .16000000+002, TSTART = .40000000+001, TOCC = .80000000+001
$END
*****

```

```

XLEFT= 14.9167    XRIGHT= 20.0000
---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE
*****

```

```

$RESULT
X = .17000000+002, .18500000+002, .67500000+001, .21000000+002,
Y = .10500000+002, .15100000+002, .16300000+002, .18300000+002, XOFF = .25000000+001, XSTART = .15000000+002, TAUON = .47376636+001,
TAUOFF = .00000000    , TDEDON = .75000000+000, TOEDOF = .15000000+001, YSS = .27450000+002, YINF = .40000000+001, ICYCLE =
ITIME = 84, ITOFF = 20, ITUNOC = 20, ITDOWN = 26, ITON = 64, ITUP = 67,
ITSET = 84, TBEGIN = .12000000+002, TOFF = .14500000+002, TUNOC = .16000000+002, TSTART = .30000000+001, TOCC = .80000000+001

```

```

$END
*****
9.000000      18.300000      -1.7000000
$OUTPUT
TIME = .9000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
10.500000     18.300000     1.0000000
$OUTPUT
TIME = .1050000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
12.000000     18.300000     3.5000000
$OUTPUT
TIME = .1200000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
13.500000     18.300000     4.7500000
$OUTPUT
TIME = .1350000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
---SW1---SYSTEM OFF
15.000000     18.300000     4.7000000
$OUTPUT
TIME = .1500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
16.500000     18.300000     3.6000000
$OUTPUT
TIME = .1650000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
$DAYOCC
DATE = 62.DAY = 1.TOCC = .8000000+001,TUNOC = .1600000+002
$END
18.000000     18.300000     2.3000000
$OUTPUT
TIME = .1800000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .3000000+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
---SW2---DECAY/RISE RESPONSE OCCURS
19.500000     16.700000     .8000000
$OUTPUT
TIME = .1950000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .36375446+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
21.000000     14.300000     -.3000000
$OUTPUT
TIME = .2100000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .33659873+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END
22.500000     12.300000     -1.3000000
$OUTPUT
TIME = .2250000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .33550849+001,TOFF = .1450000+002,TOCC = .8000000+001,
TUNOC = .1600000+002,TBEGIN = .1200000+002
$END

```

```

.00000000 10.500000 -2.1000000
$OUTPUT
TIME = .00000000 ,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TSTART = .33457973+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
1.5000000 9.4500000 -2.9500000
$OUTPUT
TIME = .15000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TSTART = .34633873+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
3.0000000 8.8000000 -3.6000000
$OUTPUT
TIME = .30000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = F,TSTART = .36125493+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
---SW4---SYSTEM ON AT FULL POWER
4.5000000 8.8000000 -3.9500000
$OUTPUT
TIME = .45000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = F,TSTART = .36773434+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
---SW5---UPRISE/DECAY RESPONSE OCCURS
$DAYOCC
DATE = 63.DAY = 1.TOCC = .70000000+001,TUNOC = .16000000+002
$SEND
6.0000000 10.500000 -3.9000000
$OUTPUT
TIME = .60000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = F,TSTART = .36773434+001,TOFF = .14500000+002,TOCC = .70000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
7.5000000 15.100000 -3.0000000
$OUTPUT
TIME = .75000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = F,TSTART = .36773434+001,TOFF = .14500000+002,TOCC = .70000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$SEND
---SW6---DAYTIME CONTROLLER TAKES OVER
*****
$RESULT
X = .17000000+002, .18500000+002, .67500000+001, .21000000+002,
Y = .10500000+002, .15100000+002, .17700000+002, .18300000+002, .17700000+002, .17700000+002, .18300000+002, .18300000+002, .18300000+002, .18300000+002,
TAUOFF = .16333456+002,TDON = .10726566+001,TDODF = .40000000+001,YSS = .27450000+002,YINF = -.40000000+001,ICYCLE = .4,
ITIME = 84,ITOFF = 10,ITUNOC = 20,ITDOWN = 26,ITON = 63,ITUP = 67,
ITSET = 84,TBEGIN = .12000000+002,TOFF = .12000000+002,TUNOC = .16000000+002,TSTART = .36773434+001,TOCC = .70000000+001
$SEND
*****
XLEFT= 14.4167 XRIGHT= 19.5000
---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE
*****
$RESULT
X = .17500000+002, .19000000+002, .92500000+001, .21000000+002,
Y = .10500000+002, .15100000+002, .14700000+002, .14700000+002, .14700000+002, .14700000+002, .18300000+002, .18300000+002, .18300000+002, .18300000+002,
TAUOFF = .16333456+002,TDON = .10726566+001,TDODF = .40000000+001,YSS = .27450000+002,YINF = -.40000000+001,ICYCLE = .4,
ITIME = 84,ITOFF = 10,ITUNOC = 20,ITDOWN = 26,ITON = 63,ITUP = 67,
ITSET = 84,TBEGIN = .11500000+002,TOFF = .11500000+002,TUNOC = .16000000+002,TSTART = .26773434+001,TOCC = .70000000+001

```

```

$ENO
*****
9.000000 18.300000 -1.7000000
$OUTPUT
TIME = .9000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .26773434+001,TOFF = .12000000+002,TOCC = .70000000+001,
TUNOC = .16000000+002,TBEGIN = .11500000+002
$END
10.500000 18.300000 1.0000000
$OUTPUT
TIME = .10500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .26773434+001,TOFF = .12000000+002,TOCC = .70000000+001,
TUNOC = .16000000+002,TBEGIN = .11500000+002
$END
---SW1---SYSTEM OFF
12.000000 18.300000 3.5000000
$OUTPUT
TIME = .12000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .26773434+001,TOFF = .12000000+002,TOCC = .70000000+001,
TUNOC = .16000000+002,TBEGIN = .11500000+002
$ENO

```

OFFSEND.S

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET <i>(See Instructions)</i>	1. PUBLICATION OR REPORT NO. 83-2720	2. Performing Organ. Report No.	3. Publication Date June 1983								
4. TITLE AND SUBTITLE An Optimum Start/Stop Control Algorithm for Heating and Cooling Systems in Buildings											
5. AUTHOR(S) Cheol Park											
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9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS <i>(Street, City, State, ZIP)</i> <table border="0" style="width: 100%;"> <tr> <td style="width: 50%;">Office of Buildings and Community Systems</td> <td style="width: 50%;">U.S. Navy Civil Engineering Laboratory</td> </tr> <tr> <td>U.S. Department of Energy</td> <td>U.S. Department of Defense</td> </tr> <tr> <td>1000 Independence Avenue, SW</td> <td>Washington, DC 20310</td> </tr> <tr> <td>Washington, DC 20585</td> <td></td> </tr> </table>				Office of Buildings and Community Systems	U.S. Navy Civil Engineering Laboratory	U.S. Department of Energy	U.S. Department of Defense	1000 Independence Avenue, SW	Washington, DC 20310	Washington, DC 20585	
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10. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.											
11. ABSTRACT <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> <p>When a building structure is occupied intermittently, energy savings can be realized from the optimal start-up and shut-down of the heating or cooling system. This strategy, known as optimum start/stop control, reduces energy consumption by delaying the start-up of the space conditioning system until the last moment and then initiating shut-down as early as possible, while maintaining a preset level of comfort during the period of building occupancy.</p> <p>Based on the bang-bang control theory, a simple optimum start/stop control algorithm is developed for computerized control systems in buildings. The optimum start time is obtained by finding the intersection of cool-down and heat-up curves that are approximated by exponential fitting of the previous and current day's data.</p> <p>Information is presented in this report on the input and output variables, logic flow, and methodology employed in developing the algorithm. A computer program listing of the optimum start/stop control algorithm written in FORTRAN 77 and sample input and output data are included in the appendices.</p>											
12. KEY WORDS <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> digital control systems; energy conservation; energy management and control systems; heating and cooling systems; optimum start/stop time; preheat time.											
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