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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
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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.

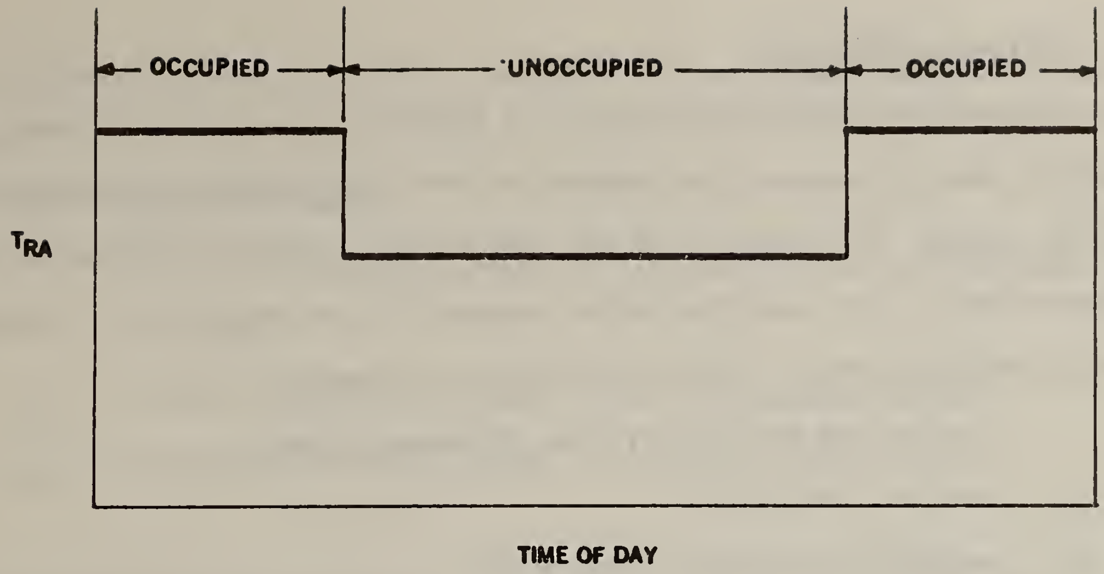

Figure 1. Room air temperature with respect to time of day under an ideal situation

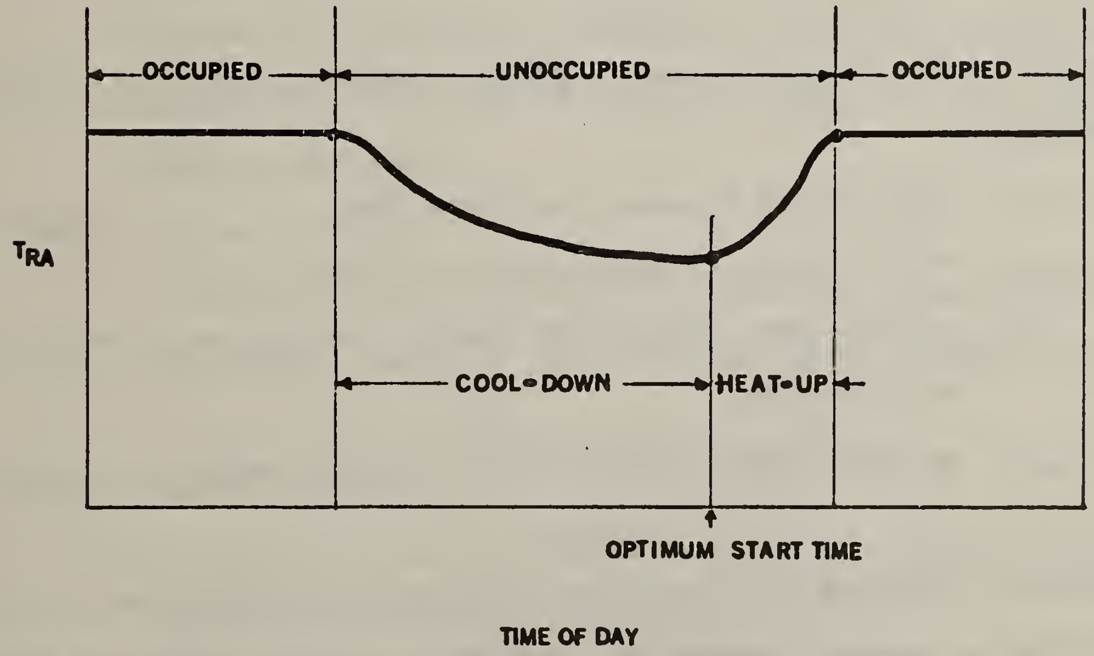

Figure 2. Room air temperature with respect to time of day under a realistic situation

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_o.

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.

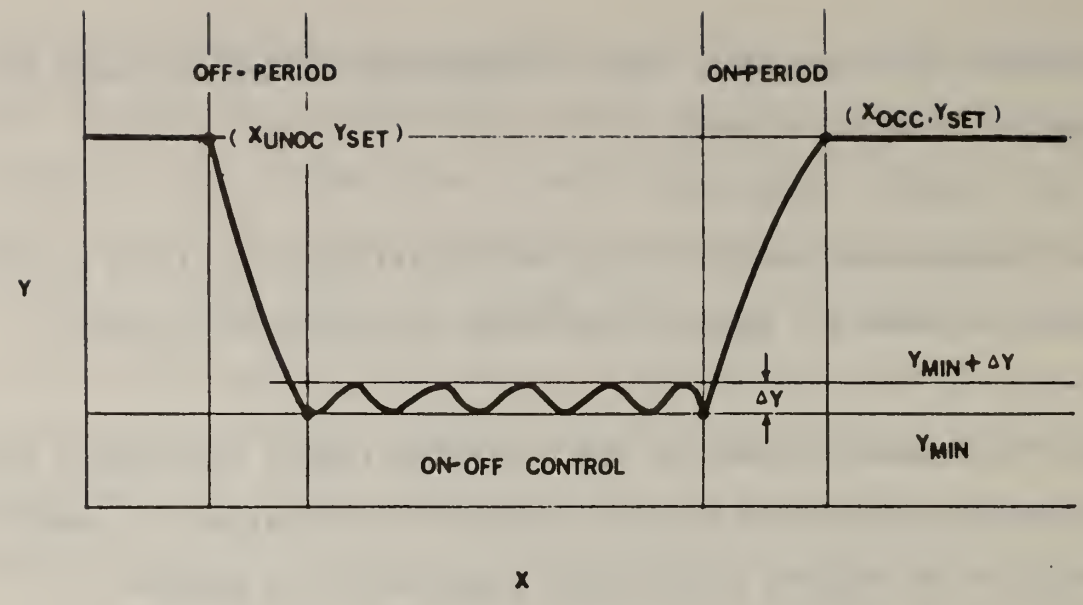

Figure 3. A case with the on-off control operation

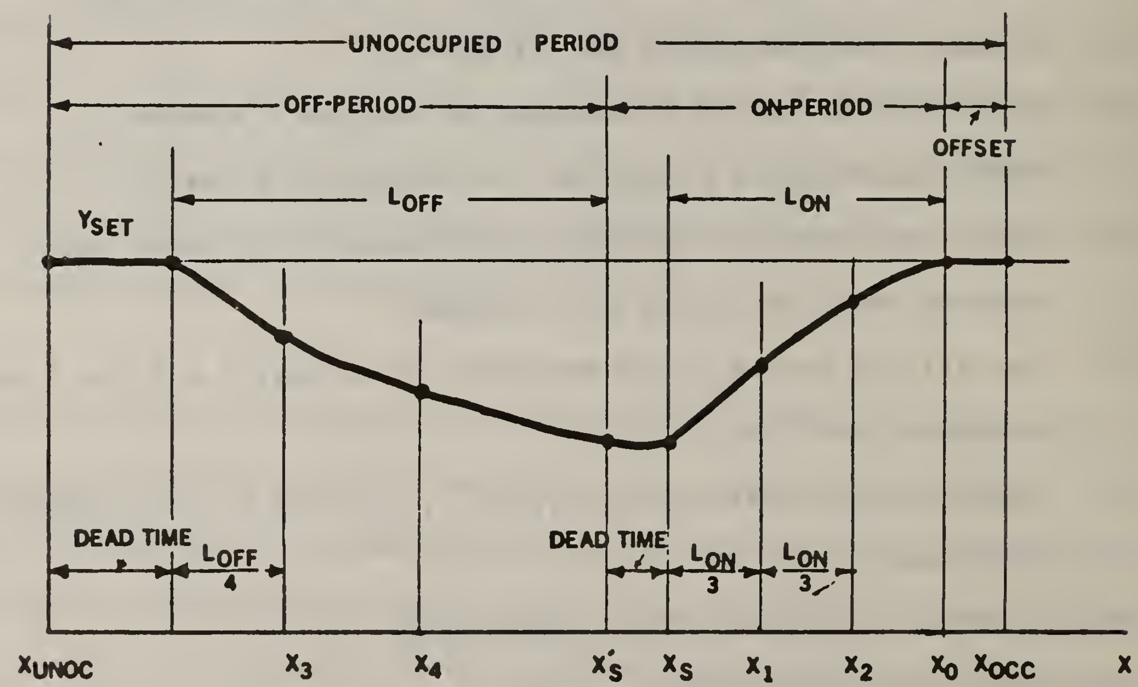

Figure 4. A typical temperature history during the initial cycle

(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

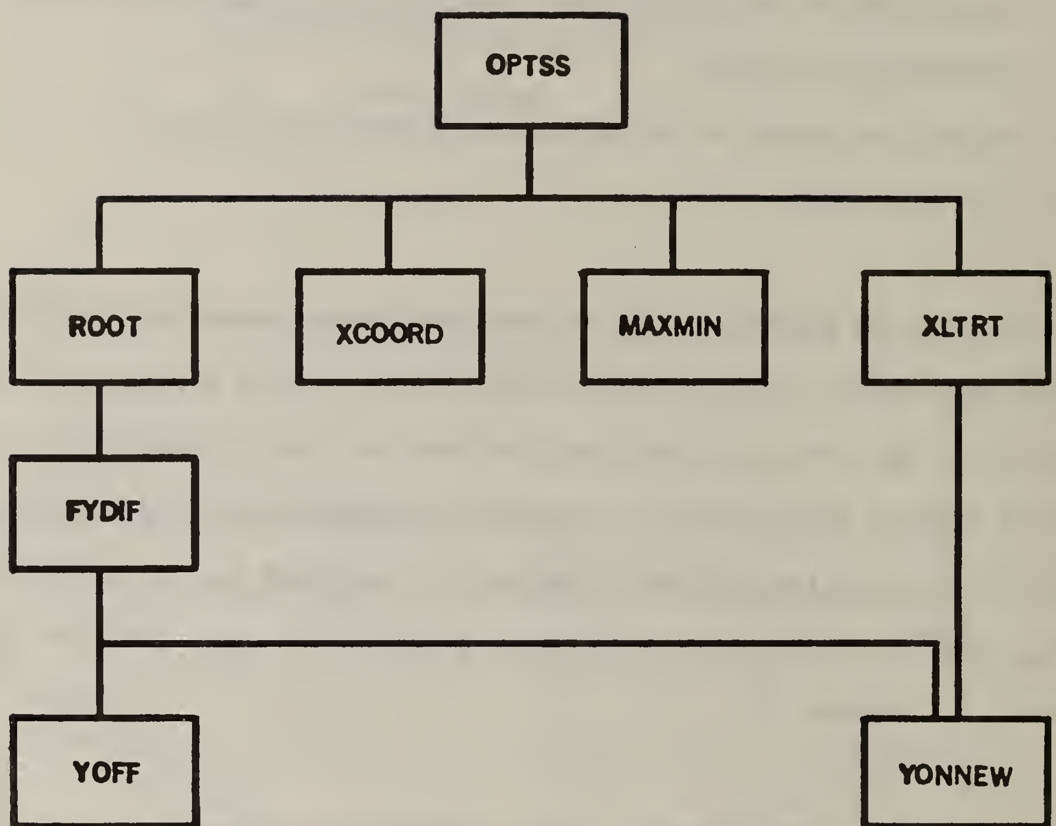

Figure 5. Relationships of subprograms

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 modifed 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).

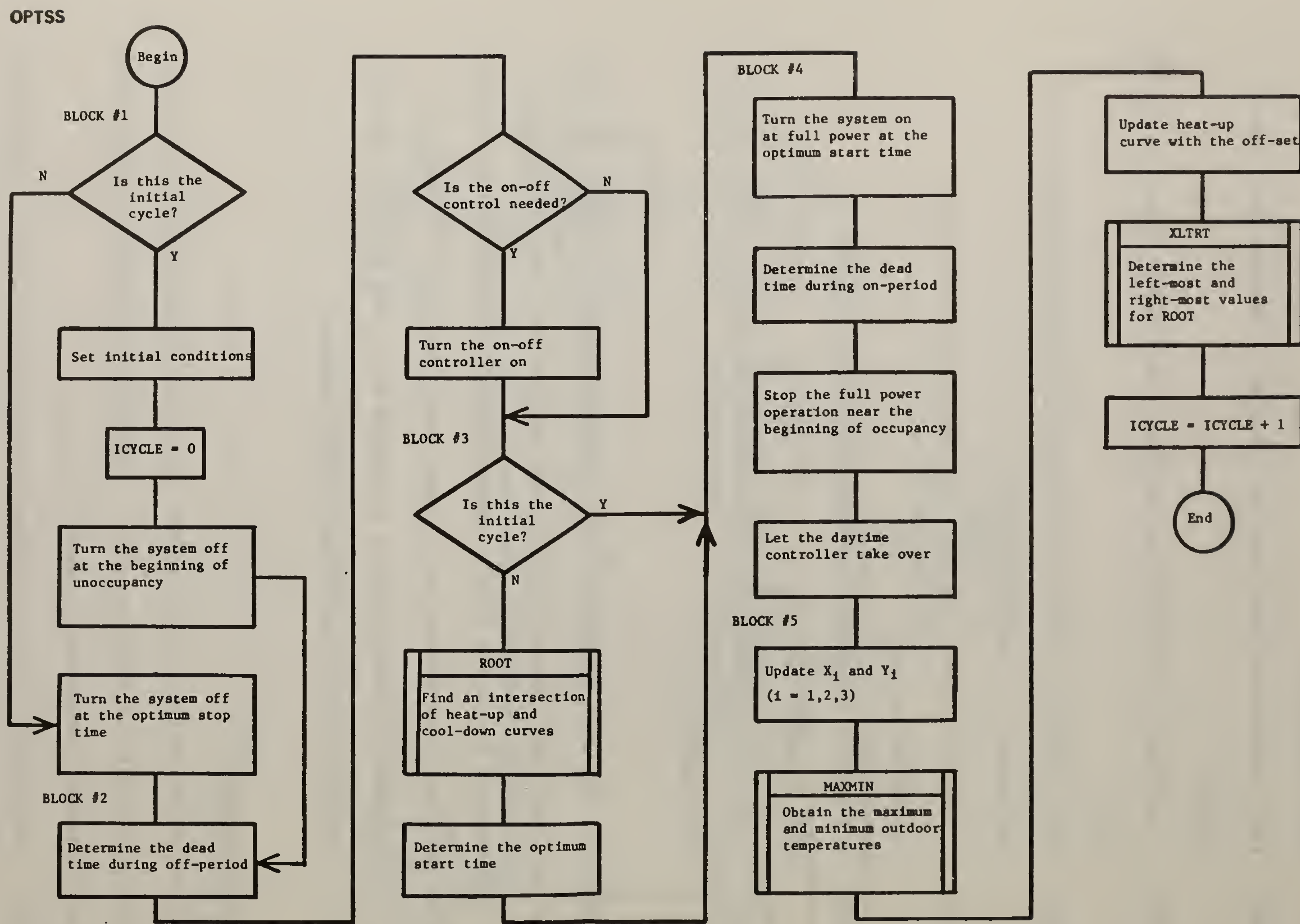

Figure 6. Flow chart of the main algorithm, OPTSS

Table 1. Cross reference table of notation

Notation in Programs	Descriptions	Notation in Flow Charts	Notation in the Text
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'	

Notation in Programs	Description	Notation in Flow Charts	Notation in the Text
HEAT	true if heating mode	HEAT	HEAT
	false if cooling mode		
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	IFLAG	
	1 if finding a root is not successful		
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	MAINTN	MAINTN
	false if the on-off control is not needed		

Table 1 (cont.)

Notation in Programs	Description	Notation in Flow Charts	Notation in the Text
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	PARTON	
	false if the system is off		
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.)

Notation in Programs	Description	Notation in Flow Charts	Notation in the Text
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.)

Notation in Programs	Descriptions	Notation in Flow Charts	Notation in the Text
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.

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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:

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

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 $x \to \infty$, and

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

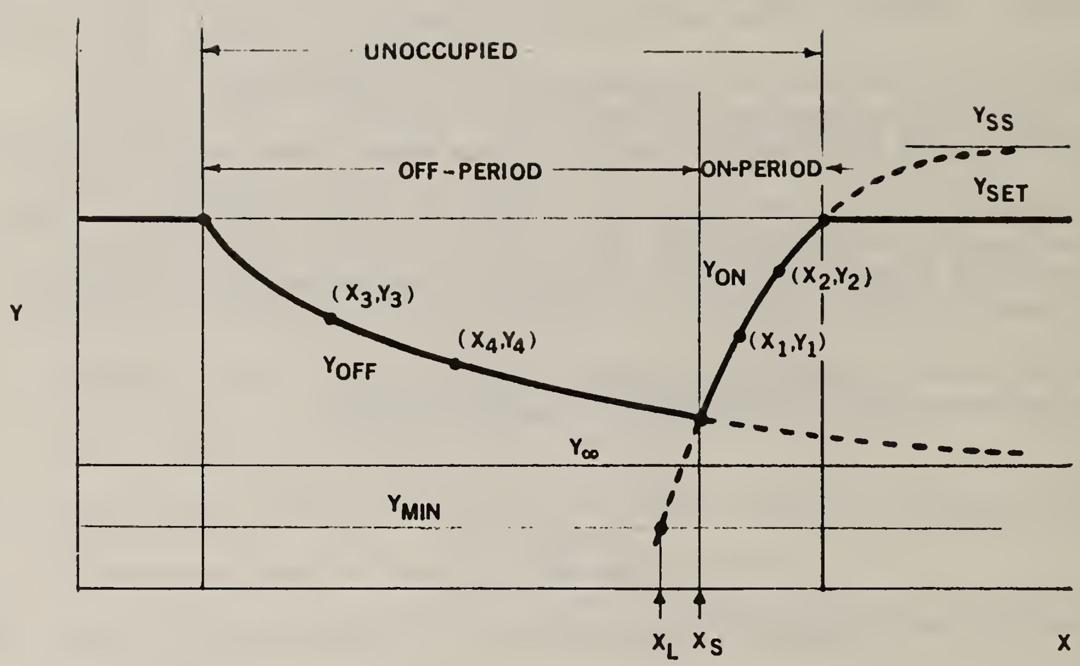

Figure A-1. Temperature history of a lightweight structure with immediate response of heating equipment

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

$$ON = \frac{x_2 - x_1}{\ell n\left(\frac{y_{SS} - y_1}{y_{SS} - y_2}\right)} \tag{2}$$

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:

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

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 $x \to \infty$, and

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

The off-period time constant is given by

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

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 asymtotic 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

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

where

x'_1 = the updated x_1, given by

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

and

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

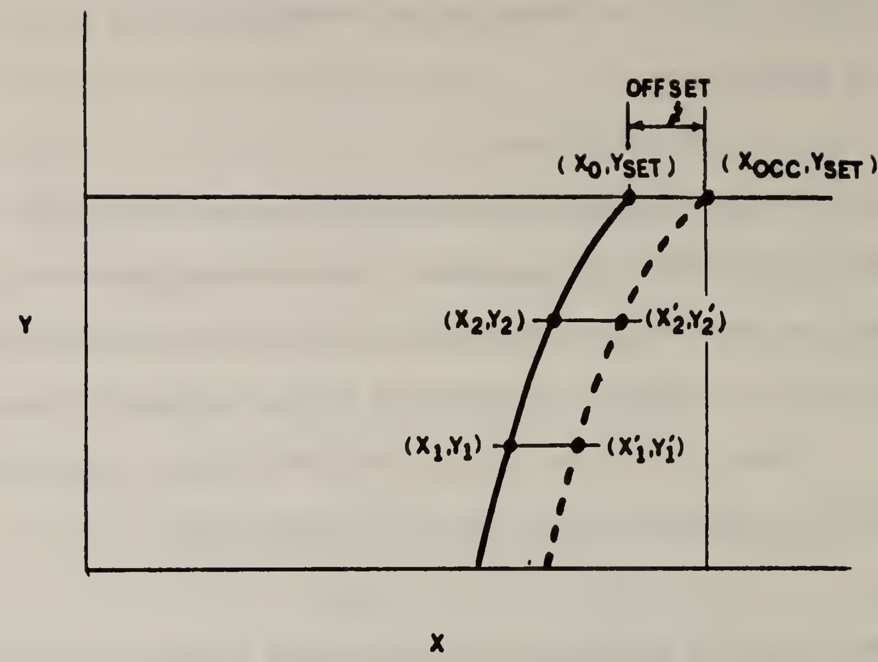

Figure A-2. The fitted curve (solid line) based on measurement and the updated curve (dotted line) during the on-period

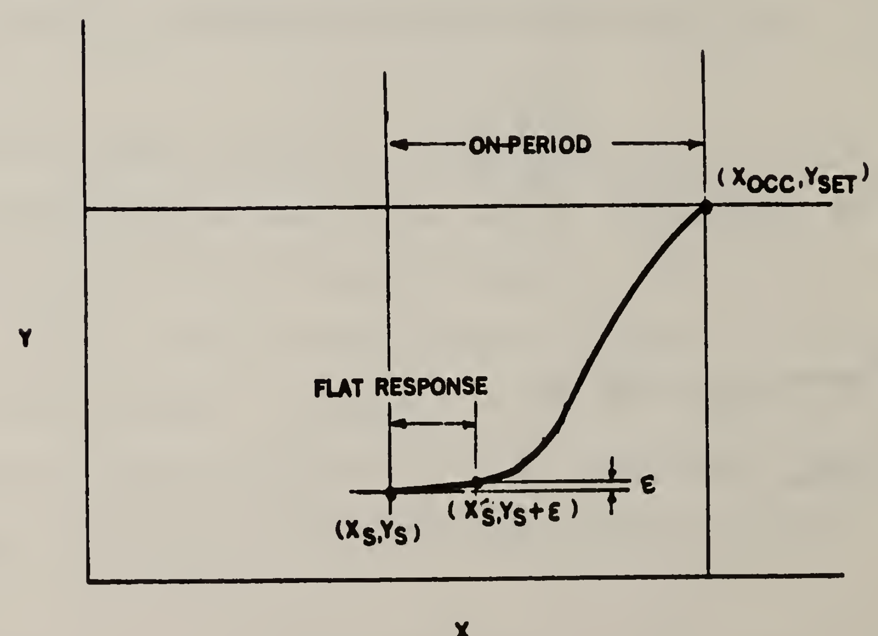

Figure A-3. The dead time during the on-period

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 $|y - y_S| < \varepsilon$, 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.

OPTSS

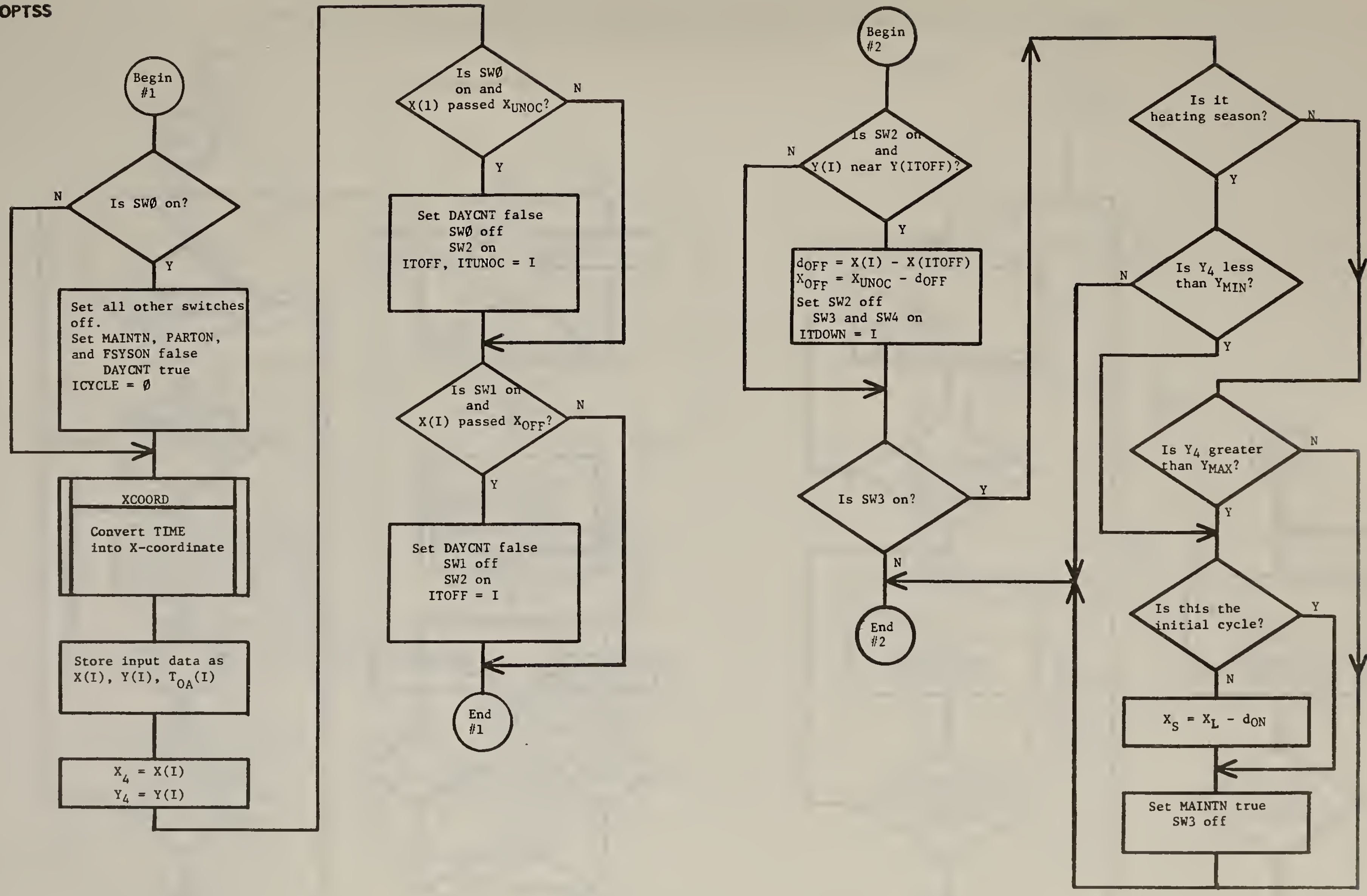

Figure B-1. Flow charts of the block 1 and 2 of the subroutine, OPTSS

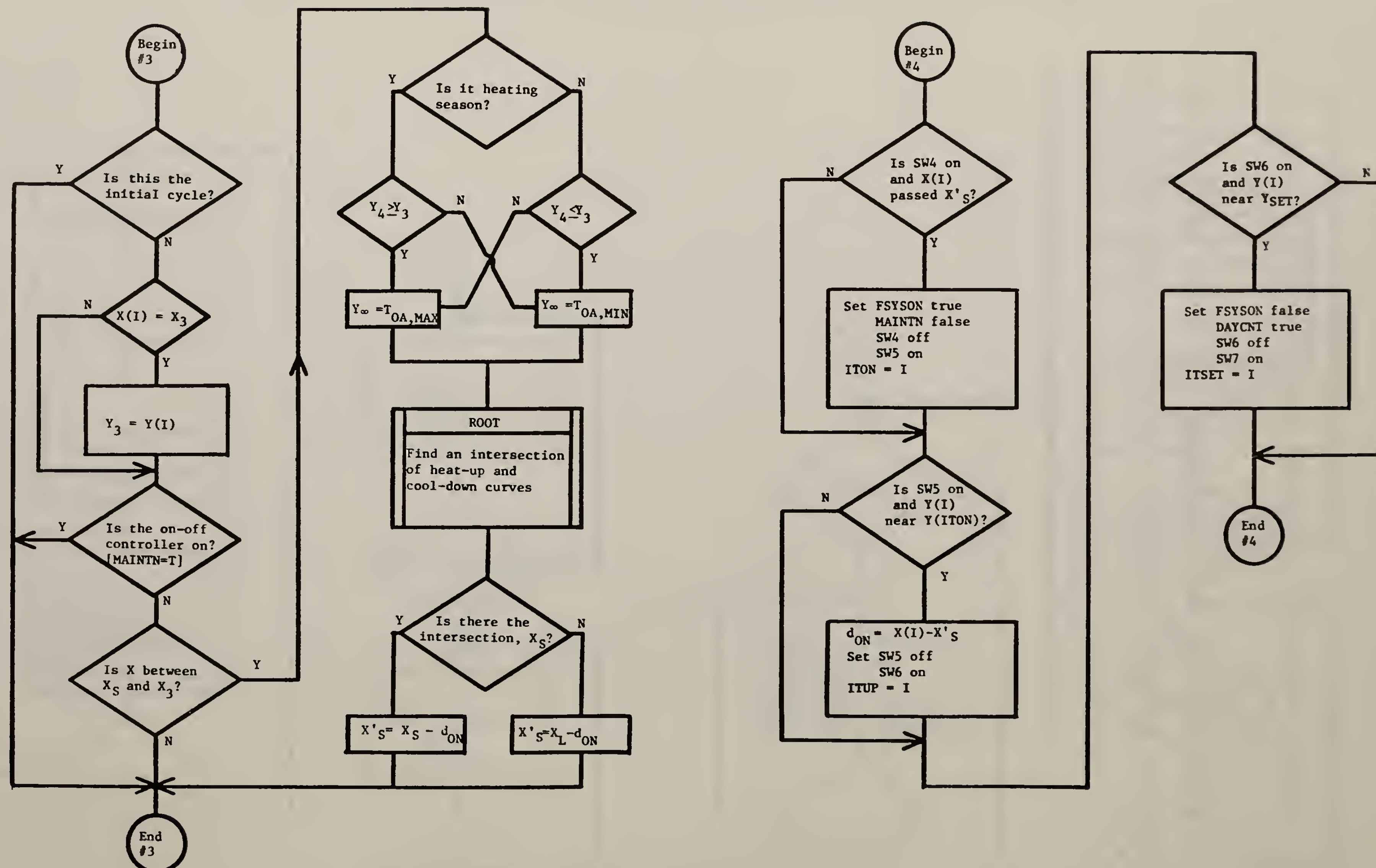

Figure B-2. Flow charts of the block 3 and 4 of the subroutine, OPTSS

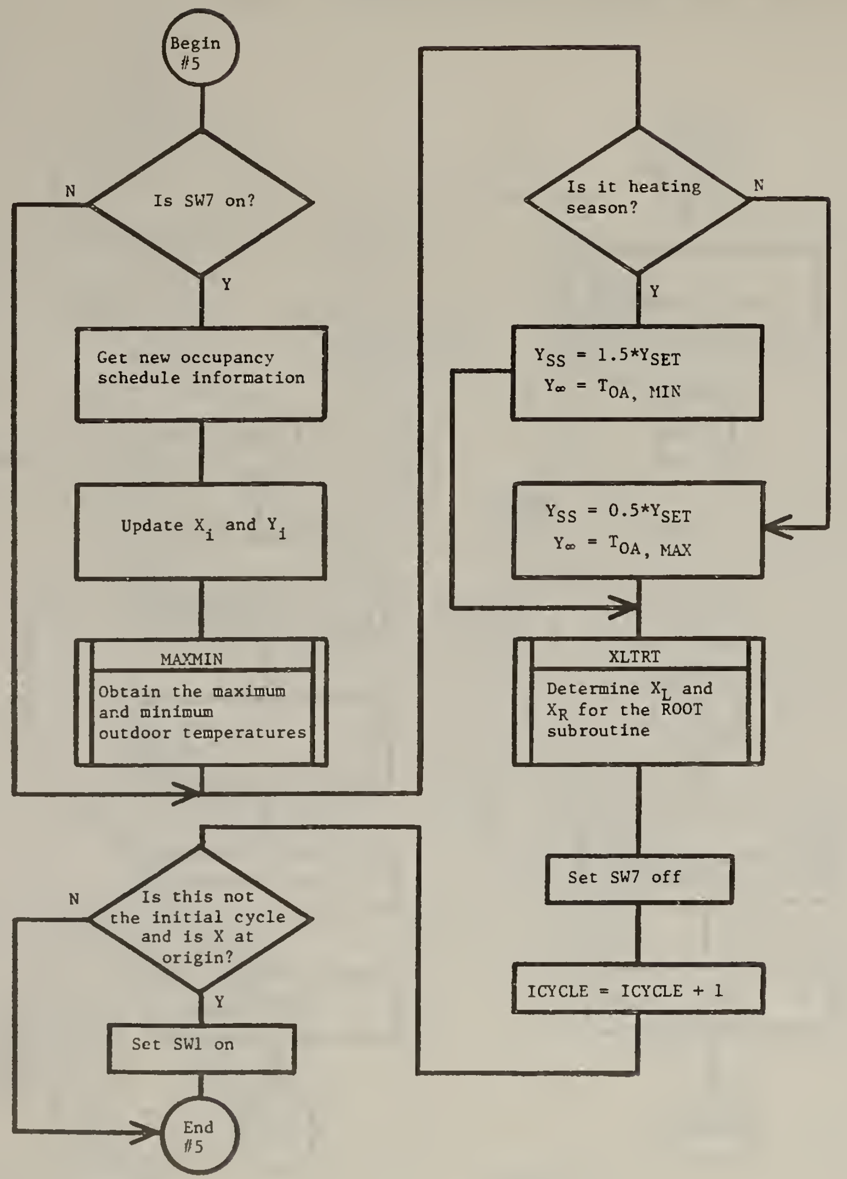

Figure B-3. Flow chart of the block 5 of the subroutine, OPTSS

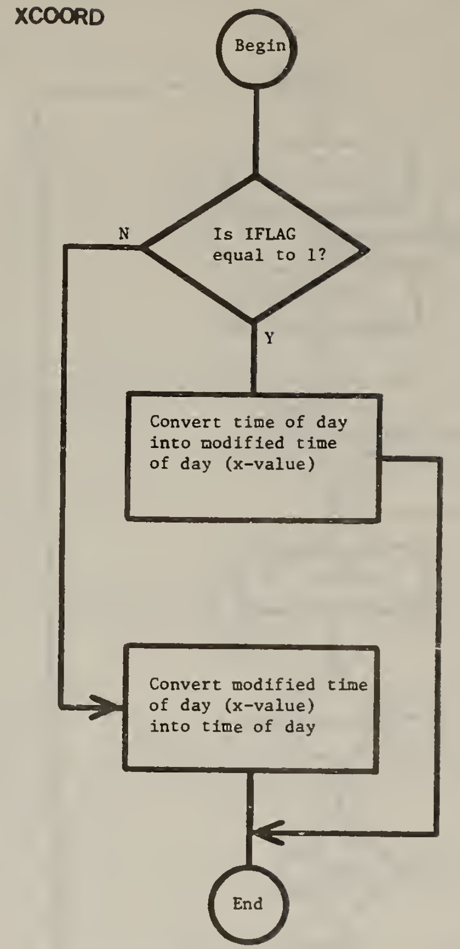

Figure B-4. Flow chart of the subroutine, XCOORD

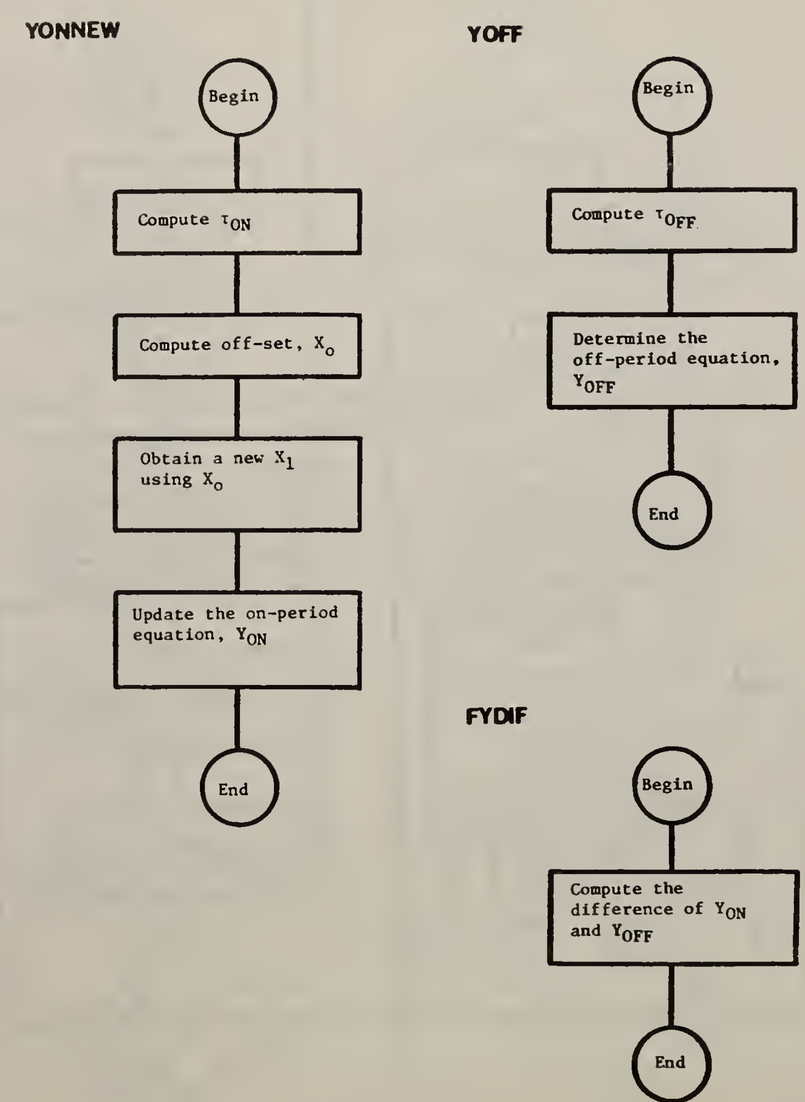

Figure B-5. Flow charts of the functions; YONNEW, YOFF, and FYDIF

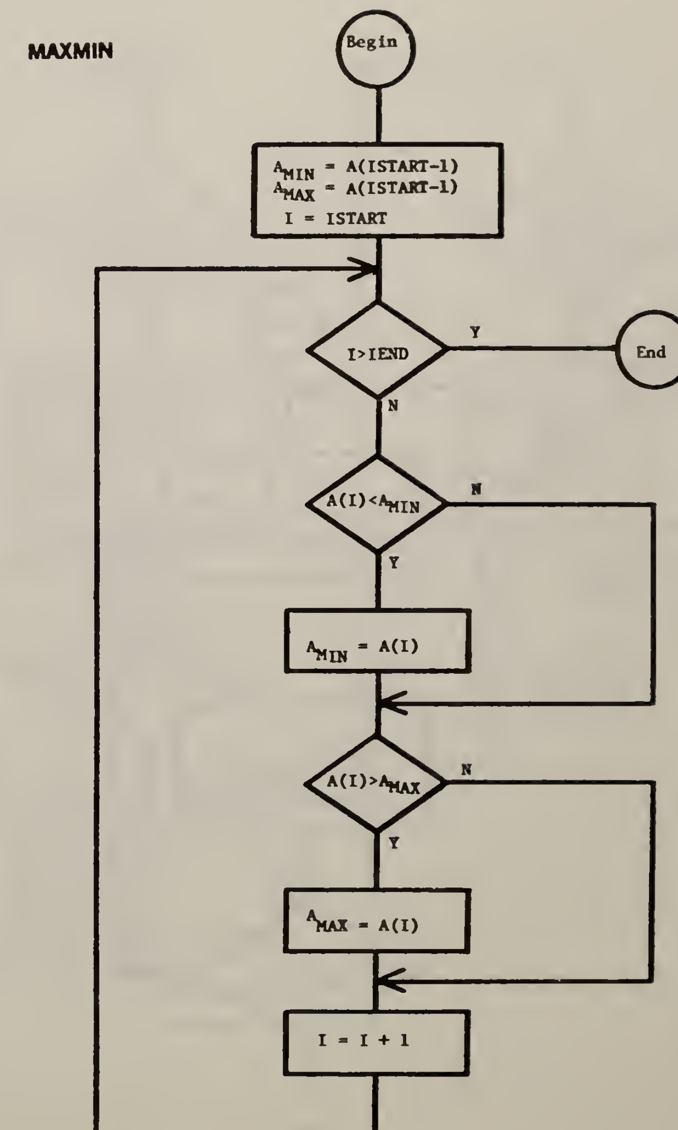

Figure B-6. Flow charts of the subroutine; MAXMIN

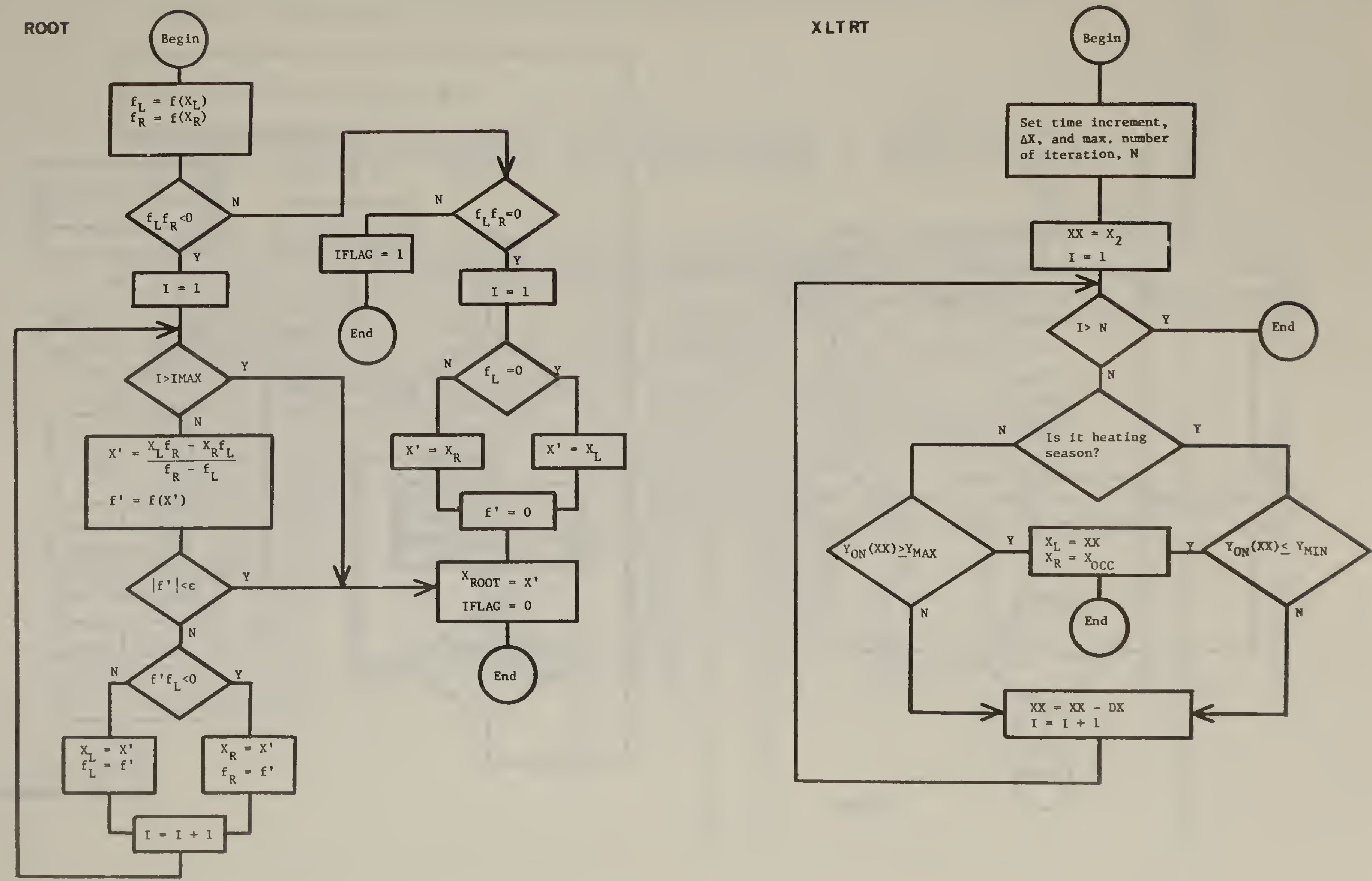

Figure B-7. Flow charts of the subroutines, ROOT and XLTRT

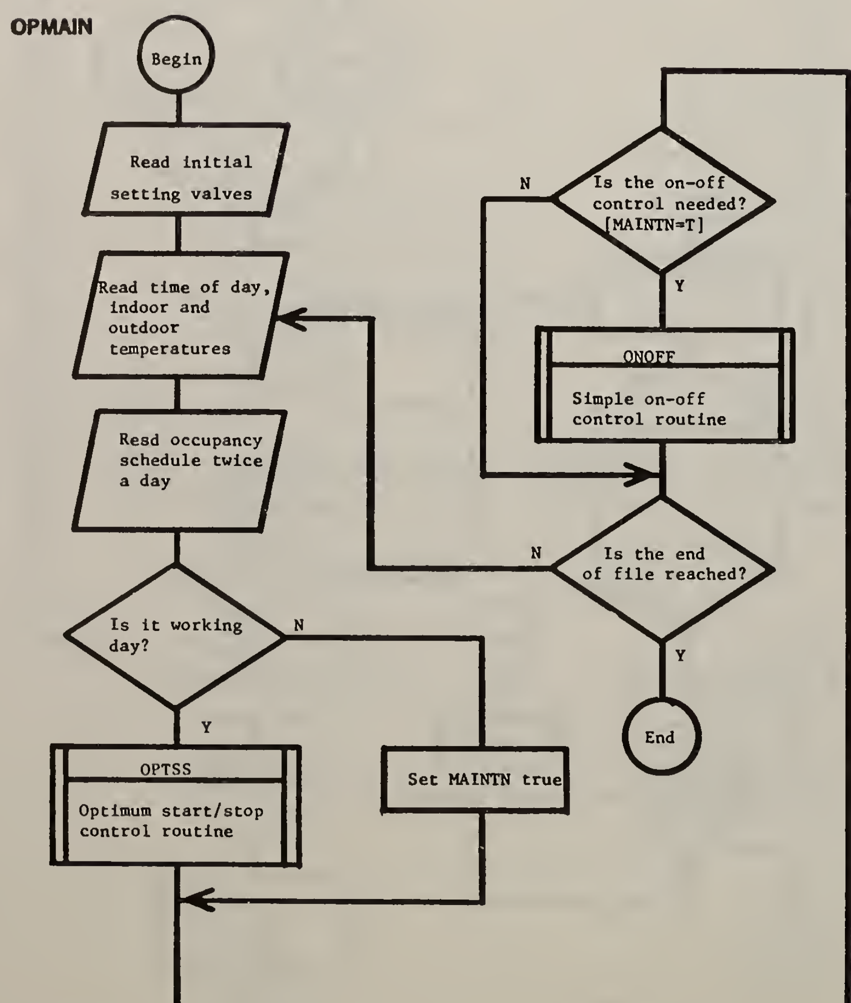

Figure B-8. Flow chart of the main program, OPMAIN

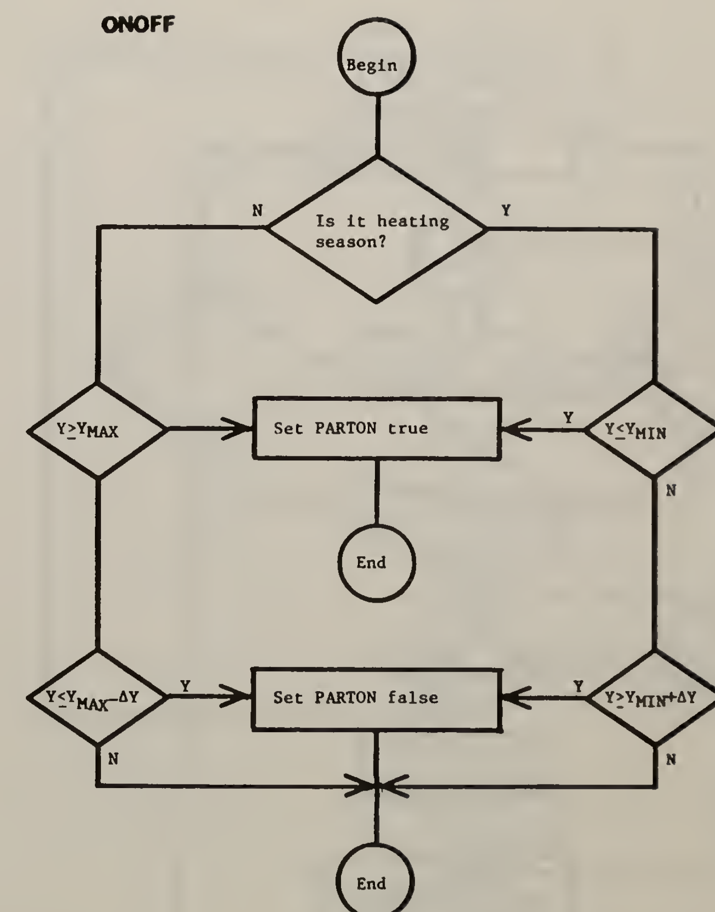

Figure B-9. Flow chart of the on-off subroutine, ONOFF

APPENDIX C. COMPUTER PROGRAM LISTING

```
Q$Q$Q$*OPT(1).OPTALL(0)
      C ************************************************************************
      C
      C    OPTSS : OPTIMUM START AND STOP CONTROL ALGORITHM
      C
      C    MAR. 3, 1983 C.P.
      C
      C ------------------------------------------------------------------------
      C
      C DAYCNT     TRUE IF THE DAYTIME CONTOLLER OPERATES
      C            FALSE IF THE DAYTIME CONTROLLER DOES NOT OPERATE
      C DELY       TEMPERATURE DIFFERENCE
      C EPS        POSITIVE SMALL NUMBER FOR ACCURACY USED IN ROOT
      C EPSOFF     POSITIVE SMALL NUMBER
      C EPSON      POSITIVE SMALL NUMBER
      C EPSSET     POSITIVE SMALL NUMBER
      C EPSX       TOLERANCE DETERMINED BY SAMPLING FREQUENCY
      C FSYSON     TRUE IF THE SYSTEM OPERATES AT FULL POWER
      C            FALSE IF THE SYSTEM IS OFF
      C HEAT       TRUE FOR HEATING MODE
      C            FALSE FOR COOLING MODE
      C ICYCLE     NUMBER OF  CYCLES (ONE CYLCE PER DAY)
      C ITDOWN     INDEX NUMBER WHERE TEMPERATURE DECAY BEGINS
      C ITIME      INDEX NUMBER OF MODIFIED TIME OF DAY
      C ITMAX      MAXIMUM NUMBER OF ITERATION TO OTAIN A ROOT USED IN ROOT
      C ITOFF      INDEX NUMBER WHERE X=XOFF
      C ITON       INDEX NUMBER WHERE X=XSTART
      C ITSET      INDEX NUMBER WHERE TEMPERATURE REACHES AT  THE SET POINT
      C ITUNOC     INDEX NUMBER WHERE X=XUNOC
      C ITUP       INDEX NUMBER WHERE TEMPERATURE RISE BEGINS
      C MAINTN     TRUE IF THE ON-OFF CONTROL IS NEEDED
      C            FALSE IF THE ON-OFF CONTROL IS NOT NEEDED
      C NMAX       TOTAL NUMBER OF SAMPLES A DAY
      C NPTHR      NUMBER OF SAMPLES IN ONE HOUR
      C PARTON     TRUE IF THE SYSTEM OPERATES WITH A PARTIAL CAPACITY
      C            FALSE IF THE SYSTEM IS OFF
      C SWI        EVENT CONTROL SWITCHES (I=0.....7)
      C TAUOFF     SYSTEM TIME CONSTANT DURING THE OFF-PERIOD
      C TAUON      SYSTEM TIME CONSTANT DURING THE ON-PERIOD
      C TBEGIN     ORIGIN OF X-COORDINATE (MILITARY TIME)
      C TDEDOF     DEAD TIME DURING THE OFF-PERIOD
      C TDEDON     DEAD TIME DURING THE ON-PERIOD
      C TEMP       INDOOR OR INTERIOR SURFACE TEMPERATURE
      C TIME       TIME OF DAY (MILITARY TIME)
      C TIMEX      MODIFIED TIME OF DAY IN SCALAR
      C TOA(*)     OUTDOOR TEMPERATURE
      C TOCC       BEGINNING TIME OF OCCUPANCY (MILITARY TIME)
      C TOFF       OPTIMUM STOP TIME (MILITARY TIME)
      C TOUT       DRY-BULB OUTDOOR TEMPERATURE
      C TSTART     OPTIMUM START TIME (MILITARY TIME)
      C TUNOC      BEGINNING TIME OF UNOCCUPANCY (MILITARY TIME)
      C X(I)       MODIFIED TIME OF DAY WITH ITS ORIGIN AT TBEGIN
      C XD         X-VALUE WHERE Y-VALUE IS EQUAL TO YSET
      C XDATA(*)   MODIFIED TIME OF DAY (X-VALUE)
      C XOCC       BEGINNING TIME OF OCCUPANCY IN X-COORDINATE
      C XOCC1      PAST VALUE OF XOCC
      C XOFF       OPTIMUM STOP TIME IN X-COORDINATE
      C XSTART     OPTIMUM START TIME IN X-COORDINATE
```

```
C  XUNOC       BEGINNING TIME OF UNOCCUPANCY IN X-COORDINATE
C  XUNOC1      PAST VALUE OF XOCC
C  Y(I)        TEMPERATURE
C  YDATA(*)    TEMPERATURE (Y-VALUE)
C  YINF        STEADY-STATE TEMPERATURE AS X GOES TO INFINITY DURING
C              THE OFF-PERIOD
C  YMAX        MAXIMUM TEMPERATURE
C  YMIN        MINIMUM TEMPERATURE
C  YSET        SET POINT TEMPERATURE (TARGET TEMPERATURE)
C  YSS         STEADY-STATE TEMPERATURE AS X GOES TO INFINITY DURING
C              THE ON-PERIOD
C
C ***********************************************************************
C
      SUBROUTINE OPTSS(TIME,TEMP,TOUT)
      LOGICAL SWO,SW1,SW2,SW3,SW4,SW5,SW6,SW7,HEAT,MAINTN,PARTON,
     & FSYSON,DAYCNT
      EXTERNAL FYDIF
      PARAMETER (NPTHR=4,NMAX=NPTHR*24)
      DIMENSION XDATA(0:NMAX),YDATA(0:NMAX),TOA(0:NMAX)
      COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
     &       /CNST/ TAUON,TAUOFF,YINF,YSS,XD
     &       /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
     &       /TSET/ TSTART,TOFF,TOCC,TUNOC,TBEGIN
      NAMELIST /RESULT/X,Y,XOFF,XSTART,TAUON,TAUOFF,TDEDON,TDEDOF,
     &    YSS,YINF,ICYCLE,ITIME,ITOFF,ITUNOC,ITDOWN,ITON,ITUP,ITSET,
     &    TBEGIN,TOFF,TUNOC,TSTART,TOCC
      DATA EPS,ITMAX/0.005,20/
      DATA SWO/.TRUE./,EPSOFF,EPSON,EPSSET/3*0.25/
C
C     INITIAL CONDITIONS
C
      EPSX=0.5/NPTHR
      IF(SWO) THEN
        ICYCLE=0
        SW1=.FALSE.
        SW2=.FALSE.
        SW3=.FALSE.
        SW4=.FALSE.
        SW5=.FALSE.
        SW6=.FALSE.
        SW7=.FALSE.
        MAINTN=.FALSE.
        PARTON=.FALSE.
        FSYSON=.FALSE.
        DAYCNT=.TRUE.
C
C     CHANGE TIME COORDINATES
C
        CALL XCOORD(XSTART,TSTART,TBEGIN,1)
        CALL XCOORD(XOCC,TOCC,TBEGIN,1)
        CALL XCOORD(XUNOC,TUNOC,TBEGIN,1)
      ENDIF
C
C     STORE INPUT DATA AS ARRAYS IN TERMS OF INDEX TIME
C
      CALL XCOORD(TIMEX,TIME,TBEGIN,1)
      ITIME=TIMEX*NPTHR
```

```
      TOA(ITIME)=TOUT
      XDATA(ITIME)=TIMEX
      YDATA(ITIME)=TEMP
      X(4)=XDATA(ITIME)
      Y(4)=YDATA(ITIME)
C
C     TURN OFF THE SYSTEM AT THE BEGINNING OF UNOCCUPANCY OF INITIAL
C     CYCLE
C
      IF(SWO.AND.ABS(XDATA(ITIME)-XUNOC).LT.EPSX) THEN
        DAYCNT=.FALSE.
        ITOFF=ITIME
        ITUNOC=ITIME
        SWO=.FALSE.
        SW2=.TRUE.
        PRINT 100
      ENDIF
C
C     TURN OFF THE SYSTEM AT THE BEGINNING OF UNOCCUPANCY AFTER INITIAL
C     CYCLE
C
      IF(SW1.AND.XDATA(ITIME).GE.XOFF) THEN
        DAYCNT=.FALSE.
        ITOFF=ITIME
        SW1=.FALSE.
        SW2=.TRUE.
        PRINT 200
      ENDIF
C
C     DETERMINE DEAD TIME DURING THE OFF-PERIOD
C
      IF(SW2.AND.ABS(YDATA(ITIME)-YDATA(ITOFF)).GE.EPSOFF) THEN
        TDEDOF=XDATA(ITIME)-XDATA(ITOFF)
        XOFF=XUNOC-TDEDOF
        ITDOWN=ITIME
        SW2=.FALSE.
        SW3=.TRUE.
        SW4=.TRUE.
        PRINT 300
      ENDIF
C
C     MAINTAIN MINIMUM LEVEL OF OPREATION
C
      IF(SW3) THEN
        IF((HEAT.AND.(Y(4).LE.YMIN)).OR.(.NOT.(HEAT).AND.
     &  Y(4).GT.YMAX)) THEN
          IF(ICYCLE.GE.1) XSTART=XLEFT-TDEDON
          MAINTN=.TRUE.
          SW3=.FALSE.
        PRINT 400
        ENDIF
      ENDIF
C
C     FIND THE INTERSECTION OF ON- AND OFF-TEMPERATURE CURVES
C
      IF(ICYCLE.GE.1) THEN
        IF(ABS(XDATA(ITIME)-X(3)).LT.EPSX) THEN
          Y(3)=YDATA(ITIME)
```

```
            ENDIF
C
            IF((.NOT.MAINTN).AND.(XDATA(ITIME).GT.X(3).AND.XDATA(ITIME)
     &       .LT.XSTART).AND.(ABS(Y(3)-Y(4)).GT.EPSSET)) THEN
C
              IF(HEAT) THEN
                IF(Y(4).GE.Y(3)) THEN
                  YINF=TOAMAX
                ELSE
                  YINF=TOAMIN
                ENDIF
              ELSE
                IF(Y(4).LE.Y(3)) THEN
                  YINF=TOAMIN
                ELSE
                  YINF=TOAMAX
                ENDIF
              ENDIF
C
              XL=XLEFT
              XR=XRIGHT
              CALL ROOT(XL,XR,EPS,ITMAX,FYDIF,XROOT,IFLAG)
              IF(IFLAG.EQ.0) THEN
                XSTART=XROOT-TDEDON
              ELSE
                XSTART=XLEFT-TDEDON
              ENDIF
            ENDIF
            CALL XCOORD(XSTART,TSTART,TBEGIN,2)
          ENDIF
C
C         TRUN ON THE SYSTEM AT OPTIMUM START TIME
C
          IF(SW4.AND.XDATA(ITIME).GE.XSTART) THEN
            FSYSON=.TRUE.
            ITON=ITIME
            MAINTN=.FALSE.
            SW4=.FALSE.
            SW5=.TRUE.
            PRINT 500
          ENDIF
C
C         DETERMINE DEAD TIME DURING THE ON-PERIOD
C
          IF(SW5.AND.ABS(YDATA(ITIME)-YDATA(ITON)).GE.EPSON) THEN
            TDEDON=XDATA(ITIME)-XSTART
            ITUP=ITIME
            SW5=.FALSE.
            SW6=.TRUE.
            PRINT 600
          ENDIF
C
C         TURN OFF THE SYSTEM NEAR THE BEGINNING OF OCCUPANCY AND CALL
C         THE DAYTIME CONTROLLER
C
          IF(SW6.AND.((ABS(YDATA(ITIME)-YSET).LE.EPSSET)
     &       .OR.(HEAT.AND.YDATA(ITIME).GE.YSET)
     &       .OR.(.NOT.HEAT.AND.YDATA(ITIME).LE.YSET))) THEN
```

```
            FSYSON=.FALSE.
            DAYCNT=.TRUE.
            ITSET=ITIME
            SW6=.FALSE.
            SW7=.TRUE.
            PRINT 700
          ENDIF
C
C         COMPUTE X- AND Y-VALUES BASED ON PREVIOUS OBSERVATION
C          AND UPDATE THEM USING NEW TOCC AND TUNOC
C
          IF(SW7) THEN
            CALL XCOORD(XOFF,TOFF,TBEGIN,2)
            PRINT 900
            PRINT RESULT
            PRINT 900
            XOCC1=XOCC
            XUNOC1=XUNOC
            IF(TUNOC.GT.TOCC) THEN
              TBEGIN=0.5*(TUNOC+TOCC)
            ELSE
              TBEGIN=0.5*(TUNOC+24.+TOCC)
              IF(TBEGIN.GE.24.) TBEGIN=TBEGIN-24.
            ENDIF
            CALL XCOORD(XOCC,TOCC,TBEGIN,1)
            CALL XCOORD(XUNOC,TUNOC,TBEGIN,1)
            K1=(ITSET-ITUP)/3+ITUP
            K2=(ITSET-ITUP)*2/3+ITUP
            IF(ICYCLE.EQ.0) THEN
              K3=(ITON-ITUNOC)/4+ITUNOC
            ELSE
              K3=(ITON-ITDOWN)/4+ITDOWN
            ENDIF
            X(1)=XDATA(K1)+XOCC-XOCC1
            X(2)=XDATA(K2)+XOCC-XOCC1
            X(3)=XDATA(K3)+XUNOC-XUNOC1
            Y(1)=YDATA(K1)
            Y(2)=YDATA(K2)
            Y(3)=YDATA(K3)
            XSTART=XSTART+XOCC-XOCC1
            XOFF=XOFF+XUNOC-XUNOC1
            CALL XCOORD(XSTART,TSTART,TBEGIN,2)
            CALL XCOORD(XOFF,TOFF,TBEGIN,2)
C
C         DETERMINE MAXIMUM AND MINIMUM OUTDOOR TEMPERATURES
C
            CALL MAXMIN(TOA,TOAMIN,TOAMAX,NMAX)
C
C         COMPUTE CONSTANTS FOR ON- AND OFF-PERIOD TEMPERATURE EQUATIONS
C
            IF(HEAT) THEN
              YSS=1.5*YSET
              YINF=TOAMIN
            ELSE
              YSS=0.5*YSET
              YINF=TOAMAX
            ENDIF
C
```

```
C      DETERMINE XLEFT AND XRIGHT
C
         CALL XLTRT(XLEFT,XRIGHT)
         ICYCLE=ICYCLE+1
         SW7=.FALSE.
         PRINT 800
         PRINT 900
         PRINT RESULT
         PRINT 900
       ENDIF
C
C        RESET SWITCH SW1 AT THE BEGINNING OF NEXT CYCLE
C
       IF(ICYCLE.GE.1.AND.ABS(TIME-TBEGIN).LT.EPSX) SW1=.TRUE.
C
C       FORMAT STATEMENTS
C
100    FORMAT(5X,'---SW0---SYSTEM OFF AT THE FIRST CYCLE')
200    FORMAT(5X,'---SW1---SYSTEM OFF')
300    FORMAT(5X,'---SW2---DECAY/RISE RESPONSE OCCURS')
400    FORMAT(5X,'---SW3---ON-OFF CONTROLLER TAKES OVER')
500    FORMAT(5X,'---SW4---SYSTEM ON AT FULL POWER')
600    FORMAT(5X,'---SW5---UPRISE/DECAY RESPONSE OCCURS')
700    FORMAT(5X,'---SW6---DAYTIME CONTROLLER TAKES OVER')
800    FORMAT(5X,'---SW7---CALCULATIONS FOR NEXT CYCLE ARE DONE')
900    FORMAT(80('*')/)
C
C
       RETURN
       END
C ***********************************************************************
C
C        FYDIF : TEMPERATURE DIFFERENCE
C
C -----------------------------------------------------------------
C
C      YONNEW  UPDATED TEMPERATURE  DURING THE HEAT-UP PERIOD
C      YOFF    TEMPERATURE  DURING THE COOL-DOWN PERIOD
C
C ***********************************************************************
C
       FUNCTION FYDIF(XX)
C
C        TEMPERATURE DIFFERENCE BETWEEN YONNEW AND YOFF
C        TO BE USED IN DETERMINATION OF INTERSECTION, XROOT
C
       FYDIF=YONNEW(XX)-YOFF(XX)
       RETURN
       END
C ***********************************************************************
C
C      YONNEW, YOFF : THE ON- AND OFF-PERIOD TEMPERATURES
C
C ***********************************************************************
C
       FUNCTION YONNEW(XX)
       COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
     &        /CNST/ TAUON,TAUOFF,YINF,YSS,XD
```

```
C
C     THE ON-PERIOD TEMPERATURE WITH ADJUSTMENT
C
      TAUON=(X(2)-X(1))/ALOG((YSS-Y(1))/(YSS-Y(2)))
      XD=X(1)-TAUON*ALOG((YSS-YSET)/(YSS-Y(1)))
      X1P=X(1)+XOCC-XD
      YONNEW=YSS-(YSS-Y(1))*EXP((X1P-XX)/TAUON)
      RETURN
C
      ENTRY YOFF(XX)
C
C     THE OFF-PERIOD TEMPERATURE
C
      TAUOFF=(X(4)-X(3))/ALOG((Y(3)-YINF)/(Y(4)-YINF))
      YOFF=(Y(3)-YINF)*EXP((X(3)-XX)/TAUOFF)+YINF
      RETURN
      END
C ***********************************************************************
C
C       ROOT : FIND A ROOT OF A FUNCTION F(X)=0 IN A GIVEN INTERVAL
C              BY THE REGULA-FALSI METHOD
C
C     REFERENCE :
C          CARNAHAN, LUTHER, AND WILKES
C          " APPLIED NUMERICAL METHODS ", JOHN WILEY, 1969, P.193
C
C     THE ORIGINAL PROGRAM WAS MODIFIDED IN FORTRAN77.
C
C -----------------------------------------------------------------
C
C     EPS     A POSITIVE SMALL NUMBER FOR ACCURACY
C     FX      SCALAR FUNCTION VALUE
C     IFLAG   0 IF FINDING A ROOT IS SUCCESSFUL
C             1 IF FINDING A ROOT IS NOT SUCCESSFUL
C     ITMAX   MAXIMUM NUMBER OF ITERATIONS
C     XL      LEFT-MOST X-VALUE
C     XR      RIGHT-MOST X-VALUE
C     XROOT   A REAL ROOT
C
C ***********************************************************************
C
      SUBROUTINE ROOT(XL,XR,EPS,ITMAX,FX,XROOT,IFLAG)
C
C*      PRINT 100,XL,XR,EPS,ITMAX
100   FORMAT(3F10.5,I5)
C
C     SET LEFTMOST AND RIGHTMOST FUNCTION VALUES
C
      FXL=FX(XL)
      FXR=FX(XR)
C
C     CHECK FOR PRESENCE OF A ROOT
C
      IF(FXL*FXR.LT.0.) THEN
C
C       BEGIN REGULA FALSI ITERATION
C
        DO 10 ITER=1,ITMAX
```

```
          X2=(XL*FXR-XR*FXL)/(FXR-FXL)
          FX2=FX(X2)
C
C         CHECK FOR CONVERGENCE
C
          IF(ABS(FX2).LE.EPS) GOTO 20
C
C         KEEP RIGHT OR LEFT SUBINTERVAL
C
          IF(FX2*FXL.LT.O.) THEN
            XR=X2
            FXR=FX2
          ELSE
            XL=X2
            FXL=FX2
          ENDIF
10        CONTINUE
          PRINT 200,ITMAX
200       FORMAT(5X,'NO CONVERGENCE AFTER' ,I5,2X,'ITERATIONS')
        ELSEIF (FXL*FXR.EQ.O.) THEN
          ITER=1
          IF(FXL.EQ.O.) THEN
            X2=XL
            FX2=O.
          ELSE
            X2=XR
            FX2=O.
          ENDIF
        ELSE
          IFLAG=1
          PRINT 300
300       FORMAT(5X,'POSSIBLY NO ROOT ')
          RETURN
        ENDIF
20      XROOT=X2
        IFLAG=O
C*        PRINT 400,ITER,XROOT,FX2
400     FORMAT(5X,'ITER = ',I5/5X,'XROOT =',F10.6/5X,'FX2 =',F10.6/)
C
        RETURN
        END
C ********************************************************************
C
C       XLTRT :  LEFTMOST AND RIGHTMOST X-VALUES FOR THE SUBROUTINE, ROOT
C
C -----------------------------------------------------------------
C
C       DX      TIME INCREMENT
C       N       NUMBER OF INTERVALS
C       XL      LEFT-MOST VALUE OF X
C       XR      RIGHT-MOST VALUE OF X
C
C ********************************************************************
C
        SUBROUTINE XLTRT(XL,XR)
        LOGICAL HEAT
        COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
     &        /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
```

```
C
C     TIME BASIS  IS HOUR, AND TIME INCREMENT IS 5 MIN.
C
      DX=5./60.
      N=(XOCC-XUNOC)/DX
      XX=X(2)
      DO 10 I=1,N
      IF(HEAT) THEN
         IF(YONNEW(XX).LE.YMIN) GOTO 20
      ELSEIF(YONNEW(XX).GE.YMAX) THEN
         GOTO 20
      ENDIF
      XX=XX-DX
10    CONTINUE
20    XL=XX
      XR=XOCC
      PRINT 100,XL,XR
100   FORMAT(5X,'XLEFT=',F10.4,5X,'XRIGHT=',F10.4/)
C
      RETURN
      END
C *********************************************************************
C
C       MAXMIN : EVALUATION OF MAXIMUM AND MINIMUM VALUES
C
C ---------------------------------------------------------------------
C
C     A        ARRAY VALUES
C     AMAX     MAXIMUM VALUE OF ARRAY VALUES
C     AMIN     MIMINUM VALUE OF ARRAY VALUES
C     IEND     INDEX NUMBER OF ENDING OF SEARCH
C     ISTART   INDEX NUMBER OF START OF SEARCH
C     NMAX     NUMBER OF SAMPLES A DAY
C     NPTHR    SAMPLEING FREQUENCY ( SAMPLES PER HOUR )
C
C *********************************************************************
C
       SUBROUTINE MAXMIN(A,AMIN,AMAX,NMAX)
       DIMENSION A(0:NMAX)
       COMMON /XY/X(4),Y(4),XOCC,XUNOC,YSET
       NPTHR=NMAX/24
       ISTART=XUNOC*NPTHR
       IEND=XOCC*NPTHR
       AMIN=A(ISTART-1)
       AMAX=A(ISTART-1)
       DO 10 I=ISTART,IEND
       IF(A(I).LT.AMIN) AMIN=A(I)
       IF(A(I).GT.AMAX) AMAX=A(I)
10     CONTINUE
C
       RETURN
       END
C ***********************************************************************
C
C     XCOORD : X-COORDINATE TRANSFORM
C
C     IFLAG   =1 FOR TRANSFORM OF TIME OF DAY INTO X-VALUE
C             =2 FOR TRANSFORM OF X-VALUE INTO TIME OF DAY
```

```
C
C ***********************************************************************
C
      SUBROUTINE XCOORD(X,TIME,TBEGIN,IFLAG)
      IF(IFLAG.EQ.1) THEN
        IF(TIME.GE.TBEGIN.AND.TIME.LE.24.)   THEN
          X=TIME-TBEGIN
        ELSE
          X=TIME+(24.-TBEGIN)
        ENDIF
      ELSE
        TIME=X+TBEGIN
        IF(TIME.GE.24.0) TIME=TIME-24.0
      ENDIF
C
      RETURN
      END
C ************************************************************************
C
C     ONOFF : THE ON-OFF CONTROL ALGORITHM
C
C ************************************************************************
C
      SUBROUTINE ONOFF(TEMP)
      LOGICAL HEAT,MAINTN,FSYSON,DAYCNT,PARTON
      COMMON /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
     &       /ONOFFC/ PARTON,DELY
C
      IF(HEAT) THEN
        IF(TEMP.LE.YMIN) PARTON=.TRUE.
        IF(TEMP.GE.YMIN+DELY) PARTON=.FALSE.
      ELSEIF(TEMP.GE.YMAX) THEN
        PARTON=.TRUE.
      ELSEIF(TEMP.LE.YMAX-DELY) THEN
        PARTON=.FALSE.
      ENDIF
C
      RETURN
      END
C ************************************************************************
C
C     OPMAIN : MAIN PROGRAM OF OPTIMUM START/STOP CONTROL
C            FOR BOTH HEATING AND COOLING SEASONS
C
C ---------------------------------------------------------------
C
C  DATE        DATE OF YEAR
C  DAY         =0 FOR NON-WORKING DAY
C              =1 FOR WORKING DAY
C  NSKIP       NUMBER OF RECORDS TO BE SKIPPED IN PRINTING OUT
C  RSCHDL      TIMES  WHEN THE SCHEDULE FILE IS READ (MILITARY TIME)
C  TITLE       TITLE OF INPUT DATA SET IN TWO ROWS
C
C ************************************************************************
C
      PROGRAM OPMAIN
      LOGICAL HEAT,MAINTN,FSYSON,DAYCNT,PARTON
      INTEGER DATE,DAY
```

```
      CHARACTER TITLE(2)*80
      PARAMETER (NPTHR=4)
      DIMENSION RSCHDL(2)
      COMMON /XY/ X(4),Y(4),XOCC,XUNOC,YSET
     &       /CNST/ TAUON,TAUOFF,YINF,YSS,XD
     &       /LIMIT/ YMIN,YMAX,HEAT,MAINTN,FSYSON,DAYCNT,XSTART
     &       /ONOFFC/ PARTON,DELY
     &       /TSET/ TSTART,TOFF,TOCC,TUNOC,TBEGIN
      NAMELIST /INIT/ DATE,DAY,TOCC,TUNOC,TSTART,
     &                YSET,YMIN,YMAX,DELY,HEAT,NSKIP
     &         /DAYOCC/ DATE,DAY,TOCC,TUNOC
     &         /OUTPUT/ TIME,MAINTN,PARTON,FSYSON,DAYCNT,
     &                  TSTART,TOFF,TOCC,TUNOC,TBEGIN
      DATA RSCHDL/6.0,18.0/
C
C     OPEN FILE 7 FOR INITIAL AND SCHEDULE INFORMATION
C     OPEN FILE 8 FOR SIMULATED DATA OF MEASURED VALUES
C
      OPEN (7,FILE='OPTIN')
      OPEN (8,FILE='OPTDATA')
      REWIND 7
      REWIND 8
C
C     READ INITIAL INPUT DATA
C
      READ(7,1000) TITLE
      READ(7,INIT)
      PRINT 1000, TITLE
      PRINT INIT
      IW=0
      I=0
C
C     READ SIMULATED MEASURED DATA AND SCHEDULE INFORMATION
C
10    READ(8,*,END=999) TIME,TEMP,TOUT
      IF(I.EQ.0) TBEGIN=TIME
      IF((ABS(TIME-RSCHDL(1)).LT.0.5/NPTHR).OR.
     & (ABS(TIME-RSCHDL(2)).LT.0.5/NPTHR)) THEN
        READ(7,DAYOCC)
        PRINT DAYOCC
      ENDIF
C
C     MAINTAIN  MINIMUM REQUIREMENT DURING NOT-WORKING DAYS
C
      IF(DAY.EQ.0) THEN
        MAINTN=.TRUE.
      ELSE
        CALL OPTSS(TIME,TEMP,TOUT)
      ENDIF
C
      IF(MAINTN) CALL ONOFF(TEMP)
      IF(IW.EQ.NSKIP+1) THEN
        PRINT *,TIME,TEMP,TOUT
        PRINT OUTPUT
        IW=0
      ENDIF
      IW=IW+1
      I=1
```

```
      GOTO 10
C
C     FORMAT STATEMENTS
C
1000  FORMAT(A80/A80)
C
999   STOP
      END
```

APPENDIX D. SAMPLE INPUT AND OUTPUT OF THE PROGRAM

INPUT DATA

OPTDATA

	TIME	TEMP	TOUT
1	12.0000	18.3000	3.5000
2	12.2500	18.3000	3.7500
3	12.5000	18.3000	4.0000
4	12.7500	18.3000	4.2500
5	13.0000	18.3000	4.5000
6	13.2500	18.3000	4.6250
7	13.5000	18.3000	4.7500
8	13.7500	18.3000	4.8750
9	14.0000	18.3000	5.0000
10	14.2500	18.3000	4.9250
11	14.5000	18.3000	4.8500
12	14.7500	18.3000	4.7750
13	15.0000	18.3000	4.7000
14	15.2500	18.3000	4.5250
15	15.5000	18.3000	4.3500
16	15.7500	18.3000	4.1750
17	16.0000	18.3000	4.0000
18	16.2500	18.3000	3.8000
19	16.5000	18.3000	3.6000
20	16.7500	18.3000	3.4000
21	17.0000	18.3000	3.2000
22	17.2500	18.3000	2.9750
23	17.5000	18.3000	2.7500
24	17.7500	18.3000	2.5250
25	18.0000	18.3000	2.3000
26	18.2500	18.1000	2.0250
27	18.5000	17.9000	1.7500
28	18.7500	17.7000	1.4750
29	19.0000	17.5000	1.2000
30	19.2500	17.1000	1.0000
31	19.5000	16.7000	.8000
32	19.7500	16.3000	.6000
33	20.0000	15.9000	.4000
34	20.2500	15.5000	.2250
35	20.5000	15.1000	.0500
36	20.7500	14.7000	-.1250
37	21.0000	14.3000	-.3000
38	21.2500	13.9500	-.4750
39	21.5000	13.6000	-.6500
40	21.7500	13.2500	-.8250
41	22.0000	12.9000	-1.0000
42	22.2500	12.6000	-1.1500
43	22.5000	12.3000	-1.3000
44	22.7500	12.0000	-1.4500
45	23.0000	11.7000	-1.6000
46	23.2500	11.4000	-1.7250
47	23.5000	11.1000	-1.8500
48	23.7500	10.8000	-1.9750
49	0.0000	10.5000	-2.1000
50	.2500	10.3000	-2.2500
51	.5000	10.1000	-2.4000
52	.7500	9.9000	-2.5500
53	1.0000	9.7000	-2.7000
54	1.2500	9.5750	-2.8250
55	1.5000	9.4500	-2.9500
56	1.7500	9.3250	-3.0750
57	2.0000	9.2000	-3.2000

	TIME	TEMP	TOUT
58	2.2500	9.1000	-3.3000
59	2.5000	9.0000	-3.4000
60	2.7500	8.9000	-3.5000
61	3.0000	8.8000	-3.6000
62	3.2500	8.7500	-3.6750
63	3.5000	8.7000	-3.7500
64	3.7500	8.6500	-3.8250
65	4.0000	8.6000	-3.9000
66	4.2500	8.7000	-3.9250
67	4.5000	8.8000	-3.9500
68	4.7500	8.9000	-3.9750
69	5.0000	9.0000	-4.0000
70	5.2500	9.3750	-3.9750
71	5.5000	9.7500	-3.9500
72	5.7500	10.1250	-3.9250
73	6.0000	10.5000	-3.9000
74	6.2500	11.2500	-3.7750
75	6.5000	12.0000	-3.6500
76	6.7500	12.7500	-3.5250
77	7.0000	13.5000	-3.4000
78	7.2500	14.3000	-3.2000
79	7.5000	15.1000	-3.0000
80	7.7500	15.9000	-2.8000
81	8.0000	16.7000	-2.6000
82	8.2500	17.1000	-2.3750
83	8.5000	17.5000	-2.1500
84	8.7500	17.9000	-1.9250
85	9.0000	18.3000	-1.7000
86	9.2500	18.3000	-1.2250
87	9.5000	18.3000	-.7500
88	9.7500	18.3000	-.2750
89	10.0000	18.3000	.2000
90	10.2500	18.3000	.6000
91	10.5000	18.3000	1.0000
92	10.7500	18.3000	1.4000
93	11.0000	18.3000	1.8000
94	11.2500	18.3000	2.2250
95	11.5000	18.3000	2.6500
96	11.7500	18.3000	3.0750
97	12.0000	18.3000	3.5000
98	12.2500	18.3000	3.7500
99	12.5000	18.3000	4.0000
100	12.7500	18.3000	4.2500
101	13.0000	18.3000	4.5000
102	13.2500	18.3000	4.6250
103	13.5000	18.3000	4.7500
104	13.7500	18.3000	4.8750
105	14.0000	18.3000	5.0000
106	14.2500	18.3000	4.9250
107	14.5000	18.3000	4.8500
108	14.7500	18.3000	4.7750
109	15.0000	18.3000	4.7000
110	15.2500	18.3000	4.5250
111	15.5000	18.3000	4.3500
112	15.7500	18.3000	4.1750
113	16.0000	18.3000	4.0000
114	16.2500	18.3000	3.8000
115	16.5000	18.3000	3.6000

	TIME	TEMP	TOUT
116	16.7500	18.3000	3.4000
117	17.0000	18.3000	3.2000
118	17.2500	18.3000	2.9750
119	17.5000	18.3000	2.7500
120	17.7500	18.3000	2.5250
121	18.0000	18.3000	2.3000
122	18.2500	18.1000	2.0250
123	18.5000	17.9000	1.7500
124	18.7500	17.7000	1.4750
125	19.0000	17.5000	1.2000
126	19.2500	17.1000	1.0000
127	19.5000	16.7000	.8000
128	19.7500	16.3000	.6000
129	20.0000	15.9000	.4000
130	20.2500	15.5000	.2250
131	20.5000	15.1000	.0500
132	20.7500	14.7000	-.1250
133	21.0000	14.3000	-.3000
134	21.2500	13.9500	-.4750
135	21.5000	13.6000	-.6500
136	21.7500	13.2500	-.8250
137	22.0000	12.9000	-1.0000
138	22.2500	12.6000	-1.1500
139	22.5000	12.3000	-1.3000
140	22.7500	12.0000	-1.4500
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

	TIME	TEMP	TOUT
174	7.2500	14.3000	-3.2000
175	7.5000	15.1000	-3.0000
176	7.7500	15.9000	-2.8000
177	8.0000	16.7000	-2.6000
178	8.2500	17.1000	-2.3750
179	8.5000	17.5000	-2.1500
180	8.7500	17.9000	-1.9250
181	9.0000	18.3000	-1.7000
182	9.2500	18.3000	-1.2250
183	9.5000	18.3000	-.7500
184	9.7500	18.3000	-.2750
185	10.0000	18.3000	.2000
186	10.2500	18.3000	.6000
187	10.5000	18.3000	1.0000
188	10.7500	18.3000	1.4000
189	11.0000	18.3000	1.8000
190	11.2500	18.3000	2.2250
191	11.5000	18.3000	2.6500
192	11.7500	18.3000	3.0750
193	12.0000	18.3000	3.5000
194	12.2500	18.3000	3.7500
195	12.5000	18.3000	4.0000
196	12.7500	18.3000	4.2500
197	13.0000	18.3000	4.5000
198	13.2500	18.3000	4.6250

INPUT DATA

OPTIN

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

OUTPUT

```
@XQT 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
$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
    ---SW0---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      .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
$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     -1.3000000
 $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
```

```
 .00000000       10.500000      -2.1000000
 $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
 1.5000000       9.4500000      -2.9500000
 $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
 3.0000000       8.8000000      -3.6000000
 $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
 4.5000000       8.8000000      -3.9500000
 $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
DATE =          62.DAY =           1.TOCC = .90000000+001.TUNOC = .17000000+002
$END
 6.0000000       10.500000      -3.9000000
 $OUTPUT
TIME = .60000000+001.MAINTN = F.PARTON = F.FSYSON = T.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000     .TOCC = .90000000+001.
TUNOC = .17000000+002.TBEGIN = .12000000+002
$END
 7.5000000       15.100000      -3.0000000
 $OUTPUT
TIME = .75000000+001.MAINTN = F.PARTON = F.FSYSON = T.DAYCNT = F.TSTART = .40000000+001.TOFF = .00000000     .TOCC = .90000000+001.
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.TAUON = .00000000     .
TAUOFF = .00000000     .TDEDON = .75000000+000.TDEDOF = .15000000+001.YSS = .00000000     .YINF = .00000000     .ICYCLE =          0.
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.TAUON = .47376636+001.
TAUOFF = .00000000     .TDEDON = .75000000+000.TDEDOF = .15000000+001.YSS = .27450000+002.YINF =-.40000000+001.ICYCLE =          1.
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
```

```
$END
**************************************************************************************
 9.0000000       18.300000     -1.7000000
 $OUTPUT
TIME = .90000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .9000000
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 10.500000       18.300000      1.0000000
 $OUTPUT
TIME = .10500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .9000000
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 12.000000       18.300000      3.5000000
 $OUTPUT
TIME = .12000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .40000000+001,TOFF = .15500000+002,TOCC = .9000000
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 13.500000       18.300000      4.7500000
 $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      4.7000000
 $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      3.6000000
 $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      2.3000000
 $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     -1.3000000
 $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 = .41742094+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 1.5000000       9.4500000      -2.9500000
 $OUTPUT
TIME = .15000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .43090498+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 3.0000000       8.8000000      -3.6000000
 $OUTPUT
TIME = .30000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .44677372+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 4.5000000       8.8000000      -3.9500000
 $OUTPUT
TIME = .45000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .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
 $DAYOCC
DATE =          63,DAY =           1,TOCC = .90000000+001,TUNOC = .17000000+002
$END
 6.0000000       10.500000      -3.9000000
 $OUTPUT
TIME = .60000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = .47176206+001,TOFF = .15500000+002,TOCC = .90000000+001,
TUNOC = .17000000+002,TBEGIN = .13000000+002
$END
 7.5000000       15.100000      -3.0000000
 $OUTPUT
TIME = .75000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = .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 =          1.
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 =          2.
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
```

```
$END
**************************************************************************************
 9.0000000       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
$END
 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
$END
 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
$END

@OFFSEND,S
```

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

@XQT 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
$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
    ---SW0---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      .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
$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      -1.3000000
 $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
```

```
 .00000000       10.500000     -2.1000000
 $OUTPUT
TIME = .00000000     ,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .00000000     ,TOCC = .90000000+00
TUNOC = .17000000+002,TBEGIN = .12000000+002
$END
 1.5000000       9.4500000     -2.9500000
 $OUTPUT
TIME = .15000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .00000000     ,TOCC = .9000000
TUNOC = .17000000+002,TBEGIN = .12000000+002
$END
 3.0000000       8.8000000     -3.6000000
 $OUTPUT
TIME = .30000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .40000000+001,TOFF = .00000000     ,TOCC = .900000
TUNOC = .17000000+002,TBEGIN = .12000000+002
$END
    ---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 = .40000000+001,TOFF = .00000000     ,TOCC = .90000000+001.
TUNOC = .17000000+002,TBEGIN = .12000000+002
$ENO
    ---SW5---UPRISE/DECAY RESPONSE OCCURS
 $DAYOCC
OATE =          62,DAY =          1,TOCC = .80000000+001,TUNOC = .16000000+002
$END
 6.0000000       10.500000     -3.9000000
 $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
 7.5000000       15.100000     -3.0000000
 $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 =          0.
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 = .47376630+001,
TAUOFF = .00000000    ,TDEDON = .75000000+000.TDEDOF = .15000000+001,YSS = .27450000+002.YINF =-.40000000+001,ICYCLE =          1.
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
*****************************************************************************************

 9.0000000       18.300000      -1.7000000
 $OUTPUT
TIME = .90000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 10.500000       18.300000       1.0000000
 $OUTPUT
TIME = .10500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 12.000000       18.300000       3.5000000
 $OUTPUT
TIME = .12000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 13.500000       18.300000       4.7500000
 $OUTPUT
TIME = .13500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = T,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
    ---SW1---SYSTEM OFF
 15.000000       18.300000       4.7000000
 $OUTPUT
TIME = .15000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 16.500000       18.300000       3.6000000
 $OUTPUT
TIME = .16500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 $DAYOCC
DATE =          62,DAY =           1,TOCC = .80000000+001,TUNOC = .16000000+002
$END
 18.000000       18.300000       2.3000000
 $OUTPUT
TIME = .18000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .30000000+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+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 = .36375446+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 21.000000       14.300000      -.30000000
 $OUTPUT
TIME = .21000000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .33659873+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 22.500000       12.300000      -1.3000000
 $OUTPUT
TIME = .22500000+002,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .33550849+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
```

```
 .00000000      10.500000     -2.1000000
 $OUTPUT
TIME = .00000000     ,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .33457973+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 1.5000000      9.4500000     -2.9500000
 $OUTPUT
TIME = .15000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .34633873+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 3.0000000      8.8000000     -3.6000000
 $OUTPUT
TIME = .30000000+001,MAINTN = F,PARTON = F,FSYSON = F,DAYCNT = F,TSTART = .36125493+001,TOFF = .14500000+002,TOCC = .80000000+001
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
    ---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 = .36773434+001,TOFF = .14500000+002,TOCC = .80000000+001.
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
    ---SW5---UPRISE/DECAY RESPONSE OCCURS
 $DAYOCC
DATE =          63,DAY =          1,TOCC = .70000000+001,TUNOC = .16000000+002
$END
 6.0000000      10.500000     -3.9000000
 $OUTPUT
TIME = .60000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = .36773434+001,TOFF = .14500000+002,TOCC = .70000000+001,
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
 7.5000000      15.100000     -3.0000000
 $OUTPUT
TIME = .75000000+001,MAINTN = F,PARTON = F,FSYSON = T,DAYCNT = F,TSTART = .36773434+001,TOFF = .14500000+002,TOCC = .70000000+001,
TUNOC = .16000000+002,TBEGIN = .12000000+002
$END
    ---SW6---DAYTIME CONTROLLER TAKES OVER
*****************************************************************************

 $RESULT
X = .17000000+002, .18500000+002, .67500000+001, .21000000+002,
Y = .10500000+002, .15100000+002, .17700000+002, .18300000+002,XOFF = .00000000     ,XSTART = .15677343+002,TAUON = .47376636+001,
TAUOFF = .16333456+002,TDEDON = .10726566+001,TDEDOF = .40000000+001,YSS = .27450000+002,YINF =-.40000000+001,ICYCLE =          1,
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
$END
*****************************************************************************

    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, .18300000+002,XOFF = .50000000+000,XSTART = .15177343+002,TAUON = .47376636+001,
TAUOFF = .16333456+002,TDEDON = .10726566+001,TDEDOF = .40000000+001,YSS = .27450000+002,YINF =-.40000000+001,ICYCLE =          2,
ITIME =          84,ITOFF =          10,ITUNOC =          20,ITDOWN =          26,ITON =          63,ITUP =          67,
ITSET =          84,TBEGIN = .11500000+002,TOFF = .12000000+002,TUNOC = .16000000+002,TSTART = .26773434+001,TOCC = .70000000+001
```

```
$END
*****************************************************************************

 9.0000000      18.300000     -1.7000000
 $OUTPUT
TIME = .90000000+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
$END

@OFFSEND.S
```

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BIBLIOGRAPHIC DATA SHEET *(See instructions)*

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Cheol Park

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8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Office of Buildings and Community Systems
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

U.S. Navy Civil Engineering Laboratory
U.S. Department of Defense
Washington, DC 20310

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

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.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

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

13. AVAILABILITY

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