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...est Method and Calculation Procedure for Determining Annual Efficiency for Vented Household Heaters and Furnaces Equipped With Modulating-Type Controls

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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A TEST METHOD AND CALCULATION PROCEDURE FOR DETERMINING ANNUAL EFFICIENCY FOR VENTED HOUSEHOLD HEATERS AND FURNACES EQUIPPED WITH MODULATING-TYPE CONTROLS

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ABSTRACT

As annual operating efficiency of vented heating equipment is affected by burner fuel and combustion air modulation, it is important to differentiate between the various types of controls in determining annual energy requirements. Test procedures for evaluating annual efficiency have already been developed and implemented by the Department of Energy (DoE) for furnaces with single-stage thermostat control. A modified test procedure is necessary to account for operation with fuel modulation. A revised procedure which accommodates two types of fuel modulating controls has recently been developed. Tests are conducted at reduced and maximum firing rates, and along with typical derived values, from a bin analysis of weather data, the fraction of the total hours for each operating mode is obtained to calculate a weighted annual efficiency. These test methods and calculation procedures are based on and are an extension to the current DoE test procedures for the single-stage type of thermostat control of central warm air furnaces.

By using the procedures developed in the report, the energy savings impact of fuel modulating controls when combined with the use of modulated combustion air is evaluated. Energy savings from 6 percent to 20 percent were determined from the increase in efficiency with both fuel and combustion air modulation. Improved efficiency was dependent on the type of thermostat control and the minimum-to-maximum fueled input; i.e., turndown ratio.

Key Words: annual efficiency; household heaters and furnace test procedures; hydraulic thermostat control; modulating control gas-fueled; two-stage thermostat.

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NOMENCLATURE

EFFYA	Annual Fuel Utilization Efficiency, in %
$L_{I,OFF}$	Off-cycle infiltration loss, in % of the fuel input rate
$L_{I,ON}$	On-cycle infiltration loss, in % of the fuel input rate
$L_{I,ON,min}$	On-cycle infiltration loss, in % of the fuel input rate at minimum input rate
$L_{I,ON,max}$	On-cycle infiltration loss, in % of the fuel input rate at maximum input rate
L_L	Latent heat loss, in % of the fuel input rate
$L_{S,OFF}$	Off-cycle sensible heat loss, in % of the fuel input rate
$L_{S,ON}$	On-cycle sensible heat loss, in % of the fuel input rate
$L_{S,SS,A}$	Sensible heat loss at steady-state operation, in % of the fuel input rate
PF	Ratio of $Q_P \div Q_{in}$ = pilot fraction
Q_{in}	Fuel energy input rate at steady-state operation (including any pilot light input), in Btu/h, $Q_{in,min}$ at minimum input, $Q_{in,max}$ at maximum input rate.
Q_{out}	Fuel energy output rate - $Q_{out,min}$ at minimum input rate, $Q_{out,max}$ at maximum input rate.
Q_P	Fuel energy input rate to pilot light in Btu/h
t_{OFF}	Off-time per cycle, in minutes
t_{ON}	On-time per cycle, in minutes
T_C	Balance point outdoor air temperature
T_{oa}	Average outdoor air temperature applicable to heater operation at minimum firing rate
$T_{oa'}$	Average outdoor air temperature applicable to heater operation between minimum and maximum rate
T_{RA}	Laboratory room temperature, in °F
η_{ss}	Steady-state efficiency, in % of fuel input rate

η_u	Part-load fuel utilization efficiency, in %
α	Oversizing factor
$\eta_{ss,min}$	Steady-state efficiency at minimum input rate
$\eta_{ss,max}$	Steady-state efficiency at maximum input rate
$\eta_{ss,hi}$	Average steady-state efficiency between minimum and maximum input rates
$\eta_{ss,wt}$	Weighted average steady-state efficiency
$\eta_{\mu,\ell o}$	Part load efficiency at the minimum input rate
$\eta_{\mu,hi}$	Part load efficiency at the maximum input rate for two-stage thermostats or for the non-cycling mode for step-modulating thermostats
$\eta_{\mu,WT}$	Weighted part-load efficiency
R_{lo}	Percentage of operating time at the low input firing rate
R_{hi}	Percentage of operating time in the non-cycling mode

1. INTRODUCTION

As annual operating efficiency of vented heating equipment is affected by burner operating modes, it is important to differentiate between the various types of controls in determining annual energy requirements. Test procedures for evaluating annual efficiency have already been developed and implemented by the Department of Energy (DoE) for heaters with single-stage control [3]*. For two-stage and step-modulating units, however, a modified test procedure is necessary to account for operation at multiple firing rates. A revised procedure which accommodates modulating-type units has recently been developed and recommended to DoE [1, 2]. A detailed review of the background for the recommendations of tests for modulating heaters in that procedure is the subject of this report.

Modulating controls investigated in this study are generally used with vented household heaters other than furnaces. However, the methods of test and the bin analysis procedures developed in this report for vented heaters are also applicable to central heating systems using the types of modulating controls described here. The only adjustment that would be needed to these procedures would be to use bin data based on the population of central furnaces in order to arrive at a national average annual efficiency specific to furnaces.

Three types of thermostatic controls are commonly used on automatically-controlled heating equipment. These are:

a. single-stage control, which cycles the heater between full input (100 percent of rating) and off;

b. two-stage control, which operates in an on-off cycling mode at either maximum input or at some reduced input which can be as low as 20 percent of maximum; and

c. step-modulating control, which steps on to a low input and then either cycles off and on at the low input if the heating load is light, or gradually increases the heat input to meet any higher heating load that cannot be met with the low firing rate.

Figure 1 illustrates the burner heat output rate and burner on periods (shaded) area) in response to increasing heating loads for each of these three types of controls.

The assumptions made in previous work [4] and as depicted by figure 1 that outdoor temperatures below 65°F would be directly proportional to heating load is valid only in a broad statistical sense. It should be understood that procedures developed here for calculating annual efficiency as well as current DoE test procedures for determining annual efficiency of the conventional type on-off thermostatically controlled heaters is intended for comparison purposes

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* Numbers in brackets indicate references in section 6.

between equipment tested only under laboratory test conditions. A comprehensive treatment to include internal heat gains, solar radiation, wind, etc., would be needed in order to be valid for small time thermostatic cycling of the installed heating system. These procedures should not be considered as being predictive of the installed annual energy use. It should be understood that a comprehensive treatment of the building and furnace interaction to predict operating costs after installation is beyond the scope of this work.

2. STEP-MODULATING CONTROLS

2.1 MODE OF OPERATION

One representation of the operating mode for the step-modulating type control is its response to room temperature (see figure 2 where room temperature and outlet gas pressure supplied to the burner from the thermostat control are shown).

Under normal operating conditions, as the ambient air temperature surrounding the liquid-filled thermostat sensing bulb drops to point A on figure 2, the control opens to allow minimum fuel flow (point B). When room air temperature rises to point C, the valve closes (point D). Operations on the ABCD rectangle is termed the "cycling" mode.

If more severe weather is encountered while the valve is open to minimum flow (point B), room temperature may continue to drop until point E is reached, at which time any further drop in room temperature would result in an increasing fuel flow. If the heating demand continues to increase with subsequent lower room temperature, fuel flow would gradually increase to maximum flow (from E to G). In another situation, if the heating demand should just equal heater output for a prolonged time, the manifold could remain partially open (point F or any other point between low fire and high fire) until the heating demand changes. Operation at the various firing rates from point B to G is termed the "noncycling" mode or modulating mode.

2.2 ENERGY CONSIDERATIONS

In developing test procedures for modulating type heaters, operation in both the cycling and non-cycling modes must be addressed. The importance of addressing both modes separately is apparent when one considers the difference in efficiency between the two modes as illustrated in figure 3. The part-load efficiency curve of figure 3 was plotted using data obtained with a room heater having a maximum rated input of 35,000 Btu/h and minimum adjusted input of 21,000 Btu/h and with a balance point temperature (T_c) of 36°F. (See section 2.2.1 for discussion of T_c.)

Annual efficiency for step-modulating units depends upon several factors including:

- percentage of the heating season operating time in each of the two modes,
- average outdoor temperature for each mode,
- average steady-state efficiency over the various firing rates in the non-cycling mode,
- infiltration loss in the non-cycling mode, and
- part-load efficiency in the cycling mode.

The first two factors can be developed by considering heater sizing and through analysis of representative weather data. The remaining factors are determined via additional test measurements and calculations. Each of the factors is described in detail in the sections that follow.

2.2.1 Percent of Operating Time in Each Mode

Two assumptions provide a basis for defining the percent of operating time spent in each of the two modes: (1) at an outdoor temperature of 65°F, heating requirements no longer exist, and (2) at the outdoor design temperature for vented room heaters of 15°F (see appendix A for development of this value) the heater output rate needed to meet the heating requirement is equal to the maximum heater output rate divided by $(1+\alpha)$ where α is the heater oversize fraction. Here output rate is defined as the product of input rate and steady-state efficiency. A relationship between heater output and outdoor temperature can then be expressed:

$$\frac{Q_{out,max}/(1+\alpha)}{Q_{out,min}} = \frac{65-15}{65-T_c} \tag{1}$$

where

$Q_{out,max}$ is rated maximum output rate,
$Q_{out,min}$ is rated minimum output rate.

T_c is the outdoor temperature where the modulating mode begins (see figure 4). This implies that heating load is a linear function of outdoor temperature. In these test procedures α is assigned a value of zero. Under this assignment, at outdoor design temperature of 15°F the heater operates at maximum firing rate.

A plot of T_c versus the ratio of minimum to maximum output is shown in figure 5 for fixed values of α. The cycling mode (as shown in figure 4) is between outdoor temperature T_c and 65°F. The modulating mode is between T_c and the minimum outdoor temperature, which for household heaters is typically 15°F. Through analysis of typical weather data, the time in each mode can then be defined as a fraction of total heating season degree hours. The analysis involves a bin method calculation of hours in various temperature ranges. The steps in the calculation are presented in the column headings of table 1. See column (14) and columns (1) through (5) of table 1. A graphical example is also shown in figure 6.

2.2.2 Average Outdoor Temperature in Each Mode

The average outdoor temperature in the cycling and non-cycling modes T_{oa} and T_{oa}', respectively (as shown in figures 7 and 8) are developed from representative national average weather data. Tabulated data and temperature calculations for one city having a 4200 degree day heating season are shown in table 1. The average of calculated values for eight cities and the basis for figures 7 and 8 are presented in table two. The eight cities are listed in appendix, table A2. These eight cities all fall within a range of ±5 percent of the national average (heater population weighted) of 4400 degree days.

Referring to table 1, calculation of T_{oa} and T_{oa}' is as follows: for each temperature range, the mean temperature (col. 2) and number of hours spent in the range (col. 3) are determined from a compilation of historial weather data [5]. From this the number of degree hours in each range (col. 5) is obtained. T_{oa} represents the average outdoor temperature between 65°F and T_c. To obtain T_{oa}, col. 5 and col. 3 are therefore summed cumulatively (upward in table 1) from 62°F to T_c yielding col. 6 and col. 7, respectively. For each T_c given in col. 2, col. 6 divided by col. 7 represents the corresponding number of degrees below 65°F. This number is given in col. 8. T_{oa} (col. 9) is 65°F minus col. 8. The same approach is taken in calculating T_{oa}' except that the cumulative summation is from 15°F to T_c rather than from 65°F to T_c. The result of these calculations is a value of T_{oa} and T_{oa}' for each T_c. A plot of these parameters for the values in table 2 is shown in figure 7. For any given heater, equation (1) can be used to determine T_c, for which values of T_{oa} and T_{oa}' can be obtained from figure 7. Alternatively, equation (1) and the results of the previous temperature calculations can be combined to eliminate the intermediate calculations of T_c. T_{oa} and T_{oa}' can be obtained from figure 8 where percent of time in cycling modes, T_{oa} and T_{oa}' (columns 5, 6a, and 6b of table 2, respectively) are plotted vs the min/max heater output ratio (col. 7 of table 2).

2.2.3 Average Steady-State Efficiency

Due to an increase in excess air at below maximum firing rates, there is usually a drop in steady-state efficiency in the non-cycling mode as fuel input rate is reduced. An average steady-state efficiency is, therefore, needed to represent operation in this mode. The average steady-state efficiency is calculated by linear interpolation between the steady-state efficiency at the minimum rated input, which corresponds to temperature, T_c, and the steady-state efficiency at the maximum rated input for the heater, which corresponds to a temperature of 15°F. These efficiencies are determined in accordance with the DoE test procedure using α=0.* The average efficiency (η_{ss}) will correspond to the efficiency when firing at temperture T_{oa}' and is given by

$$\eta_{ss} = \left[\eta_{ss,max} - \eta_{ss,min}\right] \frac{T_c - T_{oa}'}{T_c - 15} + \eta_{ss,min} \qquad (2)$$

In general, the arithmetic mean of the steady-state efficiencies may be used in place of equation (2) with a resulting error of about one percentage point.

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* The DoE test procedure [3] lists a value of α=0.7 which was applicable to central furnaces, and was originally adopted for use with vented heaters. Since the typical oversize factor is unknown for vented heaters the use of α=0.7 would be arbitrary. In order to reduce the complexity of the calculation procedures for modulating type heaters, a value of α=o is applied for all calculated efficiencies reported here.

2.2.4 Infiltration Loss in the Modulating Mode

On-period infiltration loss ($L_{I,ON}$) is an energy efficiency debit for heaters using indoor air for combustion and draft hood dilution. The loss of efficiency due to infiltration of outdoor air at T_{oa}' (which is subsequently heated to an indoor temperature of typically 70°F) is subtracted from the weighted average steady-state efficiency calculated by the above procedure. Average on-period infiltration loss is calculated in the same manner as steady-state efficiency. On-period infiltration losses are obtained via the current DoE test procedure [3] and the average infiltration is taken to be the arithmetic mean of the values determined at the maximum and minimum input rates.

3. TEST PROCEDURE AND CALCULATION

3.1 CURRENT TEST PROCEDURE

The current test procedure for determining the annual efficiency of vented heaters [3] applies only to units equipped with single-stage controls. While not directly applicable to modulating-type units, only minor modifications to the procedure are necessary to accommodate these types of controls. A cursory review of the procedure will, therefore, be provided here. A more detailed description of the procedure is provided in references [3, 4].

The existing procedure involves conducting a steady-state performance test on the heater, plus measuring flue gas temperatures at specific times during the heat-up and cool-down from steady-state conditions. Specific measurements at steady-state include flue and stack gas temperature and CO_2 concentration. Two temperature measurements during heat-up and three during cool-down provide the basis for exponential approximations for the temperature-time profiles.

In addition to the above experimental data, a knowledge of several factors describing mass flow rates through the flue and stack during on- and off-periods is required. Values for these factors may be either measured or assigned according to the type of unit under test.

Based upon the experimental data and assigned system factors, thermal losses associated with heater operation are determined. These losses expressed as a percentage of the fuel input rate are:

L_L = Latent Heat Loss due to the presence of uncondensed water vapor in the flue gas.

$L_{S,ON}$ = On-cycle Sensible Heat Loss due to the venting of combustion products and excess air at a temperature above room temperature.

$L_{L,ON}$ = On-cycle Infiltration Loss due to heating the on-period combustion and draft control air from outdoor temperature (T_{OA}) to room temperature.

$L_{S,OFF}$ = Off-period Sensible Heat Loss due to heating the off-period room air discharged at a temperature in excess of the room temperature.

$L_{I,OFF}$ = Off-period Infiltration Heat Loss due to heating the off-period room air loss from outdoor temperature to room temperature.

Steady-state efficiency is given in terms of latent heat loss, L_L, and on-period sensible heat loss at steady-state, $L_{S,ON,ss}$. Part-load efficiency, η_u, is expressed as a function of the five losses:

$$\eta_u = 100 - L_L - \frac{t_{on}}{t_{on} + PF \times t_{off}} (L_{S,ON} + L_{S,OFF} + L_{I,ON} + L_{I,OFF}) \quad (3)$$

t_{on} = typical on-period time - minutes,

t_{off} = typical off-period time - minutes,

PF = Pilot fraction (as fraction of total fuel input rate).

The part-load efficiency is then combined with the steady-state efficiency (η_{ss}) and pilot fraction to yield the annual fuel utilization efficiency.

$$\text{EFFYA} = \frac{\eta_{ss} \times \eta_u \times 4400}{\eta_{ss} \times 4400 + 2.5 \times \eta_u \times \text{PF} \times 4600} \tag{4}$$

where the additional parameters are:

4400 = average annual degree days for vented heaters (see appendix A)

4600 = average non-heating season hours per year that all the energy to the pilot is assumed wasted.

3.2 MEASUREMENTS AND CALCULATIONS FOR HEATERS WITH STEP-MODULATING CONTROLS

For single-stage heaters there is only one fuel input rate at which measurements can be made (the maximum input rate). Modulating-type heaters, however, operate both at reduced firing rate during the cycling mode and anywhere between the reduced and maximum rates during the non-cycling mode. Accordingly, test measurements must be made at the maximum input rate as well as the reduced setting. Since the heater with step-modulating control cycles on-off only at the reduced input rate, all part-load cycling losses must be determined at the reduced input. In addition, to account for operation in the non-cycling mode, as described in sections 2.2.3 and 2.2.4, $L_{S,ON}$ and $L_{I,ON}$ must be determined at maximum fire as well. It is not necessary to know either of the off-cycle losses at high fire ($L_{S,OFF}$ and $L_{I,OFF}$) because no off period loss occurs at that input rate with the step-modulating-type control.

The recommended procedure for calculating the annual fuel utilization efficiency for modulating type heaters essentially involves determination of losses and efficiencies for each of the operating modes -- cycling and non-cycling and weighting of these parameters according to the fraction of time spent in each mode.

The procedure for calculating annual efficiency for the step-modulating heaters is summarized below in nine steps. The detailed procedure consisting of 20 steps is included in appendix B, along with a sample calculation. A computer program (FBVH) for conducting the complete calculation applicable to furnaces, boilers, and vented heaters is included in appendix C.

(a) Determine minimum and maximum heater outputs from the minimum and maximum input rates and measured steady-state efficiency at these two input rates. (For details see steps 1-7 of appendix B.)

(b) Using minimum/maximum heater output from step (a), determine the percent of heating season in each mode. Find the percent of time in cycling mode from figure 8. Percent of non-cycling mode is 100 percent less the percentage of cycling mode.

(c) Determine the average outdoor temperature in the cycling mode, T_{oa}, and in the non-cycling mode, T_{oa}', from figure 8 at the point corresponding to the min/max output determined from (a).

(d) Determine part-load efficiency in the cycling mode using the value of T_{oa} and the prescribed DoE test procedure [3].

(e) Determine the average steady-state efficiency in the non-cycling mode. Use the average of steady-state efficiency measured at the maximum and minimum input rates from step (a).

(f) Determine part-load efficiency in the non-cycling mode by subtracting infiltration loss, $L_{I,ON}$, from the average steady-state efficiency in step (e). Use T_{oa}', to calculate infiltration loss in the non-cycling mode.

(g) Determine weighted average steady-state efficiency using steady-state efficiencies at the minimum input rate from step (a) and the average determined for the non-cycling mode from step (e). Weight each by the percent of heating season in each mode (determined from step (b)).

(h) Determine average part-load efficiency for the heating season using the corresponding part-load efficiencies for the cycling and non-cycling modes and the percent of heating season in each mode.

(i) Determine annual efficiency using average part-load efficiency and average steady-state efficiency.

3.3 CALCULATIONS FOR HEATERS WITH TWO-STAGE CONTROLS

This type of control cycles the burner at low fire for outside air temperatures between 65°F and T_c and at higher fire for temperatures T_c and below (see figure 1). Evaluation of the annual fuel efficiency of heaters with two-stage controls involves the same test measurements required for step-modulating type units, and only slightly different calculations. The calculations are described in detail in appendix B.

4. IMPACT OF MODULATING CONTROLS ON ENERGY CONSUMPTION

4.1 PRESENT DESIGN

Figure 3 shows that modulating controls will indeed affect annual efficiency as evidenced by the variation in part load efficiency with heating load. As shown, efficiency improves as the heating load is increased. This is due both to a reduction in heater cycling (see Modulating Mode of figure 4) and therefore, off-cycle losses, and also in the higher steady-state efficiency at the higher full input rates. The maximum efficiency of currently designed heaters is realized in the non-cycling mode.

4.2 HEATERS EQUIPPED WITH THERMAL DAMPERS

Measured on-period and off-period stack losses of a room heater with and without a thermal stack damper installed were measured. Detailed test results and data are in tables 3 & 4. Data for damper A is presented graphically in figure 9. See [6] for additional information including description of tracer gas test method use to measure the off period losses. The shaded area represents energy savings due to the damper. Figure 9 shows for that heater, as fuel input rate is reduced from maximum to lower input rates, energy savings due to the damper continuously increase. The significance of these findings is that a test conducted per the DoE test procedure [3] only at the maximum input rate does not reflect the potential energy savings of the thermal type stack damper when it is installed on a heater having a step-modulating or two-stage thermostat control.

A summary of energy savings calculated using the calculation procedure of appendix C for three heaters with three different models of thermal dampers is shown in table 5. Results presented in table 5 show that energy savings is dependent on type of heater and stack damper as well as type of thermostat used, and the reduced fuel input rate of the step-modulating type thermostat.

4.3 HEATERS WITH REDUCED COMBUSTION AIR AT REDUCED HEAT INPUT RATES

Although heaters tested have shown a reduced part-load efficiency at reduced input rates, it is possible that heaters can be designed to use less excess air at the reduced input rate, thereby, actually increasing part-load cycling mode efficiency at the lower rate to above the non-cycling mode operating efficiency. This is possible because at reduced input rates the ratio of heat transfer surface area to combustion products mass flow rate is greater. Test procedures outlined here will allow credit for any such innovative designs that result in reduced excess combustion air at reduced fuel input rate.

The potential for energy savings with reduced excess air has been demonstrated in the laboratory by intentionally reducing the excess air at reduced input rate. The excess combustion air values at a minimum input are presented in table 6 for a heater in "as received" condition and after reducing excess combustion air. Excess air was reduced in these test by using a flue baffle placed in the exit of the heat exchanger. Baffling of the heat exchanger was limited in order not to increase carbon monoxide in the flue gases above the amounts found prior to any restriction of the flue. Data obtained at the maximum firing rate and at the minimum input rate with restricted excess combustion air is shown in table 6.

The effect of reduced excess air on efficiency can be quite significant. As shown in table 6, energy savings of from 6 to 22 percent were calculated.

5. CONCLUSIONS

A procedure for evaluating the annual operating efficiency of vented heating equipment with a step-modulating thermostat or two-stage control has been developed. This procedure is essentially the same as the existing DoE test procedure for vented heaters, but calls for tests and calculations to be performed at maximum as well as minumum firing rates. Analyses of weather data for typical cities, and assumptions concerning heater sizing, provide a means of combining the cycling and non-cycling efficiencies to yield a "weighted" annual fuel efficiency.

This rated annual efficiency is considered to be reflective of the differences inherent with cycling and non-cycling modes of operation which apply with modulating-type controls. Since procedures developed here are an extension of current DoE test procedures, these procedures are believed to be useful for comparing the annual efficiency of heaters with modulating type controls vs the conventional on-of thermostat control used with some types of vented heaters. The bin calculation procedures developed here are also expected to be applicable to certain furnaces equipped with the types of fuel modulating controls investigated in this study. Predicted annual energy with any of these procedures should be considered valid only for comparison purposes between equipment tested under laboratory conditions. These procedures as well as the current DoE test procedures should not be considered predictive of installed annual operating costs. Comprehensive treatment of the building and furnace interaction which are unique to each installation would be needed for that prediction and is beyond the scope of these procedures.

Comparison of heater efficiencies with single-stage and with step-modulating controls indicates that substantial improvements can be made. Maintaining the combustion air to fuel ratio with reduced input rate is a promising means of reducing energy consumption for heaters with step-modulating and two-stage controls.

6. REFERENCES

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Table 1. Development of outdoor temperatures and time in each mode from weather data for one city (Bishop, California)

(1) Outdoor Temperature Range °F	(2) T_C Midpoint	(3) Total Hours	(4) 65°-(2)	(5) (3)x(4) Deg. Hours	(6) $\sum_{T_A=65°F}^{T_A=0°F}$ (5) Cumulative Deg. Hours	(7) $\sum_{T_A=65°F}^{T_A=0°F}$ (3) Cumulative Hours	(8) (6)÷(7)	(9) T_{oa} 65-(8)	(10) $\sum_{T_A=0°F}^{T_A=65°F}$ (5) Cumulative Deg. Hours	(11) $\sum_{T_A=0°F}^{T_A=65°F}$ (3) Cumulative Hours	(12) (10)÷(11)	(13) T_{oa}' 65°-(12)	(14) % Cycling Mode [(6)÷100,784]
0-4	2	2	63	126	100778	5114	19.7	45.3	126	2	63	2.0	
5-9	7	5	58	290	100652	5111	19.7	45.3	416	7	59.4	5.6	
10-14	12	32	53	1690	100362	5106	19.7	45.3	2106	39	54.2	10.8	
15-19	17	70	48	3360	98672	5074	19.4	45.6	5466	109	50.2	14.8	98%
20-24	22	179	43	7697	95312	5004	19.0	46.0	13163	288	45.7	19.3	95%
25-29	27	346	38	13148	87615	4825	18.1	46.9	26311	634	41.5	23.5	87%
30-34	32	449	33	14817	74467	4479	16.6	48.4	41128	1083	38.0	27.0	79%
25-39	37	563	28	15764	59650	4030	14.8	50.2	56892	1646	34.6	30.4	59%
40-44	42	634	23	14582	43886	3467	12.7	52.3	71474	2280	31.4	33.6	44%
45-49	47	676	18	12168	29304	2833	10.3	54.7	83642	2956	28.3	36.7	29%
50-54	52	698	13	9074	17136	2157	7.9	57.1	92716	3654	25.4	39.4	17%
55-59	57	737	8	5896	8062	1459	5.5	59.5	98612	4391	22.5	42.5	8%
60-64	62	722	3	2166	2166	722	3.0	62.0	100778	5113	19.7	45.3	2%

Table 2. Outdoor temperatures and time on each mode -- an average of eight cities having total heating requirements of approximately 4400 degree days

Col (5) = (4) ÷ 108,368

Col (6) = T_{oa} = average time weighted outdoor temperature in cycling mode between T_c and 65°F - See equation below

= T_{oa}' = average temperature in steady state mode between T_c and 5°F - See equation below, see note below.

Col (7) is obtained from equation (1) with = 0

(1) Temperature Range (°F)	(2) T_c	(3) Hours	(4) $\sum_{62}^{T_c}$ degree Hrs.	(5) % of Time in Cycling Mode	(6)(a) T_{oa} Cyclic	(6)(b) T_{oa}' Non-Cycling	(7) $\frac{\text{Min Output}}{\text{Max Output}}$
15-19	17	104	108368	100	44	14	0.96
20-24	22	193	103376	95	45	19	0.86
25-29	27	348	95077	88	46	23	0.76
30-34	32	552	81853	76	47	27	0.66
35-39	37	659	63637	59	49	31	0.56
40-44	42	730	45185	42	51	34	0.46
45-49	47	727	28395	26	54	37	0.36
50-54	52	683	15309	14	56	39	0.26
55-59	57	596	6430	6			--
60-64	62	554	1662	2			--

$$T_{oa} \text{ @ cyclic mode} = 65 - \left[\frac{\sum_{62}^{T_c}(65 - T_c)\,(\text{col } 3)}{\sum_{62}^{T_c}\text{col } (3)}\right] \qquad T_{oa}' \text{ @ steady-state mode} = 65 - \left[\frac{\sum_{17}^{T_c}(65-T_c)\,(\text{col } 3)}{\sum_{17}^{T_c}(\text{col } 3)}\right]$$

NOTE: All calculated values in this table are based on no oversizing ($\alpha = 0$)
Each line of Col. 6 represents the average from eight cities with individually calculated values from specific data for each city.

Table 3. Summary of stack losses and efficiencies for a room heater rated 45,000 Btu/h (13,185W)

Test Condition	$L_{S,ON}$ %	$L_{S,OFF}$ %	$L_{I,ON}$ %	$L_{I,OFF}$ %	Weighted Average Steady-State η_{ss} (%)	Part-Load Efficiency (Weighted Avg) (η_u) %	Annual Efficiency EFFYA %	Energy* Savings %
	(1) Operating as single stage thermostate (cycling mode at 41,000 Btu/h only)							
No Damper	17.1	2.7	1.8	2.9	73.0	66.7	61.6	--
Damper A	15.3	2.2	0.8	2.5	74.8	72.5	65.2	6
Damper B	16.1	2.2	0.5	2.1	73.9	71.9	64.2	4
	(2) Operating in step modulating mode - low fire at 26,000 Btu/h							
No Damper	20.8	2.9	2.3	3.7	69.7	63.8	58.8	--
Damper A	17.0	1.9	0.9	2.5	73.4	69.8	64.2	8
Damper B	16.6	2.0	0.6	2.1	73.4	70.5	64.8	9
	(3) Operating in step modulating mode - low fire at 10,000 Btu/h							
No Damper	22.7	7.2	2.6	4.1	69.9	65.2	60.1	--
Damper A	19.5	4.3	1.2	1.5	72.4	70.7	64.1	6
Damper B	23.7	2.9	0.7	2.3	69.7	67.9	62.3	3

$$*\text{Energy Saving} = 100\left[1 - \frac{\text{EFFYA no damper}}{\text{EFFYA with damper}}\right]$$

Table 4. Effect of stack damper and operating input rate on the stack (S) and Flue (F) temperature and CO_2 values and stack to flue mass flow (S/F) for room heater rated 45,000 Btu/h (13,185W)

Firing Rate % of Rated Input	-- Steady State Flue (F) -- and Stack (S) - CO_2 - %						-- Steady State Flue (F) -- and Stack (S) Temperature °F						-- S/F* --		
	No Damper		Damper "A"		Damper "B"		No Damper		Damper "A"		Damper "B"		No Damper	With Damper	
	(S)	(F)	(S)	(F)	(S)	(F)	(S)	(F)	(S)	(F)	(S)	(F)		"A"	"B"
91	1.6	7.4	2.4	7.7	2.3	7.2	207	662	252	662	259	671	6.1	4.3	4.0
58	1.1	4.9	1.6	4.3	2.0	4.7	190	550	212	504	239	547	5.7	3.5	3.1
22	0.6	1.8	1.0	2.6	1.7	2.0	136	320	167	320	194	316	4.2	3.5	1.5

* These values are calculated using the CO_2 (F) and CO_2 (S) values, the equation is:

$$S/F = 1.3 \left[R_{T,S}/R_{T,F}\right]$$

where the R_T values are the ratios of combustion air mass flow rate to stoichiometric air mass flow. R_T values are inversely proportional to CO_2 values.

Table 5. Effect of type of thermostat control on energy saving potential of thermal dampers

Type Thermostat	Type Damper	- Calculated Percent Energy Savings - Room Heater No. 1	Room Heater No. 2	Wall Furnace
Single Stage Thermostat High Fire Only Cycling Mode	A	6	4	1
	B	4	3	5
	C	3	5	2
Step Modulating Thermostat				
Adjusted to Cycle at 60% of Maximum Fire	A	8	4	1
	B	9	5	2
	C	7	3	1
Adjusted to 25% of Maximum Fire	A	6	9	-
	B	3	6	-
	C	11	2	-

NOTE: For additional details on test results and calculation procedures for heaters equipped with thermal dampers, see Ref [6].

Table 6. Effect of reduced excess combustion air on efficiency of a 35,000 Btu/h room heater (10,255W) equipped with (1) step-modulating thermostat, or (2) two-stage thermostat

Test Condition	Input Rate Max (Btu/h X1000)	Input Rate Reduced (Btu/h X1000)	CO_2 - % Max Input Flue	CO_2 - % Max Input Stack	CO_2 - % Reduced Input Flue	CO_2 - % Reduced Input Stack	Steady State Efficiency % Max Input	Steady State Efficiency % Reduced Input	Excess Air % Max Input	Excess Air % Reduced Input	Annual Efficiency % -Control Type- Step-Modulating	Annual Efficiency % -Control Type- Two-Stage	Energy Savings % -Control Type- Modulating	Energy Savings % -Control Type- Two-Stage
1) With heater as received	33.3	19.1	7.2	2.5	3.9	1.6	70	64	60	185	59	59	-	-
2) After reducing excess combustin air at reduced input	33.3	19.1	7.2	2.5	7.2	2.1	70	77	60	60	70	68	16	13
3) With reduced input adjusted to minimum	33.3	7.8	7.2	2.5	1.6	0.7	70	58	60	600	58	62	-	-
4) Reduced excess combustion air at minimum input	33.3	7.8	7.2	2.5	4.6	1.4	70	85	60	150	74	66	22	6

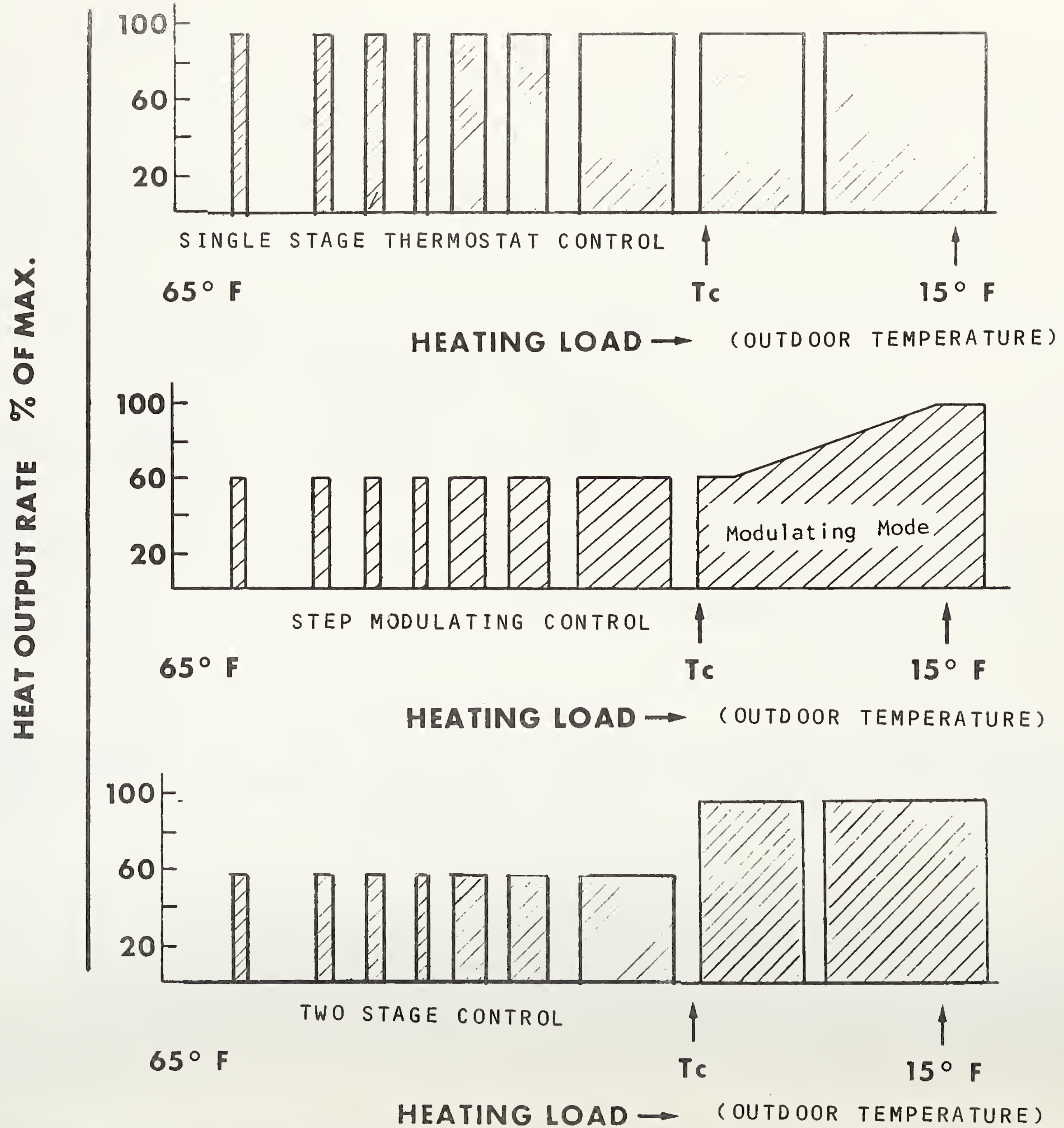


Figure 1. Typical operating modes for heaters equipped with single-stage, two-stage, and step-modulating controls

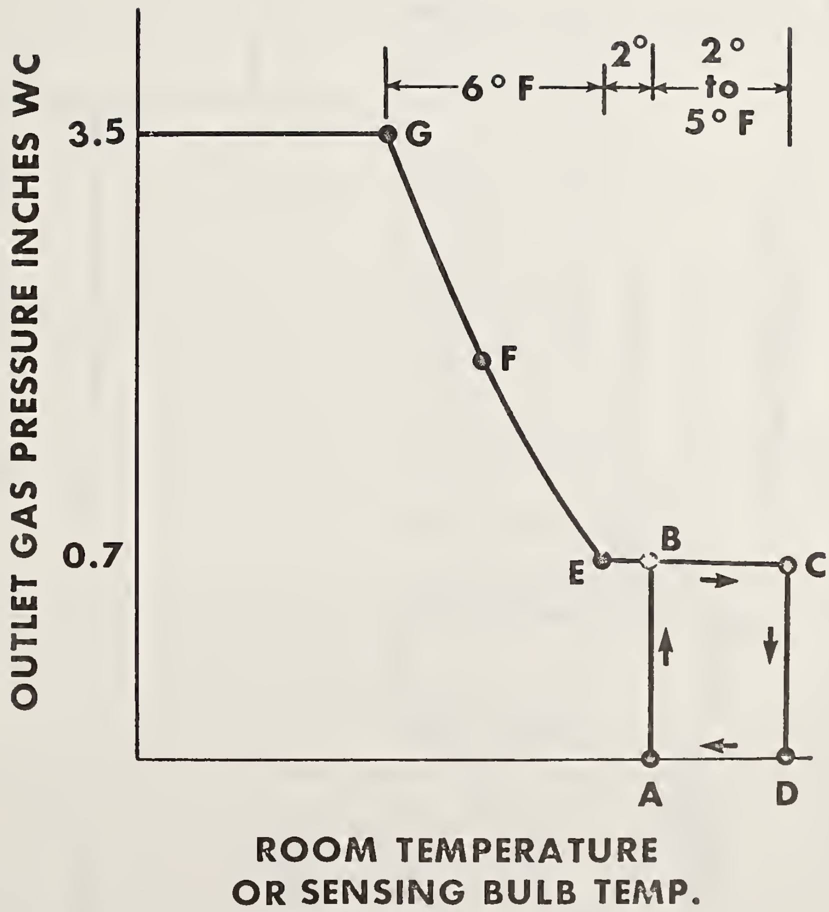


Figure 2. Outlet gas pressure from a step-modulating thermostat control in response to changing room temperature

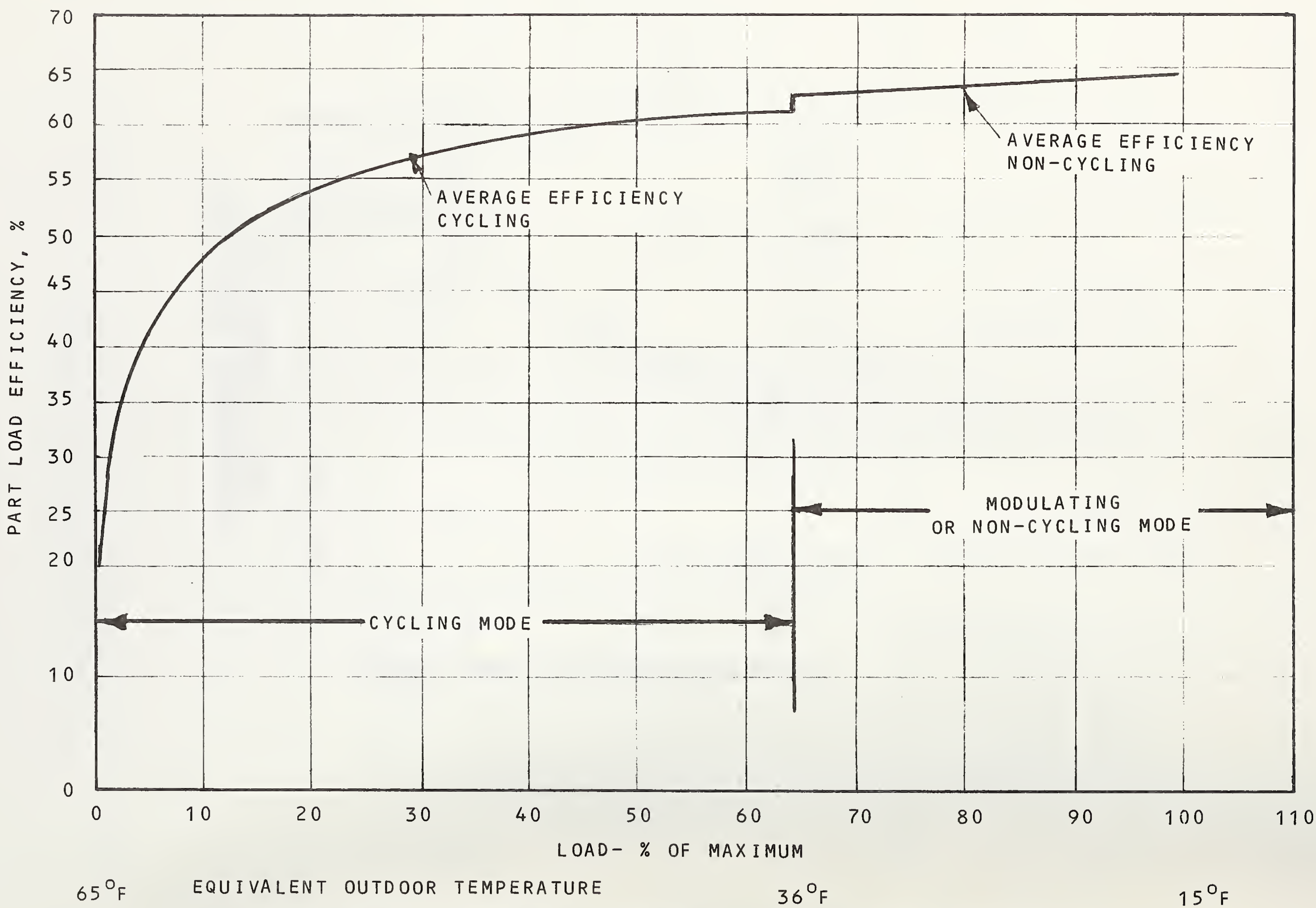


Figure 3. Part-load efficiency versus load for a heater with step-modulating control

$$\frac{\Delta T_C}{\Delta T_D} = \frac{\text{Heater Output } B}{\text{Design Heater Output } A}$$

$$T_C = 65 - 50\,\frac{B}{A}$$

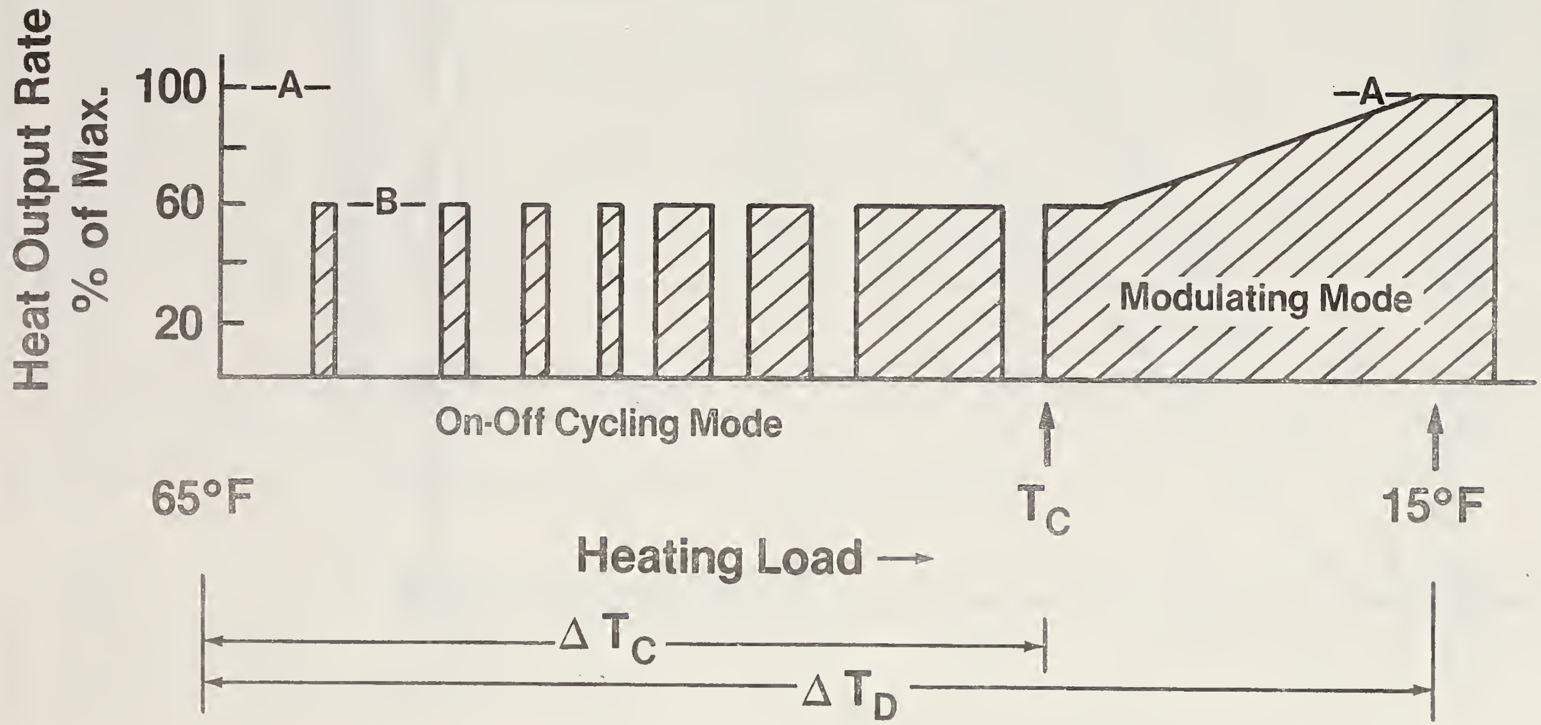


Figure 4. Burner output rate versus heating load and associated outdoor temperatures for a heater with step-modulating control

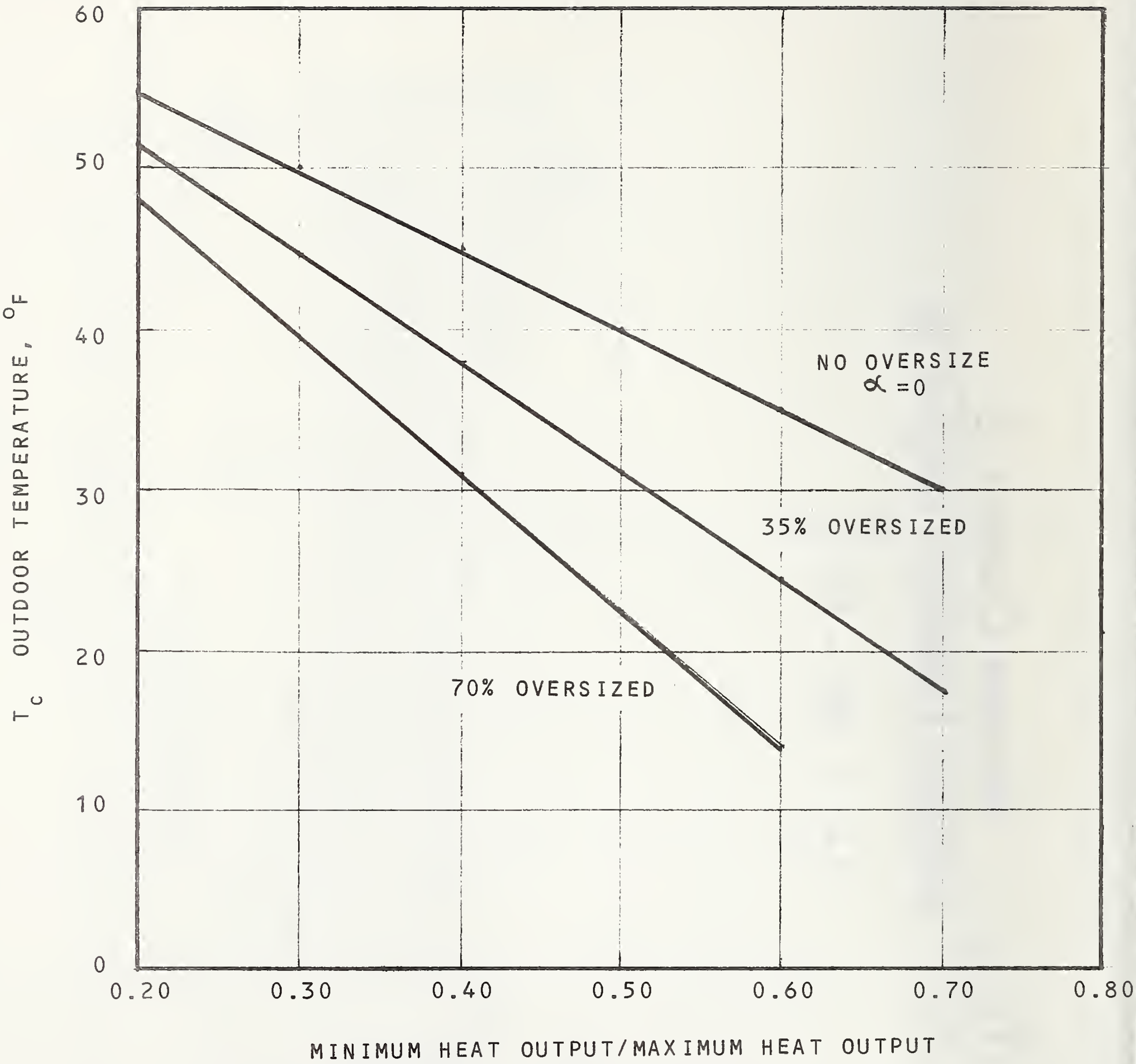


Figure 5. Balance point temperature as a function of heater output ratio

Cycling Mode Fraction = 2530 ÷ 4400
or 58%
Non-Cycling Mode = 100 − 58 = 42%

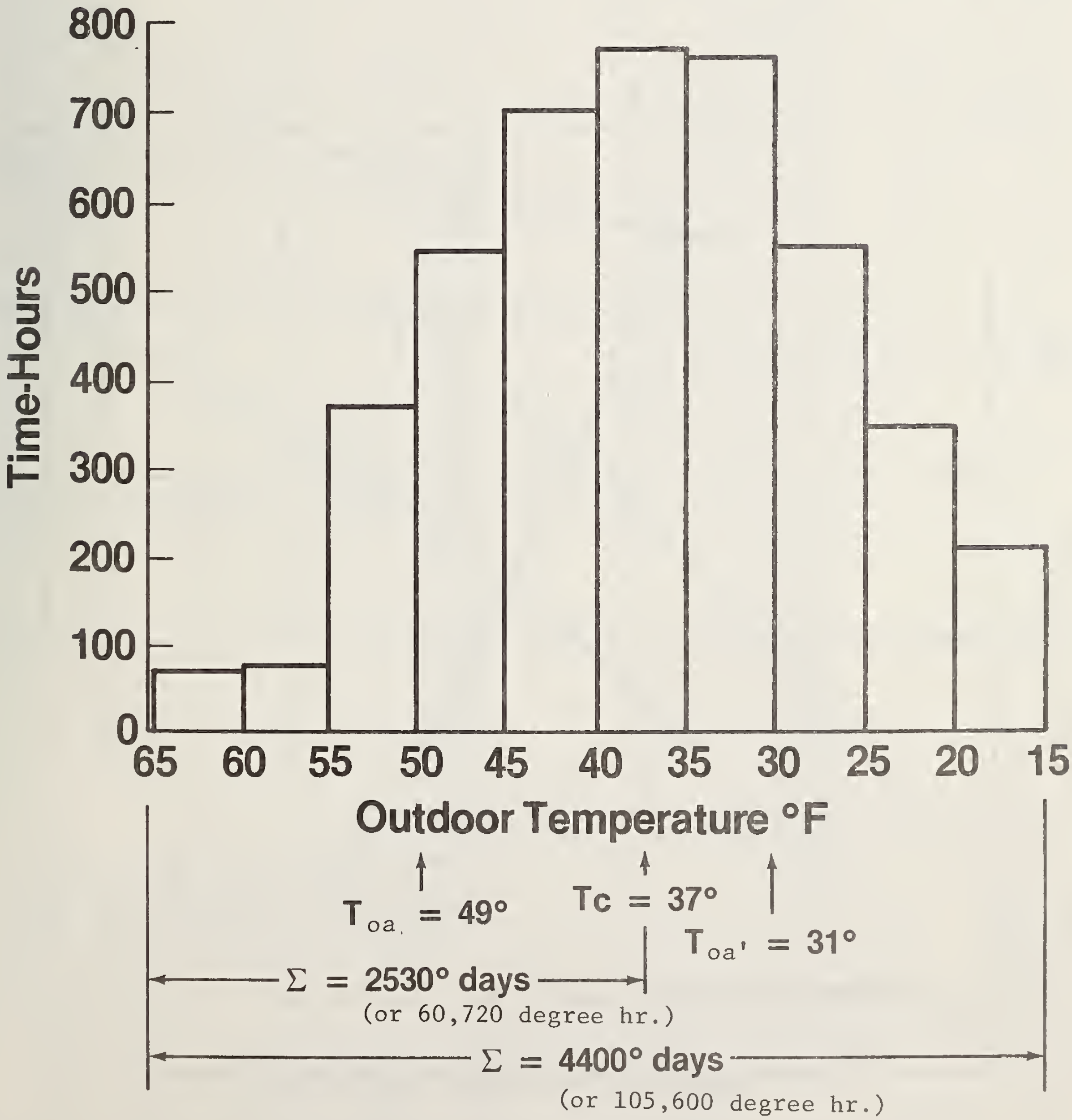


Figure 6. Example of bin method used to determine percentage of time in cycling mode

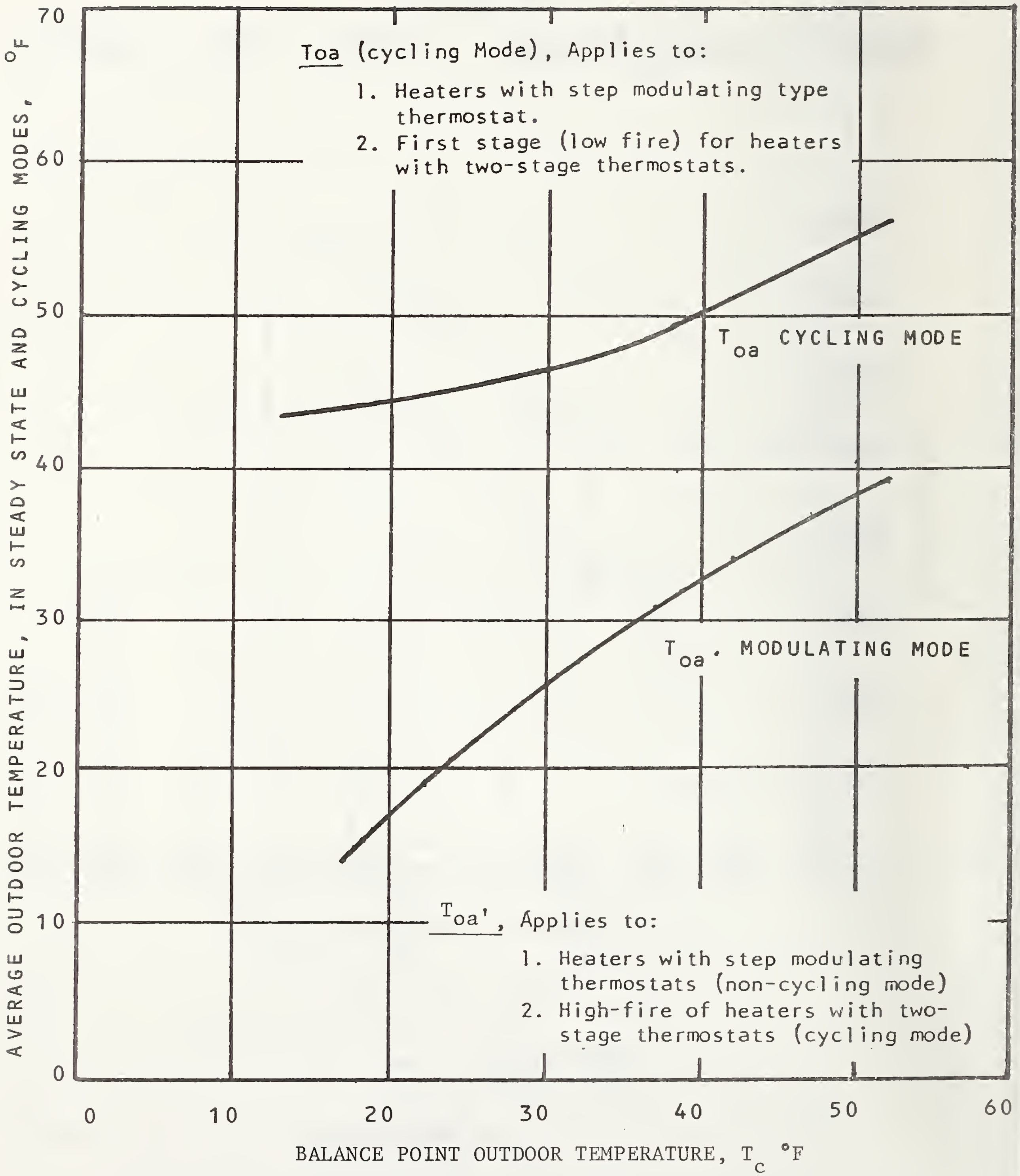


Figure 7. Average outdoor temperature in cycling and non-cycling modes versus balance point temperature (T_c)

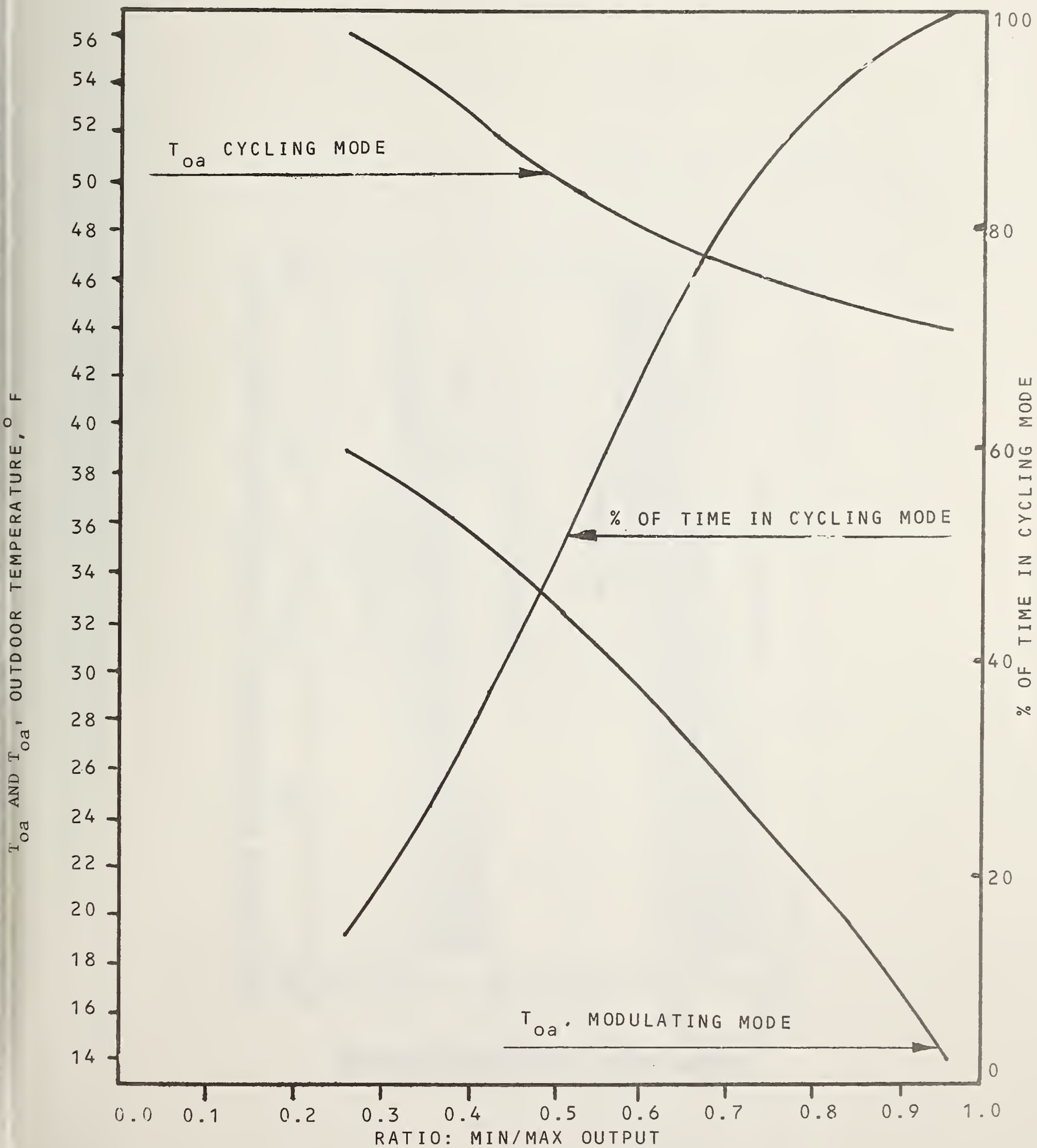


Figure 8. Average outdoor temperature and percent of time in cycling mode as a function of heater output ratio

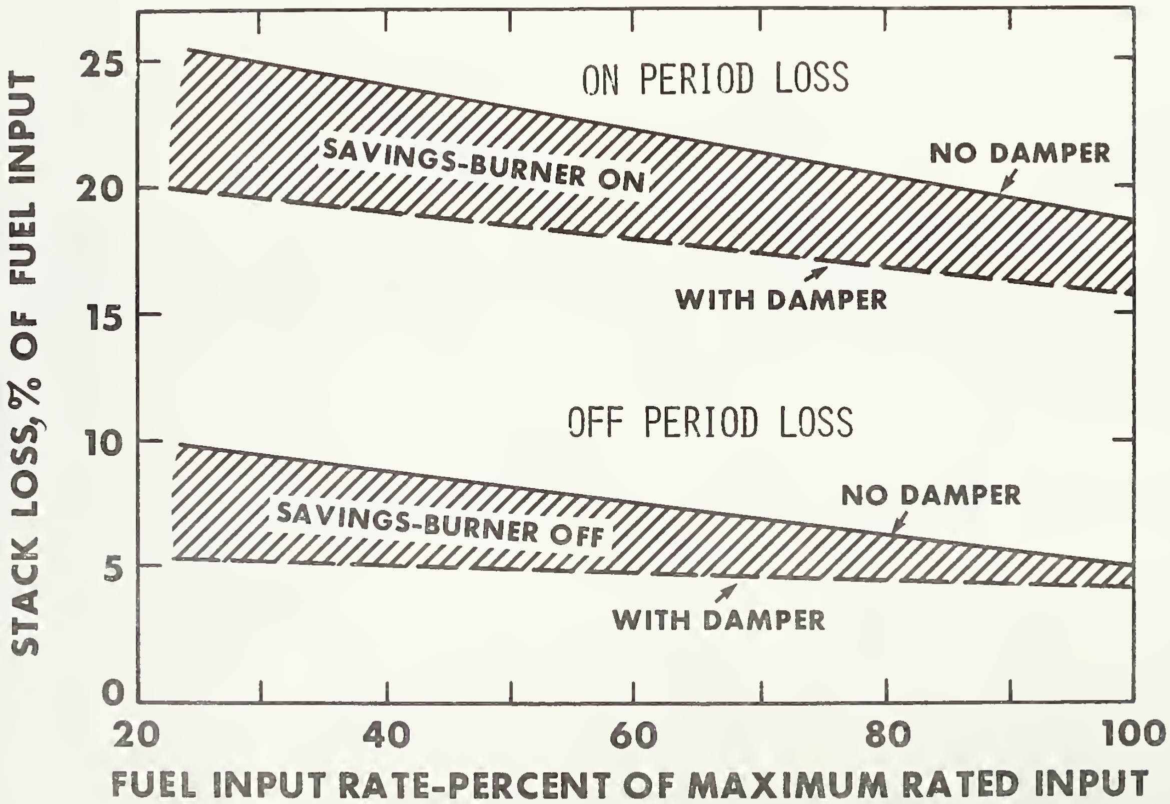


Figure 9. The effect of burner fuel input rate on the part-load loss of a room heater with and without a thermal damper

APPENDIX A

Determination of Outdoor Design Temperature and Typical Annual Heating Degree Days for Vented Household Heaters

Appendix A

Determination of Average Heating Degree Days and Design Temperature for Vented Room Heaters

The 97 1/2 winter design temperature is that dry-bulb temperature which will probably be exceeded 97 1/2 percent of the time for winter months (December, January, February). Through consideration of the geographic distribution of vented room heaters throughout the U.S., combined with analyses of weather data, a single value or design temperature, representative of a "National Average" condition, can be obtained. This value will be different than the corresponding value of 5°F for furnaces used in [4], since the geographic distribution of furnaces and room heaters is not the same.

Based on 1970 census data, the total number of room heaters installed in each of the nine geographic regions of the United States is presented in table A1. Also presented in table A1 are representative average number of heating season degree days for each of the nine regions. Based on these two pieces of information, a heater population weighted average of space heating degree days for room heaters can be obtained. Results of the average are presented at the bottom line of column (4) (4438 is rounded to 4400 degree-days, as the weighted national average). Although these data are based on the 1970 census now 11 years old, results are expected to be little affected if more recent census data were to be used since most vented heaters sold are replacement units for existing installations.

The outdoor design temperature can be approximated as the average of the design temperatures of a representative number of cities having heating seasons of about 4200 to 4600 degree-days. The heating degree-days and outdoor design temperatures for 13 cities falling in this range are presented in table A2. The average design temperature for the group is 15.7°F.

Table A-1 Population Weighted Average Space Heating Degree Days

	(1)	(2)	(3)	(4)
Census Region	Population of Vented Heaters	% of Total	Regional Average Degree Days	Population Weighted Degree Days
Pacific	3,672,950	26.6	3820	1016
Mountain	649,618	4.7	5780	271
East So. Cntrl.	1,007,956	7.3	3795	277
So. Atl.	2,683,320	19.5	3380	659
W. No. Cntrl.	1,179,377	8.6	6825	587
E. No. Cntrl.	1,640,383	11.9	6610	787
Mid. Atl.	800,859	5.8	6100	354
New Eng.	369,041	2.7	6820	184
W. So. Cntrl.	1,783,762	12.9	2350	303
Total	13,787,266			4438

Table A-2 Design Temperatures from 97 1/2% Column of ASHRAE Handbook of Fundamentals (1972)

CITY	DESIGN TEMP °F	DEGREE DAYS
Charlestown, SC	14	4476
Huntington, WV	14	4446
Philadelphia, PA	15	4486
St. Louis, MO	8	4484
Albuquerque, NM	17	4348
Evansville, IN	10	4435
Bishop, CA	15	4275
Washington, DC	15	4551
Sandberg, CA	25	4209
Eureka, CA	35	4643
Prescott, AZ	15	4654
Dover, DE	12	4660
Louisville, KY	9	4620
Avg.	15.7	

APPENDIX B

Detailed Stepwise Procedure for Calculation of Annual Efficiency for Heaters Equipped with Step-Modulating or Two-Stage Thermostat Controls

Appendix B

Detailed Stepwise Procedure for Calculation of Annual Efficiency for Heaters Equipped with Step-Modulating or Two-Stage Thermostat Controls

The first 11 steps deal with the calculation of minimum and maximum heat outputs, and fraction of time and outdoor temperature in each mode. Each of the following steps refers to a similarly numbered block in figure B-1.

1. Enter the maximum fuel input rate (including fuel supply to pilot flame).

2. Enter the steady state efficiency at the maximum input rate (determined in accordance with the DoE test procedure).*

3. Calculate and enter the maximum heat output rate = $\frac{\text{Step 1 X Step 2}}{100}$.

4. Enter the minimum (reduced) fuel input rate (including fuel supply to pilot flame).

5. Enter the steady state efficiency at reduced fuel input rate (determined in accordance with the DoE test procedure).*

6. Calculate and enter the minimum heat output rate = $\frac{\text{Step 4 X Step 5}}{100}$.

7. Calculate and enter ratio of minimum to maximum output

$$\text{RATIO} = \frac{Q_{out,min}}{Q_{out,max}} \quad \text{or} \quad \frac{\text{Step 6}}{\text{Step 3}}$$

8. Read the percentage of time in the low fire cycling mode (R_{lo}) from the graph of figure 7 for the minimum/maximum ratio corresponding to the ratio determined in step (7).

9. Calculate percentage of time in the non-cycling mode (R_{hi}).

$$R_{hi} = 100 - R_{lo} \text{ (Step 8)}$$

10, 11. Read the average outdoor temperatures for the cycling and non-cycling mode, T_{oa} and T_{oa}' respectively, from figure 7 at the point corresponding to min/max ratio determined in step (7).

In the next four steps, the average steady state efficiency and on-cycle infiltration losses for the non-cycling mode are determined.

*References 1 and 3.

12. Calculate and enter average steady state efficiency (%) for the non-cycling mode, $\eta_{ss,\ hi}$

$$\eta_{ss,\ hi} = \frac{\eta_{ss,\ min} + \eta_{ss,max}}{2} \quad \text{or} \quad \frac{\text{Step 5 + Step 2}}{2}$$

13. Enter the on-period infiltration loss ($L_{I,ON,min}$) at the minimum input rate (determined in accordance with the DoE test procedure for an outdoor temperature equal to T_{oa}, (Step 11).

14. Enter the on-cycle infiltration loss at the maximum input rate (determined in accordance with the DOE test procedure for an outdoor temperature equal to T_{oa}, (Step 11).

15. Calculate and enter the average on-cycle infiltration loss (%) for the non-cycling mode

$$L_{I,ON,avg} = \frac{L_{I,ON,min} + L_{I,ON,max}}{2} \quad \text{or} \quad \frac{\text{Step 13 + Step 14}}{2}$$

The part load efficiency, η_u, for both the cycling and non-cycling modes are determined next, and the weighted average efficiencies are then calculated.

16. Calculate and enter the part load efficiency for the non-cycling mode

$$\eta_{u,hi} = \eta_{ss,hi}\ \text{(Step 12)} - L_{I,ON,\ av}\ \text{(Step 15)}$$

17. Calculate and enter the percentage part load efficiency (%) for the [redacted]-cycling mode:

$$\eta_{u,lo} = 100 - L_L - \frac{20}{t_{ON} + PF x t_{OFF}} (L_{S,ON} + L_{I,ON} + L_{S,OFF} + L_{I,OFF})$$

where the thermal losses are determined in accordance with the DOE procedure for the minimum firing rate, at outdoor temperature equal to T_{oa} (Col 10), and $t_{ON} = t_{OFF} = 20$ min. Alternatively, $L_{S,OFF}$ and $L_{I,OFF}$ can be measured using the tracer gas technique [6]. PF is the pilot fraction (the ratio of pilot input Q_p to total fuel input Q_{in}).

18. Calculate and enter the weighted average part load efficiency for the cycling and non-cycling modes

$$\eta_{u,wt} = R_{lo} X \eta_{u,lo} + R_{hi} X \eta_{u,hi}$$

or Step 8 X Step 17 + Step 9, Step 16

19. Calculate and enter the weighted average steady state efficiency for the cycling and non-cycling modes.

$$\eta_{ss,wt} = R_{lo} \times \eta_{ss,min} + R_{hi} \times \eta_{ss,hi} \text{ or Step 8 X Step 5 + Step 9 X Step 12}$$

The annual fuel efficiency for modulating type heaters is finally calculated using the weighted efficiencies from steps 18 and 19.

20. $$\text{EFFYA} = \frac{\eta_{ss,wt} \times \eta_{u,wt} \times 4400}{\eta_{ss,wt} \times 4400 + 2.5\ \eta_{u,wt} \times PF \times 4600}$$

Procedure for Calculating Annual Efficiency for Heaters with Two-Stage Controls

The calculations listed above for heaters with step-modulating controls will, with slight modification, accommodate heaters with two-state controls. The modifications are as follows:

- o replace step (12) with the equality: $\eta_{ss,hi} = \eta_{ss,max}$
- o delete steps (13) through (15), and
- o replace step (~~17~~ 16) with a calculation similar to that of step (~~16~~ 17) but for the maximum input rate and an outdoor temperature equal to T_{oa}'.

The annual fuel efficiency given by step (20) will then be for a heater with two-stage contol.

FIGURE B - 1

For Step Modulating Type Heaters (Operating in a Cycling Mode at Reduced Input Rate (Low Fire) and Non-Cycling Mode at Intermediate Input Rates Between Low and Maximum Rated Input

1	2	3	4	5	6	7	8
Maximum Fuel Input Btu/h	n_{ss} @ Max. Input Rate %	Max. Heat Output Rate [(1)x(2)]÷100	Reduced Input Rate Btu/h	n_{ss} @ Reduced Input Rate %	Reduced Heat Output [(4)x(5)]÷100	Reduced ÷ Max. Heat Output (6) ÷ (3)	% of Time @ Reduced Input Cycling Mode from (7) & fig. 7

9	10	11	12	13	14	15
% of Time @ Non-Cycling Mode = 100%-(8)	Average T_{oa} Cycling Mode From Fig. 7	Average T_{oa}' Modulating Mode From Fig. 7	Average n_{ss} in Non-Cycle Mode [(2)+(5)]÷2	$L_{I,ON}$ @ Reduced Input %	$L_{I,ON}$ @ Max. Input %	Average $L_{I,ON}$ [(13)+(14)]÷2 %

16	17	18	19	20
N_u - % Non-Cycling Mode (12) - (15)	n_u - % cycling mode	Average n_u = [(9)(16)+(17)(8)]÷100 %	Average n_{ss} = [(12)(9)+(5)(8)]÷100 %	EFFYA From (18) & (19) %

APPENDIX C

Computer Program for the Evaluation of Annual Fuel Utilization Efficiency and Energy Consumption of Vented Heating Equipment With Single-Stage, Two-Stage, and Step-Modulating Thermostats

Appendix C

Computer Program for the Evaluation of Annual Fuel Efficiency of Heating Equipment With Single-Stage, Two-Stage, and Step-Modulating Control

Program Description

The computer program to be described here is based on the original program NBSFBS5 developed in 1978 by Kelly, et al [2]. While maintaining the previous structure of NBSFBS5, the present program handles heating equipment with single-stage, two-stage, and step-modulating input, and permits the use of tracer gas measurements in determining off-cycle losses (see Reference). The computer program consists of a main program, entitled FBVH, and four subroutines: SENLOS,* WEIGHT, OFFLOS, and FUNT4. It is written in ASCII Fortran and should be compatible with most Fortran V processors with a minimum of change.

The main program FBVH, as its predecessor, chooses calculation paths, makes appropriate calls to subroutines, and performs calculation steps based on input information. The theoretical calculations and the order in which the calculations proceeds are essentially the same as in NBSFBS5. For single-stage controls, a straight-through path, identical to that in NBSFBS5, is taken. For step-modulating and two-stage controls, outdoor temperatures and time in each mode are determined via a call to WEIGHT, and two passes through the calculation stream are then taken. In the first pass, input data for the maximum firing rate and outdoor temperature T_{oa}, are used. In the second pass, required parameters are saved, and data for the minimum firing rate and outdoor temperature $T_{oa'}$ are used. Weighted efficiencies are calculated in accordance with section 3.2.

Subroutine SENLOS determines values for steady state: latent heat loss L_L, sensible heat loss $L_{S,ON,ss}$, and steady state efficiency η_{SS} as well as other parameters. This SENLOS version contains the stack to flue mass flow ratio S/F (SFR) computed from stoichiometric relationships and is used in place of the input value of SFR for all calculations (the computed value was previously used only if it was greater than the input value of SFR).

Subroutine WEIGHT assigns values for average outdoor temperatures in the cycling and non-cycling modes (T_{oa} and T_{oa}' respectively), and the fraction of time in the cycling mode. WEIGHT is called only for step-modulating and two-stage heaters.

The subroutine OFFLOS calculates off-cycle sensible heat and infiltration losses based on the tracer gas technique described in Reference 6. For this calculation, which is optional, twenty measurements of tracer concentration in stack gas are required at one-minute intervals, along with the initial tracer concentration, and tracer gas flow rate and temperature.

Subroutine FUNT 4 calculates functions required for the analytical determination of off-cycle stack losses (the current DOE and default means of calculating off-cycle losses). FUNT 4 is unchanged from the NBSFBS5 version.

*SENLOS used in this procedure is modified from another form of the SENLOS given in Reference 2 with NBSFBS5.

A flow chart of FBVH including corresponding statement numbers from the program listing, is shown in figure C1. This figure does not include all program details but only those essential differences between FBVH and NBSFBS5. The majority of the theoretical calculations are performed in statements 132 through 256 and are described in detail in Reference 4. The complete program listing, with subroutines, is shown in figure C2.

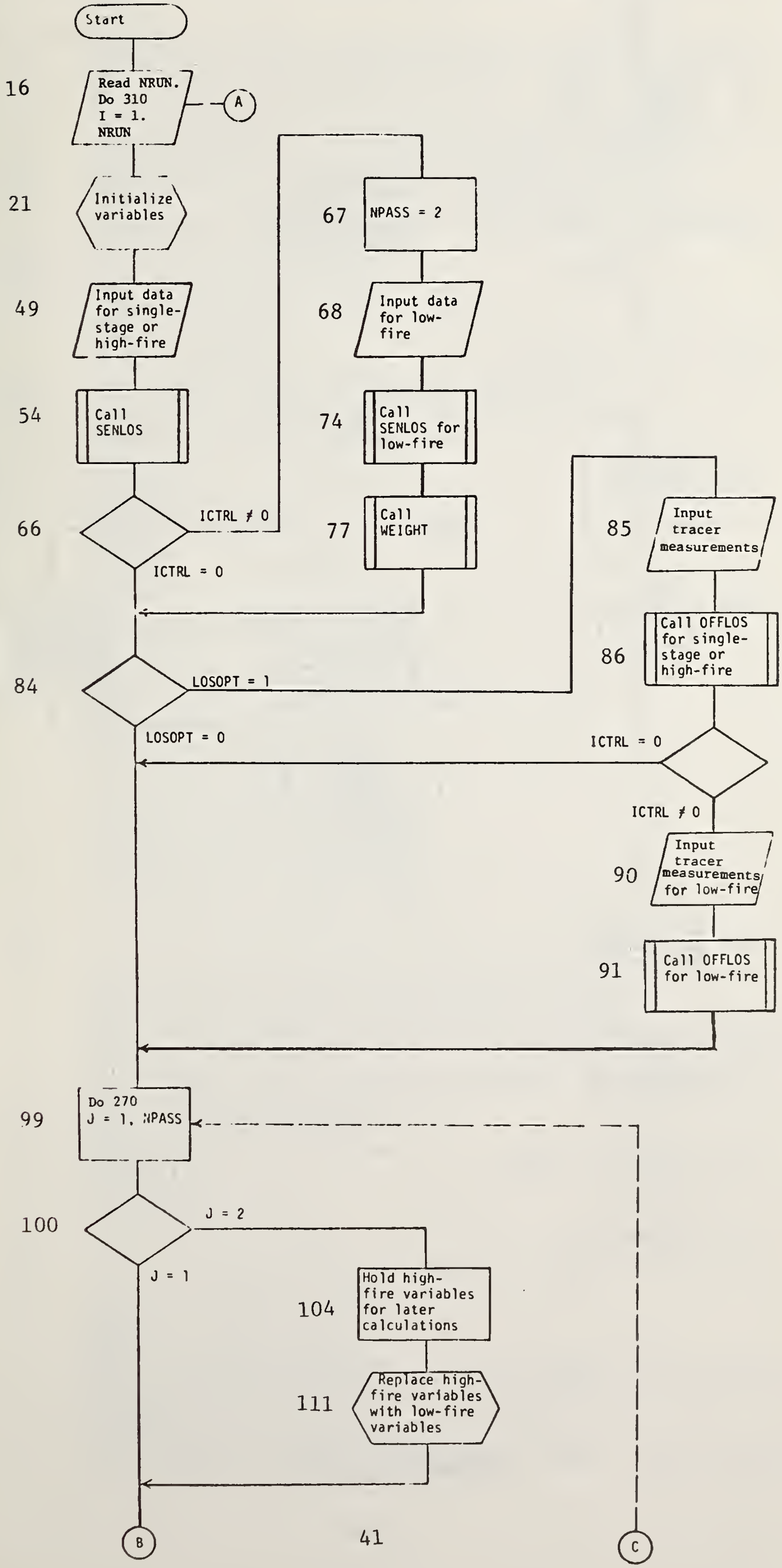
Input Data Format

The input data file or element for FBVH must be consistent with the format shown in figure C3. A sample data form is presented as figure C4 for comparison. It should be noted that when ICTRL and LOSOPT are selected such that some lines in figure C3 are omitted in the data file, blank lines should not be inserted; the line numbers in the data file will therefore differ from those in figure C3 in certain cases.

Sample Input and Output

Sample sets of computer program output for a heater with a step-modulating and with a two-stage control are presented in figures C4 and C5 respectively.

Figure C1. Flow chart of main program, FBVH



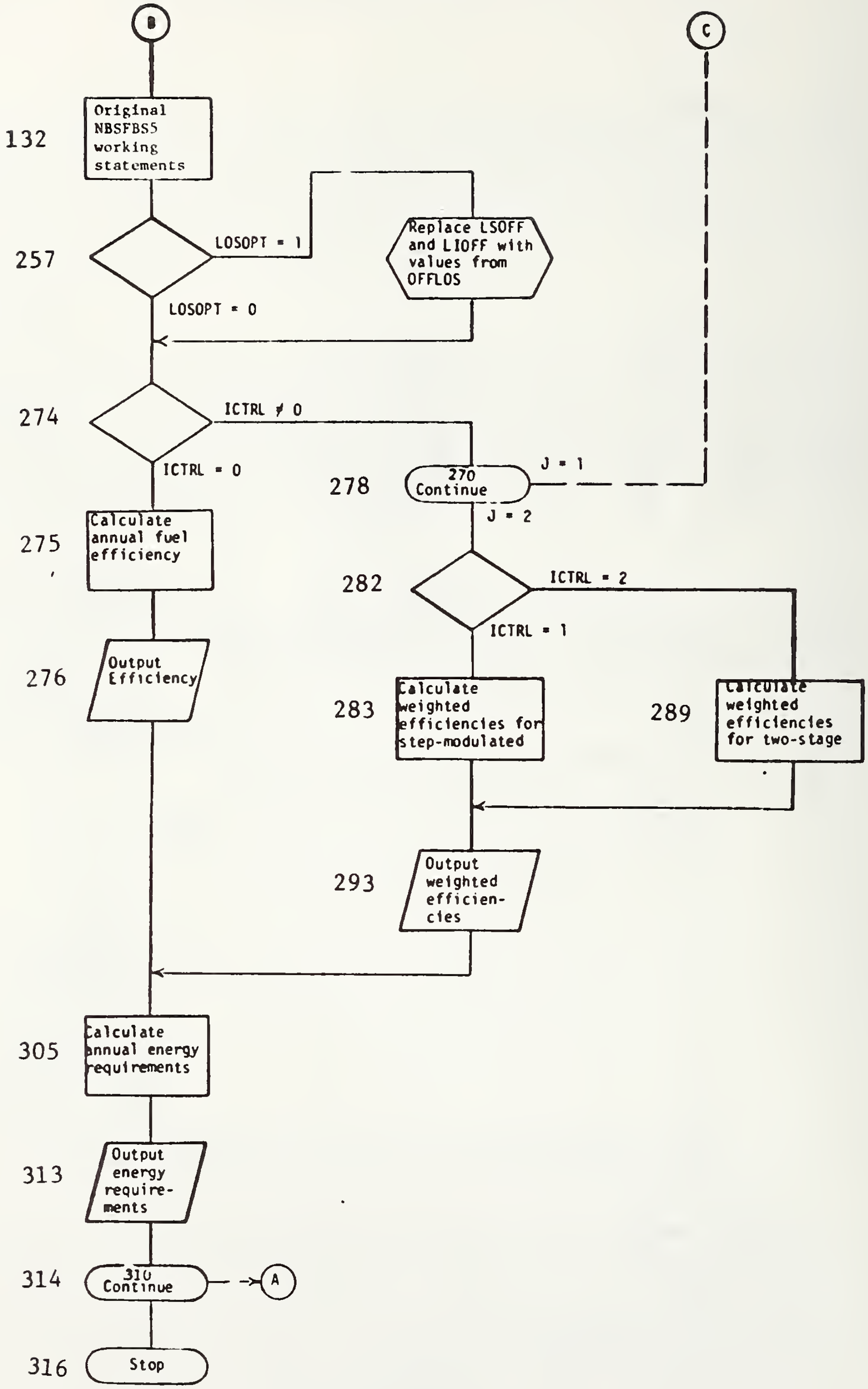


Figure C1 (cont)

Figure C2. Main program and subroutine listings; main program FBVH

```
HTRS*BOIL6A(1).FBVH(3)
C       PROGRAM FOR THE EVALUATION OF FURNACE/BOILER/VENTED HEATER
C       SYSTEMS WITH SINGLE, TWO-STAGE, OR STEP-MODULATED INPUT.
C       THIS PROGRAM IS BASED ON THE ORIGINAL PROGRAM NBSFBVH
C       (BOIL6) DEVELOPED IN 1978 BY KELLY,CHI,AND KUKLEWICZ.
C       WHILE MAINTAINING THE STRUCTURE OF BOIL6, THE PRESENT
C       PROGRAM PERMITS THE USE OF TRACER GAS MEASUREMENTS IN
C       DETERMINING OFF-CYCLE LOSSES, AND HANDLES HEATING EQUIP-
C       MENT WITH SINGLE, TWO-STAGE, OR STEP-MODULATED INPUT.
C
        DIMENSION TITLE(20,2),CONC(20),TS(20),CONCM(20),TSM(20)
        DATA PHI,REFTRM /0.7,70./
C
C       INPUT NUMBER OF DATA SETS
C
        WRITE (6,500)
        READ (5,*) NRUN
        DO 310 I=1,NRUN
C
C       INITIALIZE COUNTER AND HIGH-FIRE VARIABLES
C
        NPASS=1
        QSOFFH=0.
        QIOFFH=0.
        QSOFFM=0.
        QIOFFM=0.
        QINH=0.
        EFYSSH=0.
        EFFYUH=0.
        QIONH=0.
C
C       I/O SYSTEM PARAMETERS
C
        READ (5,510) TITLE
        WRITE (6,520) ((TITLE(II,JJ),II=1,20),JJ=1,2)
        READ (5,*) IFB,INST,ICTRL,LOSOPT
        IF (IFB.EQ.1) WRITE (6,530)
        IF (IFB.EQ.2) WRITE (6,540)
        IF (IFB.EQ.3) WRITE (6,550)
        IF (INST.EQ.1) WRITE (6,560)
        IF (INST.EQ.2) WRITE (6,570)
        IF (ICTRL.EQ.0) WRITE (6,580)
        IF (ICTRL.EQ.1) WRITE (6,590)
        IF (ICTRL.EQ.2) WRITE (6,600)
        IF (LOSOPT.EQ.0) WRITE (6,610)
        IF (LOSOPT.EQ.1) WRITE (6,620)
C
C       I/O DATA FOR MAXIMUM FIRING RATE AND CALL SENLOS
C
        READ (5,*) NSYS,IFUEL,HHV,QIN,QP,PE,BE,XCO2S
        WRITE (6,630) NSYS,IFUEL,HHV,QIN,QP,PE,BE,XCO2S
        READ (5,*) TSSSX,XCO2F,TFSS,TFON1,TFON2,TFOFF3,TFOFF4,TFOFF5
        WRITE (6,640) TSSSX,XCO2F,TFSS,TFON1,TFON2,TFOFF3,TFOFF4,TFOFF5
        READ (5,*) TRA,QJ,SFR,DF,DS,Y
        CALL SENLOS (IFUEL,NSYS,XCO2S,TSSSX,XCO2F,TFSS,HHVA,AFR,QL,RT,
       2 QSSS,EFFYSS,TRA,IFB,SFR)
        WRITE (6,650) TRA,QJ,SFR,DF,DS,Y
        READ (5,*) TON,TOFF,TOA
        WRITE (6,660) TON,TOFF,TOA
        PF=QP/QIN
        CJ=3.3
        IF (IFB.EQ.2) CJ=4.7
        IF (INST.EQ.1) CJ=0.
C
C       I/O DATA FOR MINIMUM FIRING RATE, CALL SENLOS AND WEIGHT
C
        IF (ICTRL.EQ.0) GO TO 10
        NPASS=2
        READ (5,*) QINM,XCO2SM
        WRITE (6,670) QINM,XCO2SM
        READ (5,*) TSSSXM,XCO2FM,TFSSM,TFON1M,TFON2M,TFOF3M,TFOF4M,TFOF5M
        WRITE (6,640) TSSSXM,XCO2FM,TFSSM,TFON1M,TFON2M,TFOF3M,TFOF4M,
       2 TFOF5M
        READ (5,*) TRAM,SFRM,DFM,DSM
        CALL SENLOS (IFUEL,NSYS,XCO2SM,TSSSXM,XCO2FM,TFSSM,HHVA,AFR,QL,
       2 RTM,QSSSM,EFYSSM,TRAM,IFB,SFRM)
```

```
      WRITE (6,680) TRAM,SFRM,DFM,DSM
      CALL WEIGHT (QIN,EFFYSS,QINM,EFYSSM,RLOW,TOALO,TOAHI)
      RHIGH=1.-RLOW
      WRITE (6,690) RLOW,RHIGH,TOALO,TOAHI
      TOA=TOAHI
C
C     I/O TRACER GAS DATA AND CALCULATED OFF-CYCLE LOSS IF LOSOPT=1
C
10    IF (LOSOPT.EQ.0) GO TO 20
      READ (5,*) (CONC(J),TS(J),J=1,20),CONCI,VTTT,TROOM
      CALL OFFLOS (CONC,TS,CONCI,VTTT,TROOM,TOA,QIN,QSOFFH,QIOFFH)
      WRITE (6,700) (CONC(J),J=1,10),(TS(J),J=1,10),(CONC(J),J=11,20),
     2 (TS(J),J=11,20),CONCI,VTTT,TROOM,QSOFFH,QIOFFH
      IF (ICTRL.EQ.0) GO TO 20
      READ (5,*) (CONCM(J),TSM(J),J=1,20),CONCIM,VTTTM,TROOMM
      CALL OFFLOS (CONCM,TSM,CONCIM,VTTTM,TROOMM,TOALO,QINM,QSOFFM,
     2 QIOFFM)
      WRITE (6,710) (CONCM(J),J=1,10),(TSM(J),J=1,10),(CONCM(J),J=11,20)
     2 ,(TSM(J),J=11,20),CONCIM,VTTTM,TROOMM,QSOFFM,QIOFFM
20    WRITE (6,720)
C
C     LOOP THRU BOIL6 WORKING CALCULATIONS NPASS TIMES
C
      DO 270 J=1,NPASS
      IF (J.EQ.1) GO TO 30
C
C     HOLD NECESSARY VARIABLES FOR MODULATING AND TWO STAGE CALCULATIONS
C
      QINH=QIN
      EFYSSH=EFFYSS
      EFFYUH=EFFYU
      QIONH=QION
C
C     REPLACE MAXIMUM FIRE VARIABLES WITH MINIMUM FIRE VARIABLES
C
      QIN=QINM
      TFSS=TFSSM
      TFON1=TFON1M
      TFON2=TFON2M
      TFOFF3=TFOF3M
      TFOFF4=TFOF4M
      TFOFF5=TFOF5M
      TRA=TRAM
      SFR=SFRM
      DF=DFM
      DS=DSM
      RT=RTM
      QSSS=QSSSM
      EFFYSS=EFYSSM
      TOA=TOALO
      WRITE (6,730)
30    REFTOA=TOA
      WRITE (6,740) PF,HHVA,AFR,QL,CJ,RT,QSSS,EFFYSS
C
C      *** COLUMNS 31 THROUGH 43 IN NBSIR 78-1543 ***
C
      TSSS=(TFSS-TRA)/SFR+TRA
      IF (IFB.EQ.2) GO TO 40
      C1=2.
      C2=0.5
      C3=7.5
      C4=1.5
      GO TO 50
40    C1=4.5
      C2=1.
      C3=18.75
      C4=3.75
50    IF (TFSS.EQ.TFON1.AND.TFSS.EQ.TFON2) GO TO 60
      TAON=C1/ALOG((TFSS-TFON1)/(TFSS-TFON2))
      ZETFOX=(TFSS-TFON1)*EXP(C2/TAON)
      GO TO 70
60    TAON=0.
      ZETFOX=0.
70    CONTINUE
      TAOFF=C3/ALOG((TFOFF3-TFOFF5)/(TFOFF4-TFOFF5))
```

Figure C2 (cont)

```
      SIFOX=(TFOFF3-TFOFF5)*EXP(C4/TAOFF)
      SIFIX=TFOFF5-TRA
      IF (NSYS.GT.8) GO TO 90
      IF (NSYS.GT.4.AND.DS.LE.(DF/SFR)) GO TO 80
      DSF=DF/(SFR*DS)
      SISIX=DSF*SIFIX
      SISOX=DSF*SIFOX
      GO TO 100
   80 SISIX=SIFIX
      SISOX=SIFOX
      GO TO 100
   90 SISIX=0.
      SISOX=0.
  100 CS=1.+(REFTRM-REFTOA)*EFFYSS/(100.*(TFSS-REFTRM))
      IF (NSYS.LT.9) CS=0.
      CSON=24.*(1.+RT*AFR)/HHVA
      IF (NSYS.GT.8) GO TO 120
      IF (NSYS.GT.4) GO TO 110
      CSOFF=DF*CSON*(TFSS+460.+REFTRM-TRA)**1.19/(TFSS-TRA)**0.56
      GO TO 130
  110 CSOFF=DS*SFR*CSON*(TSSS+460.+REFTRM-TRA)**1.19/(TSSS-TRA+REFTRM-
     2 REFTOA)**0.56
      GO TO 130
  120 CSOFF=DF*CSON*(TFSS+460.+REFTRM-TRA)**1.19/(TFSS-TRA+REFTRM-
     2 REFTOA)**0.56
  130 IF (NSYS.GT.8) GO TO 140
      CION=PHI*SFR*CSON
      CIOFF=DS*CION*(TSSS-TRA+530.)**1.19/(TSSS-TRA+REFTRM-REFTOA)**0.56
      GO TO 150
  140 CION=0.
      CIOFF=0.
  150 WRITE (6,750) TSSS,TAON,ZETFOX,TAOFF,SIFOX,SIFIX,SISIX,SISOX
      WRITE (6,760) CS,CSON,CSOFF,CION,CIOFF
C
C      *** COLUMNS 44 THROUGH 53 IN NBSIR 78-1543 ***
C
      IF ((HHV/HHVA).LE.0.95) WRITE (6,770)
      IF ((HHV/HHVA).GE.1.05) WRITE (6,780)
      IF (TFSS.EQ.TFON1.AND.TFSS.EQ.TFON2) GO TO 160
      TTON=TON/TAON
      GO TO 170
  160 TTON=10.**20
  170 TTOFF=TOFF/TAOFF
      FON=SIFOX*EXP(-TTOFF)/(TFSS-TFOFF5)
      FOFF=ZETFOX*EXP(-TTON)/(TFSS-TFOFF5)
      FONOF=1.-FON*FOFF
      FFON=(1.-FON)/FONOF
      FFOFF=(1.-FOFF)/FONOF
C      *** CII=.90 IF IID EQUIPPED UNIT ***
      IF (QP.LT.0.1) FFOFF=FFOFF*.90
      IF (NSYS.GT.8) GO TO 180
      ZETFO=FFON*ZETFOX
      SIFO=FFOFF*SIFOX
      SIFI=SIFIX
      SISO=FFOFF*SISOX
      SISI=SISIX
      GO TO 190
  180 ZETFO=CS*FFON*ZETFOX
      SIFO=1.22*SIFOX*FFOFF
      SIFI=1.22*SIFIX
      SISO=0.
      SISI=0.
  190 WRITE (6,790) TOA,TON,TOFF,TTON,TTOFF,ZETFO,SIFO,SIFI
C
C      *** COLUMNS 54 THROUGH  59 IN N8SIR 78-1543 ***
C
      IF (NSYS.GT.8) GO TO 210
      IF (NSYS.GT.4) GO TO 200
      N=4
      CALL FUNT4 (N,SIFO,TTOFF,REFTOA,REFTRM,F3,F4)
      F5=0.
      F6=0.
      N=8
      CALL FUNT4 (N,SISO,TTOFF,REFTOA,REFTRM,F7,F8)
      QSON=QSSS-CSON*ZETFO*(1.-EXP(-TTON))/TTON
```

Figure C2 (cont)

```
      QSOFF=CSOFF*(F3+SIFI*F4)*TOFF/TON
      QION=CION*(REFTRM-REFTOA)
      QIOFF=CIOFF*(REFTRM-REFTOA)*(F7+SISI*F8)*TOFF/TON
      GO TO 220
200   CONTINUE
      F3=0.
      F4=0.
      N=6
      CALL FUNT4 (N,SISO,TTOFF,REFTOA,REFTRM,F5,F6)
      N=8
      CALL FUNT4 (N,SISO,TTOFF,REFTOA,REFTRM,F7,F8)
      QSON=QSSS-CSON*ZETFO*(1.-EXP(-TTON))/TTON
      QSOFF=CSOFF*(F5+SISI*F6)*TOFF/TON
      QION=CION*(REFTRM-REFTOA)
      QIOFF=CIOFF*(REFTRM-REFTOA)*(F7+SISI*F8)*TOFF/TON
      GO TO 220
210   CONTINUE
      F3=0.
      F4=0.
      F7=0.
      F8=0.
      N=6
      CALL FUNT4 (N,SIFO,TTOFF,REFTOA,REFTRM,F5,F6)
      QSON=CS*QSSS-CSON*ZETFO*(1.-EXP(-TTON))/TTON
      QSOFF=CSOFF*(F5+SIFI*F6)*TOFF/TON
      QION=0.
      QIOFF=0.
220   CONTINUE
C
C     USE MEASURED VALUES FOR OFF-CYCLE LOSS IF LOSOPT=1
C
      IF (LOSOPT.EQ.0) GO TO 240
      IF (J.EQ.2) GO TO 230
      QSOFF=QSOFFH
      QIOFF=QIOFFH
      GO TO 240
230   QSOFF=QSOFFM
      QIOFF=QIOFFM
240   IF (NSYS.GT.8) QIOFF=0.
C
C     FINISH UP BOIL6 CALCULATIONS
C
      IF (INST.EQ.2) GO TO 250
      EFFYU=100.-QL-TON*(QSON+QSOFF+QION+QIOFF)/(TON+PF*TOFF)
      GO TO 260
250   EFFYU=100.-QL-CJ*QJ-TON*(QSON+QSOFF)/(TON+PF*TOFF)
260   WRITE (6,800) SISO,SISI,F3,F4,F5,F6,F7,F8
      WRITE (6,810) QSON,QSOFF,QION,QIOFF,EFFYU
      IF (ICTRL.GE.1) GO TO 270
      EFFYA=EFFYU*EFFYSS*4400/(EFFYSS*4400+2.5*EFFYU*PF*4600)
      WRITE (6,820) EFFYA
      GO TO 300
270   CONTINUE
C
C     CALCULATE WEIGHTED EFFICIENCIES FOR MODULATING AND TWO-STAGE
C
      IF (ICTRL.EQ.2) GO TO 280
      EFYSSA=(EFYSSH+EFYSSM)/2.
      QIONA=(QIONH+QION)/2.
      EFYU=EFYSSA-QIONA
      EFYUW=EFYU*RHIGH+EFFYU*RLOW
      EFYSSW=EFYSSA*RHIGH+EFYSSM*RLOW
      GO TO 290
280   EFYUW=EFFYUH*RHIGH+EFFYU*RLOW
      EFYSSW=EFYSSH*RHIGH+EFYSSM*RLOW
      EFYU=EFFYUH
290   EFFYAW=EFYUW*EFYSSW*4400/(EFYSSW*4400+2.5*EFYUW*PF*4600)
      WRITE (6,830) EFYU,EFFYU,EFYUW
      WRITE (6,840) EFYSSH,EFYSSM,EFYSSW
      WRITE (6,850) EFFYAW
C
C     RELOAD HIGH-FIRE VARIABLES
C
      QIN=QINH
      EFFYSS=EFYSSH
```

Figure C2 (cont)

```
      EFFYU=EFYUW
C
C     CALCULATE ANNUAL FUEL REQUIREMENTS
C
300   A=100000./(341300.*(PE+Y*BE)+(QIN-QP)*EFFYU)
      B=2.*A*QP*EFFYU/100000.
      IF (QP.LT.0.1) B=0.
      C=0.38
      DHR=EFFYSS*QIN/100000.
      80H=2080.*(A*C*DHR-8)
      AFUEL=(QIN-QP)*80H+8760.*QP
      AELEC=(PE+Y*BE)*80H
      WRITE (6,860) AFUEL,AELEC
310   CONTINUE
      WRITE (6,870)
      STOP
C
C     FORMAT STATEMENTS
C
500   FORMAT (/5X,31HINPUT DATA -- @ADD FILE.ELEMENT/)
510   FORMAT (20A4)
520   FORMAT (//2(5X,20A4/))
530   FORMAT (/5X,7HFURNACE)
540   FORMAT (/5X,6HBOILER)
550   FORMAT (/5X,13HVENTED HEATER)
560   FORMAT (5X,16HINSTALLED INDOOR)
570   FORMAT (5X,17HINSTALLED OUTDOOR)
580   FORMAT (5X,18HSINGLE STAGE INPUT)
590   FORMAT (5X,20HSTEP MODULATED INPUT)
600   FORMAT (5X,15HTWO STAGE INPUT)
610   FORMAT (5X,30HASSIGNED VALUES FOR OFF-LOSSES)
620   FORMAT (5X,30HMEASURED VALUES FOR OFF-LOSSES)
630   FORMAT (///5X,13HINPUT VALUES //5X,6H1)NSYS4X,7H2)IFUEL3X,
     2 5H3)HHV5X,5H4)QIN5X,4H5)QP6X,4H6)PE6X,4H7)BE6X,7H8)XCO2S/I7,I10,
     3 6X,8(1PE10.2))
640   FORMAT (/5X,6H9)TSSS4X,8H10)XCO2F2X,7H11)TFSS3X,8H12)TFON12X,
     2 8H13)TFON22X,9H14)TFOFF31X,9H15)TFOFF41X,9H16)TFOFF5/3X,
     3 8(1PE10.2))
650   FORMAT (/5X,6H17)TRA4X,5H18)QJ5X,6H19)S/F4X,5H20)DF5X,5H21)DS,5X,
     2 8H22)Y     /3X,8(1PE10.2))
660   FORMAT (/5X,4HTON=F6.2,4X,5HTOFF=F6.2,5X,4HTOA=F5.1)
670   FORMAT (///5X,47HADDITIONAL INPUT VALUES FOR MINIMUM FIRING RATE//
     2 5X,6H1)NSYS4X,7H2)IFUEL3X,5H3)HHV5X,5H4)QIN5X,4H5)QP6X,4H6)PE6X,
     3 4H7)BE6X,7H8)XCO2S/3(7X,3H---),3X,1PE10.2,4X,3H---,2(7X,3H---),
     4 3X,1PE10.2)
680   FORMAT (/5X,6H17)TRA4X,5H18)QJ5X,6H19)S/F4X,5H20)DF5X,5H21)DS,5X,
     2 8H22)Y     /3X,1PE10.2,4X,3H---,3X,3(1PE10.2),4X,3H---)
690   FORMAT (//5X,49HFRACTION OF TIME IN LOW FIRE/CYCLING MODE       = ,
     2 F5.3/5X,49HFRACTION OF TIME IN HIGH FIRE/NON-CYCLING MODE = F5.3/
     3 5X,40HOUTDOOR AIR TEMP FOR CYCLING MODE      = F6.2/5X,
     4 40HOUTDOOR AIR TEMP FOR NON-CYCLING MODE = F6.2)
700   FORMAT (///5X,22HFLUE LOSS MEASUREMENTS//
     2 63H TIME     0-1     1-2     2-3     3-4     4-5     5-6     6-7     7-8
     3 13H  8-9     9-10/6H CONC 10(1X,F6.1)/6H TEMP 10(1X,F6.1)//
     4 63H TIME    10-11   11-12   12-13   13-14   14-15   15-16   16-17   17-18
     5 13H 18-19   19-20/6H CONC 10(1X,F6.1)/6H TEMP 10(1X,F6.1)//5X,
     6 26HINITIAL CONC(ENTRATION) = 1PE10.2/5X,
     7 27HMETER VOLUME/BUBBLE TIME = 1PE10.2/5X,
     8 24HTEST ROOM TEMPERATURE = 1PE10.2//5X,
     9 17HQSOFF MEASURED = 1PE10.2/5X,17HQIOFF MEASURED = 1PE10.2)
710   FORMAT (//5X,19HMINIMUM FIRE VALUES//
     2 63H TIME     0-1     1-2     2-3     3-4     4-5     5-6     6-7     7-8
     3 13H  8-9     9-10/6H CONC 10(1X,F6.1)/6H TEMP 10(1X,F6.1)//
     4 63H TIME    10-11   11-12   12-13   13-14   14-15   15-16   16-17   17-18
     5 13H 18-19   19-20/6H CONC 10(1X,F6.1)/6H TEMP 10(1X,F6.1)//5X,
     6 26HINITIAL CONC(ENTRATION) = 1PE10.2/5X,
     7 27HMETER VOLUME/BUBBLE TIME = 1PE10.2/5X,
     8 24HTEST ROOM TEMPERATURE = 1PE10.2//5X,
     9 17HQSOFF MEASURED = 1PE10.2/5X,17HQIOFF MEASURED = 1PE10.2)
720   FORMAT (///5X,18HCALCULATED VALUES-/)
730   FORMAT (///5X,40HCALCULATED VALUES -- MINIMUM FIRING RATE/)
740   FORMAT (/5X,5H23)PF5X,7H24)HHVA3X,6H25)A/F4X,5H26)QL5X,5H27)CJ5X,
     2 5H28)RT5X,7H29)QSSS3X,9H30)EFFYSS/3X,8(1PE10.2))
750   FORMAT (/5X,7H31)TSSS3X,8H32)TAUON2X,9H33)ZETFOX1X,9H34)TAUOFF,1X,
     2 9H35)PSIFOX1X,9H36)PSIFIX1X,9H37)PSISIX1X,9H38)PSISOX/3X,
```

Figure C2 (cont)

```
         3 8(1PE10.2))
  760     FORMAT (/5X,5H39)CS5X,7H40)CSON3X,8H41)CSOFF2X,7H42)CION3X,
         2 8H43)CIOFF/3X,5(1PE10.2))
  770     FORMAT (///5X,46H*** WARNING-HEATING VALUE OF TEST FUEL IS TOO ,
         2 7HLOW ***///)
  780     FORMAT (///5X,46H*** WARNING-HEATING VALUE OF TEST FUEL IS TOO ,
         2 8HHIGH ***///)
  790     FORMAT (/5X,6H44)TOA4X,6H45)TON4X,7H46)TOFF3X,7H47)TTON3X,
         2 8H48)TTOFF,2X,8H49)ZETFO2X,8H50)PSIFO2X,8H51)PSIFI/3X,
         3 8(1PE10.2))
  800     FORMAT (/5X,8H52)PSISO2X,8H53)PSISI2X,5H54)F35X,5H55)F45X,
         2 5H56)F55X,5H57)F65X,5H58)F75X,5H59)F8/3X,8(1PE10.2))
  810     FORMAT (/5X,7H60)QSON3X,8H61)QSOFF2X,7H62)QION3X,8H63)QIOFF2X,
         2 8H64)EFFYU/3X,5(1PE10.2))
  820     FORMAT (///5X,25HANNUAL FUEL EFFICIENCY = F6.2)
  830     FORMAT (///5X,36HPART-LOAD EFFICIENCY -- HIGH FIRE = F6.2/5X,
         2 35HPART-LOAD EFFICIENCY -- LOW FIRE = F6.2/5X,
         3 40HWEIGHTED AVERAGE PART-LOAD EFFICIENCY = F6.2)
  840     FORMAT (/5X,39HSTEADY-STATE EFFICIENCY -- HIGH FIRE = F6.2/5X,
         2 38HSTEADY-STATE EFFICIENCY -- LOW FIRE = F6.2/5X,
         3 43HWEIGHTED AVERAGE STEADY-STATE EFFICIENCY = F6.2)
  850     FORMAT (/5X,42HWEIGHTED AVERAGE ANNUAL FUEL EFFICIENCY = F6.2)
  860     FORMAT (5X,33HANNUAL FUEL ENERGY CONSUMPTION = 1PE10.3,1X,3HBTU/
         2 5X,39HANNUAL ELECTRICAL ENERGY CONSUMPTION = 1PE10.3,1X,3HBTU)
  870     FORMAT (///5X,16HPROGRAM COMPLETE//)
          END
```

Subroutine WEIGHT

```
HTRS*BOIL6A(1).WEIGHT(3)
          SUBROUTINE WEIGHT(QIN,EFFYSS,QINM,EFYSSM,RLOW,TOALO,TOAHI)
    C
    C     SUBROUTINE TO DETERMINE THE FRACTION OF HEATING SEASON IN
    C     MINIMUM FIRE/CYCLING MODE AND IN MAXIMUM FIRE/NON-CYCLING
    C     MODE,AS WELL AS THE CORRESPONDING OUTDOOR AIR TEMPERATURE
    C     FOR EACH MODE,I.E.,TOALO AND TOAHI
    C
          DIMENSION RLO(9),TOAL(9),TOAH(9)
          DATA RLO/0.01,0.09,0.21,0.33,0.45,0.57,0.69,0.81,0.89/
          DATA TOAL/59.4,57.9,55.2,53.0,51.1,49.5,47.7,45.9,45.0/
          DATA TOAH/42.1,40.6,38.2,36.1,33.9,31.6,28.6,24.3,21.7/
    C
          HIMAX=QIN*EFFYSS/100.
          HIMIN=QINM*EFYSSM/100.
          RATIC=HIMIN/HIMAX
          N=0
    C
    C     ASSIGN VALUES FOR RLOW, TOALO, AND TOAHI
    C
          IF(RATIO.LE.0.15) N=1
          IF(RATIO.LE.0.26.AND.RATIO.GT.0.15) N=2
          IF(RATIO.LE.0.35.AND.RATIO.GT.0.26) N=3
          IF(RATIO.LE.0.43.AND.RATIO.GT.0.35) N=4
          IF(RATIO.LE.0.50.AND.RATIO.GT.0.43) N=5
          IF(RATIO.LE.0.57.AND.RATIO.GT.0.50) N=6
          IF(RATIO.LE.0.66.AND.RATIO.GT.0.57) N=7
          IF(RATIO.LE.0.79.AND.RATIO.GT.0.66) N=8
          IF(RATIO.GT.0.79) N=9
          RLOW=RLO(N)
          TOALO=TOAL(N)
          TOAHI=TOAH(N)
          RETURN
          END
```

Figure C2 (cont)

Subroutine SENLOS

```
HTRS*BOIL6A(1).SENLOS(1)
              SUBROUTINE SENLOS(IFUEL,NSYS,XCO2S,TSSSX,XCO2F,TFSS,HHVA,AFR,QL,RT
             *,QSSS,EFFYSS,TRA,IF8,SFR)
        C      ***CALCULATION  OF HHVA AFR QL RT QSSS EFFYSS ***
        C      ***APRIL 1978*** FOR USE WITH N8SF8S 5 ***
              DIMENSION HHV(6),AF(6),Q(6),ART(6),BRT(6),CA(5),CF(6,5)
              DATA (HHV(J),J=1,6)/19800.,19500.,20120.,18500.,21500.,20890./
              DATA (AF(J),J=1,6)/14.56,14.49,14.45,11.81,15.58,15.36/
              DATA (Q(J),J=1,6)/6.55,6.50,9.55,10.14,7.99,7.79/
              DATA (ART(J),J=1,6)/.0679,.06668,.09194,.09646,.0841,.0808/
              DATA (BRT(J),J=1,6)/14.22,14.34,10.96,10.10,12.60,12.93/
              DATA (CA(J),J=1,5)/2.5462121E-1,-3.0260126E-5,2.7608571E-8,-7.4253
             *321E-12,6.4307377E-16/
              DATA (CF(1,K),K=1,5)/2.4416834E-01,3.3711449E-6,8.8906305E-9,-1.36
             *19019E-12,-1.4367410E-16/
              DATA (CF(2,K),K=1,5)/2.4361163E-1,3.6702686E-6,8.7098897E-9,-1.309
             *4378E-12,-1.5029209E-16/
              DATA (CF(3,K),K=1,5)/2.5949478E-01,-4.9475802E-06,1.3885838E-8,-2.
             *8059994E-12,3.7682444E-17/
              DATA (CF(4,K),K=1,5)/2.6598442E-1,-7.7561435E-6,1.5833852E-8,-3.41
             *94210E-12,1.2158977E-16/
              DATA (CF(5,K),K=1,5)/2.5163639E-1,-6.4144604E-7,1.1315073E-8,-2.06
             *56792E-12,-5.4897330E-17/
              DATA (CF(6,K),K=1,5)/2.5011247E-1,1.7737005E-7,1.0820337E-8,-1.922
             *0641E-12,-7.3013274E-17/
              HHVA=HHV(IFUEL)
              AFR=AF(IFUEL)
              QL=Q(IFUEL)
              RT=(BRT(IFUEL)/XCO2F)+ART(IFUEL)
              XCO2=XCO2F
              TSS=TFSS+459.69
        C      *** SFR TEST ONLY FOR VENTED HEATERS WITH DRAFT HOODS ***
              IF(IFB.NE.3.OR.XCO2S.LT.0.1) GO TO 30
              RTS= (BRT(IFUEL)/XCO2S)+ ART(IFUEL)
              CALSFR = 1.3*(RTS/RT)
              SFR = CALSFR
        30    IF(XCO2S.LT.0.1.OR.TSSSX.LT.0.1) GO TO 50
              XCO2=XCO2S
              TSS=TSSSX+459.69
        50    CONTINUE
              RTX=ART(IFUEL)+(BRT(IFUEL)/XCO2)
              QF=0.
              QA=0.
              DO 100 I=1,5
              QF=QF+CF(IFUEL,I)*(TSS**I-(TRA+459.69)**I)
        100   QA=QA+CA(I)*(TSS**I-(TRA+459.69)**I)
              QSSS=(1.+AFR)*QF+(RTX-1.)*AFR*QA
              QSSS=100.*QSSS/HHVA
              EFFYSS=100.-QL-QSSS
              RETURN
              END
```

Subroutine OFFLOS

```
HTRS*BOIL6A(1).OFFLOS(2)
              SUBROUTINE OFFLOS(CONC,TS,CONCI,VTTT,TROOM,TOA,QIN,QSOFF,QIOFF)
        C
        C     SUBROUTINE TO CALCULATE OFF-CYCLE FLUE LOSSES BASED ON MEASURED
        C     VALUES OF TRACER GAS CONCENTRATION AND STACK TEMPERATURE
        C
              DIMENSION CONC(20),TS(20)
              OFFLS=0.0
              OFFLI=0.0
              DO 10 J=1,20
              RATIO=(CONCI-CONC(J))/CONC(J)
              FLOW=0.01*VTTT*RATIO/60.
              OFFLS=OFFLS+0.24*FLOW*(TS(J)-TROOM)
              OFFLI=OFFLI+0.24*FLOW*(70.0-TOA)
        10    CONTINUE
              QSOFF=300.*OFFLS/QIN
              QIOFF=300.*1.3*0.7*OFFLI/QIN
              RETURN
              END
```

Figure C2 (cont)

```
HTRS*BOIL6A(1).FUNT4(1)
      SUBROUTINE FUNT4(N,SI,TTOFF,REFTOA,REFTRM,FI,FJ)
      T1=REFTRM-REFTOA
      C1=1.
      T2=REFTRM+460.
      IF(N.EQ.4) T1=0.
      IF(N.EQ.8) C1=0.0
      X=0.
      FI =0.
      FJ =0.
      DX =TTOFF /500.
      FF11=(SI+T1)**0.56*SI**C1/(SI+T2)**1.19
      FF21=(SI+T1+100.)**0.56*(SI+100.)**C1/(SI+T2+100.)**1.19
      DO 100 I=1,250
      X=X+DX
      XX=SI *EXP(-X)
      FF12=(XX+T1)**0.56*XX**C1/(XX+T2)**1.19
      FF22=(XX+T1+100.)**0.56*(XX+100.)**C1/(XX+T2+100.)**1.19
      X=X+DX
      XX=SI *EXP(-X)
      FF13=(XX+T1)**0.56*(XX)**C1/(XX+T2)**1.19
      FF23=(XX+T1+100.)**0.56*(XX+100.)**C1/(XX+T2+100.)**1.19
      FI =FI +(FF11+4.*FF12+FF13)
      FJ =FJ +(FF21+4.*FF22+FF23)
      FF11=FF13
  100 FF21=FF23
      IF((ABS(FJ-FI )).LE.0.0000001) GO TO 110
      FJ =(FJ -FI )/(100.*TTOFF )
      FJ =DX *FJ /3.
      GO TO 120
  110 FJ =0.
  120 FI =FI *DX /(3.*TTOFF )
      RETURN
      END
```

Figure C2 (cont)

Figure C3. Input data format for FBVH

Line 1: NRUN (integer)

NRUN = number of sets of test data to be analyzed. Lines 2 through 53 should be repeated NRVN times in the stored data file/element

Line 2: TITLE

TITLE = one to 80 alphanumeric characters describing the test conditions/data

Line 3: SUBTITLE

SUBTITLE = one to 80 alphanumeric characters describing the test conditions/data

Line 4: IFB, INST, ICTRL, LOSOPT (all integers)

IFB = 1 for furnaces
= 2 for boilers
= 3 for vented heaters

INST = 1 for vented heating equipment installed indoors
= 2 for vented heating equipment installed outdoors and floor furnaces

ICTRL = 0 for single stage controls
= 1 for step modulating controls
= 2 for two stage controls

LOSOPT = 0 for analytic determination of off-cycle stack losses (method used in References 1 and 4)
= 1 for determination of off-cycle stack losses from tracer gas technique (see Reference 6)

Line 5: NSYS, IFUEL, HHV, QP, PE, BE, XCO25
Line 6: TSSS, XCO2F, TFSS, TFON1, TFON2, TFOFF3, TFOFF4, TFOFF5
Line 7: TRA, QJ, SFR, DF, DS, Y

Measured quantities/assigned values defined in Reference 4, evaluated at maximum firing rate

Line 8: TON, TOFF, TOA

$$\left.\begin{array}{l}\text{TON} = 20 \text{ min}\\ \text{TOFF} = 20 \text{ min}\\ \text{TOA} = 45°\text{F}\end{array}\right\} \text{ For Vented Heaters}$$

See Reference 4 for values for other types of heating equipment.

OMIT LINES 9-11 for single stage controls (ICTRL = 0)

Line 9: QINM, XCO2SM

Line 10: TSSSM, XCO2FM, TFSSM, TFON1M, TFON2M, TFOF3M, TFOF4M, TFOF5M

Line 11: TRAM, SFRM, DFM, DSM

Measured quantities/assigned values evaluated at minimum firing rate

OMIT LINES 12-53 for Analytic Determination of Off-Cycle Losses (LOSOPT = 0)

Lines 12-31· CONC, TS

CONC = measured concentration of tracer gas in sample taken from stack, PPM
TS = measured stack gas temperature, °F

Twenty sets of concentration and temperature measurements for a cooldown following steady state operation at <u>maximum</u> fire. For more details on tracer measurements see Reference 3.

Line 32: CONCI, VTTT, TROOM

CONCI = concentration of active traver gas in the tracer gas in PPM, eg., for a carbon monoxide/nitrogen tracer gas mixture consisting of 50.8 percent carbon monoxide, CT = 508,000 PPM

VTTT = volumetric flow rate of tracer gas, cm^3/sec

TROOM = test room temperature, °F
Values for test at maximum firing rate.

OMIT LINES 33-53 For Single Stage Controls (ICTRL = 0)

Lines 33-52: CONCM TSM
Twenty sets of concentration and temperature measurement for a cooldown following steady state operation at <u>minimum</u> fire.

Line 53: CONCIM, VTTTM, TROOMM

Values for test at minimum firing rate.

Figure C3 (cont)

Figure C4. Input data form for FBVH

FBVH DATA	RUN #	DATE

	LINE #								
	1	NRUN							
	2	TITLE							
	3	SUBTITLE							
	4	IFB	INST	ICTRL	LOSOPT				
MAXIMUM INPUT	5	NSYS	IFUEL	HHV	QIN	QP	PE	BE	XCO2S
MAXIMUM INPUT	6	TSSS	XCO2F	TFSS	TFON1	TFON2	TFOFF3	TFOFF4	TFOFF5
MAXIMUM INPUT	7	TRA	QJ	SFR	DF	DS	Y		
	8	TON	TOFF	TOA					
MINIMUM INPUT	9	QINM	XCO2SM						
MINIMUM INPUT	10	TSSSM	XCO2FM	TFSSM	TFON1M	TFON2M	TFOF3M	TFOF4M	TFOF5M
MINIMUM INPUT	11	TRAM	SFRM	DFM	DSM				

MAXIMUM INPUT

LINE #	TIME	CONC	TS
12	0-1		
13	1-2		
14	2-3		
15	3-4		
16	4-5		
17	5-6		
18	6-7		
19	7-8		
20	8-9		
21	9-10		
22	10-11		
23	11-12		
24	12-13		
25	13-14		
26	14-15		
27	15-16		
28	16-17		
29	17-18		
30	18-19		
31	19-20		
	CONCI	VTTT	TROOM
32			

MINIMUM INPUT

LINE #	TIME	CONCM	TSM
33	0-1		
34	1-2		
35	2-3		
36	3-4		
37	4-5		
38	5-6		
39	6-7		
40	7-8		
41	8-9		
42	9-10		
43	10-11		
44	11-12		
45	12-13		
46	13-14		
47	14-15		
48	15-16		
49	16-17		
50	17-18		
51	18-19		
52	19-20		
	CONCIM	VTTTM	TROOMM
53			

```
@XQT BOIL6A.FBVH

    INPUT DATA -- @ADD FILE.ELEMENT


@ADD.P            MUL9BHI-MED1

             REDUCED PILOT. NORMAL COOLDOWN @ HIGH FIRE.
    NORMAL COOLDOWN @ MED FIRE

    VENTED HEATER
    INSTALLED INDOOR
    STEP MODULATED INPUT
    ASSIGNED VALUES FOR OFF-LOSSES


    INPUT VALUES

    1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
     1          3         2.01+004   4.03+004   5.85+002    .00       7.25-002   1.90+000

    9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
    2.30+002   7.36+000   6.19+002   4.69+002   5.95+002   2.84+002   1.54+002   1.08+002

    17)TRA     18)QJ      19)S/F     20)DF      21)DS      22)Y
    7.20+001    .00       4.82+000   1.00+000   1.00+000   1.38+000

    TON= 20.00     TOFF= 20.00      TOA= 45.0


    ADDITIONAL INPUT VALUES FOR MINIMUM FIRING RATE

    1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
      ---        ---        ---      2.50+004     ---        ---        ---      1.30+000

    9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
    1.85+002   4.40+000   4.91+002   3.74+002   4.86+002   2.05+002   1.38+002   1.08+002

    17)TRA     18)QJ      19)S/F     20)DF      21)DS      22)Y
    7.20+001     ---      4.29+000   1.00+000   1.00+000     ---

    FRACTION OF TIME IN LOW FIRE/CYCLING MODE       =  .690
    FRACTION OF TIME IN HIGH FIRE/NON-CYCLING MODE  =  .310
    OUTDOOR AIR TEMP FOR CYCLING MODE     =  47.70
    OUTDOOR AIR TEMP FOR NON-CYCLING MODE =  28.60


    CALCULATED VALUES-
```

Figure C5. Program output for a heater with step-modulating control

```
23)PF      24)HHVA    25)A/F     26)QL      27)CJ      28)RT      29)QSSS    30)EFFYSS
1.45-002   2.01+004   1.45+001   9.55+000    .00       1.58+000   1.66+001   7.39+001

31)TSSS    32)TAUON   33)ZETFOX  34)TAUOFF  35)PSIFOX  36)PSIFIX  37)PSISIX  38)PSISOX
1.86+002   1.09+000   2.37+002   5.59+000   2.30+002   3.60+001   7.47+000   4.78+001

39)CS      40)CSON    41)CSOFF   42)CION    43)CIOFF
 .00       2.84-002   3.38+000   9.59-002   1.25+001

44)TOA     45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
2.86+001   2.00+001   2.00+001   1.83+001   3.58+000   2.34+002   2.30+002   3.60+001

52)PSISO   53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
4.78+001   7.47+000   3.78-001   8.02-003    .00        .00       5.17-003   2.47-005

60)QSON    61)QSOFF   62)QION    63)QIOFF   64)EFFYU
1.62+001   2.25+000   3.97+000   2.78+000   6.56+001


CALCULATED VALUES -- MINIMUM FIRING RATE

23)PF      24)HHVA    25)A/F     26)QL      27)CJ      28)RT      29)QSSS    30)EFFYSS
1.45-002   2.01+004   1.45+001   9.55+000    .00       2.58+000   1.71+001   7.34+001

31)TSSS    32)TAUON   33)ZETFOX  34)TAUOFF  35)PSIFOX  36)PSIFIX  37)PSISIX  38)PSISOX
1.70+002   6.34-001   2.57+002   6.39+000   1.23+002   3.60+001   8.39+000   2.86+001

39)CS      40)CSON    41)CSOFF   42)CION    43)CIOFF
 .00       4.57-002   5.43+000   1.37-001   2.01+001

44)TOA     45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
4.77+001   2.00+001   2.00+001   3.15+001   3.13+000   2.54+002   1.23+002   3.60+001

52)PSISO   53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
2.86+001   8.39+000   1.81-001   7.67-003    .00        .00       3.82-003   3.22-005

60)QSON    61)QSOFF   62)QION    63)QIOFF   64)EFFYU
1.67+001   2.48+000   3.06+000   1.83+000   6.67+001


PART-LOAD EFFICIENCY -- HIGH FIRE =  70.09
PART-LOAD EFFICIENCY -- LOW FIRE =  66.71
WEIGHTED AVERAGE PART-LOAD EFFICIENCY =  67.76

STEADY-STATE EFFICIENCY -- HIGH FIRE =  73.85
STEADY-STATE EFFICIENCY -- LOW FIRE =  73.37
WEIGHTED AVERAGE STEADY-STATE EFFICIENCY =  73.44

WEIGHTED AVERAGE ANNUAL FUEL EFFICIENCY =  65.47
ANNUAL FUEL ENERGY CONSUMPTION =  3.701+007 BTU
ANNUAL ELECTRICAL ENERGY CONSUMPTION =  8.031+001 BTU


PROGRAM COMPLETE
```

Figure C5 (cont)

```
@XQT BOIL6A.FBVH

    INPUT DATA -- @ADD FILE.ELEMENT


@ADD.P            MUL9BHI-MED1

            REDUCED PILOT, NORMAL COOLDOWN @ HIGH FIRE,
    NORMAL COOLDOWN @ MED FIRE

    VENTED HEATER
    INSTALLED INDOOR
    TWO STAGE INPUT
    ASSIGNED VALUES FOR OFF-LOSSES


    INPUT VALUES

    1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       3)XCO2S
     1          3         2.01+004   4.03+004   5.85+002    .00       7.25-002   1.90+000

    9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
    2.30+002   7.36+000   6.19+002   4.69+002   5.95+002   2.84+002   1.54+002   1.08+002

    17)1RA     18)QJ      19)S/F     20)DF      21)DS      22)Y
    7.20+001    .00       4.82+000   1.00+000   1.00+000   1.38+000

    TON= 20.00     TOFF= 20.00      TOA= 45.0


    ADDITIONAL INPUT VALUES FOR MINIMUM FIRING RATE

    1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
      ---        ---        ---      2.50+004     ---        ---        ---      1.30+000

    9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
    1.85+002   4.40+000   4.91+002   3.74+002   4.86+002   2.05+002   1.38+002   1.08+002

    17)TRA     18)QJ      19)S/F     20)DF      21)DS      22)Y
    7.20+001     ---      4.29+000   1.00+000   1.00+000     ---

    FRACTION OF TIME IN LOW FIRE/CYCLING MODE        =  .690
    FRACTION OF TIME IN HIGH FIRE/NON-CYCLING MODE =  .310
    OUTDOOR AIR TEMP FOR CYCLING MODE      =  47.70
    OUTDOOR AIR TEMP FOR NON-CYCLING MODE =  28.60


    CALCULATED VALUES-
```

Figure C6. Program output for a heater with two-stage control

```
23)PF      24)HHVA    25)A/F     26)QL      27)CJ      28)RT      29)QSSS    30)EFFYSS
1.45-002   2.01+004   1.45+001   9.55+000    .00       1.58+000   1.66+001   7.39+001

31)TSSS    32)TAUON   33)ZETFOX  34)TAUOFF  35)PSIFOX  36)PSIFIX  37)PSISIX  38)PSISOX
1.86+002   1.09+000   2.37+002   5.59+000   2.30+002   3.60+001   7.47+000   4.78+001

39)CS      40)CSON    41)CSOFF   42)CION    43)CIOFF
 .00       2.84-002   3.38+000   9.59-002   1.25+001

44)TOA     45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
2.86+001   2.00+001   2.00+001   1.83+001   3.58+000   2.34+002   2.30+002   3.60+001

52)PSISO   53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
4.78+001   7.47+000   3.78-001   8.02-003    .00        .00       5.17-003   2.47-005

60)QSON    61)QSOFF   62)QION    63)QIOFF   64)EFFYU
1.62+001   2.25+000   3.97+000   2.78+000   6.56+001


CALCULATED VALUES -- MINIMUM FIRING RATE


23)PF      24)HHVA    25)A/F     26)QL      27)CJ      28)RT      29)QSSS    30)EFFYSS
1.45-002   2.01+004   1.45+001   9.55+000    .00       2.58+000   1.71+001   7.34+001

31)TSSS    32)TAUON   33)ZETFOX  34)TAUOFF  35)PSIFOX  36)PSIFIX  37)PSISIX  38)PSISOX
1.70+002   6.34-001   2.57+002   6.39+000   1.23+002   3.60+001   8.39+000   2.86+001

39)CS      40)CSON    41)CSOFF   42)CION    43)CIOFF
 .00       4.57-002   5.43+000   1.37-001   2.01+001

44)TOA     45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
4.77+001   2.00+001   2.00+001   3.15+001   3.13+000   2.54+002   1.23+002   3.60+001

52)PSISO   53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
2.86+001   8.39+000   1.81-001   7.67-003    .00        .00       3.82-003   3.22-005

60)QSON    61)QSOFF   62)QION    63)QIOFF   64)EFFYU
1.67+001   2.48+000   3.06+000   1.83+000   6.67+001


PART-LOAD EFFICIENCY -- HIGH FIRE =  65.57
PART-LOAD EFFICIENCY -- LOW FIRE =  66.71
WEIGHTED AVERAGE PART-LOAD EFFICIENCY =  66.36

STEADY-STATE EFFICIENCY -- HIGH FIRE =  73.85
STEADY-STATE EFFICIENCY -- LOW FIRE =  73.37
WEIGHTED AVERAGE STEADY-STATE EFFICIENCY =  73.52

WEIGHTED AVERAGE ANNUAL FUEL EFFICIENCY =  64.16
ANNUAL FUEL ENERGY CONSUMPTION =  3.772+007 BTU
ANNUAL ELECTRICAL ENERGY CONSUMPTION =  8.212+001 BTU


PROGRAM COMPLETE
```

Figure C6 (cont)

NBS-114A (REV. 2-80)

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5. AUTHOR(S)

Esher Kweller and Robert Palla

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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WASHINGTON, D.C. 20234

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Washington, DC 20585

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☐ 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)

As annual operating efficiency of vented heating equipment is affected by burner fuel and combustion air modulation, it is important to differentiate between the various types of controls in determining annual energy requirements. Test procedures for evaluating annual efficiency have already been developed and implemented by the Department of Energy (DoE) for furnaces with single-stage thermostat control. A modified test procedure is necessary to account for operation with fuel modulation. A revised procedure which accommodates two types of fuel modulating controls has recently been developed. Tests are conducted at reduced and maximum firing rates, and along with typical derived values from a bin analysis of weather data, the fraction of the total hours for each operating mode is obtained to calculate a weighted annual efficiency. These test methods and calculation procedures are based on and are an extension to the current DoE test procedures for the single-stage type of thermostat control of central warm air furnaces.

By using the procedures developed in the report, the energy savings impact of fuel modulating controls when combined with the use of modulated combustion air is evaluated. Energy savings from 6 percent to 20 percent were determined from the increase in efficiency with both fuel and combustion air modulation. Improved efficiency was dependent on the type of thermostat control and the minimum-to-maximum fuel input; i.e., turndown ratio.

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

annual efficiency; household heaters and furnace test procedures; hydraulic thermostat control; modulating control gas-fueled; two-stage thermostat.

13. AVAILABILITY

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