NBSIR 78-1543

RECOMMENDED TESTING AND CALCULATION PROCEDURES FOR DETERMINING THE SEASONAL PERFORMANCE OF RESIDENTIAL CENTRAL FURNACES AND BOILERS

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Sponsored by
The Department of Energy
12th & Pennsylvania Ave., NW
Washington, D.C. 20461

September 1978

U.S. DEPARTMENT OF COMMERCE,
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ABSTRACT

As part of the requirements of the Energy Policy and Conservation Act (PL 94-163) passed by Congress in December 1975, the Department of Energy (formerly the Federal Energy Administration) directed the National Bureau of Standards to develop test procedures for certain covered consumer products, including residential central furnaces and boilers. This report summarizes the National Bureau of Standards' recommendations on how these central heating appliances may be tested in the laboratory and the resulting data used to calculate their annual fuel utilization efficiencies and annual operating costs.

Key Words: Annual operating costs; boilers; fossil-fuel heating systems; furnaces; part-load performance; rating procedures; seasonal efficiency.

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NOMENCLATURE

A_D	net area of stack or flue damper plate
A_S	cross sectional area of stack where flue or stack damper is located, in sq in
A/F	mass ratio of stoichiometric air to fuel
BE	electrical power to circulating air blower or water pump, in kW
C_{IID}	correction factors for units using intermittent devices or cycling pilots
C_J	jacket loss factor
C_S, C_S'	on-period and off-period correction factors for outdoor units, units intended for installation in unheated spaces or units equipped with direct vent systems
C_T	concentration by volume of tracer gas present in flue gas
$C_{t,OFF}$	cool-down temperature profile correction factor for the effect of cycling
$C_{t,ON}$	heat-up temperature profile correction factor for the effect of cycling
DD	degree days
D_o	stack or flue damper effectiveness factor
D_F	off-cycle draft factor for flue gas flow
D_P	power burner effectiveness factor
D_S	off-cycle draft factor for stack gas flow
$EFFY_A$	Annual Fuel Utilization Efficiency
E_{IN}	measured electrical power input for electric furnaces and boilers, in watts
F3, F4, F5, F6, F7, F8	functions defined by Figures 3 through 8
HHV	measured higher heating value of test gas, in Btu/lb
HHV_A	average higher heating value of typical fuel, in Btu/lb
HLH	heating-load hours, in hours
HR	number of non-heating season hours that pilot light is assumed wasted
$K_{I,OFF}$	multiplication factor for infiltration loss during off-period
$K_{I,ON}$	multiplication factor for infiltration loss during on-period
$K_{S,OFF}$	multiplication factor for sensible heat loss during off-period
$K_{S,ON}$	multiplication factor for sensible heat loss during on-period
$L_{I,OFF}$	off-cycle infiltration loss, in %
$L_{I,ON}$	on-cycle infiltration loss, in %
L_J	jacket loss, in %
$L_{L,A}$	latent heat loss, in %

$L_{S,OFF}$	off-cycle sensible heat loss, in %
$L_{S,ON}$	on-cycle sensible heat loss, in %
$L_{S,SS,A}$	sensible heat loss at steady-state operation, in %
$\dot{m}_{F,OFF}$	off-cycle flue gas flow rate, in lb/min
$\dot{m}_{F,SS}$	flue gas flow rate at steady-state operation, in lb/min
P_B	barometric pressure, in inches of Hg
PE	electrical power to power burner, in kW
PF	ration of Q_P to Q_{IN}
Q_{IN}	fuel energy input rate at steady-state operation (including any pilot light input), in Btu/hr
Q_P	fuel energy input rate to pilot light in Btu/h
$R_{T,F}$	ratio of combustion air to stoichiometric air
$R_{T,S}$	ratio of combustion air and draft relief air to stoichiometric air
S/F	ratio of stack gas mass flow rate to flue gas mass flow rate at steady-state operation and an average outdoor temperature equal to 42°F (5.6°C)
t	time, in min
t_{OFF}	off-time per cycle, in min
t_{ON}	on-time per cycle, in min
t_1, t_2, t_3, t_4	different times at which flue and/or stack gas temperature are measured, in min.
t^+	delay time between burner shut off and blower shut off, in minutes
t^-	delay time between burner start up and blower start up, in minutes
T_{FUEL}	type of fuel defined in step 2 of section 4.2
$T_{F,OFF}$	off-period flue gas temperature while the system is in cyclic operation, in °F
$T^*_{F,OFF}$	off-period flue gas temperature when tracer gas concentration is measured, in °F
$T_{F,OFF,X}$	off-cycle flue gas temperature after shut down of the system from steady-state operation, in °F
$T_{F,ON}$	on-cycle flue gas temperature while the system is in cyclic operation, in °F
$T_{F,ON,X}$	on-cycle flue gas temperature after start-up of the system from "equilibrium" condition, in °F
$T_{F,SS}$	flue gas temperature at steady-state, in °F
$T_{F,OFF}(\infty)$	minimum flue gas temperature, in °F
T_{OA}	average outdoor air temperature assumed equal to 42°F (5.6°C)
T_{RA}	laboratory room temperature, in °F
$T_{S,OFF}$	off-cycle stack gas temperature while the system is in cyclic operation, in °F
$T_{S,OFF,X}$	off-cycle stack gas temperature after shut down of the system from steady-state operation, in °F

$T_{S,ON}$	on-cycle stack gas temperature while the system is in cyclic operation, in °F
$T_{S,ON,X}$	on-cycle stack gas temperature after start-up of the system from "equilibrium" condition, in °F
$T_{S,SS}$	calculated stack gas temperature at steady-state, under typical field conditions, in °F
$T_{S,SS,X}$	measured steady-state stack gas temperature, in °F
$T_{S,OFF}(\infty)$	minimum stack gas temperature, in °F
T_T	temperature of tracer gas entering flow meter
$X_{CO_2,F}$	concentration by volume of CO_2 present in dry flue gas, in %
$X_{CO_2,S}$	concentration by volume of CO_2 present in dry stack gas, in %
$\dot{V}_T$	flow rate of tracer gas in cu ft/min
y	ratio of blower on time to burner on time
α	oversizing factor
γ	angle stack or flue damper plate makes when closed with plane perpendicular to axis of stack or flue
$\Delta T_{F,SS}$	temperature difference defined as $T_{F,SS} - T_{RA}$
$\Delta T_{S,SS}$	temperature difference defined as $T_{S,SS} - T_{RA}$
η_{SS}	steady-state efficiency
η_u	part-load fuel utilization efficiency
θ_F	temperature difference defined as $(T_{F,SS} - T_{F,ON})$
$\theta_{F,O}$	temperature difference defined by step 49 in section 4.2
$\theta_{F,O,X}$	temperature difference defined by step 33 in section 4.2
ρ_F	density of flue gas, in lb/cu ft
τ_{ON}	heat-up time constant defined in step 32 of section 4.2, in min
τ_{OFF}	cool-down time constant defined in step 34 of section 4.2, in min
ϕ	infiltration parameter assumed equal to 0.7
ψ_F	temperature difference defined as $(T_{F,OFF} - T_{F,OFF}(\infty))$
$\psi_{F,O}$	temperature difference defined by step 50 in section 4.2
$\psi_{F,O,X}$	temperature difference defined by step 35 in section 4.2
$\psi_{F,\infty}$	temperature difference defined by step 51 in section 4.2
$\psi_{F,\infty,X}$	temperature difference defined by $(T_{F,OFF}(\infty) - T_{RA})$
$\psi_{S,O}$	temperature difference defined by step 52 in section 4.2
$\psi_{S,O,X}$	temperature difference defined by step 38 in section 4.2
$\psi_{S,\infty}$	temperature difference defined by step 52 in section 4.2
$\psi_{S,\infty,X}$	temperature difference defined by step 37 in section 4.2

1. INTRODUCTION

The test and calculation procedures recommended herein apply to residential central furnaces and boilers.

The recommended test procedures for gas and oil-fueled equipment are based upon the heat-loss method and were developed utilizing test results gathered in the laboratory by NBS, laboratory and field results obtained by several subcontractors, and information and data supplied by industry. The underlying philosphy was to keep the test procedures as simple as possible while still obtaining the data required to predict the seasonal performance of these appliances, thus keeping the testing costs within reasonable limits.

In order to keep the test procedures simple, the effect of heating load, cycling rate, chimney height, oversizing, the type of draft control device, the infiltration characteristics of a typical residence and weather are accounted for in the calculation procedure prescribed for determining the annual fuel utilization efficiency and annual operating cost. This calculation procedure, which is based upon results obtained from a computer model (DEPAF) developed at NBS and work done by a subcontractor (Honeywell), rates the performance of furnaces and boilers having different energy saving features, such as intermittent ignition devices, stack dampers, power burners, direct vent systems, etc. Although Appendix B contains a computerized version of the calculation procedure, the procedure was developed with the intention that it could be carried out by a person using either a non-programmable or a programmable calculator. It was felt that this was necessary to make it usable by the small furnace and boiler manufacturers who might not have access to computer facilities.

Partly as a consequence of being a manual procedure and partly as a result of the present state-of-the-art, many assumptions and simplifications had to be incorporated in the calculation procedure which tends to limit its generality. For example, units are considered to be located either within the heated space or out-of-doors, indoor units are given credit for jacket losses but not for heat transferred to the house from the chimney or vent pipe, and no attempt is made to account for the fact that oil-fired units tend to soot up and are usually not as carefully adjusted in the field as they are in the laboratory. As a consequence of this last simplification, the steady state and annual fuel utilization efficiencies obtained by using the recommended tests and calculation procedures on oil-fired equipment give results which are probably several percentage points too high. As a result, NBS recommends that additional research be carried out to improve and refine the procedures described herein and that care be exercised about generalizing the procedures to applications that they were not designed to handle. In addition, it is the authors' belief that the testing and calculation procedures must be periodically reviewed and updated as manufacturers develop new and more energy efficient products.

1.1 Description of Recommended Test Procedures

Currently, testing and rating requirements for gas and oil-fueled central furnaces and boilers are described in a number of standards, including ANSI Z21.47-1973 and ANSI Z91.1-1972 for gas and oil-fired furnaces, ANSI Z21.13-1974 for gas-fired low-pressure boilers and the Hydronic Institute's "Testing and Rating Standard for Cast Iron and Steel Heating Boilers" for oil-fired central heating boilers. These standards all require a steady-state performance test and do not account for any part-load or seasonal performance effects. In order to estimate the seasonal efficiency and annual operating cost of fossil-fuel heating systems, it is necessary to account for the various heating system losses under cyclic operating conditions and for the effect of combustion and draft control air on infiltration. The test procedures recommended in section 2 provide information which can be used to take these effects into account. They require measurements of the steady-state performance of a furnace or boiler plus the determination of its flue temperature profile while warming up from a cold start and cooling down from steady-state operation.

The steady-state performance test requires measuring either the steady-state flue gas temperature and the concentration by volume of carbon dioxide in the dry flue gas or, in the case of gas-fired furnaces with draft diverters, measuring the steady-state stack gas temperature and concentration by volume of carbon dioxide in dry stack gas. This latter method is employed because the integral draft diverter usually makes accurate measurement upstream of the diverter difficult. The warm-up and cool-down flue gas temperature profiles are determined by making two discrete flue gas temperature measurements during warm-up and two or three discrete measurements during cool-down and approximating the flue gas temperature profiles using the procedure described in Appendix A. The use of discrete warm-up and cool-down temperature measurements reduces the amount of data required and greatly simplifies the process of data reduction. The times at which these discrete flue gas temperature measurements are made were chosen to minimize the errors involved in calculating the on-cycle and off-cycle losses. As a result, different sets of times are recommended for furnaces and boilers.

In addition to the above-mentioned tests, certain factors, which describe the flow rates through the flue and stack during the on and off periods, are assigned according to type of equipment under test. The factor S/F, which is the ratio of stack mass flow rate to flue mass flow rate under steady-state operation and at an average outdoor temperature of 42°F (5.56°C), is used to estimate the infiltration losses during both the on and off-cycles. By assigning values which are based upon field data, the need to simulate field conditions in the laboratory (e.g. a high chimney, a low outdoor temperature, a typical barometric damper setting, etc.) is avoided. A factor D_F represents the ratio of the mass flow rate through the flue during the off-cycle to that occurring during the on-cycle at identical flue gas temperatures. A similar quantity, D_S, is the ratio of the stack mass flow rates during the off-period to the stack mass flow rate during the on-period at identical stack gas temperatures. The values of D_F and D_S depend upon whether the system being tested employs an automatic stack damper and/or a power burner. If a unit is equipped with a stack damper, its effectiveness is determined by measuring the amount of stack area which the damper blocks during the off-cycle. Furnaces or boilers using power burners may employ an assigned factor of $D_F = 0.40$ or directly measure the effectiveness of the power burner at reducing off-period flow by employing a tracer gas to determine the mass flow rate in the flue while the burner is off.

Whenever possible the test methods recommended herein have been based upon existing consensus standards and procedures presently employed by manufacturers to evaluate the performance of central heating equipment. This was done to reduce the amount of duplicate testing required and to obtain a set of performance tests which would be within the capabilities of the entire furnace and boiler industry.

1.2 Description of the Calculation Procedure for Determining the Fuel Utilization Efficiency and the Annual Operating Cost

A step-by-step calculation procedure for determining the fuel utilization efficiency based upon an average U.S. weather pattern is given in section 4.1 for gas and oil-fired central heating equipment. The background equations which form the basis for this procedure are described in Appendix A and a worksheet is provided in Figure 10 to assist in keeping track of the experimental data and the various step-by-step calculations. The fuel utilization efficiency is used in section 4.2 to estimate the annual cost of operation in different climatic regions and an average operating cost for the country. A brief summary of the basic equations used in the calculation procedure is given in Appendix A. A computerized version in Fortran V of the procedure described in sections 4.1 and 4.2 is contained Appendix B.

The first 22 steps in the calculation procedure involve simply the recording of the experimental data, the assigned value of the factor S/F, and the assigned or measured values of D_F, D_S and y.

The steady-state latent and sensible losses and the steady-state efficiency, η_{SS}, are determined in steps 24 through 30. The flue-gas and stack-gas temperature profiles, corresponding to warm-up from a cold start and cool-down from steady-state operation, are then approximated as described in Appendix A by simple exponential functions having the form ($a\ e^{-t/\tau}+b$). The parameters in these functions (τ_{ON}, τ_{OFF}, $\theta_{F,0,X}$, $\psi_{F,0,X}$, $\psi_{F,\infty,X}$, $\psi_{S,0,X}$, and $\psi_{S,\infty,X}$) are determined (steps 31 through 38) from the warm-up, cool-down and steady-state flue temperature measurements and are corrected for the effect of cycling (steps 49 through 53) to obtain the flue-gas and stack-gas temperature-vs-time profiles which would exist if the unit were operating in the field at a heating load factor equal to 22.5%. For outdoor units or units designed to use outdoor air for combustion and draft control, a further adjustment to these profiles is made using correction factors C_S and C_S' to account for the fact that the air used for combustion has an average temperature of 42°F (5.56°C).

The flue-gas and stack-gas temperature-vs-time profiles are employed, along with the factors describing the on and off cycle air flow rates, to calculate the dynamic system losses $L_{S,ON}$, $L_{S,OFF}$, $L_{I,ON}$, and $L_{I,OFF}$ (steps 60 through 63) at the average heating load factor and the average outdoor temperature of 22.5% and 42°F (5.56°C), respectively. These losses, together with the latent loss, jacket loss on outdoor units, and the pilot light loss during the non-heating season, are then used to calculate the average heating season efficiency η_u. The annual fuel utilization efficiency, $EFFY_A$ (step 67) is then determined based upon the assumption that the ratio of the furnace's (or boiler's) steady-state output to the heating requirement the furnace must meet in a typical residence at the outdoor design temperature is equal to 1.7. Although the values of η_u and $EFFY_A$ thus determined are based upon evaluating the dynamic system losses at the heating season's average outdoor temperature and the corresponding heating load factor, this was found to give good agreement with more complex calculations of the fuel utilization efficiency based upon six outdoor temperature bins.

In section 4.2, a procedure is given for determining the number of burner operating hours and annual operating cost in different geographical regions of the country and for buildings with different design heating requirements. It is recommended that the annual cost of operation be calculated for a number of standardized design heating requirements in order to encourage the consumer to purchase the most efficient furnace or boiler that is capable of heating his home and to facilitate the comparison of fossil-fuel heating systems with heat pumps. A procedure is also recommended in this section for calculating an average operating cost for the United States.

1.3 Definitions

In order to facilitate the readers understanding of this report, a brief description of the more important terms, as they are used herein, is given below.

barometric draft regulator or barometric damper - a device designed to maintain a constant draft within a furnace or boiler.

draft diverter - a device that is an integral part of a furnace or boiler and which is designed to (1) provide for the exhaust of the products of combustion in the event of no draft, back draft, or stoppage beyond the draft diverter, (2) prevent a back draft from entering the furnace, (3) neutralize the effect of stack action of the chimney or gas vent upon the operation of the furnace or boiler.

draft hood - a device which performs the same functions as a draft diverter but is not an integral part of the furnace or boiler and is connected to the furnace or boiler by a short length of flue pipe.

flue - a conduit between the flue outlet of the furnace and the draft diverter, draft hood, barometric draft regulator or vent terminal through which the products of combustion pass prior to the point of draft relief.

flue damper - a device installed between the furnace and draft diverter, draft hood, barometric draft regulator or vent terminal (on a unit not equipped with a draft control device) and which is designed to automatically open the venting system when the appliance is in operation and to automatically close the venting system when the appliance is in a standby condition.

flue gases - reaction products resulting from the combustion of a fuel with the oxygen of air, including the inerts and any excess air.

flue losses - the sum of the sensible and latent heat losses above room temperature of the flue gases leaving the furnace.

higher heating value (HHV) - the heat produced per unit of fuel when complete combustion takes place at constant pressure and the products of combustion are cooled to the initial temperature of the fuel and air and when the water vapor formed during combustion is condensed.

induced draft - the drawing of combustion air into the furnace or boiler by mechanical means

power burner - a burner which supplies air for combustion at a pressure exceeding atmospheric pressure or a burner which depends on the draft induced by a fan incorporated in the furnace for proper operation. It may incorporate a device on its air inlet which automatically opens the air inlet when the appliance is in operation and automatically closes it when the appliance is in a standby condition.

stack - the portion of the exhaust system downstream of the draft diverter, draft hood or barometric draft regulator.

stack damper - a device installed downstream of the draft diverter, draft hood or barometric draft regulator and which is designed to automatically open the venting system when the appliance is in operation and to automatically close off the venting system when the appliance is in a standby condition.

stack gases - the flue gases combined with dilution air that enters the draft diverter, draft hood or barometric draft regulator.

steady-state conditions - equilibrium conditions as indicated by temperature variations in three successive readings taken 15 minutes apart of not more than (1) 3°F (1.7°C) in the stack gas temperature for units equipped with draft diverters or 5°F (2.8°C) in the flue gas temperature for units equipped with draft hoods, barometric draft regulators or direct vent systems, and (2) 4°F (2.2°C) in the outlet water temperature of hot water boilers.

vent/air intake terminal - a device which is located on the outside of the building and is connected to a furnace by a system of conduits. It is composed of an air intake terminal through which air for combustion is taken from the outside atmosphere and a vent terminal from which flue gases are discharged.

2. TEST INSTALLATION AND INSTRUMENTATION

The testing requirements for gas and oil-fired furnaces and boilers generally consist of a steady-state performance test, several measurements of the flue gas temperature as the units warm up and cool down and the selection and/or measurement of various factors which describe the air flow rate through the unit and the draft control device during the on and off cycles. The test procedure for electric furnaces and boilers requires measuring the steady-state rate of energy input to the electric heaters and the indoor-air circulating blower. These results are then used in the calculation procedure described in section 4 to calculate an average seasonal efficiency and the cost of operation for the furnace or boiler in different climatic regions.

2.1 Installation of Test Plenum, Duct Work, and Piping

2.1.1 Gravity Central Furnaces (Including Direct-Vent Systems)

Gravity central furnaces shall be installed and equipped with a vertical supply test plenum or extended casing and horizontal test ducts as described in sections 2.9.1 of ANSI Standard Z21.47-1973.

2.1.2 Forced Air Central (Including Direct-Vent Systems)

Gas-fueled forced air central furnaces shall be equipped with a plenum and test duct as described in sections 2.1.9 and 2.1.10 of ANSI Standard Z21.47-1973. Oil-fired forced air furnaces shall be equipped with a plenum and test duct as described in section 6.2 of ANSI Standard Z91.1-1972.

2.1.3 Low Pressure Steam and Hot Water Boilers (Including Direct-Vent Systems)

Install gas-fueled steam and hot water boilers as prescribed in Section 2.9 of ANSI Standard Z21.13-1974. Install oil-fueled steam and hot water boilers as prescribed in sections 7.0 and 8.1.1 through 8.1.3 in the Hydronic Institute Testing and Rating Standard for Cast Iron and Steel Heating Boilers, Jan. 1977 edition.

2.1.4 Electric Central Furnaces

Install equipment for testing in accordance with ARI Standard 280-74, Section 4 and Figure 1.

2.1.5 Electric Boilers

Install equipment in accordance with manufacturer's instructions.

2.2 Flue and Stack Requirements

2.2.1 Gravity and Forced-Air Central Furnaces

2.2.1.1 Gas-fueled gravity and forced-air central furnaces employing draft diverters. - Gas-fueled gravity and forced-air central furnaces employing draft diverters with vertically discharging outlets shall have attached to and vertically above the diverter outlet, a test stack having a length of five (5) feet and a cross-sectional area the same size as the furnace outlet. The test stack shall be covered with insulation having a R value of not less than 7 ($°F - h - ft^2/Btu$) and an outer layer of aluminum foil. Furnaces employing draft diverters having horizontally discharging outlets shall have attached to the diverter outlet a 90-degree elbow and a vertical test stack having a length of 5 feet. The elbow and test stack shall be covered with insulation having an R value of not less than 7 ($°F - h - ft^2/Btu$) and an outer layer of aluminum foil.

2.2.1.2 Gas-fueled gravity and forced-air central furnaces which employ draft hoods. - Gas-fueled gravity and forced-air central furnaces which employ draft hoods having vertically discharging outlets shall be tested with the draft hood in place and a five-foot-long pipe attached to the hood outlet. Gas-fueled furnaces having a horizontally discharging hood outlet shall be tested with the draft hood in place and an elbow and a five-foot-long vertical pipe attached to the hood outlet. The cross-sectional area of the elbow and pipe shall be the same size as the hood discharge outlet. All flue pipe upstream of the diverter shall be covered with insulation having an R value of 7 ($°F - h - ft^2/Btu$) and an outer layer of aluminum foil.

2.2.1.3 Oil-fueled forced-air central furnaces. - Flue connections for oil-fueled forced-air central furnaces are to be as described in Figures 1 and 2 of ANSI Standard Z91.1-1972. All elbows and flue connectors shall have the same cross-sectional area as the furnace outlet and shall be covered as described in Figure 2 of ANSI Standard Z91.1-1972 with insulation having an R value not less than 7 ($°F - h - ft^2/Btu$) and an outer layer of aluminum foil. There shall be no opening between the furnace and the point where the flue gas sample is to be taken or the flue gas temperature is to be measured. If a barometric draft regulator is incorporated in the furnace, it shall be sealed during all tests.

2.2.2 Gas- and Oil-Fueled Low-Pressure Steam and Hot Water Boilers (Not Including Direct-Vent Systems)

Gas-fueled low-pressure steam and hot water boilers employing draft diverters shall have the same flue and stack requirements as described in sections 2.2.1.1 for gas-fueled furnaces with draft diverters.

Gas-fueled low-pressure steam and hot water boilers employing draft hoods shall have the same flue and stack requirements as described in sections 2.2.1.2 for gas-fueled furnaces with draft hoods.

Flue connections for oil-fueled low-pressure steam and hot water boilers are the same as those described in section 2.2.1.3 for oil-fueled forced-air central furnaces.

2.2.3 Direct-Vent Systems

The exhaust/air intake system supplied by the manufacturer shall be in place during all tests. Units intended for installation with a variety of vent-pipe lengths shall be tested with the minimum vent length recommended by the manufacturer. A furnace or boiler employing a direct-vent system shall not be connected to a chimney or induced draft source, but shall depend for venting of the combustion products solely on the provision for venting incorporated in the furnace and the exhaust/air intake system supplied with it. On units which are not designed to significantly preheat the incoming air, the first 18 inches of vent pipe downstream of the furnace outlet shall be covered with a layer of insulation having an R value not less than 7 ($°F - h - ft^2/Btu$) and an outer layer of aluminum foil. Care should be taken to not block the air intake with insulation, where appropriate. Units designed to significantly preheat the incoming combustion air shall have all surfaces of the vent/air intake system exposed to ambient air, and where temperature exceeds the room temperature by more than 30°F (16.7°C), covered with insulation having an R value not less than 7 ($°F - h - ft^2/Btu$) and a layer of aluminum foil.

2.3 Fuel Supply

2.3.1 Natural Gas

For a furnace or boiler utilizing natural gas, maintain the gas supply to the unit under test at a normal inlet test pressure immediately ahead of all controls at 7 to 10 inches water column. The regulator outlet pressure at normal test pressure shall be that recommended by the manufacturer. Use natural gas having a specific gravity of approximately 0.65 and a higher heating value within ± 5% of 1025 Btu per standard cubic foot. Determine the actual higher heating value in Btu's per standard cubic foot for the natural gas to be used in the test with an error no greater than one percent.

2.3.2 Propane Gas

For a furnace or boiler utilizing propane gas, maintain the gas supply to the unit under test at a normal inlet pressure immediately ahead of all controls of 11 to 13 inches water column and a specific gravity of 1.53. The regulator outlet pressure, on units so equipped, shall be approximately that recommended by the manufacturer. Use propane HD-5 having a specific gravity of approximately 1.53 and a higher heating value within ± 5% of 2500 Btu's per standard cubic foot. Determine the actual higher heating value in Btu's per standard cubic foot for the propane to be used in the test with an error no greater than one percent.

2.3.3 Other Test Gas

The specific gravity of other test gases shall approximate the values given in Table IX of ANSI Standard Z21.47-1973. The test pressures immediately ahead of all controls shall be maintained between the "normal" and "increased" values of test pressures given in Table X in the above ANSI Standard. The measured higher heating values shall be within ± 5% of the values specified in Table IX, in ANSI Standard Z21.47-1973. The actual higher heating value of the gas used in the test shall be determined with an error no greater than one percent.

2.3.4 Fuel Oil

For a furnace or boiler utilizing fuel oil, the fuel oil used shall be No. 1 or No. 2 fuel oil and shall conform to the specifications outlined in Tables 2 and 3 of ANSI Standard Z91.1-1972. The higher heating value of the test fuel oil shall be measured with an error no greater than one percent.

2.3.5 Electrical Supply

For an electric furnace or boiler, or for an auxiliary electric component of the gas- and oil-fueled furnace or boiler, maintain the electrical supply to the test unit within one percent of the nameplate voltage for the entire portion of the test cycle. If a voltage range is used for nameplate voltage, maintain the electrical supply within one percent of the center of the nameplate voltage range.

2.4 Burner Adjustments

2.4.1 Gas-Burner Adjustments

Burners of gas-fueled furnaces and boilers shall be adjusted to their maximum Btu ratings at the test pressure specified in 2.3 of this section. The burner input rate shall be corrected to standard conditions of 60°F (15.6°C) and 30 inches of mercury and shall be within ± 2% of the hourly Btu rating specified by the manufacturer, as measured after 15 minutes of operation starting with all parts of the furnace at room temperature. The primary air shutters shall be set in accordance with the manufacturers' recommendation to give a good flame at this adjustment and shall not result in the deposit of carbon during any test specified herein.

If a vent-limiting means is provided on a gas pressure regulator, it shall be in place during all tests.

2.4.2 Oil-Burner Adjustments

The burners of oil-fueled furnaces and boilers shall be adjusted to give the CO_2 reading recommended by the manufacturer and an hourly Btu input during the steady-state performance test described below which is within ± 2% of the furnace manufacturer's specified normal hourly Btu input rating. Smoke in the flue shall not exceed a No. 1 smoke during the steady-state performance test as measured by the procedure in ANSI Standard Z11.182-1965 (R1971) (ASTM D 2156-65(1970)). If the smoke in the flue exceeds No. 1 during the steady-state tests, the burner shall be readjusted to give a lower CO_2 reading and all tests shall be started over. The average draft over the fire and in the flue during the steady-state performance test shall be that recommended by the manufacturer and draft fluctuations shall not exceed 0.005 inches of water gauge. No additional adjustments to the burner shall be made during the required series of performance tests. The instruments and measuring apparatus for this test are described in section 6.3 of ANSI Standard Z91.1-1972.

2.5 Circulating Air, Steam or Water Flow Adjustments

2.5.1 Gas-Fueled Forced-Air Central Furnaces (Including Direct-Vent Systems)

The external static pressure and air throughput rate shall be adjusted as specified in sections 2.1.11, 2.1.12 and 2.1.13 of ANSI Standard Z21.47-1973. Outlet air temperature shall be measured in accordance with section 2.1.9 of the same standard.

2.5.2 Gas-Fueled Gravity Central Furnaces (Including Direct-Vent Systems)

The air flow rate through the furnace shall be such that the average normal air temperature rise at steady-state operation is not greater than 130°F above the inlet air temperature when the furnace is equipped with the vertical test plenum or extended casing and horizontal test ducts as described in section 2.1.1. Measure the outlet air temperature as specified in sections 2.9.1 of ANSI Standard Z21.47-1973. The inlet air temperature shall be measured at the center of the plane of each inlet air opening by means of a single No. 24 AWG thermocouple, suitably shielded from direct radiation.

2.5.3 Oil-Fueled Forced-Air Central Furnaces (Including Direct-Vent Systems)

The external static pressure and air thoughput rate shall be adjusted as specified in Table 5 and Section 6.2 of ANSI Standard Z91.1-1972.

2.5.4 Gas- and Oil-Fueled Low-Pressure Steam and Hot Water Boilers (Including Direct-Vent Systems)

The water flow rate for hot water boilers shall be adjusted to produce a water temperature rise, during steady-state operation, between 120°F (48.9°C) and 165°F (73.9°C) and an outlet water temperature of 200°F (93.3°C) plus or minus 5°F (2.8°C). For steam boilers, the steady-state performance test described in 3.1 shall be conducted at atmospheric pressure or at a pressure not exceeding 2 pounds per square inch gauge.

2.5.5 Electric Central Furnaces

Use the air quantity and pressures specified by ARI Standard 280-74, sections 6.2.1 and 6.2.3.

2.5.6 Electric Boilers

The flow of water or steam shall be as specified in section 2.5.4 for gas- and oil-fueled boilers.

2.6 <u>Location of Temperature Measuring Instrumentation</u>

2.6.1 Gas-Fueled Gravity and Forced-Air Furnaces and Gas-Fueled Boilers (Including Direct-Vent Systems)

For units employing a draft diverter, install nine thermocouples, wired in parallel, in a horizontal plane in the five-foot test stack located one foot from the test stack inlet. The length of all thermcouple leads shall be equal before paralleling. Locate one thermocouple in the center of the test stacks. Locate eight thermocouples along imaginary lines intersecting at right angles in this horizontal plane at points one third and two thirds of the distance between the center of pipe and the pipe wall.

For units which employ a draft hood or units which employ a direct-vent system which does not significantly preheat the incoming combustion air, install nine thermocouples, wired in parallel, in a horizontal plane located within 12 inches (304.8 mm) of the furnace or boiler outlet and upstream of the draft hood on units so equipped. The length of all thermocouple leads shall be equal before paralleling. Locate one thermocouple in the center of the flue pipe and eight thermocouples along imaginary lines intersecting at right angles in this horizontal plane at points one third and two thirds of the distance between the center of the pipe and the pipe wall.

For furnaces or boilers which employ direct-vent systems that significantly preheat the incoming combustion air, install nine thermocouples, wired in parallel, in a plane parallel to and located within six inches (152.4 mm) of the vent/air intake terminal. The length of all thermocouple leads shall be equal before paralleling. Locate one thermocouple in the center of the flue pipe and eight thermocouples along imaginary lines intersecting at right angles in this plane at points one third and two thirds of the distance between the center of the flue pipe and the pipe wall.

Use bead-type thermocouples having wire size not greater than No. 24 American Wire Gauge (AWG). If there is a possibility that the thermocouples could receive direct radiation from the fire, install radiation shields on the fire side of the thermocouples only and position the shields so that they do not touch the thermocouple junctions.

The locations of thermocouples used for measuring conditioned warm air are described in ANSI Z21.47-1973, sections 2.1.9 and 2.9.1. The temperature of the inlet air shall be established by means of a single No. 24 AWG bead-type thermocouple, suitably shielded from direct radiation and located in the center of the plane of each inlet air opening.

The inlet and outlet water temperature on gas-fueled hot water boilers shall be measured as shown in Figure 3 of ANSI Standard Z21.13-1974.

2.6.2 Oil-Fueled Forced-Air Central Furnaces and Boilers (Including Direct-Vent Systems)

Install nine thermocouples, wired in parallel and having equal length leads, in a plane perpendicular to the axis of the flue pipe. This plane shall be located at the position shown in Figure 2 of ANSI Standard Z91.1-1972 for a single thermocouple, except that on direct vent systems which significantly preheat the incoming combustion air, it shall be located within 6 inches (152.4 mm) of the outlet of the vent/air intake terminal. Locate one thermocouple in the center of the flue pipe and eight thermocouples along imaginary lines intersecting at right angles in this plane at points one third and two thirds of the distance between the center of the pipe and the pipe wall.

Use bead-type thermocouples having a wire size not greater than No. 24 American Wire Gauge (AWG). If there is a possibility that the thermocouples could receive direct radiation from the fire, install radiation shields on the fire side of the thermocouples only and position the shields so that they do not touch the thermocouple junctions.

The location of thermocouples for measuring conditioned warm air are described in section 6.2 of ANSI Standard Z91.1-1972. The temperature of the inlet air shall be established by means of a single thermocouple, suitably shielded from direct radiation and located in the center of the plane of each inlet air opening.

The inlet and outlet water temperature on oil-fueled hot water boilers shall be measured as described in section 7.4 and Figure 2 of the January 1977 edition of the Hydronic Institute Standard "Testing and Rating Standard for Cast Iron and Steel Heating Boilers".

2.6.3 Electric Furnace

Install nine thermocouples, wired in parallel and having equal length leads, as shown in Figure 1 of ARI Standard 280-74, for measuring the conditioned warm air temperature. The temperature of the inlet air shall be established by means of a single thermocouple suitably shielded from radiation and located in the center of the plane of each inlet air opening. Use bead-type thermocouples having a wire size not greater than No. 24 American Wire Gauge (AWG).

2.6.4 Electric Boilers

The inlet and outlet water temeprature on electric hot water boilers shall be measured as specified in section 2.6.2 for oil-fueled hot water boilers.

2.7 Combustion Measurement Instrumentation

The sample of stack and flue gases for furnaces and boilers shall be analyzed to determine the concentration by volume of carbon dioxide present in the dry stack or flue gas with instrumentation which will result in a reading having an error no larger than $\pm$ 0.1 percentage point.

2.8 Energy Flow Instrumentation

Install one or more instruments, which measure the quantity of electrical energy, gas flow, or fuel oil supplied to the furnace, or boiler as appropriate, with an error no greater than one percent.

2.9 Room Ambient Temperature

During the time period required to perform all the testing and measurement procedures specified in section 3, the room temperature shall remain within $\pm$ 5°F ($\pm$ 2.8°C) of the value T_{RA} measured during the steady-state performance test. At no time during these tests shall the room temperature exceed 100°F (37.8°C) or fall below 65°F (18.3°C). Use the procedure outlined in section 2.1.14 of ANSI Standard 21.47-1973 to measure room temperature.

2.10 Equipment Used to Measure Mass Flow Rate in Flue and Stack

The tracer gas chosen for this task should have a density which is less than or approximately equal to the density of air. It shall be of different chemical species or different concentration from the flue gas to be measured and shall be unreactive with the environment to be encountered. Instrumentation used to measure the concentration of tracer gas may be either the batch or continuous type which will result in a reading having an error no larger than $\pm$ 2% of the value of the concentration measured.

3. TESTING AND MEASUREMENTS

3.1 Steady-State Testing

3.1.1 Gas-Fueled Gravity and Forced-Air Central Furnaces and Gas-Fueled Low-Pressure Steam and Hot Water Boilers (Including Direct-Vent Systems)

The following procedure is to be used for gas-fueled gravity and forced-air central furnaces and gas-fueled boilers (including direct-vent systems).

The furnace or boiler shall be set up as specified in 2.1, 2.2 and 2.3. Begin the steady-state performance test by operating the burner and the circulating air blower or water pump, with the adjustments specified by 2.4.1 and 2.5, until steady-state conditions are attained, as indicated by a temperature variation in three successive readings taken 15 minutes apart, of not more than: [1] 3°F (1.7°C) in the stack gas temperature for furnaces and boilers equipped with draft diverters or 5°F (2.8°C) in the flue gas temperature for furnaces and boilers equipped with either draft hoods or direct-vent systems, and [2] 4°F (2.2°C) in the outlet water temperature for hot water boilers.

On units employing draft diverters, measure the room temperature (T_{RA}) as described in 2.9 and measure the steady-state stack gas temperature ($T_{S,SS,X}$) using the nine thermocouples located in the 5-foot test stack as specified in 2.6.1. A sample of the stack gases shall be secured in the plane where $T_{S,SS,X}$ is measured, and analyzed to determine the concentration by volume of carbon dioxide ($X_{CO_2,S}$) presented in dry stack gas.

On units employing draft hoods or direct-vent systems, measure the room temperature (T_{RA}) as described in 2.9, and measure the steady-state flue gas temperature, ($T_{F,SS}$), using the nine thermocouples located in the flue pipe, as described in section 2.6.1. A sample of the flue gas shall be secured in the plane of temperature measurement and analyzed to determine the concentration by volume of CO_2 ($X_{CO_2,F}$) present in dry flue gas.

The steady-state heat input rate (Q_{in}) including pilot gas shall be determined by multiplying the measured higher heating value of the test gas by the steady-state gas input rate corrected to standard conditions of 60°F and 30 inches of mercury. Use measured values of gas temperature and pressure at the meter and the barometric pressure to correct the metered gas flow rate to standard conditions.

Measure the steady-state electric power to the power burner (PE) on units so equipped. For furnaces, measure the steady-state electrical power to the conditioned air blower (BE). For hot water boilers, use a steady-state water pump power of BE = 0.13 kW.

After the above test measurements have been completed on units employing draft diverters, a sample of the flue gases shall be secured at the inlet to the draft diverter and analyzed to determine the concentration of CO_2 ($X_{CO_2,F}$) present in dry flue gas. In obtaining this sample of flue gas, the sampling probe should be moved around in the heat exchanger outlet to assure that an average value will be obtained for the CO_2 concentration. For units with multiple heat exchanger outlets, draw an equal size sample from each outlet to obtain the average CO_2 concentration for the unit. The draft diverter relief opening shall then be blocked and the draft diverter and flue gas collection box (on a power-vented unit) covered with insulation having an R value no less than 7 (°F - h - ft^2/Btu) and an outer layer of aluminum foil. If the unit is turned off during the process of blocking the diverter relief opening, it shall be run until steady-state conditions (as defined above) are again achieved. The test stack outlet shall then be progressively restricted until the concentration of CO_2 in flue gas samples secured from the test stack in the plane where $T_{S,SS,X}$ was measured is within ± 0.2 percentage points of the previously determined value of $X_{CO_2,F}$. The flue gas temperature ($T_{F,SS}$) shall be measured using the nine thermocouples located in the 5-foot test stack as specified in 2.6.1.

3.1.2 Oil-Fueled Forced-Air Central Furnaces and Oil-Fueled Low-Pressure Steam and Hot Water Boilers (Including Direct-Vent Systems)

The furnace or boiler shall be set up and adjusted as specified in sections 2.1, 2.2 and 2.3.4. Begin the steady-state performance test by operating the burner and the circulating air blower or water pump with the adjustments specified by 2.4.2 and 2.5 unitl steady-state conditions are attained, as indicated by a temperature variation in three successive readings taken 15 minutes apart, of not more than: [1] 5°F (2.8°C) in the flue gas temperature and [2] 4°F (2.2°C) in the outlet water temperature for hot water boilers.

Smoke in the flue shall not exceed a No. 1 smoke during the steady-state performance test, as measured by the procedure developed in ANSI Standard Z11.182-1965 (R1971) (ASTM D 2156-65 (1970)). The average draft over the fire and in the breeching during the steady-state performance test shall be that recommended by the manufacturer, and draft fluctuations shall not exceed 0.005 inches of water gauge.

Measure the room temperature (T_{RA}) as described in 2.9 and measure the steady-state flue gas temperature ($T_{F,SS}$) using nine thermocouples located in the flue pipe as described in 2.6.2. A sample of the flue gas shall be secured in the plane of temperature measurement and analyzed to determine the concentration by volume of CO_2 ($X_{CO_2,F}$) present in dry flue gas.

Measure and record the steady-state heat input rate (Q_{in}) and the steady-state electrical power to the power burner (PE) on units so equipped. For furnaces, measure the steady-state electrical power to the conditioned air blower (BE). For hot water boilers, use a steady-state water pump power of BE = 0.13 kW.

3.1.3 Electric Forced-Air Central Furnaces

The steady-state test for electric furnaces is a measurement of the rated power input (E_{in}), in watts, in accordance with the test procedure specified in ARI Standard 280-74, section 5.1. All measurements taken shall be at the standard rating condition described in 6.2.1 of Standard 280-74. Electrical supply shall be as specified in section 2.3.5.

3.1.4 Electric Boilers

Flow conditions shall be as specified in section 2.5.6. Electrical supply shall be as specified in section 2.3.5. The boiler shall be operated until steady-state conditions are reached, as indicated by a temperature variation in three successive readings taken 15 minutes apart of not more than 4°F (2.2°C), in the outlet water temperature for hot water boilers. Three measurements of the total power input to the boiler shall be made at 10-minute intervals and averaged to find the rated power input (E_{in}), in watts.

3.2 Flue Temperature Measurements -- Cool-Down Test

3.2.1 Gas- and Oil-Fueled Gravity and Forced-Air Central Furnaces (Including Direct-Vent Systems)

After steady-state testing is completed, the main burner shall be turned off and the flue gas temperature measured by means of the nine thermocouples described above, at 1.5 ($T_{F,OFF}(t_3)$) and 9.0 ($T_{F,OFF}(t_4)$) minutes after the burner shuts off. Units employing stack dampers and draft diverters or draft hoods shall have the damper control by-passed so that the damper remains open during the cool-down test. During this off-period, there shall be a time delay, t^+, between burner shut-down and blower shut-down of either three minutes or until the supply air temperature drops to a value of 40°F (22.2°C) above the inlet air temperature, whichever results in the longer blower on-time. An exception to this is if the furnace employs a single motor to drive a power burner and an indoor air circulating blower, the blower and the burner shall be turned off together. If the blower delay time exceeds 3 minutes, the time t^+ between burner shut-off and blower shut-off shall be measured using a stop watch. For oil-fueled furnaces not equipped with stack dampers, a means shall be provided during the cool-down test to maintain the draft in the flue pipe within -0.001 and +0.005 inches of water gauge of the average draft maintained during the steady-state test described in 3.1, if the optional test in 3.6 is being carried out, and within $\pm$ 0.01 inches of water gauge of the average steady-state draft if it is not. For a direct-vent system with a flue damper or a furnace equipped with both a stack damper and a barometric damper, the flue or stack damper shall be closed during the cool-down test. The main burner(s) shall remain off until equilibrium conditions are attained, as indicated by variations in the flue gas temperature of not more than 3°F (1.7°C) in three successive readings taken 15 minutes apart. For units employing a continuously burning pilot light, a third flue gas temperature measurement shall then be made to determine the off-period minimum flue gas temperature ($T_{F,OFF,}(\infty)$). For units not employing a continuously burning pilot light, $T_{F,OFF,}(\infty)$ shall be set equal to the room temperature T_{RA}. During this cool-down test, the energy input rate to the pilot light (Q_p), if the unit is so equipped, shall also be measured to within an accuracy of $\pm$ 3%. Record all measured values.

3.2.2 Gas- and Oil-Fueled Boilers (Including Direct-Vent Systems)

After steady-state testing has been completed, turn the main burner(s) off and measure the flue gas temperature at 3.75 ($T_{F,OFF}(t_3)$) and 22.5 ($T_{F,OFF}(t_4)$) minutes after the burner shuts off, using the nine thermocouples described above. During this off-period, no water shall be allowed to circulate through the hot water boilers. A third flue gas temperature measurement shall then be made 45 minutes after the burner shuts off, to determine the off-period minimum flue gas temperature ($T_{F,OFF,}(\infty)$). During this cool-down test, the energy input rate to the pilot light (Q_p), if the unit is so equipped, shall be measured with an error no larger than $\pm$ 3%. Record all measured values. For oil-fueled units not equipped with stack dampers, a means shall be provided to maintain the draft in the flue within -0.001 and +0.005 inches of water gauge of the average draft maintained during the steady-state test described in section 3.1 if the optional test in 3.6 is being carried out, and within $\pm$0.01 inches of water gauge of the average steady-state draft if it is not. For direct-vent systems with flue dampers or boilers equipped with both stack dampers and barometric dampers, the flue or stack damper shall be closed during the cool-down test.

3.3 Flue Gas Temperature Measurements -- Heat-Up Test

3.3.1 Gas- and Oil-Fueled Central Furnaces (Including Direct-Vent Systems)

After equilibrium conditions are achieved following the cool-down test and the required measurements performed, the furnace shall be turned on and the flue gas temperature measured, using the nine thermocouples described above, at 0.5 ($T_{F,ON}(t_1)$) and 2.5 ($T_{F,ON}(t_2)$) minutes after the main burner(s) comes on. During this on-period, there shall be a time delay, t^-, between the burner start-up and blower start-up of 1.5 minutes. Two exceptions to this are: if the furnace employs a single motor to drive a power burner and an indoor air circulating blower, both shall be started together, and if a 1.5 minute blower delay time results in the operation of the high limit control to shut the burner off, the fan control shall be permitted to automatically start the blower provided, if it is adjustable, it is set to turn the blower on at the highest flue gas temperature. If the fan control is permitted to start the blower, the time delay, t^-, between burner and blower start-up shall be measured using a stop watch. Record the measured temperatures. During the heat-up test for oil-fueled furnaces, the draft in the flue pipe shall be maintained within $\pm$0.01 inches of the manufacturer's recommended on-period draft.

3.3.2 Gas- and Oil-Fueled Boilers (Including Direct-Vent Systems)

Fifty minutes after the main burner(s) is turned off for the cool-down test, the steam or hot water boiler shall be turned on and the flue gas temperature measured, using the nine thermocouples described above, at 1.0 ($T_{F,ON}(t_1)$) and 5.5 ($T_{F,ON}(t_2)$) minutes after the main burner(s) comes on. The pump circulating the water through the hot water boiler shall be started simultaneously with the main burner(s) and the water flow rate shall be the same as that maintained during the steady-state test described in section 3.1. During the heat-up test for oil-fired boilers, the draft in the flue pipe shall be maintained within $\pm$0.01 inches of water column of the manufacturer's recommended on-period draft. Record the measured temperatures.

3.4 Jacket Loss Measurement

A jacket loss test is specified only for units intended to be installed outdoors. Measure the jacket loss (L_j) in accordance with the following ANSI standards, and record the total loss and ambient room temperature during the test:

(a) Electric and gas-fueled gravity and forced-air central furnaces - ANSI Z21.47-1973, section 2.9.1 and Appendix F.

(b) Electric and gas- or oil-fueled low-pressure steam and hot water boiler - ANSI Z21.47-1973, section 2.9.1 and Appendix F.

(c) Oil-fueled forced-air central furnaces - Z91.1-1972, Appendix B.

3.5 Measurement for Determining Effectiveness of Automatic Stack Damper

The effectiveness of an automatic stack damper (D_o), in furnaces so equipped, shall be determined by measuring the cross-sectional area of the stack (A_S), the net area of the damper plate (A_D) (the area of the damper plate minus the area of any holes in the plate), and the angle which the damper plate makes when closed with a plane perpendicular to the axis of the stack. The equation in section 4.3 is then employed to calculate D_o.

3.6 Optional Procedure for Determining D_P, D_F and D_S for Systems Equipped with Power Burners

On power-burner systems not employing automatic stack dampers or power-burner systems with a stack damper and a draft diverter or draft hood, D_F shall be measured during the cool-down test described in section 3.2. On systems for which the flue or stack damper is to be closed during the cool-down test described in section 3.2, D_P shall be measured during a separate cool-down test. This separate cool-down test shall be conducted after the heat-up test described in section 3.3 is completed. It shall be conducted by letting the unit run after the heat-up test until steady-state conditions are reached, as indicated by temperature variation in three successive readings taken 15 minutes apart of not more than plus or minus 5°F (2.8°C) in the flue gas temperature and 4°F (2.2°C) in the outlet water temperature for hot water boilers, and then shutting the unit off with the stack or flue damper controls by-passed or adjusted so that the stack or flue damper remains open during the resulting cool-down period. If a draft was maintained on oil-fueled units in the flue pipe during the steady-state performance test described in section 3.1, the same draft (within -0.001 and +0.005 inches of water gauge of the average steady-state draft) shall be maintained during this cool-down period.

The flue gas mass flow rate ($\dot{m}_{F,OFF}$) during the cool-down test described above shall be measured at a specific off-period flue gas temperature and then corrected to obtain its value at the steady-state flue gas temperature ($T_{F,SS}$), using the procedure described in 4.4.

Within one minute after the unit is shut off to start the cool-down test for determining D_P, begin feeding a tracer gas into the combustion chamber at a constant flow rate of $\dot{V}_T$, and at a point which will allow for the best possible mixing with the air flowing through the chamber. On units equipped with an oil-fired power burner, the best location for injecting this tracer gas appears to be through a hole drilled in the blast tube. The value of V_T shall be periodically measured with an instantaneously reading flow meter which will result in a reading having an error no larger than $\pm$ 3% of the quantity measured and shall be less than 1% of the air flow rate through the furnace. If a combustible tracer gas is used, there should be a delay period between the time the unit is shut off and the time the tracer gas is first injected, to prevent ignition of the tracer gas. Great care should be exercised when employing tracer gases which are combustible or dangerous, to prevent human injury.

Between 5 and 6 minutes after the unit is shut off to start the cool-down test, the flue gas temperature, $T^{*}_{F,OFF}$, shall be measured using the nine thermocouples described above. At the same instant the flue gas temperature is measured, the percent volumetric concentration of tracer gas, C_T, in the flue gas shall also be measured in the same plane where $T^{*}_{F,OFF}$ is determined. The concentration of tracer gas shall be obtained using an instrument which will result in a reading having an error no larger than $\pm$ 2% of the value of C_T measured and may be either a batch or continuous reading type instrument. If the sampling arrangement on a continuously reading instrument results in a delay time between drawing of a sample and its analysis, this delay should be taken into account so that the temperature measurement and the measurement of tracer gas concentration coincide. In addition, the temperature of the tracer gas entering the flow meter (T_T) and the barometric pressure (P_B) shall also be determined.

The rate of the flue gas mass flow through the furnace and the factors D_P, D_F, and D_S are calculated by the equations in sections 4.4.1, 4.4.2, and 4.4.3.

3.7 Additional Requirements for Furnaces which Modulate or Vary Fuel Input Without Controlling Excess Combustion Air

A furnace which is equipped with a mechanism for reducing the rate of fuel input but does not provide a means for controlling excess combustion air, shall be tested at its maximum firing rate in accordance with test procedures in section 3. These test results shall be used to calculate a seasonal efficiency and an annual operating cost which is based upon this maximum fixed fuel input rate.

4. CALCULATION OF DERIVED RESULTS FROM TEST MEASUREMENT

The test procedures for furnaces and boilers was outlined in sections 2 and 3 above. A calculation procedure is described below, in subsection 4.1, for determining the annual fuel utilization efficiency, $EFFY_A$, for gas- and oil-fired central heating equipment. The fuel utilization efficiency for electric furnaces and boilers is assumed to be 100% for indoor units, and is given by $EFFY_A = (100 - 3.3L_J)$ and $EFFY_A = (100 - 4.7L_J)$ for electric furnaces and boilers, respectively, intended for installation out of doors or in unheated spaces (such as an attic or a crawl space). In subsection 4.2, recommended procedures for calculating the annual cost of operation in different climate regions of the country and an average operating cost for the continental United States are described. Sections 4.3 and 4.4 provide additional calculations relating to gas- or oil-fueled furnaces and boilers equipped with stack dampers and/or power burners.

4.1 Recommended Procedure for Calculating the Annual Fuel Utilization Efficiency for Fossil-Fuel Heating Systems

The recommended procedure for calculating the annual fuel utilization efficiency, $EFFY_A$, consists of these types of tasks, namely:

- Collection of measured quantities from the tests and characteristic constants (see tables 2 and 3) associated with the system under evaluation.

- Calculation of losses (i.e., latent heat loss, $L_{L,A}$, on-cycle sensible heat loss, $L_{S,ON}$, off-cycle sensible heat loss, $L_{S,OFF}$, on-cycle infiltration loss, $L_{I,ON}$, off-cycle infiltration loss, $L_{I,OFF}$) and the annual fuel utilization efficiency, $EFFY_A$. These tasks are performed by carrying out each of the following numbered steps and entering the result in the column having the same number on the worksheet (Figure 10).

Numbered Steps and Columns in Figure 10 are as follows:

1. Enter column 1 the system number SYS# (see tables 1 and 2) for type of system under evaluation.

2. Enter type of fuel used, TFUEL. Use "1" for No. 1 oil, "2" for No. 2 oil, "3" for natural gas, "4" for manufactured gas, "5" for propane, and "6" for butane.

3. Enter measured higher heating value of fuel used, HHV, in Btu/lb.

4. Enter fuel input rate (including fuel supply to pilot flame) at full-load steady-state operation, Q_{IN}, in Btu/h.

5. Enter fuel input rate to pilot flame, Q_P, in Btu/h.

6. Enter power burner electric energy input rate at full-load steady-state operation, PE, in kW.

7. Enter circulating-air blower (or circulating-water pump) electric energy input rate at full-load steady-state operation, BE, in kW.

8. For furnaces or boilers with draft diverters: Enter the CO_2 concentration $X_{CO_2,S}$ (% of volume) in dry stack gas at full-load steady-state operation measured in accordance with section 2. For units employing draft hoods, barometric damper or direct vent systems: Enter 0.0 in column 8.

9. For furnaces or boilers with draft diverters: Enter the stack gas temperature at full-load steady-state operation, $T_{S,SS,X}$, measured in accordance with section 2.

   For units employing draft hood, barometric dampers or direct vent systems: Enter 0.0 in column 9.

10. Enter the CO_2 concentration $X_{CO_2,F}$ (% by volume) in dry flue gas at full-load steady-state operation measured in accordance with section 2.

11. Enter the flue gas temperature at full-load steady-state operation, $T_{F,SS}$ measured in accordance with section 2.

12., 13. Enter the flue gas temperatures in °F at the start-up of the system burner from equilibrium, $T_{F,ON}(t_1)$ and $T_{F,ON}(t_2)$ in columns 12 and 13, respectively.

   For furnace: t_1 = 0.5 minute, t_2 = 2.5 minutes.
   For boiler: t_1 = 1 minute, t_2 = 5.5 minutes.

14., 15. Enter the flue gas temperatures in °F after the shut-down of the system burner from steady-state operation, $T_{F,OFF}(t_3)$ and $T_{F,OFF}(t_4)$ in columns 14 and 15, respectively.
   For furnace: t_3 = 1.5 minutes, t_4 = 9 minutes.
   For boiler: t_3 = 3.75 minutes, t_4 = 22.5 minutes.

16. Enter the minimum flue gas temperature in °F as measured in accordance with section 3.2 while the burner is off, $T_{F,OFF}(\infty)$. For furnaces not employing a continuously operating pilot light, $T_{F,OFF}(\infty)$ equals the room temperature.

17. Enter the laboratory room temperature, T_{RA}, in °F.

18. For indoor unit: Enter 0.0 in column 18.
   For outdoor unit or units intended for installation in unheated spaces (such as an attic or a crawl space): Enter jacket loss L_J, measured in accordance with section 2.

19. Enter the average ratio of stack-gas mass flow rate to flue-gas mass flow rate at full-load steady state operation, S/F. S/F is selected from tables 1 and 2 for the SYS# (column 1) under consideration.

20. Enter the off-cycle flue gas draft factor, D_F, selected from tables 1 and 2 for the SYS# (column 1) under consideration or measured in accordance with section 3.6.

21. For SYS# (column 1) equal to 9 through 12: Enter 0.0 in column 20.

For SYS# (column 1) equal to 1 through 8: Enter off-cycle stack gas draft factor, D_S. D_S may either be selected from table 1 for the SYS# (column 1) under consideration or determined in accordance with section 3.6.

22. Enter value of y equal to $1 + (\frac{t^+ - t^-}{3.87})$ for furnaces, and y equal to 1.00 for boilers or furnaces employing a single motor to drive a power burner and an indoor-air circulating blower.

23. Calculate and enter the ratio of pilot flame fuel input rate to the system full-load fule (including pilot flame fuel) input rate:

$$PF = \frac{Q_P \text{ (col. 5)}}{Q_{IN} \text{ (col. 4)}}$$

24. For the type of fuel used, obtain the average higher heating value, HHV_A, in Btu/lb from table 3 and enter in column 24. Calculate

$\frac{HHV \text{ (col. 3)}}{HHV_A \text{ (col. 24)}}$ and proceed to step 25 only if $0.95 \le \frac{HHV \text{ (col. 3)}}{HHV_A \text{ (col. 24)}} \le 1.05$.

25., 26. Read average values of stoichiometric air-to-fuel ratio, A/F, and latent heat loss $L_{L,A}$ from table 3 for TFUEL (column 2) under consideration, and enter these values in columns 25 and 26, respectively.

27. Enter C_J equal to 3.3 for furnaces and 4.7 for boilers.

28. Using TFUEL (column 2) and $X_{CO_2,F}$ (column 10), read from figure 1 the ratio of combustion air to stoichiometric air, $R_{T,F}$ and enter this value.

29. For furnaces or boilers with draft diverters: Using TFUEL (column 2) and $X_{CO_2,S}$ (column 8), read from figure 1 the ratio of the sum of combustion and relief air to stoichiometric air, $R_{T,S}$. Then using this $R_{T,S}$ value and $\Delta T_{S,SS} = [T_{S,SS,X}$ (column 9) $- T_{RA}$ (column 17)] read from figure 2 for the TFUEL (column 2) under consideration the average sensible heat loss at full-load steady-state operation $L_{S,SS,A}$ and enter this value in column 29.

For units equipped with draft hoods, barometric dampers or direct-vent systems: Using value of $R_{T,F}$ (column 28) and $\Delta T_{F,SS} = [T_{F,SS}$ (column 11) $- T_{RA}$ (column 17)] read from figure 2 the average sensible heat loss at steady-state operation, $L_{S,SS,A}$ and enter this value in column 29.

30. Calculate and enter the steady-state efficiency (excluding jacket loss).

$$\eta_{ss} = 100 - L_{L,A} \text{ (col. 26)} - L_{S,SS,A} \text{ (col. 29)}.$$

31. Calculate and enter in column 31.

$$T_{S,SS} = \frac{1}{(S/F) \text{ (col. 19)}} \times [T_{F,SS} \text{ (col. 11)} - T_{RA} \text{ (col. 17)}] + T_{RA} \text{ (col. 17)}$$

32. Calculate and enter on-cycle time constant

$$\tau_{ON} = \frac{(t_2 - t_1)}{\ell n \left[\frac{T_{F,SS}(\text{col. } 11) - T_{F,ON}(t_1)(\text{col. } 12)}{T_{F,SS}(\text{col. } 11) - T_{F,ON}(t_2)(\text{col. } 13)} \right]}$$

where $(t_2 - t_1) = 2$ for furnace, and $(t_2 - t_1) = 4.5$ for boiler.

33. Calculate and enter effective flue gas temperature difference at start-up under test conditions:

$$\theta_{F,O,X} = [T_{F,SS}(\text{col. } 11) - T_{F,ON}(t_1)(\text{col. } 12)] \times e^{\frac{t_1}{\tau_{ON}(\text{col. } 32)}}$$

where $t_1 = 0.5$ for furnace and $t_1 = 1$ for boiler.

34. Calculate and enter off-cycle time constant:

$$\tau_{OFF} = \frac{(t_4 - t_3)}{\ell n \left[\frac{T_{F,OFF}(t_3)(\text{col. } 14) - T_{F,OFF}(\infty)(\text{col. } 16)}{T_{F,OFF}(t_4)(\text{col. } 15) - T_{F,OFF}(\infty)(\text{col. } 16)} \right]}$$

where $(t_4 - t_3) = 7.5$ for furnace and $(t_4 - t_3) = 18.75$ for boiler.

35. Calculate and enter effective flue gas temperature difference at shut down under test conditions:

$$\psi_{F,O,X} = [T_{F,OFF}(t_3)(\text{col. } 14) - T_{F,OFF}(\infty)(\text{col. } 16)]\ e^{\frac{t_3}{\tau_{OFF}(\text{col. } 34)}}$$

where $t_3 = 1.5$ for furnace and $t_3 = 3.75$ for boiler.

36. Calculate and enter minimum flue gas temperature difference above the room temperature:

$$\psi_{F,\infty,X} = T_{F,OFF}(\infty)\ (\text{col. } 16) - T_{RA}(\text{col. } 17)$$

37. For SYS# (col. 1) equal to 1 through 4 and systems 5 through 8 for which $(S/F)(\text{col. } 19) \times D_S(\text{col. } 21) > D_F(\text{col. } 20)$, calculate and enter in column 37:

$$\psi_{S,\infty,X} = \frac{D_F(\text{col. } 20) \times \psi_{F,\infty,X}(\text{col. } 36)}{(S/F)(\text{col. } 19) \times D_S(\text{col. } 21)}$$

For SYS# (col. 1) equal to 5 through 8 for which $(S/F)(\text{col. } 19) \times D_S(\text{col. } 21) \leq D_F$ (col. 20), calculate and enter in column 37:

$$\psi_{S,\infty,X} = \psi_{F,\infty,X}\ (\text{col. } 36).$$

For SYS# (col. 1) equal to 9 through 12: Leave column 37 blank.

38. For SYS# (col. 1) equal to 1 through 4 and systems 5 through 8 for which (S/F) (col. 19) X D_S (col. 21) > D_F (col. 20), calculate and enter in column 38:

$$\psi_{S,O,X} = \frac{D_F(\text{col. } 20) \text{ X } \psi_{F,O,X}(\text{col. } 35)}{(S/F)(\text{col. } 19) \text{ X } D_S(\text{col. } 21)}$$

For SYS# (col. 1) equal to 5 through 8 for which (S/F)(col. 19) X D_S(col. 21) $\leq D_F$ (col. 20), calculate and enter in column 38:

$$\psi_{S,O,X} = \psi_{F,O,X}(\text{col. } 35).$$

For SYS# (col. 1) equal to 9 through 12: Leave column 38 blank.

39. For SYS# (col. 1) equal to 1 through 8: Leave column 39 blank.

For SYS# (col. 1) equal to 9 through 12: Calculate and enter a correction factor for the use of outdoor air instead of indoor air for combustion:

$$C_S = 1 + \frac{28 \text{ X } \eta_{ss}(\text{col. } 30)}{[T_{F,SS}(\text{col. } 11) - T_{RA}(\text{col. } 17)]\ (100)}$$

40. Calculate and enter multiplication factor for sensible heat loss during the on-period, $K_{S,ON}$:

$$K_{S,ON} = \frac{24 \text{ X } [1 + R_{T,F}(\text{col. } 28) \text{ X } (A/F)(\text{col. } 25)]}{HHV_A(\text{col. } 24)}$$

41. Calculate and enter multiplication factor for sensible heat loss during the off-period, $K_{S,OFF}$.

For SYS# (col. 1) equal to 1 through 4:

$$K_{S,OFF} = \frac{(T_{F,SS}(\text{col. } 11) - T_{RA}(\text{col. } 17) + 530)^{1.19}}{(T_{F,SS}(\text{col. } 11) - T_{RA}(\text{col. } 17))^{0.56}} \text{ X } D_F(\text{col. } 20) \text{ X } K_{S,ON}(\text{col. } 40)$$

For SYS# (col. 1) equal to 5 through 8:

$$K_{S,OFF} = \frac{(T_{S,SS}(\text{col. } 31) - T_{RA}(\text{col. } 17) + 530)^{1.19}}{(T_{S,SS}(\text{col. } 31) - T_{RA}(\text{col. } 17) + 28)^{0.56}} \text{ X } D_S(\text{col. } 21) \text{ X}$$

$$\text{X } (S/F)(\text{col. } 19) \text{ X } K_{S,ON}(\text{col. } 40)$$

For SYS# (col. 1) equal to 9 through 12:

$$K_{S,OFF} = \frac{(T_{F,SS}(\text{col. } 11) - T_{RA}(\text{col. } 17) + 530)^{1.19}}{(T_{F,SS}(\text{col. } 11) - T_{RA}(\text{col. } 17) + 28)^{0.56}} \text{ X } D_F(\text{col. } 20) \text{ X } K_{S,ON}(\text{col. } 40)$$

42. For SYS# (col. 1) equal to 1 through 8: Calculate and enter multiplication factor for infiltration loss during the on-period:

$$K_{I,ON} = (0.7) \text{ X } (S/F)(\text{col. } 19) \text{ X } K_{S,ON}(\text{col. } 40)$$

For SYS# (col. 1) equal to 9 through 12: Leave column 42 blank.

43. For SYS# (col. 1) equal to 1 through 8: Calculate and enter in column 43 the multiplication factor for infiltration loss during the off-period:

$$K_{I,OFF} = \frac{(T_{S,SS}(\text{col. } 31) - T_{RA}(\text{col. } 17) + 530)^{1.19}}{(T_{S,SS}(\text{col. } 31) - T_{RA}(\text{col. } 17) + 28)^{0.56}} \text{ X } K_{I,ON}(\text{col. } 42) \text{ X } D_S(\text{col. } 21)$$

For SYS# (col. 1) equal to 9 through 12: Leave column 43 blank.

44. Enter the value of the average outdoor temperature, T_{OA} equal to 42°F.

45. For furnace: Enter column 45 the average on-time per cycle, t_{ON}, equal to 3.87 minutes.

For boiler: Enter column 45 the average on-time per cycle, t_{ON}, equal to 9.68 minutes.

46. For furnace: Enter column 46 the average off-time per cycle, t_{OFF}, equal to 13.30 minutes.

For boiler: Enter column 46 the average off-time per cycle, t_{OFF}, equal to 33.26 minutes.

47., 48. Calculate $t_{ON}(\text{col. } 45)/\tau_{ON}(\text{col. } 32)$ and $t_{OFF}(\text{col. } 46)/\tau_{OFF}(\text{col. } 34)$ and enter columns 47 and 48, respectively.

49., 50., 51., 52., 53. Correct the heat-up and cool-down temperature profiles for the effect of cycling:

For SYS# (col. 1) equal to 1 through 8, calculate and enter:

$$\theta_{F,O} \ (\text{col. } 49) = C_{t,ON}\theta_{F,O,X}(\text{col. } 33)$$

$$\psi_{F,O} \ (\text{col. } 50) = C_{t,OFF}\psi_{F,O,X} \ (\text{col. } 35)$$

$$\psi_{F,\infty} \ (\text{col. } 51) = \psi_{F,\infty,X} \ (\text{col. } 36)$$

$$\psi_{S,O} \ (\text{col. } 52) = C_{t,OFF} \ \psi_{S,O,X} \ (\text{col. } 38)$$

$$\psi_{S,\infty} \ (\text{col. } 53) = \psi_{S,\infty,X} \ (\text{col. } 37)$$

For SYS# (col. 1) equal to 9 through 12, leave columns 52 and 53 blank; calculate and enter:

$$\theta_{F,0}\text{(col. 49)} = C_{t,ON} \times C_S\text{(col. 39)} \times \theta_{F,0,X} \text{ (col. 33)}$$

$$\psi_{F,0}\text{(col. 50)} = C_{t,OFF} \times C_S{}' \times \psi_{F,0,X} \text{ (col. 35)}$$

$$\psi_{F,\infty}\text{(col. 51)} = C_S{}' \times \psi_{F,\infty,X} \text{ (col. 36)}$$

where $C_S{}' = 1.22$

$$C_{t,ON} = \frac{\left(1 - \dfrac{\psi_{F,0,X}\text{(col. 35)} \times e^{-\left(\frac{t_{OFF}}{\tau_{OFF}}\right)\text{(col. 48)}}}{(T_{F,SS}\text{(col. 11)} - T_{F,OFF}(\infty)\text{(col. 16)})}\right)}{\left(1 - \dfrac{\theta_{F,0,X}\text{(col. 33)} \times \psi_{F,0,X}\text{(col. 35)} \times e^{-\left(\left(\frac{t_{ON}}{\tau_{ON}}\right)\text{(col. 47)} + \left(\frac{t_{OFF}}{\tau_{OFF}}\right)\text{(col. 48)}\right)}}{(T_{F,SS}\text{(col. 11)} - T_{F,OFF}(\infty)\text{(col. 16)})^2}\right)}$$

$$C_{t,OFF} = \frac{(C_{IID})\left(1 - \dfrac{\theta_{F,0,X}\text{(col. 33)} \times e^{-\left(\frac{t_{ON}}{\tau_{ON}}\right)\text{(col. 47)}}}{(T_{F,SS}\text{(col. 11)} - T_{F,OFF}(\infty)\text{(col. 16)})}\right)}{\left(1 - \dfrac{\theta_{F,0,X}\text{(col. 33)} \times \psi_{F,0,X}\text{(col. 35)} \times e^{-\left(\left(\frac{t_{ON}}{\tau_{ON}}\right)\text{(col. 47)} + \frac{t_{OFF}}{\tau_{OFF}}\text{(col. 48)}\right)}}{(T_{F,SS}\text{(col. 11)} - T_{F,OFF}(\infty)\text{ (col. 16)})^2}\right)}$$

$$C_{IID} = \begin{cases} 1 \text{ for units with continuously operating pilot lights} \\ 0.90 \text{ for units with intermittent ignition devices or cycling pilots.} \end{cases}$$

54. For SYS# (col. 1) equal to 1 through 4: Read from figure 3 and enter column 54: $F3[\psi_{F,0}\text{(col. 50)}, (t_{OFF}/\tau_{OFF})\text{(col. 48)}]$.

    For SYS# (col. 1) equal to 5 through 12: Leave column 54 blank.

55. For SYS# (col. 1) equal to 1 through 4: Read from figure 4 and enter column 55: $F4[\psi_{F,0}\text{(col. 50)}, (t_{OFF}/\tau_{OFF})\text{(col. 48)}]$.

    For SYS# (col. 1) equal to 5 through 12: Leave column 55 blank.

56. For SYS# (col. 1) equal to 1 through 4: Leave column 56 blank.

    For SYS# (col. 1) equal to 5 through 8: Read from figure 5 and enter column 56: $F5[\psi_{S,0}\text{(col. 52)}, (t_{OFF}/\tau_{OFF})\text{(col. 48)}]$.

For SYS# (col. 1) equal to 9 through 12: Read from figure 5 and enter column 56: $F5[\psi_{F,0}(\text{col. } 50), (t_{OFF}/\tau_{OFF})(\text{col. } 48)]$.

57. For SYS# (col. 1) equal to 1 through 4: Leave column 57 blank.

For SYS# (col. 1) equal to 5 through 8: Read from figure 6 and enter column 57: $F6[\psi_{S,0}(\text{col. } 52), (t_{OFF}/\tau_{OFF})(\text{col. } 48)]$.

For SYS# (col. 1) equal to 9 through 12: Read from figure 6 and enter in column 57: $F6[\psi_{F,0}(\text{col. } 50), (t_{OFF}/\tau_{OFF})(\text{col. } 48)]$.

58. For SYS# (col. 1) equal to 1 through 8: Read from figure 7 and enter column 58: $F7[\psi_{S,0}(\text{col. } 52), (t_{OFF}/\tau_{OFF})(\text{col. } 48)]$.

For SYS# (col. 1) equal to 9 through 12: Leave column 58 blank.

59. For SYS# (col. 1) equal to 1 through 8: Read from figure 8 and enter column 59: $F8[\psi_{S,0}(\text{col. } 52), (t_{OFF}/\tau_{OFF})(\text{col. } 48)]$.

For SYS# (col. 1) equal to 9 through 12: Leave column 59 blank.

60. For SYS# (col. 1) equal to 1 through 8: Calculate and enter on-cycle sensible heat loss:

$$L_{S,ON} = L_{S,SS,A}(\text{col. } 29) - K_{S,ON}(\text{col. } 40) \times \theta_{F,0}(\text{col. } 49) \times \frac{1}{(t_{ON}/\tau_{ON})(\text{col. } 47)}$$

$$\times \left(1 - e^{-\frac{t_{ON}}{\tau_{ON}}(\text{col. } 47)}\right).$$

For SYS# (col. 1) equal to 9 through 12: Calculate and enter on-cycle sensible heat loss:

$$L_{S,ON} = C_S(\text{col. } 39) \times L_{S,SS,A}(\text{col. } 29) - K_{S,ON}(\text{col. } 40) \times \theta_{F,0}(\text{col. } 49)$$

$$\times \frac{1}{(t_{ON}/\tau_{ON})(\text{col. } 47)} \times \left(1 - e^{-\frac{t_{ON}}{\tau_{ON}}(\text{col. } 47)}\right).$$

61. For SYS# (col. 1) equal to 1 through 4, calculate and enter the off-period sensible heat loss:

$$L_{S,OFF} = K_{S,OFF}(\text{col. } 41) \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}(\text{col. } 45)} \times [F3 (\text{col. } 54) + \psi_{F,\infty}(\text{col. } 51)$$

$$\times F4 (\text{col. } 55)].$$

For SYS# (col. 1) equal to 5 through 8, calculate and enter the off-period sensible heat loss:

$$L_{S,OFF} = K_{S,OFF}(\text{col. } 41) \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}(\text{col. } 45)} \times [F5 (\text{col. } 56) + \psi_{S,\infty}(\text{col. } 53)$$

$$\times F6 (\text{col. } 57)].$$

For SYS# (col. 1) equal to 9 through 12, calculate and enter the off-period sensible heat loss:

$$L_{S,OFF} = K_{S,OFF}(\text{col. } 41) \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}\ (\text{col. } 45)} \times [F5\ (\text{col. } 56) + \psi_{F,\infty}(\text{col. } 51) \times F6\ (\text{col. } 57)].$$

62. For SYS# (col. 1) equal to 1 through 8: Calculate and enter on-cycle infiltration heat loss:

$$L_{I,ON} = K_{I,ON}(\text{col. } 42) \times [70 - T_{OA}(\text{col. } 44)]$$

For SYS# (col. 1) equal to 9 through 12: Enter on-cycle infiltration heat loss, $L_{I,ON} = 0$.

63. For SYS# (col. 1) equal to 1 through 8: Calculate and enter off-cycle infiltration loss:

$$L_{I,OFF} = K_{I,OFF}(\text{col. } 43) \times [70 - T_{OA}(\text{col. } 44)] \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}\ (\text{col. } 45)} \times$$

$$\times\ [F7\ (\text{col. } 58) + \psi_{S,\infty}\ (\text{col. } 53) \times F8\ (\text{col. } 59)]$$

For SYS# (col. 1) equal to 9 through 12: Enter off-cycle infiltration heat loss, $L_{I,OFF} = 0$.

64. Calculate and enter part-load fuel utilization efficiency, for indoor unit:

$$\eta_u = 100 - L_{L,A}(\text{col. } 26) - \frac{t_{ON}\ (\text{col. } 45)}{t_{ON}(\text{col. } 45) + PF(\text{col. } 23)t_{OFF}(\text{col. } 46)}$$

$$\times\ [L_{S,ON}(\text{col. } 60) + L_{S,OFF}(\text{col. } 61) + L_{I,ON}(\text{col. } 62) + L_{I,OFF}(\text{col. } 63)].$$

For outdoor unit or units intended for installation in unheated spaces (such as an attic or crawl space)

$$\eta_u = 100 - L_L\ (\text{col. } 27) - C_J(\text{col. } 27) \times L_J(\text{col. } 18)$$

$$- \frac{t_{ON}(\text{col. } 45)}{t_{ON}(\text{col. } 45) + PF(\text{col. } 23)t_{OFF}(\text{col. } 46)} \times [L_{S,ON}(\text{col. } 60) + L_{S,OFF}(\text{col. } 61)].$$

65. Enter the value of the average annual heating degree days for the U.S., DD, equal to 5200.

66. Enter the average total number of non-heating season hours per year that the energy to the pilot light is assumed wasted, HR, equal to 4600.

67. Calculate and enter annual fuel utilization efficiency:

$$EFFY_A = \frac{\eta_{SS}(\text{col. } 30) \times \eta_u(\text{col. } 64) \times DD\ (\text{col. } 65)}{\eta_{SS}(\text{col. } 30) \times DD\ (\text{COL. } 65) + (2.5) \times \eta_u(\text{col. } 64) \times PF\ (\text{col. } 23) \times [1.7]\ [HR(\text{col.}66)]}$$

4.2 Recommended Procedure for Calculating the Annual Cost of Operation of a Furnace or Boiler Located in Different Climatic Regions of the Country and in Buildings with Different Design Heating Requirements

The annual cost of operating a gas- or oil-fired furnace or boiler located in various geographic locations of the United States and in buildings with different design heating requirements shall be determined using the following three-step procedure:

Step 1. Determine the number of burner operating hours using the equation:

$$\text{Burner Operating Hours} = A\ (HLH)\ (C)\ (\text{design heating requirement}) - B\ (HLH)$$

where the number of heating load hours, HLH, may be obtained from Figure 9 for the region of interest, the "design heating requirement" is the heating requirement to be met by the furnace or boiler in kBtu per hour at the 97 1/2 percent outdoor design temperature, and C = 0.77 is an "experience factor" which tends to improve the agreement between the average calculated burner operating hours and the average burner operating hours found in the field. It is strongly recommended that this "experience factor" be eliminated as soon as an improved method is available to more accurately estimate residential heating requirements. Typical values for the design heating requirement are given in Table 4 for different furnace or boiler output capacities Q_{OUT}, where $Q_{OUT} \equiv \eta_{SS}$ (col. 30) X Q_{IN} (col. 4) rounded off to the nearest 1000 Btu/h for units intended for installation in a heated space and

$$Q_{OUT} \equiv \left(\frac{Q_{IN}\ (\text{col. } 4)}{100}\right)(\eta_{SS}\ (\text{col. } 30) - 3.3\ L_J\ (\text{col. } 18))$$ rounded off to the nearest

1000 Btu/h for units intended for installation out of doors or in an unheated space. The constants A and B are unique to the unit under tests and may be calculated using information contained in the work sheet and the following expressions:

$$A = \frac{100{,}000}{341{,}300\ (PE + y\ BE) + (Q_{IN} - Q_p)\ \eta_u},$$

$$B = \frac{(2)(A)(Q_p)(\eta_u)}{100{,}000}$$

$$\text{where } y = \begin{cases} 1 + \left(\dfrac{t^+ - t^-}{3.87}\right) & \text{for furnace} \\ 1.00 & \text{for boilers or furnaces employing a single motor to drive a power burner and an indoor-air circulating blower.} \end{cases}$$

Step 2. Determine the annual fuel consumption (in Btu) and the annual electricity consumption (in kWh) using:

$$\text{Annual Fuel Consumption} = (Q_{IN} - Q_p)(\text{Burner Operating Hours}) + 8760\ Q_p$$

$$\text{Annual Electricity Consumption} = (PE + yBE)(\text{Burner Operating Hours})$$

Step 3. The annual cost of operation is then:

$$\text{Annual Cost of Operation} = (\text{Annual Fuel Consumption})\left(\frac{1}{K}\right)(\$ \text{ per unit of fuel}) + (\text{Annual Electricity Consumption})(\$ \text{ per kWh}),$$

where K is the Btu content per unit of fuel that the fuel cost is given in terms of (e.g. K = 100,000 Btu/therm if cost is given in dollars per therm; K = 140,000 Btu/gallon if cost is expressed as dollars per gallon of No. 2 fuel oil). The annual cost of operation should be rounded off to the nearest five dollars.

The annual cost of operating an electric furnace or boiler in various geographic locations of the United States and in buildings with different design heating requirements shall be determined using the equation:

$$\text{Annual Cost of Operation} = \frac{100\ (\text{HLH})(\text{C})(\text{design heating requirement})}{\text{EFFY}_A} \times \frac{1}{3.413}\ (\$\ \text{per kWh})$$

$$\text{where } \text{EFFY}_A = \eta_{SS} = \begin{cases} 100 & \text{for units intended for installation in a heated space} \\ (100 - 3.3\ L_J) & \text{for electric furnaces intended for installation out of doors or in unheated spaces (such as an attic or a crawl space)} \\ (100 - 4.7\ L_J) & \text{for electric boilers intended for installation out of doors or in unheated space (such as an attic or a crawl space)} \end{cases}$$

and $C \equiv 0.77$ is the "experience factor" mentioned above.

The number of heating load hours, HLH, for different geographical regions is given in Figure 10, and the "design heating requirement" is the building heating requirement in kBtu per hour at the 97 1/2 percent outdoor design temperature. Typical value for the design heating requirement are given in Table 4 for electric furnaces and boilers having different output capacities Q_{OUT}, where $Q_{OUT} = (E_{IN})(3.413)$ rounded off to the nearest 1000 Btu/h for units intended for installation in a heated space and $Q_{OUT} \equiv \frac{(E_{IN})(3.413)}{100}(100 - 3.3\ L_J)$ for units intended for installation out of doors or in an unheated space. The annual cost of operation should be rounded off to the nearest five dollars.

In order to facilitate performance comparison by the consumer of furnaces, boilers and heat pumps, it is recommended that the annual cost of operation be calculated for all of the appropriate typical design heating requirements shown in Table 4 and for a variety of heating load hours, HLH. For example, a furnace with an output capacity of 80 kBtu/h could have its annual cost of operation calculated at design heating requirements of 40, 45, 50 and 60 kBtu/h, and heating load hours of 750, 1250, 1750, 2250 and 2750 hours. This approach has the advantage of being able to handle different sizing relationships between the furnace or boiler and a residence's design heating requirement in different geographical locations and could be incorporated, along with the effect of different fuel costs, in a table having the following form:

REGION	DESIGN HEATING REQUIREMENT (kBtu/h)	EFFY_A	COST OF FUEL ($/THERM) .20	.25	.30	.35	.40
I (750 HLH)	40 45 50 60						
II (1250 HLH)	40 45 50 60						
III (1750 HLH)	40 45 50 60						
IV (2250 HLH)	40 45 50 60						
V (2750 HLH)	40 45 50 60						

If a single operating cost figure is required for a furnace or boiler that represents the national average, it is recommended that the preceding appropriate equations be used with HLH set equal to 2080 hours and the design heating requirement set equal to the average design heating requirement given in Table 4 for the appropriate value of furnace or boiler output capacity Q_{OUT}.

4.3 Additional Calculations for Furnaces or Boilers Utilizing an Automatic Stack (or flue) Damper

Calculate the automatic stack (or flue) damper effectiveness, D_o, defined as:

$$D_o = \sqrt{\frac{5}{5 + \dfrac{(2.6)\left(\dfrac{A_D'}{A_S}\right)^{1.58}}{\left(1 - \left(\dfrac{A_D'}{A_S}\right)\right)^2}}}$$

where $A_D' = A_D \cos(\gamma)$

A_S = cross sectional area of the stack determined in accordance with section 3.5 of this appendix, in square inches

A_D = net area of the damper plate determined in accordance with section 3.5 of this appendix, in square inches

γ = the angle the damper makes when closed with a plane perpendicular to the axis of the stack determined in accordance with section 3.5.

4.4 Additional Calculation Procedures for Furnaces or Boilers Equipped with Power Burners

4.4.1 Optional Procedure for Determination of D_P for Furnaces or Boilers Employing a Power Burner

Calculate the ratio (D_P) of the rate of flue-gas mass flow through the furnace or boiler during the off-period, $\dot{m}_{F,OFF}(T_{F,SS})$, to the rate of flue-gas mass flow during the on-period, $\dot{m}_{F,SS}(T_{F,SS})$, and defined as:

$$D_P = \frac{\dot{m}_{F,OFF}(T_{F,SS})}{\dot{m}_{F,SS}(T_{F,SS})} = \frac{[\dot{m}_{F,OFF}(T^*_{F,OFF})]\ K'}{\dot{m}_{F,SS}(T_{F,SS})} = \frac{\left[\dfrac{(\dot{V}_T)(\rho_F)(100 - C_T)}{C_T}\right] K'}{[(R_{T,F})A/F + 1]\ \dfrac{Q_{IN}}{(HHV_A)(60)}}$$

$$K' = \begin{cases} \left[\dfrac{T_{F,SS} - T_{RA}}{T^*_{F,OFF} - T_{RA}}\right]^{0.56} \left[\dfrac{T^*_{F,OFF} + 460}{T_{F,SS} + 460}\right]^{1.19}, & \text{for gas-fueled units or} \\ & \text{oil-fueled units for which no draft is maintained during the steady-state tests or cool down test.} \\ 1, & \text{for oil-fueled units tested with an imposed draft as described in section 3.6.} \end{cases}$$

$\dot{V}_T$ = flow rate of tracer gas through the furnace measured in accordance with section 3.6, in cubic feet per minute.

C_T = concentration by volume of tracer gas present in the flue gas sample measured in accordance with section 3.6, in percent.

ρ_F = the density the flue gas would have at the measured barometric pressure, P_B, and the measured temperature, T_T, in lb. per cu. ft. It may be approximated by the equation:

$$\rho_F \simeq 1.325 \frac{P_B}{T_T + 460}$$

T_T = temperature of tracer gas entering the flow meter measured in accordance with section 3.6, in degrees Fahrenheit.

P_B = barometric pressure measured in accordance with section 3.6, in inches of mercury.

4.4.2 Optional Procedure for Determination of Off-Cycle Draft Factor for Flue-Gas Flow for Furnaces or Boilers Employing a Power Burner

Calculate the off-cycle draft factor for flue gas flow, D_F, defined as:

for systems numbered 2, 4, 6, 8 or 10: $D_F = D_P$

for system number 12: $D_F = (D_P)(D_o)$,

4.4.3 Optional procedure for Determination of Off-Cycle Draft Factor for Stack-Gas Flow for Furnaces or Boilers Employing a Power Burner

Calculate the off-cycle draft factor for stack-gas flow, D_S, defined as:

for system number 2: $D_S = 1.0$

for system number 4: $D_S = (0.79 + D_P)/1.4$

for system number 6: $D_S = D_o$

for system number 8:

$$D_S = \begin{cases} (D_o)(D_p), & \text{if } D_o \le \dfrac{1}{(S/F)} \\ (D_o)(D_p) + \dfrac{\left(0.85 - (D_o)(D_p)\right)\left(D_o - \dfrac{1}{(S/F)}\right)}{\left(1 - \dfrac{1}{(S/F)}\right)}, & \text{if } D_o > \dfrac{1}{(S/F)} \end{cases}$$

Table 1. Factors Describing Air Flow Rate for Gas and Oil-Fired Furnaces or Boilers Utilizing Indoor Air for Combustion and Draft Control

Type of Burner	Units Without a Stack Damper but with Draft Hood or Draft Diverter				Units Without a Stack Damper but with Barometric Draft Control				Units With a Stack Damper and Draft Hood or Draft Diverter				Units With a Stack Damper and Barometric Draft Control			
	System #	S/F	D_F	D_S	System#	S/F	D_F	D_S	System #	S/F	D_F	D_S	System#	S/F	D_F	D_S
Atmospheric	1	2.4	1.0	1.0	3	1.4	1.0	1.0	5	2.4	1.0	D_o	7	1.4	1.0	D_o
Power	2	2.4	0.4	1.0	4	1.4	0.4	0.85	6	2.4	0.4	D_o	8	1.4	0.4	$(D_o)(D_p')$

$$\text{where} \quad D_p' = \begin{cases} 0.4, & D_o \leq \dfrac{1}{(S/F)} \\[2ex] 0.4 + \dfrac{(0.85 - (0.4)(D_o))\left(D_o - \dfrac{1}{(S/F)}\right)}{D_o\left(1 - \dfrac{1}{(S/F)}\right)}, & D_o > \dfrac{1}{(S/F)} \end{cases}$$

The above factors were developed by the National Bureau of Standards and are based upon information in the public literature, laboratory and computer simulation studies conducted at NBS, and laboratory and field data obtained by several research firms under contract to NBS and DoE.

Table 2. Factors Describing Air Flow Rates for Gas or Oil-Fired Furnaces/Boilers Intended for Installation Out of Doors or in Unheated Spaces (such as an attic or crawl space) or Intended for Indoor Installation but Equipped With a Direct Vent System

Type of Burner	Units Without a Stack or Flue Damper		Units With a Flue Damper		Type of Draft	S/[illegible]
	System #	D_F	System #	D_F	None	1
Atmosphere	9	1.00	11	D_o	barometric damper	1.4
Power	10	0.40	12	$0.40 \times D_o$	draft diverter	2.4

The above factors were developed by the National Bureau of Standards and are based upon information in the public literature, laboratory and computer simulation studies conducted at NBS, and laboratory and field data obtained by several research firms under contract to NBS and DoE.

Table 3. Values of Higher Heating Value (HHV_A), Stoichiometric Air/Fuel Ratio (A/F), and Latent Heat Loss ($L_{L,A}$) for Typical Fuels

Fuels	HHV_A (Btu/lb)	A/F(--)	$L_{L,A}$ (%)
No.1 Oil	19,800	14.56	6.55
No.2 Oil	19,500	14.49	6.50
Natural Gas	20,120	14.45	9.55
Manufactured Gas	18,500	11.81	10.14
Propane	21,500	15.58	7.99
Butane	20,890	15.36	7.79

Table 4. Average and Typical Design Heating Requirements for Furnaces and Boilers with Different Output Capacities

Furnace or Boiler Output Capacity, Q_{OUT} (Btu/h)	Average Design Heating Requirements (kBtu/h)	Typical Design Heating Requirements (kBtu/h)
26,000 - 34,000	20	15, 20
35,000 - 42,000	25	20, 25, 30
43,000 - 51,000	30	25, 30, 35
52,000 - 59,000	35	30, 35, 40, 45
60,000 - 76,000	40	35, 40, 45, 50
77,000 - 93,000	50	40, 45, 50, 60
94,000 - 110,000	60	50, 60, 70, 80
111,000 - 127,000	70	60, 70, 80, 90
128,000 - 144,000	80	70, 80, 90, 100
145,000 - 161,000	90	80, 90, 100, 110, 120
162,000 - 178,000	100	90, 100, 110, 120, 130
179,000 - 195,000	110	100, 110, 120, 130, 140
196,000 - 237,000	130	120, 130, 140, 150, 160
238,000 - 271,000	150	120, 140, 160, 180, 200
272,000 - 305,000	170	140, 160, 180, 200, 220

Table 5. Parameters For Calculating Steady State Sensible Heat Loss ($L_{S,SS,A}$) And Steady State Efficiency (η_{SS})

FUEL	HHV_A	A/F	$L_{L,A}$	A	B	CF(1)	CF(2)	CF(3)	CF(4)	CF(5)
No. 1 Oil	19,800	14.56	6.55	0.0679	14.22	2.4416834×10^{-1}	3.3711449×10^{-6}	8.8906305×10^{-9}	$-1.3619019 \times 10^{-12}$	$-1.4367410 \times 10^{-16}$
No. 2 Oil	19,500	14.49	6.50	0.06668	14.34	2.4361163×10^{-1}	3.6702686×10^{-6}	8.7098897×10^{-9}	$-1.3094378 \times 10^{-12}$	$-1.5029209 \times 10^{-16}$
Natural Gas	20,120	14.45	9.55	0.09194	10.96	2.5949478×10^{-1}	$-4.9475802 \times 10^{-6}$	1.3885838×10^{-8}	$-2.8059994 \times 10^{-12}$	$3.7682444 \times 10^{-17}$
Manufactured Gas	18,500	11.81	10.14	.09646	10.10	2.6598442×10^{-1}	$-7.7561435 \times 10^{-6}$	1.5833852×10^{-8}	$-3.4194210 \times 10^{-12}$	$1.2158977 \times 10^{-16}$
Propane	21,500	15.58	7.99	.08410	12.60	2.5163639×10^{-1}	$-6.4144604 \times 10^{-7}$	1.1315073×10^{-8}	$-2.0656792 \times 10^{-12}$	$-5.4897330 \times 10^{-17}$
Butane	20,890	15.36	7.79	.08080	12.93	2.5011247×10^{-1}	1.7737005×10^{-7}	1.0820337×10^{-8}	$-1.9220641 \times 10^{-12}$	$-7.3013274 \times 10^{-17}$

	CA(1)	CA(2)	CA(3)	CA(4)	CA(5)
Air	2.5462121×10^{-1}	$-3.0260126 \times 10^{-5}$	2.7608571×10^{-8}	$-7.4253321 \times 10^{-12}$	$6.4307377 \times 10^{-16}$

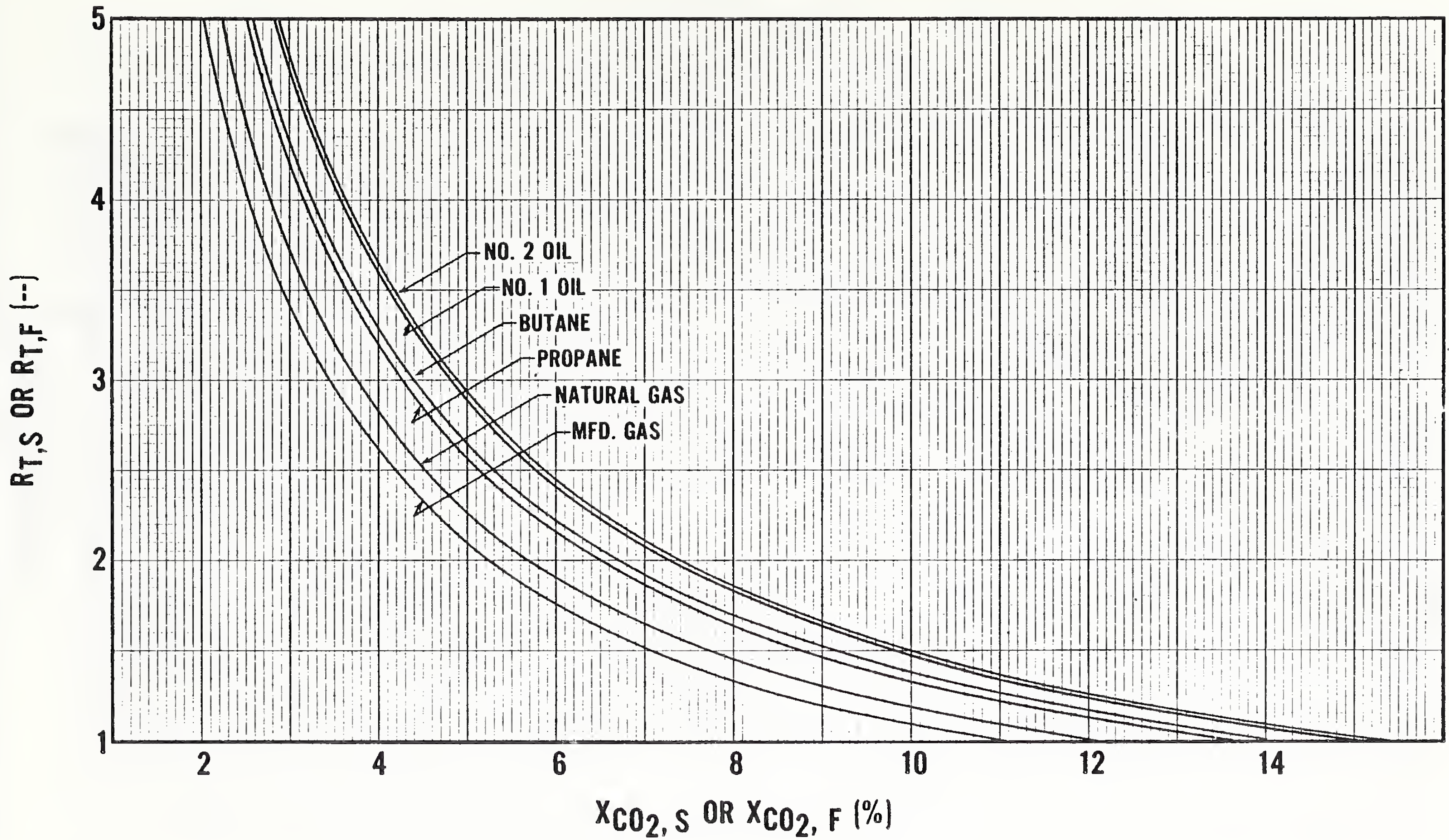


Fig. 1. Ratio of Total Combustion to Stoichiometric Air Versus Carbon Dioxide Concentration

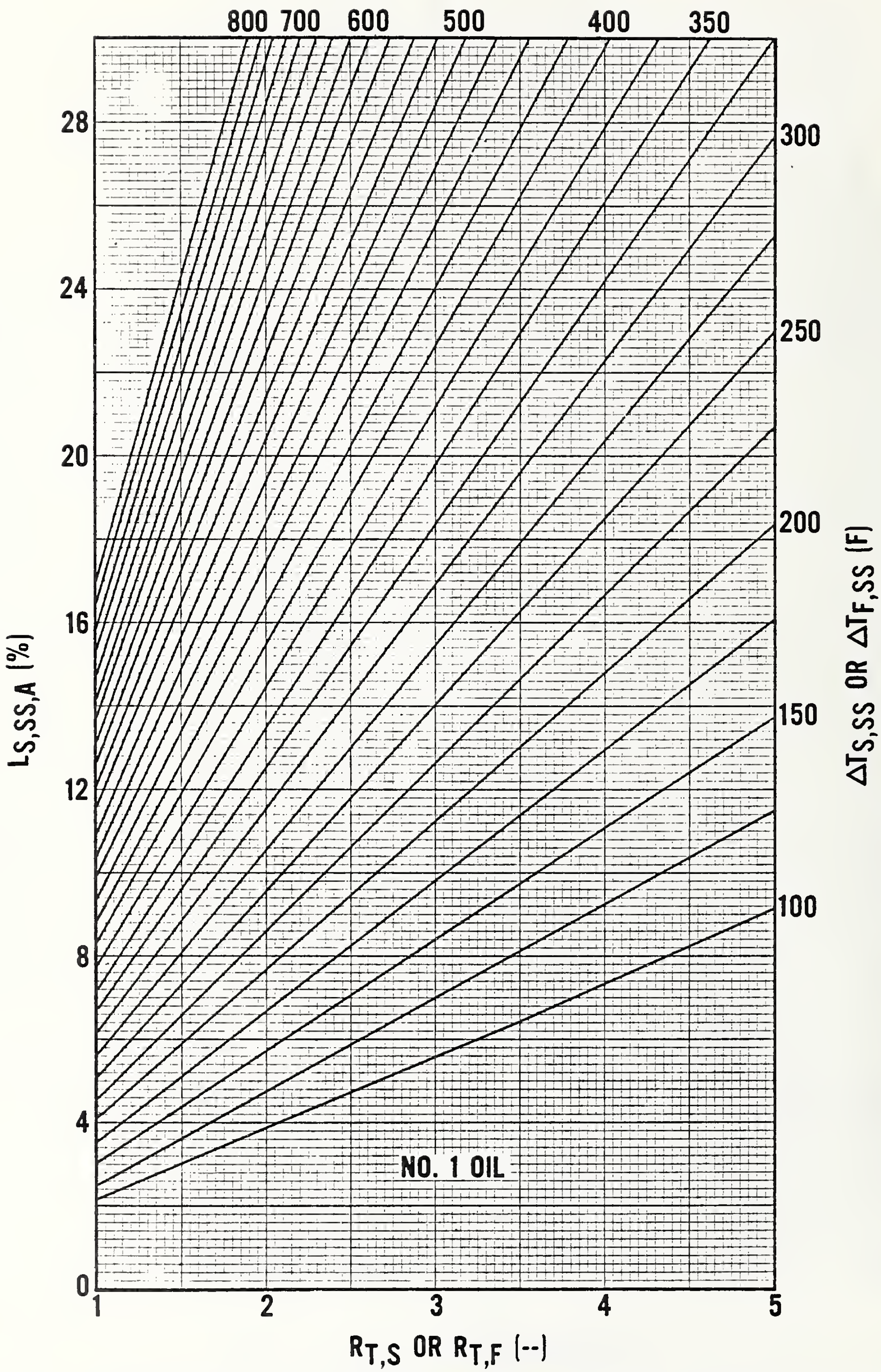


Fig. 2A. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For No. 1 Oil)

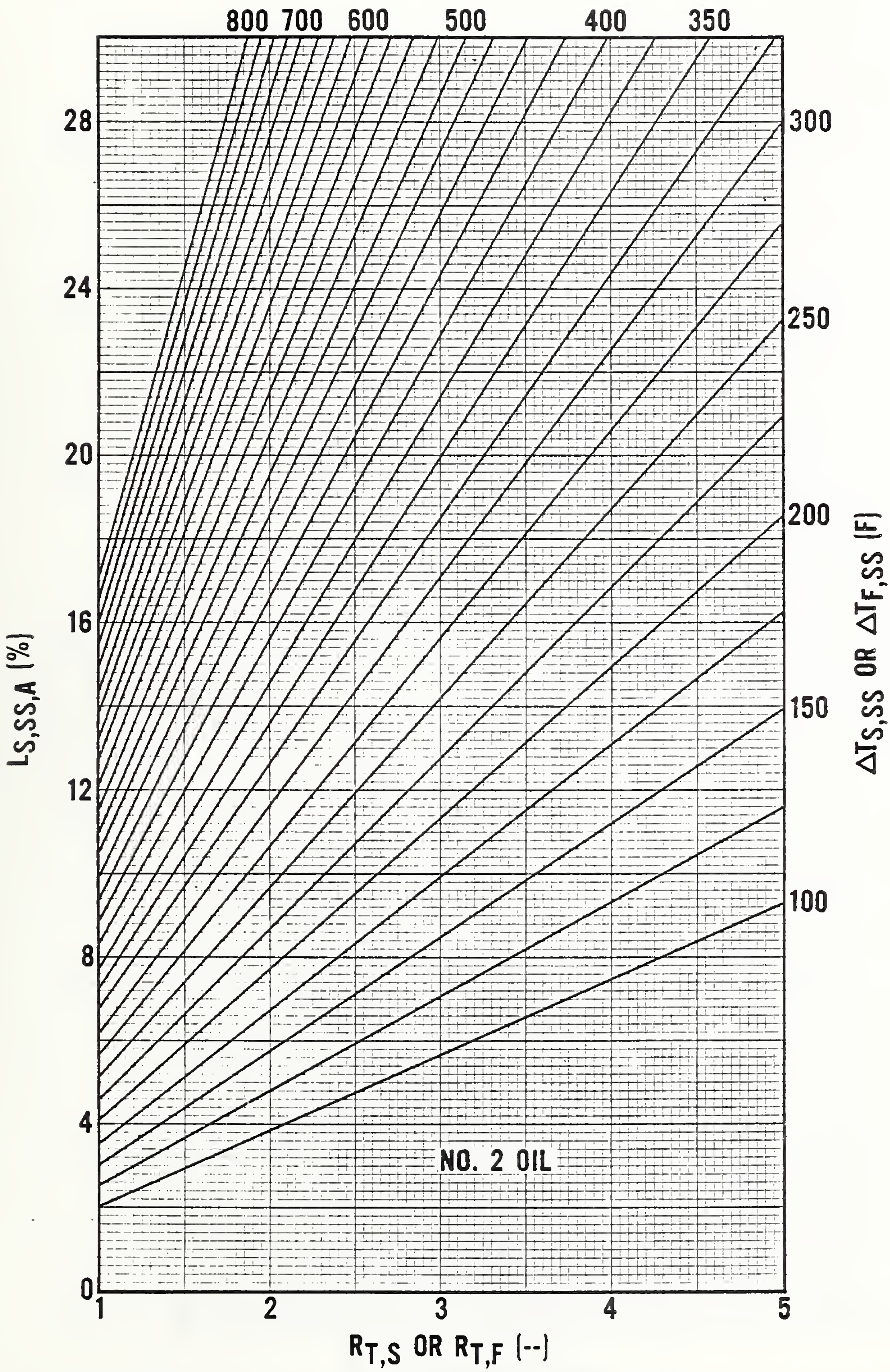


Fig. 2B. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For No. 2 Oil)

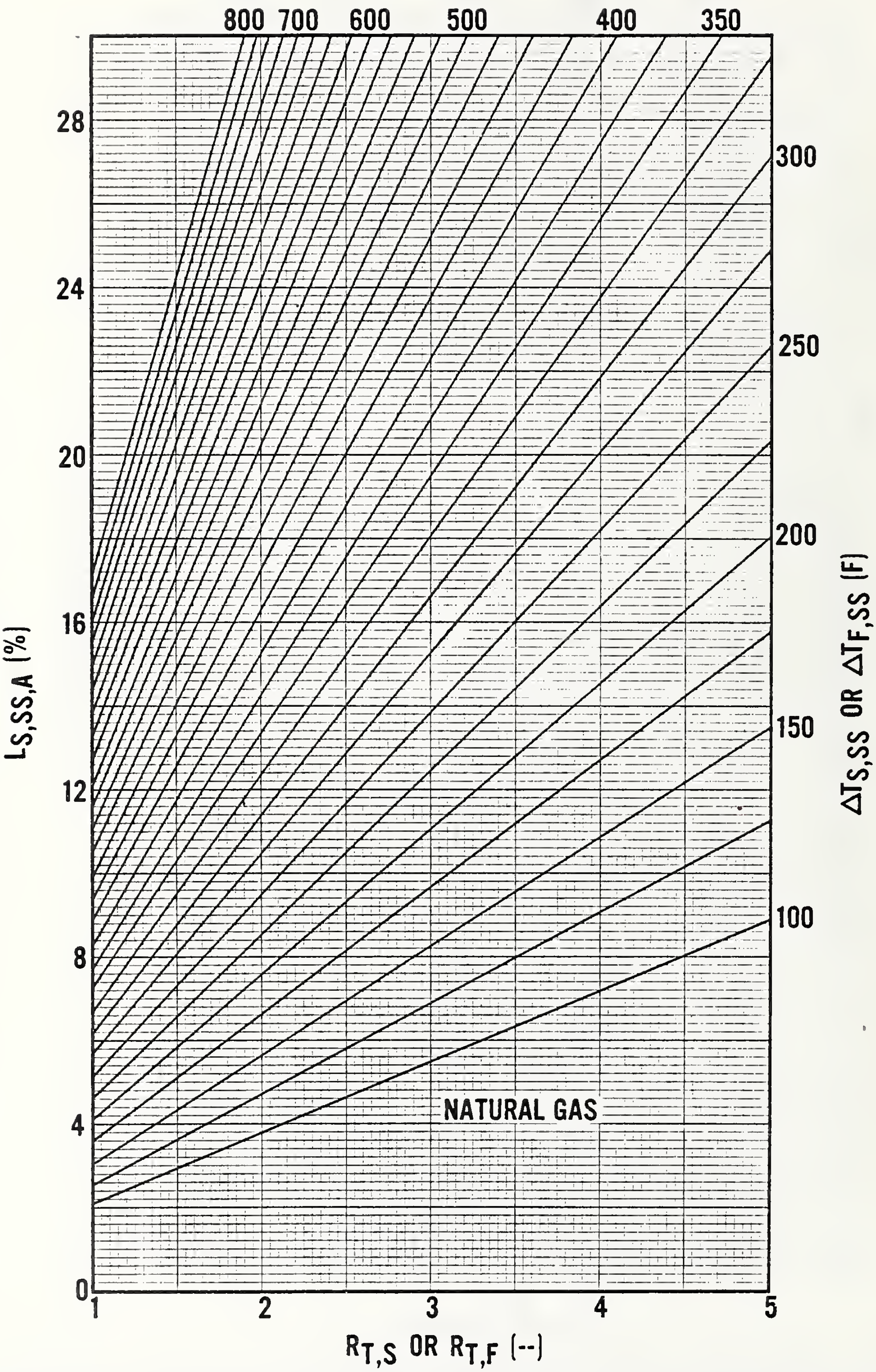


Fig. 2C. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Natural Gas)

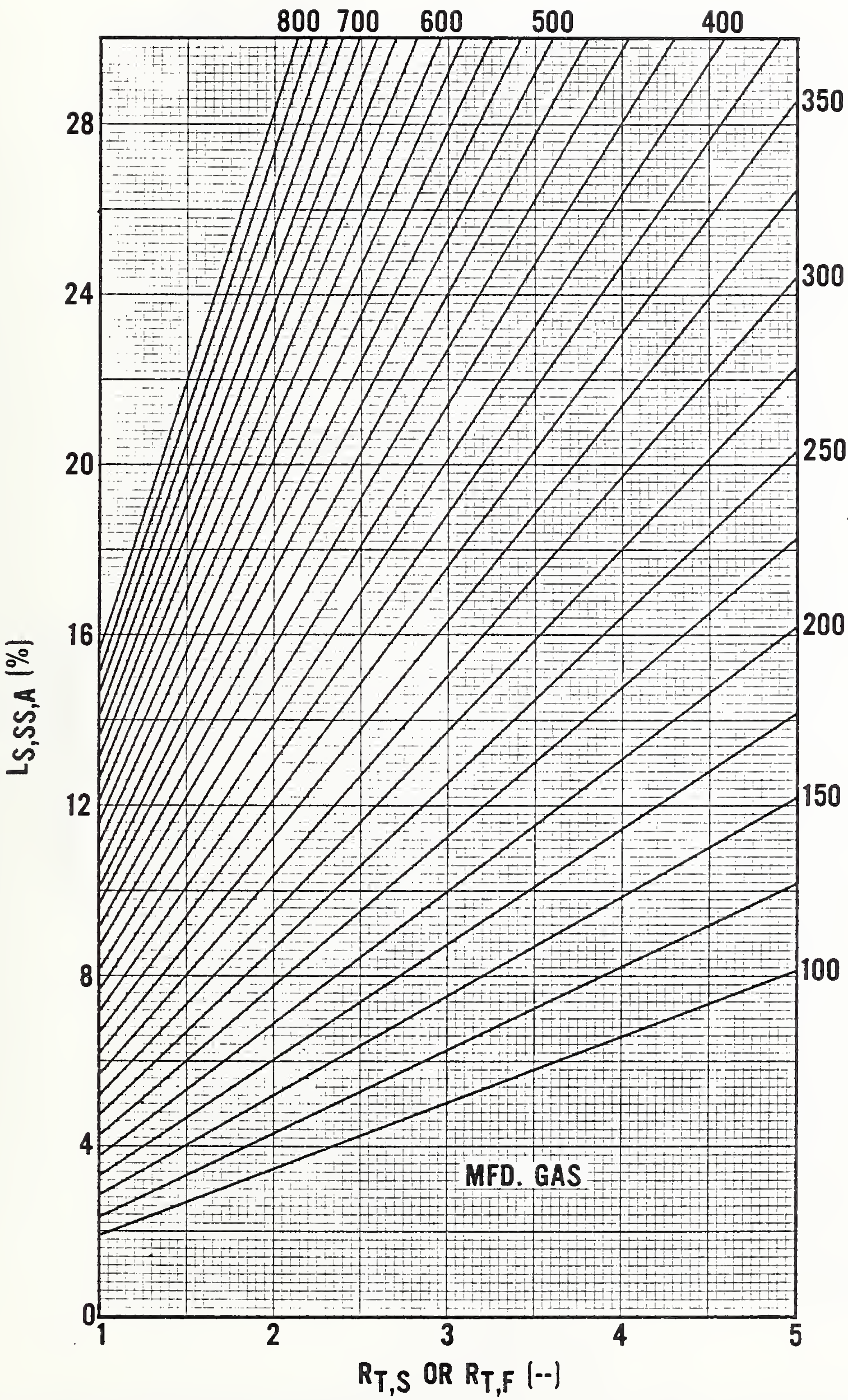


Fig. 2D. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Manufactured Gas)

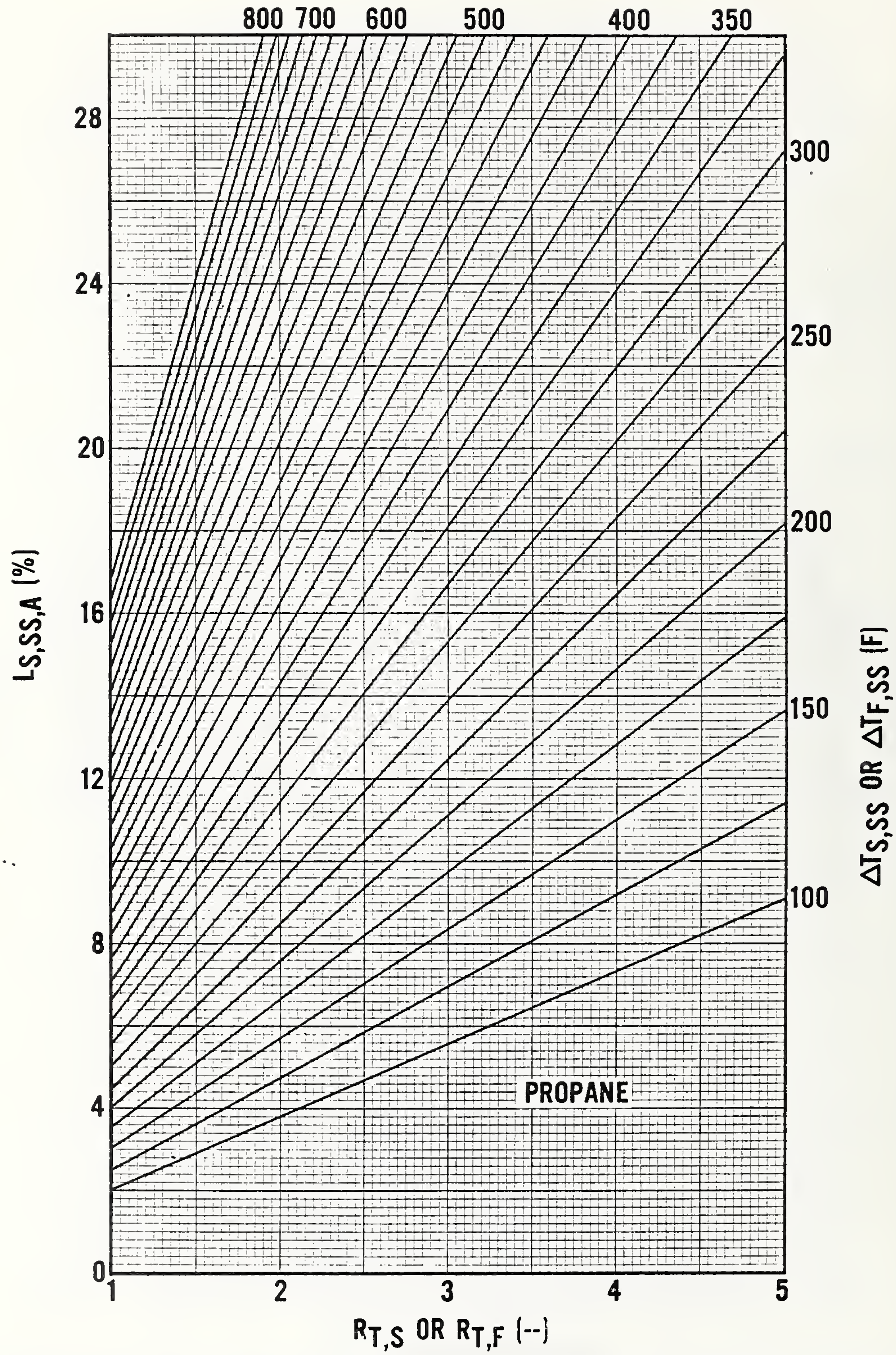


Fig. 2E. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Propane)

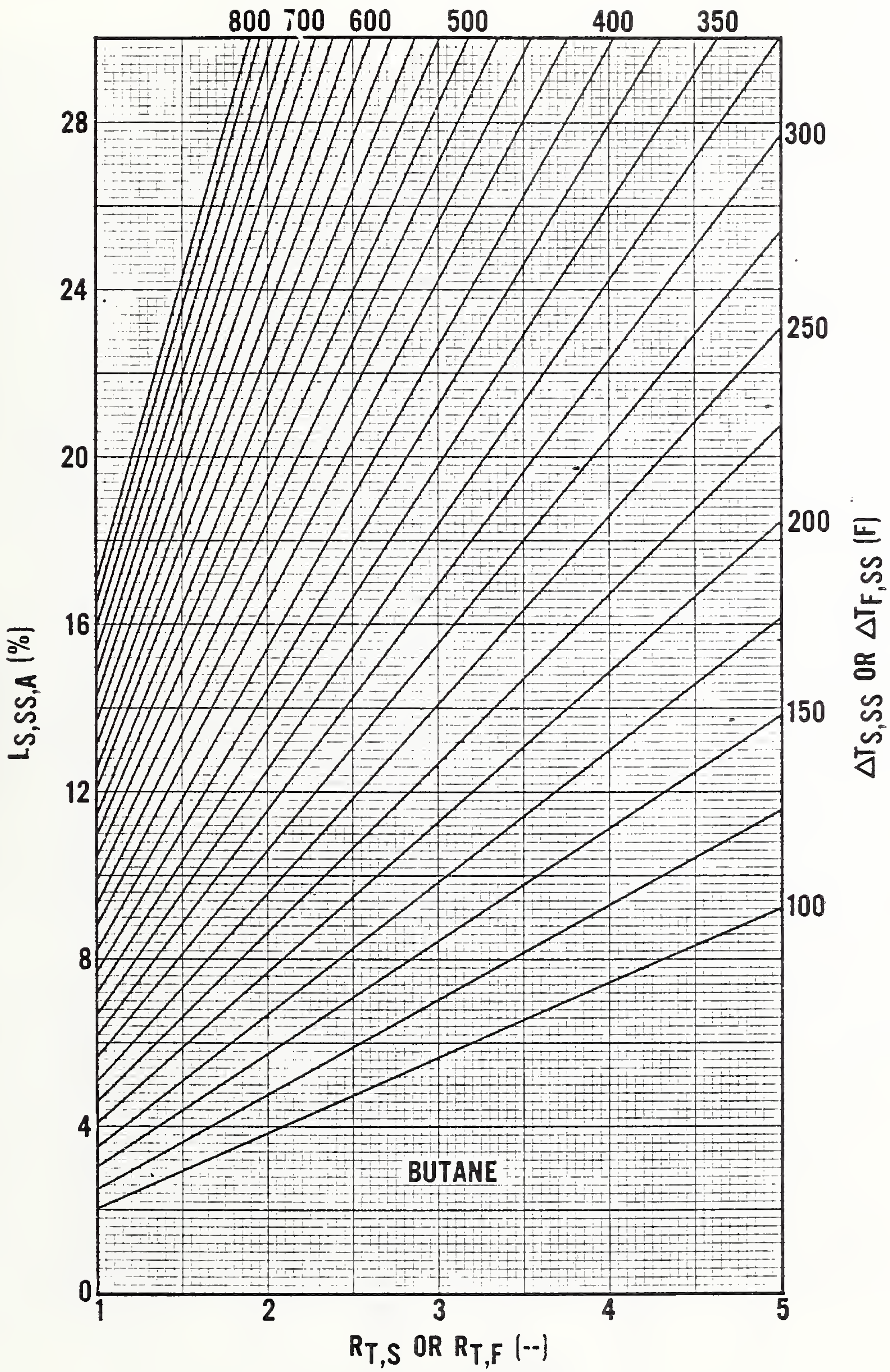


Fig. 2F. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Butane)

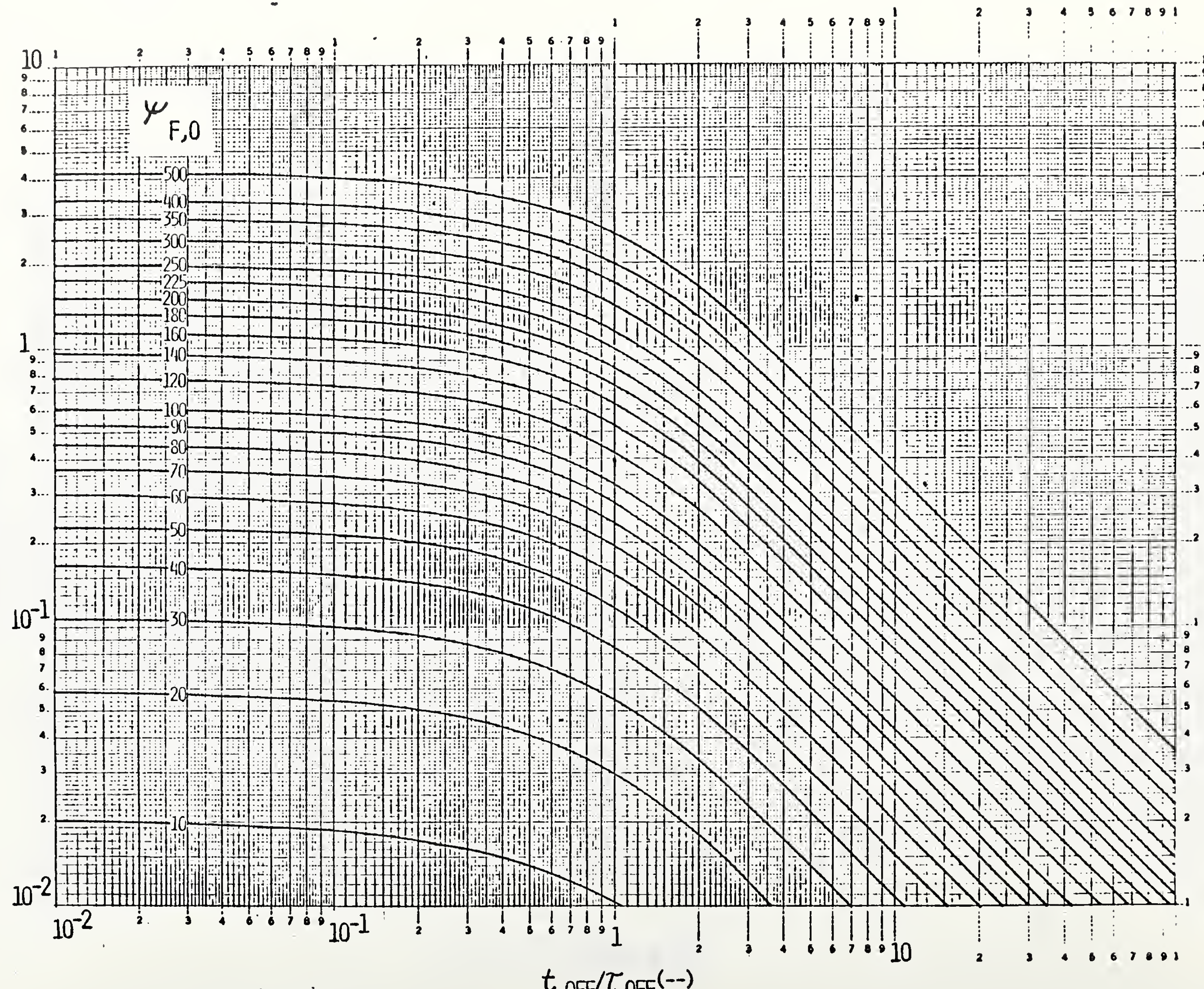


Fig. 3. Values of the F3 Function

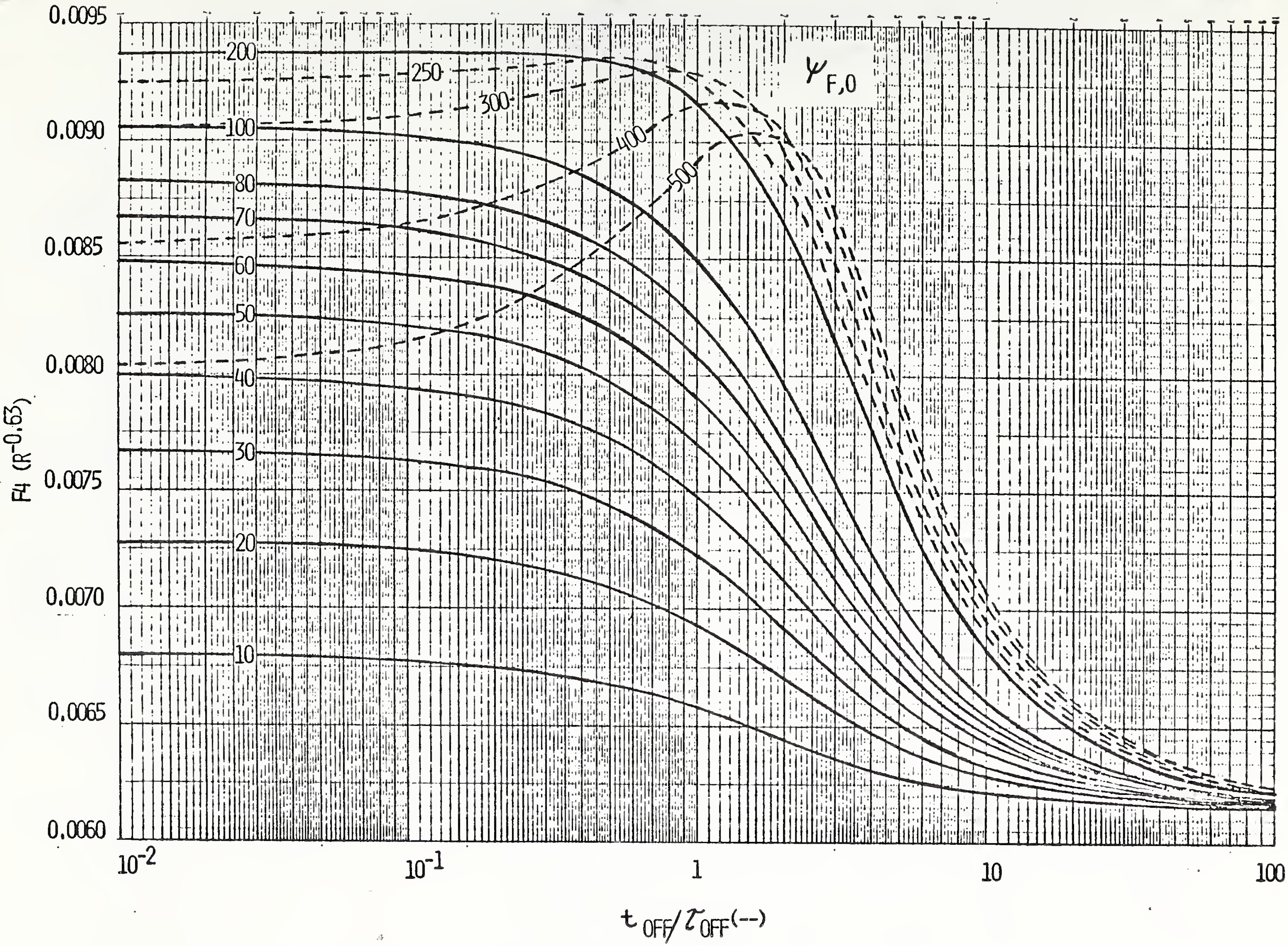


Fig. 4. Values of the F4 Function

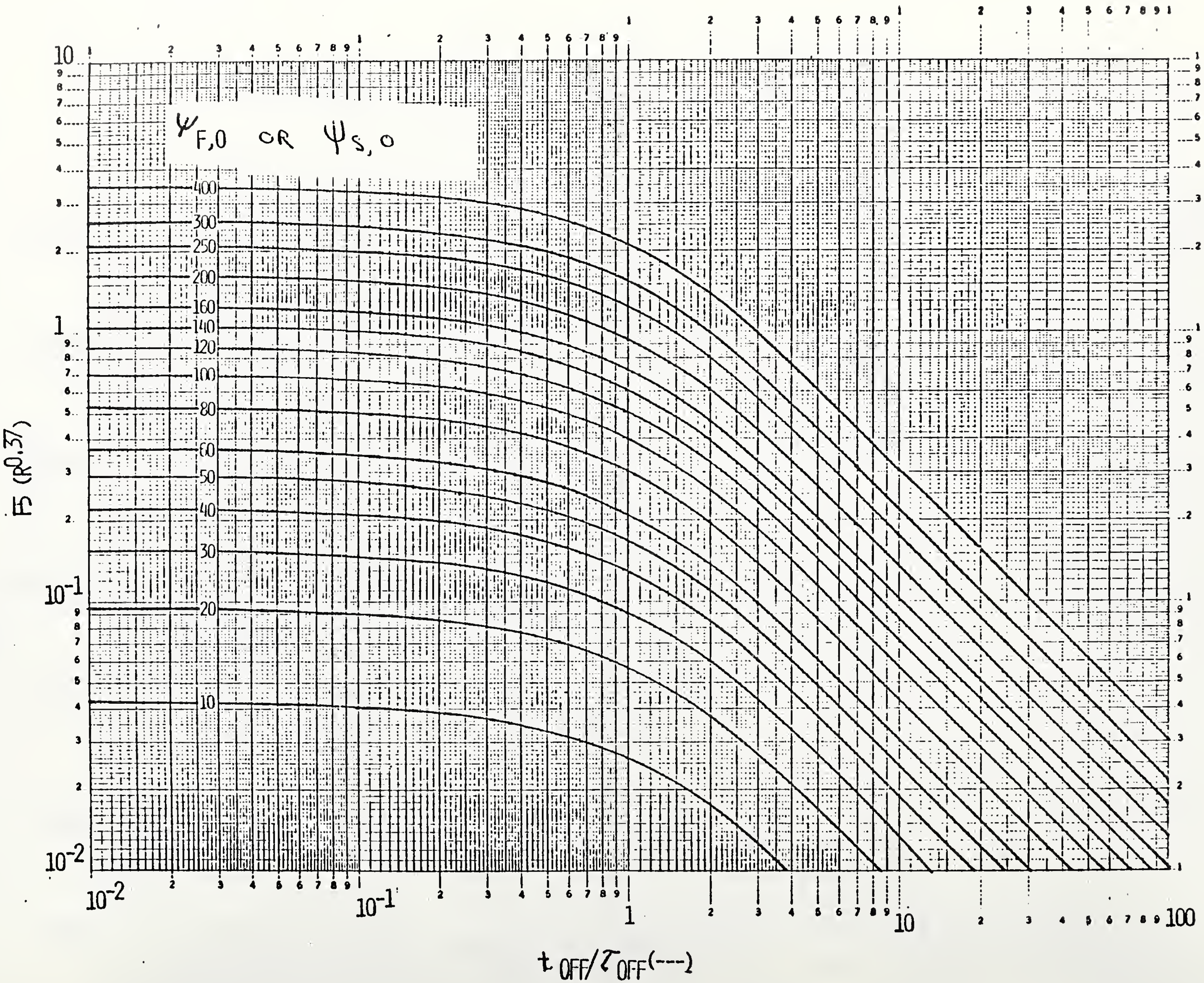


Fig. 5. Values of the F5 Function

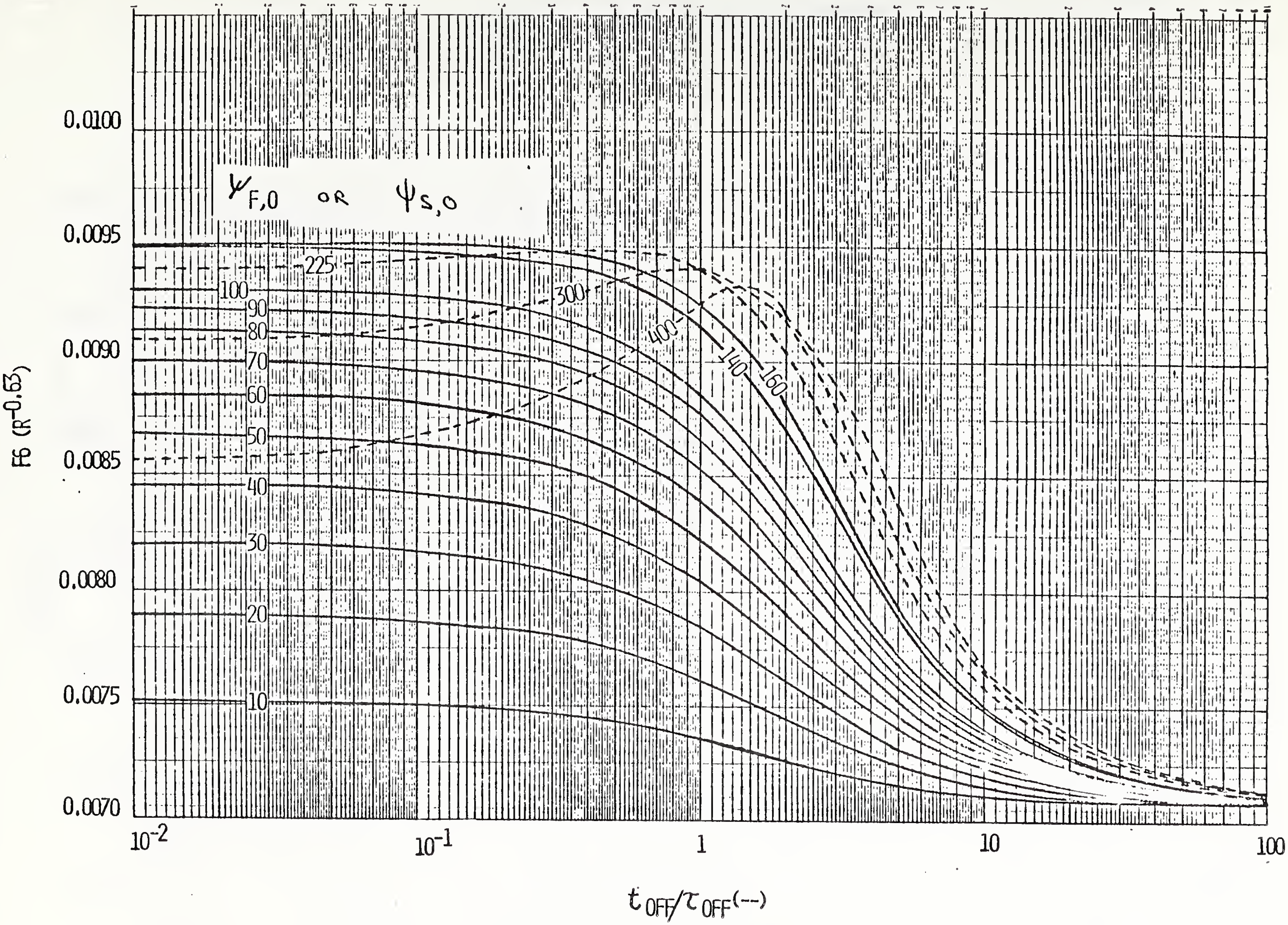


Fig. 6. Values of the F6 Function

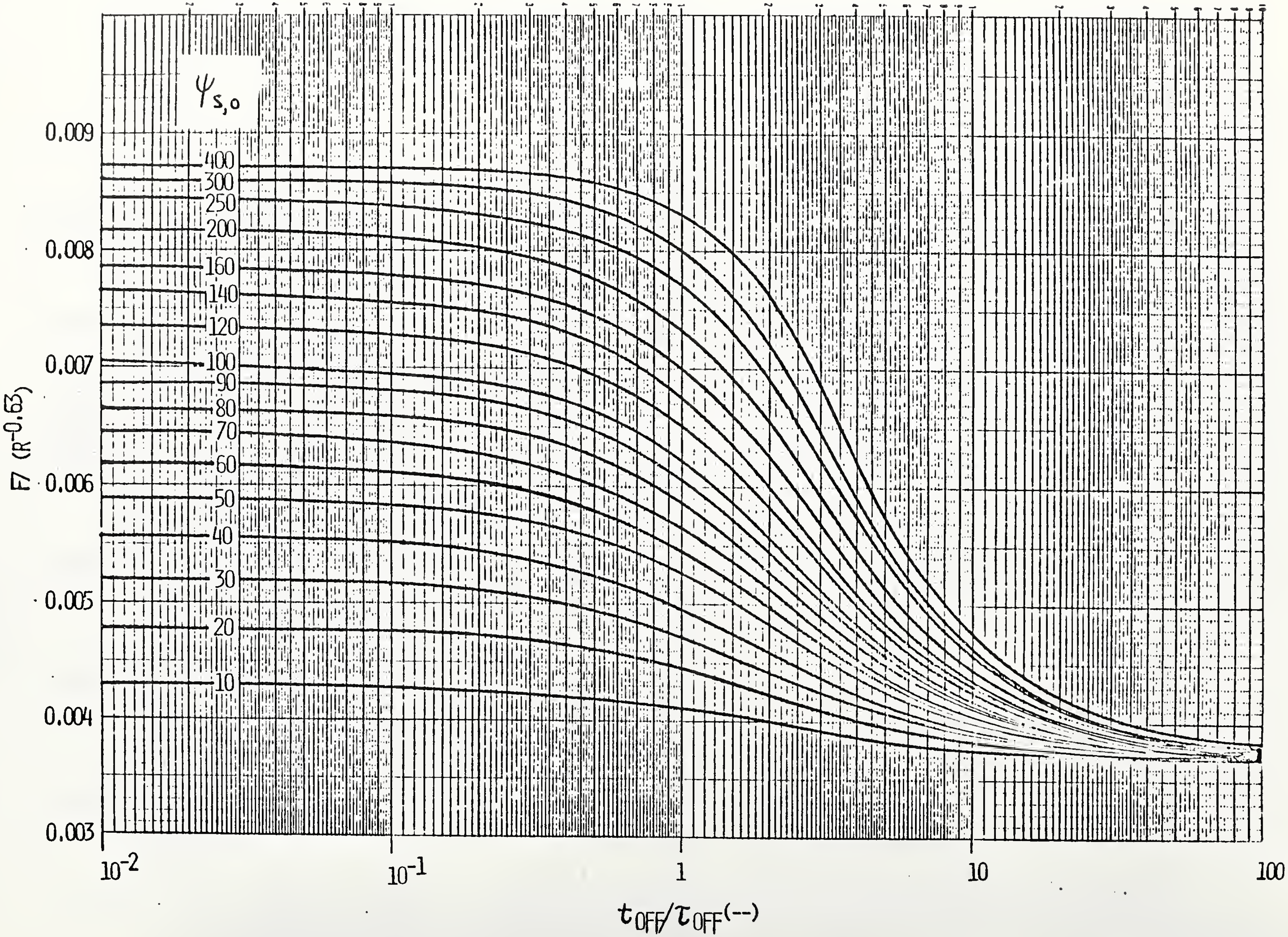


Fig. 7. Values of the F7 Function

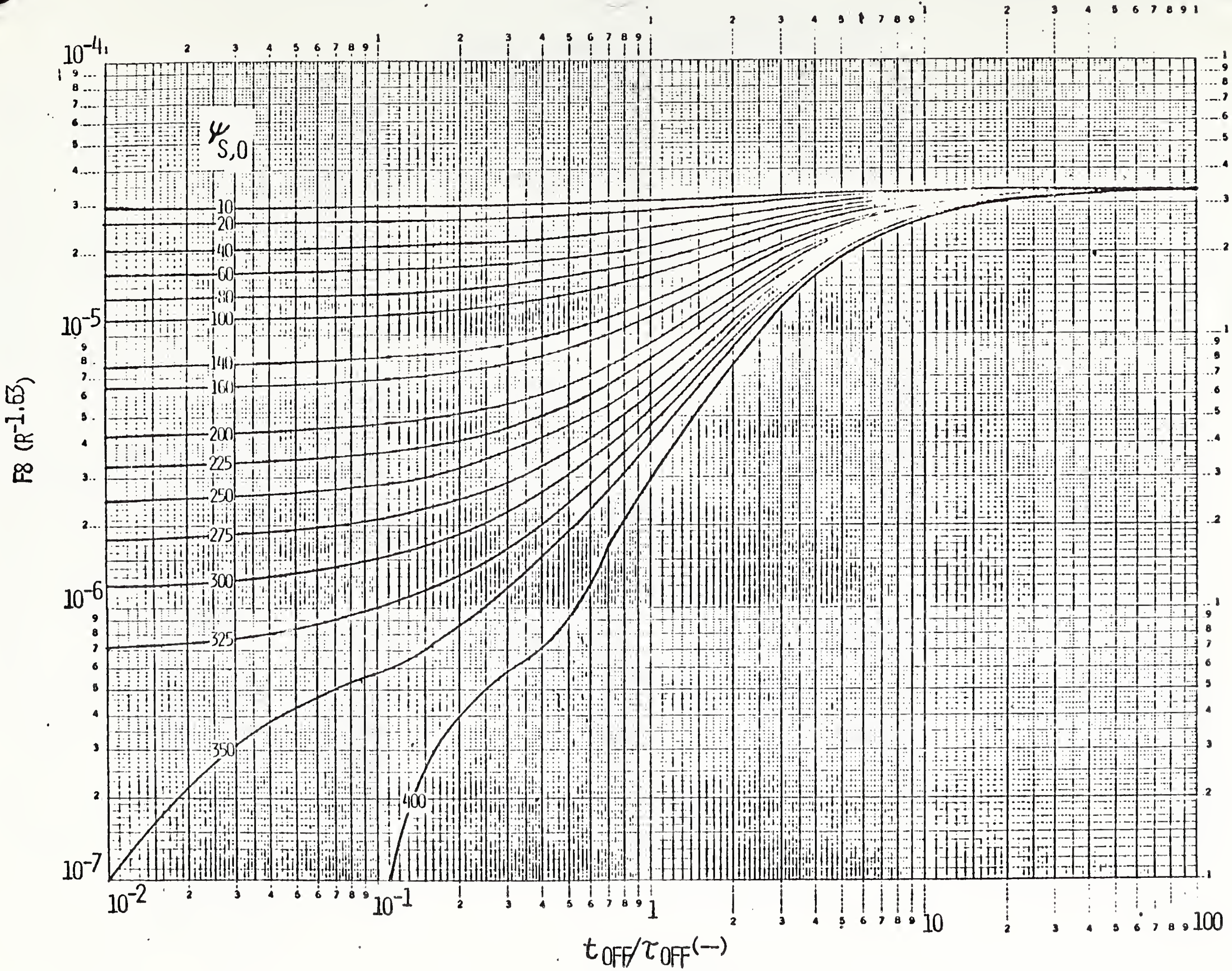
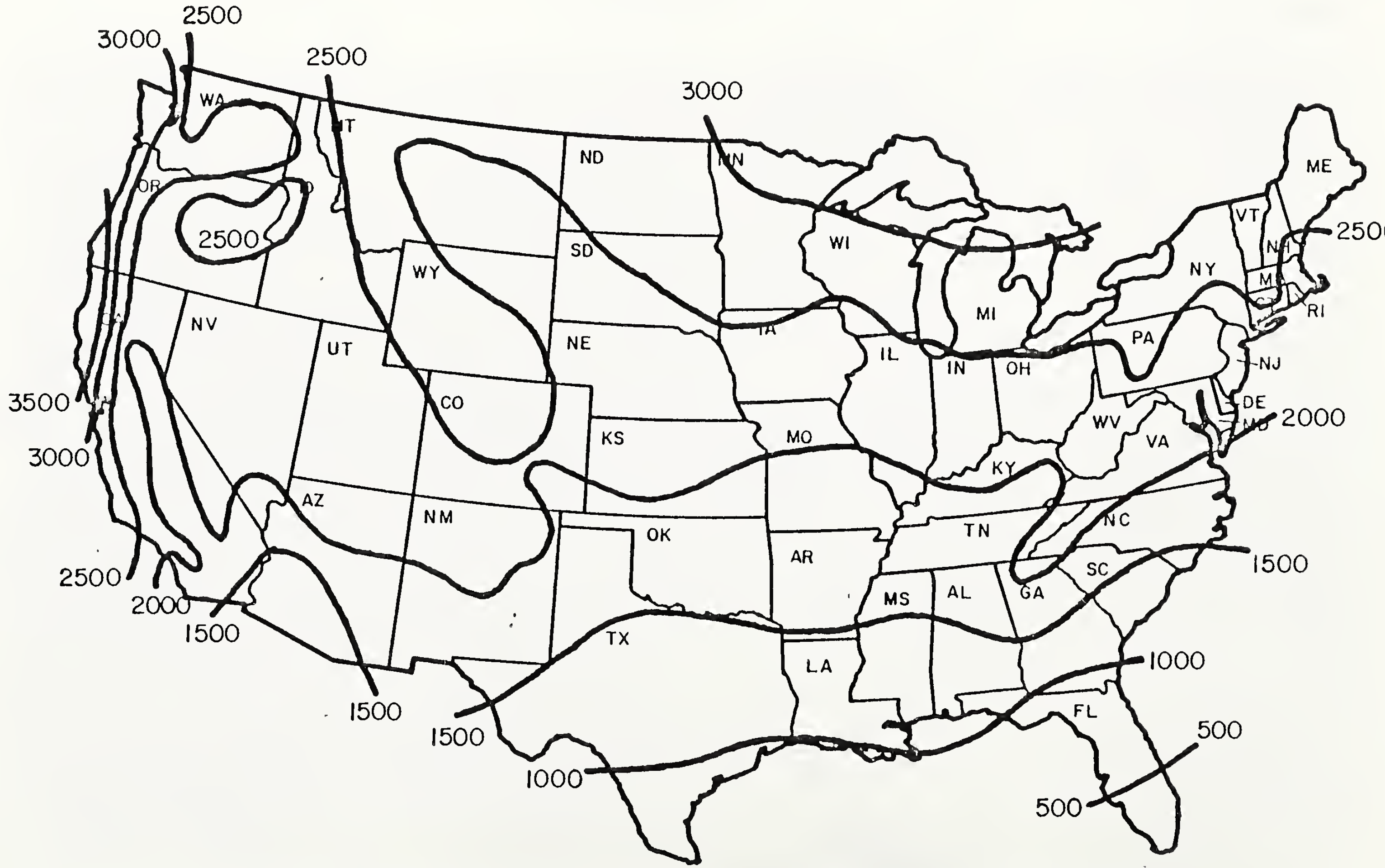


Fig. 8. Values of the F8 Function



This map is reasonably accurate for most parts of the United States but is necessarily highly generalized, and consequently not too accurate in mountainous regions, particularly in the Rockies.

Fig. 9. Map of Heating Load Hours

FIGURE 10

WORK SHEET FOR FURNACE/BOILER SYSTEM

Measured Quantities and System Characteristic Constants

1	2	3	4	5	6	7	8
SYS# (-)	TFUEL (-)	HHV Btu/lb.	Q_{IN} Btu/hr.	Q_P Btu/hr.	PE kW	BE kW	$X_{CO_2,S}$ %

9	10	11	12	13	14	15	16
$T_{S,SS,X}$ F	$X_{CO_2,F}$ %	$T_{F,SS}$ F	$T_{F,ON}(t_1)$ F	$T_{F,ON}(t_2)$ F	$T_{F,OFF}(t_3)$ F	$T_{F,OFF}(t_4)$ F	$T_{F,OFF}(\infty)$ F

17	18	19	20	21	22
T_{RA} F	L_J %	S/F (-)	D_F (-)	D_S (-)	y (-)

Derived System Parameters

23	24	25	26	27	28	29	30
PF (-)	HHV_A Btu/lb.	A/F (-)	$L_{L,A}$ %	C_J (-)	$R_{T,F}$ (-)	$L_{S,SS,A}$ %	η_{SS} %

31	32	33	34	35	36	37	38
$T_{S,SS}$ F	τ_{ON} minutes	$\theta_{F,O,X}$ F	τ_{OFF} minutes	$\psi_{F,O,X}$ F	$\psi_{F,\infty,X}$ F	$\psi_{S,\infty,X}$ F	$\psi_{S,O,X}$ F

39	40	41	42	43
C_S (-)	$K_{S,ON}$ (%)/F	$K_{S,OFF}$ (%)/$R^{0.37}$	$K_{I,ON}$ (%)/F	$K_{I,OFF}$ (%)/$R^{0.37}$

Calculation of System Losses and Annual Fuel Utilization Efficiency

44	45	46	47	48	49	50	51
T_{OA} F	t_{ON} minutes	t_{OFF} minutes	t_{ON}/τ_{ON} (-)	t_{OFF}/τ_{OFF} (-)	$\theta_{F,O}$ F	$\psi_{F,O}$ F	$\psi_{F,\infty}$ F

52	53	54	55	56	57	58	59
$\psi_{S,O}$ F	$\psi_{S,\infty}$ F	F3 $R^{0.37}$	F4 $R^{-0.63}$	F5 $R^{0.37}$	F6 $R^{-0.63}$	F7 $R^{-0.63}$	F8 $R^{-1.63}$

60	61	62	63	64	65	66	67
$L_{S,ON}$ %	$L_{S,OFF}$ %	$L_{I,ON}$ %	$L_{I,OFF}$ %	η_u %	DD °F-days	HR hours	$EFFY_A$ %

APPENDIX A

Technical Background Information

A1. Calculating the Steady-State Sensible Heat Loss ($L_{S,SS,A}$) and the Steady-State Efficiency (η_{SS}) for Gas and Oil-Fired Furnaces and Boilers

The following equations give results which are virtually indentical with those obtained from Figures 1 and 2A through 2F:

$$R_{T,a} = A + \frac{B}{X_{CO_2,a}}$$

$$L_{S,SS,A} = \frac{100}{HHV_A} \sum_{i=1}^{5} \left\{ [(1 + A/F)(CF(i)) + (A/F)(R_{T,a} - 1)(CA(i))] \right.$$
$$\left. \times \quad [(T_{a,SS,X} + 460)^i - (T_{RA} + 460)^i] \right\}$$

$$\eta_{SS} = 100 - L_{L,A} - L_{S,SS,A}$$

where the "a" is a dummy subscript which should be replaced by "S" if measured values of $X_{CO_2,S}$ and $T_{S,SS,X}$ are used and by "F" if measured values of $X_{CO_2,F}$ and $T_{F,SS,X} \equiv T_{F,SS}$ are employed. Table 5 summarizes the values of A, B, HHV_A, CF(i), and $L_{L,A}$ for six different fuels and values for the coefficients CA(i) for air.

A2. Brief Description of Heat Loss Equations

There are three major losses which are associated with most fossil-fuel-fired heating systems; they are the latent heat loss ($L_{L,A}$), the on-period sensible heat loss ($L_{S,ON}$), and the off-period sensible heat loss ($L_{S,OFF}$). Additional heat losses for a unit, using indoor air for combustion and draft control, are the on-period infiltration loss, $L_{I,ON}$ and the off-period infiltration loss, $L_{I,OFF}$. For furnace or boiler installed in an indoor heated space, it is assumed that there are no jacket or duct losses and the heat passing through the jacket and ducts will heat the living area of the residence. Heat contributed by the flue pipe and chimney is, however, neglected due to the wide variation possible among different installations. For units installed out of doors or in unheated spaces, the annual fuel utilization efficiency is reduced by a term which accounts for jacket losses.

Latent Heat Loss

The latent heat loss, $L_{L,A}$, is due to the presence of uncondensed water vapor in the flue gas. This is dependent upon the hydrogen content in the fuel, and is constant for a given type of fuel. The latent losses for six different fuels are given in Table 3. Also shown in Table 3 are typical values of higher heating value (HHV) and stoichiometric mass ratios of air to fuel (A/F) for these fuels. These values are used in the calculations of the other losses.

On-Period Sensible Heat Loss

The on-period sensible heat loss, $L_{S,ON}$, is due to the heating of combustion products and excess air from room temperature to the flue gas temperature. The sensible heat loss at steady-state $L_{S,SS,A}$ can be calculated from the measured flue (or stack) gas temperature and carbon dioxide concentration using the equations in A1 or figures 1 and 2A through 2F. The sensible heat loss during the on-period, $L_{S,ON}$, is, however, less than $L_{S,SS}$ when a unit is operating at part-load because the temperature of the heat-exchanger wall at start-up is lower than that during the steady-state operation. By measuring the flue gas temperature at two different times, t_1 and t_2, during the heat-up test, a time constant, τ_{ON}, can be evaluated using the equation:

$$\tau_{ON} = \frac{t_2 - t_1}{\ln\left[\dfrac{T_{F,SS} - T_{F,ON}(t_1)}{T_{F,SS} - T_{F,ON}(t_2)}\right]} .$$

Knowing the value of τ_{ON}, the temperature difference, $\theta_F(t)$, between the flue gas at time t and its steady-state temperature can be determined any time during the on-period using the equation:

$$\theta_F(t) = \theta_{F,0}\ e^{-\frac{t}{\tau_{ON}}} , \qquad \text{(A1)}$$

$$\text{where } \theta_{F,0} = \begin{cases} C_{t,ON}\ \theta_{F,0,X}, & \text{for units using indoor air for combustion.} \\ C_{t,ON}\ \theta_{F,0,X}\ C_S, & \text{for units using outdoor air for combustion.} \end{cases}$$

and $\theta_{F,0,X}$ is equal to $[T_{F,SS} - T_{F,ON}(t_1)]\ e^{+(t_1/\tau_{ON})}$.

The quantity $C_{t,ON}$ is a correction factor for the relative length of the on and off-periods and is given by:

$$C_{t,ON} = \frac{1 - \dfrac{\psi_{F,0,X}}{T_{F,SS} - T_{F,OFF}(\infty)}\ e^{-\frac{t_{OFF}}{\tau_{OFF}}}}{1 - \dfrac{\theta_{F,0,X}\ \psi_{F,0,X}}{[T_{F,SS} - T_{F,OFF}(\infty)]^2}\ e^{-\left(\frac{t_{ON}}{\tau_{ON}} + \frac{t_{OFF}}{\tau_{OFF}}\right)}}$$

and $\psi_{F,0,X}$ is defined just prior to equation (A4). The quantity $C_S = 1 + \dfrac{(70 - 42)\ \eta_{SS}}{(T_{F,SS} - T_{RA})(100)}$ corrects the on-period flue gas temperature for the fact the average outdoor air temperature is 42°F (5.56°C).

Figure A-1 and A-3 illustrate how the flue gas temperature is approximated from data obtained during the heat-up test and how the resulting profile is corrected for the effect of cycling and the use of outdoor combustion air, respectively. With the temperature profile during the on-period defined by equation A1, the value of $L_{S,ON}$ can be calculated by the equation:

$$L_{S,ON} = L_{S,SS} - \frac{(.24)(100)}{(Q_{IN})(t_{ON})} \int_0^{t_{ON}} (\dot{m}_{F,ON})(\theta_F(t))\ dt$$

$$= L_{S,SS} - \frac{K_{S,ON}}{(t_{ON}/\tau_{ON})}\ (\theta_{F,0})(1 - e^{-\frac{t_{ON}}{\tau_{ON}}}) \qquad \text{(A2)}$$

where HHV and A/F are the typical higher heating value and the typical stoichiometric air/fuel ratio, respectively, $K_{S,ON} \equiv \dfrac{24\ [1 + R_{T,F}(A/F)]}{HHV_A}$, and $L_{S,SS} = L_{S,SS,A}$ for units using indoor air for combustion and $L_{S,SS} = (C_S)(L_{S,SS,A})$ for units using outdoor air for combustion.

On-Cycle Infiltration Loss

The furnaces and boilers which use indoor air for combustion, the on-cycle infiltration loss, $L_{I,ON}$ is due to heating on-cycle combustion and relief air from outdoor temperature to room temperature. A fraction ϕ equal to 0.7 of the total combustion and draft air is assumed to be charged against the heating system. It is also assumed that the on-period flue and stack flow rates are constant. Hence the value of $L_{I,ON}$ can be calculated by the equation which is equal to the product of ϕ, the on-cycle stack mass flow rate and the sensible enthalpy difference between an assumed indoor temperature of 70°F (21.1°C) and the average outdoor temperature of 42 °F (5.56°C):

$$L_{I,ON} = \frac{24\ \phi(S/F)[1 + (R_{T,F})(A/F)]\ (70 - 42)}{HHV_A} = K_{I,ON}(70 - 42) \qquad \text{(A3)}$$

where $K_{I,ON} = (\phi)(S/F)(K_{S,ON})$. For furnaces or boilers using outdoor combustion air $L_{I,ON} = 0$.

Off-Period Losses

The off-period sensible loss, $L_{S,OFF}$, and for units using indoor air for combustion, the off-period infiltration loss, $L_{I,OFF}$, are due, respectively, to heating the off-period draft air to a temperature in excess of the indoor air temperature and to heating the off-cycle draft and relief air from the outdoor air temperature to the indoor air temperature. For calculating these losses, the time history of the off-period flue and stack temperatures is required. Assuming the off-period flue and stack-gas temperature delays can be approximated by simple exponential functions, the time constant for the off-period (τ_{OFF}) is calculated by a use of the test data $T_{F,OFF}(t_3)$, $T_{F,OFF}(t_4)$, and $T_{F,OFF}(\infty)$ and the equation:

$$\tau_{OFF} = \frac{t_4 - t_3}{\ln\left[\dfrac{T_{F,OFF}(t_3) - T_{F,OFF}(\infty)}{T_{F,OFF}(t_4) - T_{F,OFF}(\infty)}\right]}$$

Defining the quantities:

$$\psi_{F,O,X} = [T_{F,OFF}(t_3) - T_{F,OFF}(\infty)]\ e^{+\,t_3/\tau_{OFF}} \quad \text{and} \quad \psi_{F,\infty,X} = [T_{F,OFF}(\infty) - T_{RA}],$$

the flue gas temperature can then be calculated any time during the off-period using the equation:

$$T_{F,OFF}(t) = \psi_{F,O}\ e^{-\,t/\tau_{OFF}} + \psi_{F,\infty} + T_{RA}\ , \qquad \text{(A4)}$$

where $\psi_{F,O} = \psi_{F,O,X} C_{t,OFF}$ and $\psi_{F,\infty} = \psi_{F,\infty,X}$ for units using indoor air for combustion, and $\psi_{F,O} = \psi_{F,O,X}\, C_{t,OFF}\, C'_S$ and $\psi_{F,\infty} = \psi_{F,\infty,X}\, C'_S$ for units using outdoor air for combustion.

For furnaces and boilers employing indoor combustion air, the stack gas temperature is found as follows:

$$T_{S,OFF}(t) = \psi_{S,0}\, e^{-t/\tau_{OFF}} + \psi_{S,\infty} + T_{RA} \tag{A5}$$

where $\psi_{S,0} = \psi_{S,0,X}\, C_{t,OFF}$

$$\left.\begin{aligned} \psi_{S,0,X} &= \psi_{F,0,X} \\ \psi_{S,\infty} &= \psi_{F,\infty,X} \end{aligned}\right\} \text{ if the unit employs a stack damper and } D_S(S/F) \leq D_F$$

$$\left.\begin{aligned} \psi_{S,0,X} &= \frac{(D_F)(\psi_{F,0,X})}{(S/F)(D_S)} \\ \psi_{S,\infty} &= \frac{(D_F)(\psi_{F,\infty,X})}{(S/F)(D_S)} \end{aligned}\right\} \text{ if the unit does not employ a stack damper or the unit employs a stack damper and } (D_S)(S/F) > D_F.$$

In the above equations, the factor $C_S' \equiv 1.22$ corrects for the fact that the average temperature of the air entering a furnace or boiler utilizing outdoor combustion air is assumed to be 42°F (5.56°C), while the quantity $C_{t,OFF}$ is a correction factor for the relative length of the on and off periods and is given by:

$$C_{t,OFF} = \frac{C_{IID}\left(1 - \dfrac{\theta_{F,0,X}}{T_{F,SS} - T_{F,OFF}(\infty)}\, e^{-\frac{t_{ON}}{\tau_{ON}}}\right)}{1 - \dfrac{\theta_{F,0,X}\,\psi_{F,0,X}}{[T_{F,SS} - T_{F,OFF}(\infty)]^2}\, e^{-\left(\frac{t_{ON}}{\tau_{ON}} + \frac{t_{OFF}}{\tau_{OFF}}\right)}} ,$$

where $C_{IID} = 1$ for units with continuously operating pilot lights and $C_{IID} = 0.9$ for units with intermittent ignition devices or cycling pilot lights. This last factor, C_{IID}, is introduced to allow the seasonal fuel utilization efficiency to be set equal to the part-load efficiencies at the average outdoor temperature as discussed later in this section. The temperatures $T_{F,OFF}(t_5)$ and T_{RA} are the minimum off-period flue gas temperature, and the room air temperature, respectively. For units equipped with an automatic stack damper and having a $D_S \leq D_F/(S/F)$, it has been assumed that there is no dilution air passing through the draft control device during the off-period and consequently the flue and stack gas temperatures are identical.

The procedures employed for approximating the flue gas temperature from data obtained during the cool down tests and then correcting the resulting profile for the effect of cycling and the use of outdoor combustion air is illustrated in figure A-2 and A-3, respectively.

With the time histories of flue and stack gas temperatures known, the time histories of flue and stack flow rates during the off-period can be calculated from a consideration of the hydrostatic pressure difference between the flue gas and the ambient air and the basic theory of turbulent flow. The resulting equations are [2,4]:

$$\dot{m}_{F,OFF} = D_F \dot{m}_{F,ON}\left(\frac{T_{F,OFF} - T_{RA}}{T_{F,SS} - T_{RA}}\right)^{0.56}\left(\frac{T_{F,SS} - T_{RA} + 530}{T_{F,OFF} - T_{RA} + 530}\right)^{1.19} \text{, for units using indoor air for combustion} \tag{A6a}$$

$$\dot{m}_{S,OFF} = D_S\dot{m}_{S,ON}\left(\frac{T_{S,OFF} - T_{RA} + 70 - 42}{T_{S,SS} - T_{RA} + 70 - 42}\right)^{0.56}\left(\frac{T_{S,SS} - T_{RA} + 530}{T_{S,OFF} - T_{RA} + 530}\right)^{1.19}, \text{ for} \qquad \text{(A6b)}$$

units using indoor air for combustion

$$\dot{m}_{F,OFF} = D_F\dot{m}_{F,ON}\left(\frac{T_{F,OFF} - T_{RA} + 70 - 42}{T_{F,SS} - T_{FA} + 70 - 42}\right)^{0.56}\left(\frac{T_{F,SS} - T_{RA} + 530}{T_{F,OFF} - T_{RA} + 530}\right)^{1.19}, \text{ for} \qquad \text{(A7)}$$

units using outdoor air for combustion

where $\dot{m}_{F,ON} = \frac{Q_{in}}{HHV}[1 + (R_{T,F})(A/F)]$, $m_{S,ON} = (S/F)\ m_{F,ON}$, and

$T_{S,SS} \equiv (1/(S/F))[T_{F,SS} - T_{RA}] + T_{RA}$. The off-period loss $L_{S,OFF}$ can then be calculated for units which use indoor combustion air but are not equipped with automatic stack dampers using the following equation:

$$L_{S,OFF} = \frac{(100)(0.24)}{(Q_{in})(t_{ON})}\int_0^{t_{OFF}} \dot{m}_{F,OFF}(T_{F,OFF} - T_{RA})\ dt = \frac{(100)(0.24)(D_F)[1 + (R_{T,F})(A/F)]}{(HHV_A)\ (t_{ON})}$$

$$\times \frac{(T_{F,SS} - T_{RA} + 530)^{1.19}}{(T_{F,SS} - T_{RA})^{0.56}} \times \int_0^{t_{OFF}} \frac{(T_{F,OFF} - T_{RA})^{1.56}}{(T_{F,OFF} - T_{RA} + 530)^{0.56}}\ dt \qquad \text{(A8)}$$

where $T_{F,OFF}$ is given by equation (A4).

Four units which use indoor air for combustion and employ stack dampers, some of the air which passes through the heat exchanger during the off-period could enter the living area of the residence through the relief opening in the draft diverter and contribute to heating the house. As a consequence, the off-period loss is obtained for units with stack dampers from the equation:

$$L_{S,OFF} = \frac{(100)(0.24)}{(Q_{in})(t_{ON})}\int_0^{t_{OFF}} \dot{m}_{S,OFF}(T_{S,OFF} - T_{RA})\ dt = \frac{(100)(0.24)(D_S)(S/F)[1 + (R_{T,F})(A/F]}{(HHV_A)(t_{ON})}$$

$$\times \frac{(T_{S,SS} - T_{RA} + 530)^{1.19}}{(T_{S,SS} - T_{RA} + 70 - 42)^{0.56}} \int_0^{t_{OFF}} \frac{(T_{S,OFF} - T_{RA} + 70 - 42)^{0.56}}{(T_{S,OFF} - T_{RA} - 530)^{1.19}} (T_{S,OFF} - T_{RA})\ dt \qquad \text{(A9)}$$

where $T_{S,OFF}$ is given by equation (A5).

For furnaces and boilers using outdoor combustion air, the off-period loss is obtained as follows:

$$L_{S,OFF} = \frac{(100)(0.24)}{(Q_{IN})(t_{ON})} \int_0^{t_{OFF}} \dot{m}_{F,OFF}(T_{F,OFF} - T_{RA})\, dt = \frac{(100)(0.24)(D_F)[1 + (R_{T,F})(A/F)]}{(HHV_A)(t_{ON})}$$

$$\times \frac{(T_{F,SS} - T_{RA} + 530)^{1.19}}{(T_{F,SS} - T_{RA} + 70 - 42)^{0.56}} \int_0^{t_{OFF}} \frac{(T_{F,OFF} - T_{RA} + 70 - 42)^{0.56}}{(T_{F,OFF} - T_{RA} + 530)^{1.19}} (T_{F,OFF} - T_{RA})\, dt \qquad \text{(A10)}$$

where $T_{F,OFF}$ is given by equation (A4).

The off-period infiltration loss $L_{I,OFF}$ can be calculated for units, with and without automatic stack dampers, using indoor air for combustion from the expression:

$$L_{I,OFF} = \frac{(100)(0.24)}{(Q_{in})(t_{ON})} \phi \int_0^{t_{OFF}} \dot{m}_{S,OFF} (70 - 42)\, dt =$$

$$= \frac{(100)(0.24)(\phi)(D_S)(S/F)[1 + (R_{T,F})(A/F)]}{(HHV_A)(t_{ON})} \quad \frac{(T_{S,SS} - T_{RA} + 530)^{1.19}}{(T_{S,SS} - T_{RA} + 70 - 42)^{0.56}} \qquad \text{(A11)}$$

$$\times (70 - 42) \int_0^{t_{OFF}} \frac{(T_{S,OFF} - T_{RA} + 70 - 42)^{0.56}}{(T_{S,OFF} - T_{RA} + 530)^{1.19}}\, dt$$

where $T_{S,OFF}$ is given by equation (A5). For units using outdoor air for combustion $L_{I,OFF} = 0$.

To facilitate evaluation of the off-period losses, the following functions have been calculated and plotted in figures 3 through 8:

$$F3\,(\psi_{F,o}, t_{OFF}/\tau_{OFF}) = \frac{1}{t_{OFF}/\tau_{OFF}} \int_0^{\frac{t_{OFF}}{\tau_{OFF}}} \frac{\left(\psi_{F,o}\, e^{-\frac{t}{\tau_{OFF}}}\right)^{1.56}}{\left(\psi_{F,o}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}}\, d\frac{t}{\tau_{OFF}} \qquad \text{(A12)}$$

$$F4\ (\psi_{F,0}, t_{OFF}/\tau_{OFF}) = \frac{1}{100\ (t_{OFF}/\tau_{OFF})} \int_0^{\frac{t_{OFF}}{\tau_{OFF}}} \left[\frac{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 100\right)^{1.56}}{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 630\right)^{1.19}} - \frac{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}}\right)^{1.56}}{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}} \right] d\,\frac{t}{\tau_{OFF}} \tag{A13}$$

$$F5\ (\psi_{F,0}, t_{OFF}/\tau_{OFF}) = \frac{1}{t_{OFF}/\tau_{OFF}} \int_0^{\frac{t_{OFF}}{\tau_{OFF}}} \frac{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 28\right)^{0.56} \left(\psi_{F,0}\, e^{\frac{t_{OFF}}{\tau_{OFF}}}\right)}{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}}\, d\,\frac{t}{\tau_{OFF}} \tag{A14}$$

$$F6\ (\psi_{F,0}, t_{OFF}/\tau_{OFF}) = \frac{1}{100\ X(t_{OFF}/\tau_{OFF})} \; X \int_0^{\frac{t_{OFF}}{\tau_{OFF}}} \left[\frac{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 128\right)^{0.56} \left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 100\right)}{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 630\right)^{1.19}} - \frac{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 28\right)^{0.56} \psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}}}{\left(\psi_{F,0}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}} \right] d\,\frac{t}{\tau_{OFF}} \tag{A15}$$

$$F7\left(\psi_{S,O},\ t_{OFF}/\tau_{OFF}\right) = \frac{1}{(t_{OFF}/\tau_{OFF})}\int_{o}^{\frac{t_{OFF}}{\tau_{OFF}}} \frac{\left(\psi_{S,O}\, e^{-\frac{t}{\tau_{OFF}}} + 28\right)^{0.56}}{\left(\psi_{S,O}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}}\, d\,\frac{t}{\tau_{OFF}} \qquad \text{(A16)}$$

$$F8\left(\psi_{S,O}, t_{OFF}/\tau_{OFF}\right) = \frac{1}{100 \text{ X } (t_{OFF}/\tau_{OFF})} \qquad \text{(A17)}$$

$$\text{X} \int_{o}^{\frac{t_{OFF}}{\tau_{OFF}}} \left[\frac{\left(\psi_{S,O}\, e^{-\frac{t_{OFF}}{\tau_{OFF}}} + 128\right)^{0.56}}{\left(\psi_{S,O}\, e^{-\frac{t}{\tau_{OFF}}} + 630\right)^{1.19}} - \frac{\left(\psi_{S,O}\, e^{-\frac{t}{\tau_{OFF}}} + 28\right)^{0.56}}{\left(\psi_{S,O}\, e^{-\frac{t}{\tau_{OFF}}} + 530\right)^{1.19}} \right] d\,\frac{t}{\tau_{OFF}}$$

In addition the following multiplication factors are defined:

$$K_{S,OFF} = \begin{cases} \dfrac{(T_{F,SS} - T_{RA} + 530)^{1.19}(D_F)(K_{S,ON})}{(T_{F,SS} - T_{RA})^{0.56}}, & \text{for units without stack dampers using indoor combustion air} \\[2ex] \dfrac{(T_{S,SS} - T_{RA} + 530)^{1.19}(D_S)(S/F)(K_{S,ON})}{(T_{S,SS} - T_{RA} + 70 - 42)^{0.56}}, & \text{for units with stack dampers using indoor combustion air} \\[2ex] \dfrac{(T_{F,SS} - T_{RA} + 530)^{1.19}(D_F)(K_{S,ON})}{(T_{F,SS} - T_{RA} + 70 - 42)^{0.56}}, & \text{for units using outdoor combustion air} \end{cases} \qquad \text{(A18)}$$

and

$$K_{I,OFF} = \frac{(T_{S,SS} - T_{RA} + 530)^{1.19}\ (K_{I,ON})(D_S)}{(T_{S,SS} - T_{RA} + 70 - 42)^{0.56}}, \quad \text{for units using indoor air for combustion.} \qquad \text{(A19)}$$

Using the above functions F3 through F8 and factors $K_{S,OFF}$ and $K_{I,OFF}$, the off-cycle sensible and infiltration heat losses can be approximated as follows:

$$L_{S,OFF} = K_{S,OFF} \times [F3(\psi_{F,O}, \frac{t_{OFF}}{\tau_{OFF}}) + \psi_{F,\infty} \times F4(\psi_{F,O}, \frac{t_{OFF}}{\tau_{OFF}})] \times \frac{t_{OFF}}{t_{ON}} \text{ , for} \tag{A20a}$$

units without stack dampers using indoor combustion air.

$$L_{S,OFF} = K_{S,OFF} \times [F5(\psi_{S,O}, \frac{t_{OFF}}{\tau_{OFF}}) + \psi_{S,\infty} \times F6(\psi_{S,O}, \frac{t_{OFF}}{\tau_{OFF}})] \frac{t_{OFF}}{t_{ON}} \text{ , for units} \tag{A20b}$$

with stack dampers using indoor combustion air.

$$L_{S,OFF} = K_{S,OFF} \times [F5(\psi_{F,O}, \frac{t_{OFF}}{\tau_{OFF}}) + \psi_{F,\infty} \times F6(\psi_{F,O}, \frac{t_{OFF}}{\tau_{OFF}})] \times \frac{t_{OFF}}{t_{ON}} \text{ , for units} \tag{A20c}$$

using outdoor air for combustion.

$$L_{I,OFF} = K_{I,OFF} \times (70 - 42) \times [(F7(\psi_{S,O}, \frac{t_{OFF}}{\tau_{OFF}}) + \psi_{S,\infty} \times F8(\psi_{S,O}, \frac{t_{OFF}}{\tau_{OFF}})] \times \frac{t_{OFF}}{t_{ON}} \text{ , for units using indoor combustion air.} \tag{A21}$$

Part-Load and Annual Fuel Utilization Efficiencies

During the initial development of this calculation procedure, the various loss terms were evaluated to find the efficiency in six different temperature bins and then combined with weather data on the number of heating season hours in each bin to calculate a seasonal efficiency for the furnace or boiler. It was discovered that the seasonal efficiency thus obtained was very close to the efficiency that the unit had when operating at the average outdoor temperature for the heating season providing that a correction factor, $C_{IID} = 0.9$, was added for units equipped with intermittent ignition devices or cycling pilots. It was, therefore, decided to evaluate the part-load efficiency, η_u, of a furnace or boiler operating at the average outdoor temperature of 42°F (5.56°C) and use this to approximate the unit's efficiency during the heating season. Assuming the unit is 70% oversized at the average outdoor design temperature of 5°F (-15°C), the approximate on and off-times at an outdoor temperature of 42°F (5.56°C) can be obtained using the equations:

$$X = \frac{1}{1.7} \left(\frac{65 - 42}{65 - 5} \right) \text{ , } t_{ON} = \frac{(60)(X)}{(4)(N)(X)(1-X)} \text{ , and } t_{OFF} = \frac{60}{(4)(N)(X)(1-X)} - t_{ON},$$

where X is the units load factor and N is the furnace or boiler's cycling rate at half-load. With N set equal to 5 for furnaces and 2 for boilers, one obtains t_{ON} = 3.87 min and t_{OFF} = 13.3 min for furnaces, and t_{ON} = 9.68 min and t_{OFF} = 33.26 min for boilers. Using these on and off-times in equations (A2), (A3), (A20), and (A21), the efficiency of the furnace or boiler during the heating season is assumed to be:

$$\eta_u = 100 - L_{L,A} - \frac{t_{ON}}{t_{ON} + \left(\frac{Q_P}{Q_{IN}}\right) t_{OFF}} [L_{S,ON} + L_{S,OFF} + L_{I,ON} + L_{I,OFF}] \text{ , for units} \tag{A22a}$$

located in an indoor heated space,

and

$$\eta_u = 100 - L_{L,A} - (C_J)(L_J) - \frac{t_{ON}}{t_{ON} + \left(\frac{Q_P}{Q_{IN}}\right) t_{OFF}} [L_{S,ON} + L_{S,OFF}], \quad \text{for} \tag{A22b}$$

units located out-of-doors or in unheated spaces,

where L_J is the measured jacket loss (in percent) and C_J equals 3.3 for furnaces and 4.7 for boilers.

The annual fuel utilization efficiency may then be obtained from the equation:

$$EFFY_A = \frac{(\eta_{SS})(\eta_u)(5200)}{(\eta_{SS})(5200) + (2.5)(\eta_u)\left(\frac{Q_P}{Q_{IN}}\right)(1.7)(4600)} \tag{A23}$$

A3 Calculation of Burner Operating Hours

The equation for Burner Operating Hours in section 4.2 is obtained by simultaneously solving the two algebraic equations:

burner operating hours =

$$= \frac{\text{heating season fuel consumption} - (2 \times \text{HLH} - \text{burner operating hours})Q_P}{Q_{IN}}, \tag{A24}$$

heating season fuel consumption =

$$= \frac{\text{annual building load} - (3413)(PE + yBE)(\text{burner operating hours})}{\eta_u}, \tag{A25}$$

and setting the annual building load equal to (HLH) (C) (design heating requirement), where $C \equiv 0.77$ is an "experience factor" which tends to improve the agreement between the calculated results and existing field data. The heating load hours, HLH, was defined using:

$$HLH = \frac{24(\text{Degree Days for the Region})}{65 - ODT}, \tag{A26}$$

where ODT is the outdoor design temperature for the region at which the design heating requirement is determined. Equation (A26) was used to generate Figure 9, based upon the 97 1/2 percent outdoor design temperature for each region.

A4 Correction Factor, C_S and C_S', for Use of Outdoor Air for Combustion

Since the indoor air is used for combustion under the test condition (see sections 2 & 3) an on-period correction factor (C_S) is required to be applied to the test data, if the unit is intended to use outdoor air for combustion.

The effectiveness ε of a heat exchanger for the boiler/furnace system can be defined:

$$\varepsilon = \frac{Q}{C_P m_{F,ON}(T_{AF} - T_{IA})} \tag{A27}$$

where Q is the rate of heat transfer from the combustion products to the returning circulating air, C_p the gas specific heat, $m_{F,ON}$ the flue gas flow rate, T_{AF} the adiabatic flame temperature and T_{IA} the temperature of returning circulating air. Let subscripts IA or OA stand for the values obtained when the indoor or outdoor air is used, respectively. Equation A27 can be re-written as follows:

$$\varepsilon = \frac{Q_{IA}}{C_p m_{F,ON}(T_{AR,IA} - T_{IA})} = \frac{Q_{OA}}{C_p m_{F,ON}(T_{AF,ON} - T_{IA})} \tag{A28}$$

As it can readily be shown that $T_{AF,OA}$ is euqal to $[T_{AF,IA} - (T_{IA} - T_{OA})]$, a rearrangement of equation A28 yields:

$$Q_{OA} = Q_{IA} - \frac{C_p m_{F,ON}(T_{IA} - T_{OA}) \times Q_{IA}}{C_p m_{F,ON}(T_{AF,IA} - T_{IA})} = Q_{IA} - \frac{\eta_{ss}}{100} \times C_p m_{F,ON}(T_{IA} - T_{OA}) \tag{A29}$$

Substituting $Q_{OA}/(C_p m_{F,ON})$ and $Q_{IA}/C_p m_{F,ON}$ by $[T_{AF,IA} - (T_{IA} - T_{OA})]$ and $[T_{AF},_{IA} - T_{F,IA}]$ respectively, equation A29 becomes:

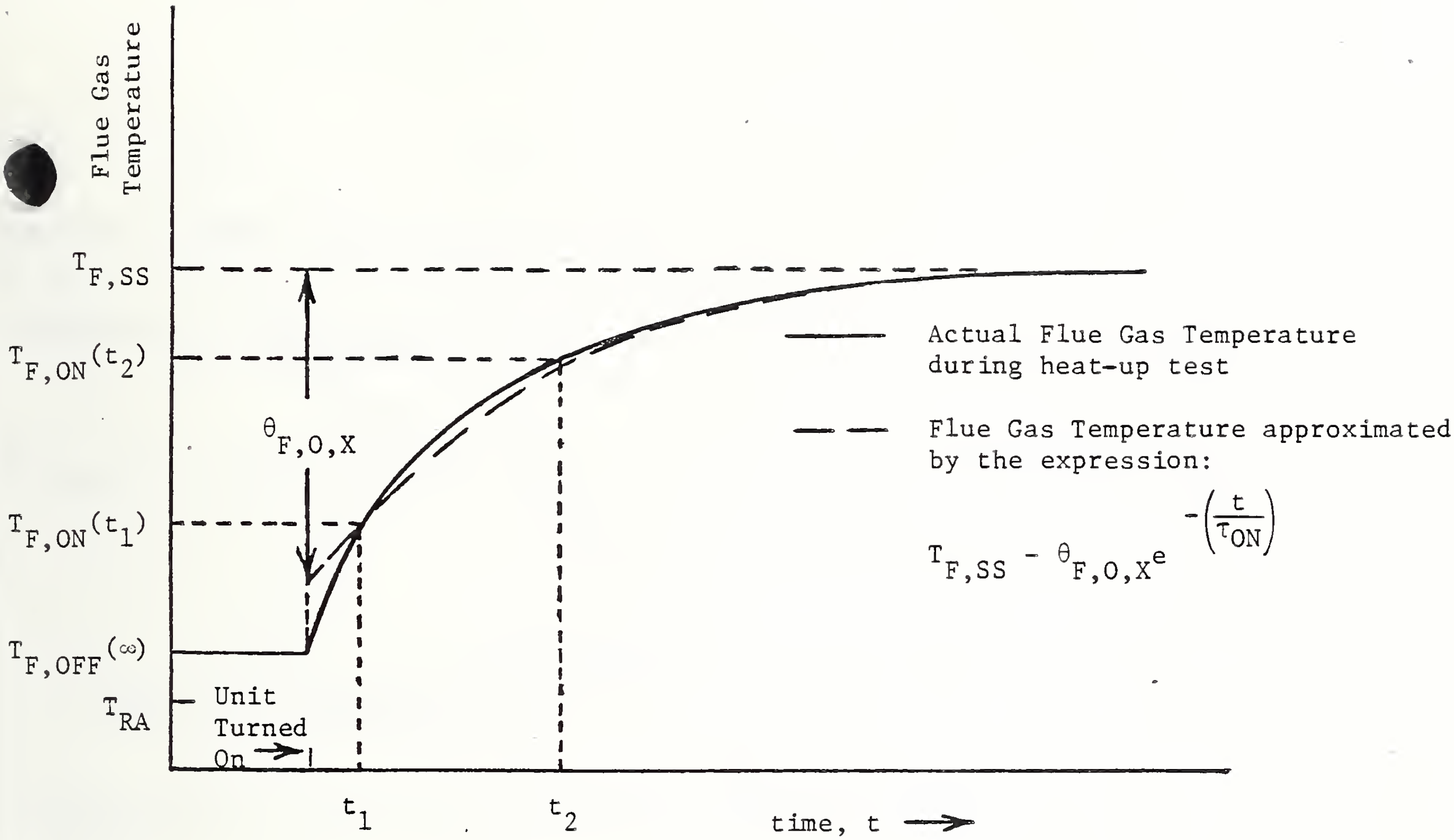
$$(T_{F,OA} - T_{OA}) = (T_{F,IA} - T_{IA}) \times [1 + \frac{\eta_{ss} \times (T_{IA} - T_{OA})}{100 \times (T_{F,IA} - T_{IA})}] \tag{A30}$$

As the sensible heat losses at steady-state, using outdoor and indoor air, are proportional to $(T_{F,OA} - T_{OA})$ and $(T_{F,IA} - T_{IA})$, respectively, and T_{IA}, T_{OA} and $T_{F,IA}$ are equal to 70, 42, and $T_{F,SS}$ respectively, the ratio of sensible heat loss using outdoor air to that using indoor air C_S can be obtained from equation A30.

$$C_S = 1 + \frac{28 \times \eta_{ss}}{T_{F,SS} - 70} \tag{A31}$$

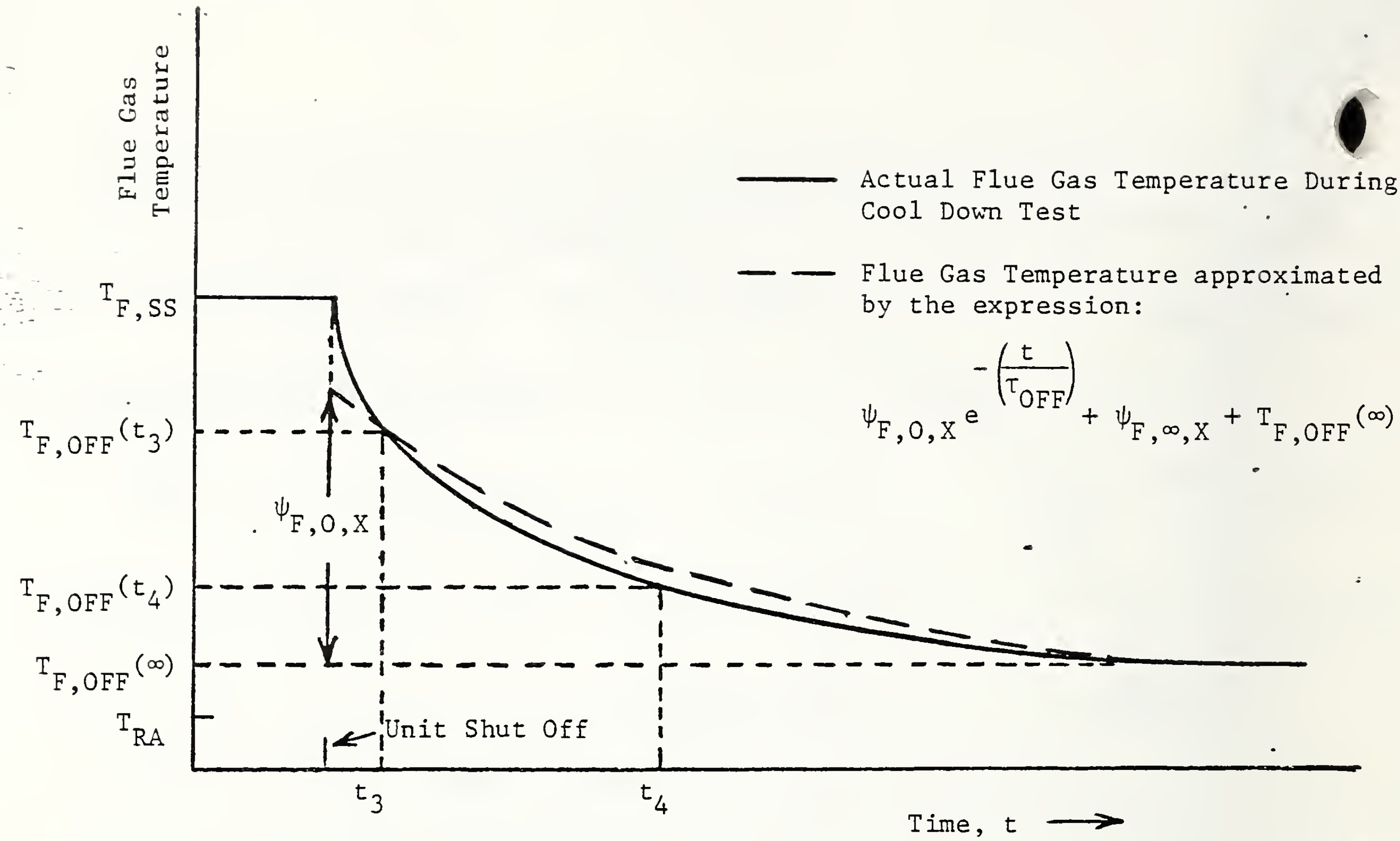
In summary, equation A31 has been derived to correct the on-period flue temperature for the unit using outside air.

To correct for the fact that during the off-period outdoor air is also passing through the heat exchanger, which tends to cool the unit off, a constant factor $C_S' = 1.22$ was introduced in steps 50 and 51 of the procedure for calculating the annual fuel utilization efficiency. This factor, which multiplies the off-period temperature difference $\psi_{F,O,X}$ and $\psi_{F,\infty,X}$, was generated for a typical furnace using the NBS furnace simulation model DEPAF. It should be considered as an approximate method of handling this increased off-period cooling rate for units using outdoor combustion air. Future work is needed to develop a more rigorous correction procedure.



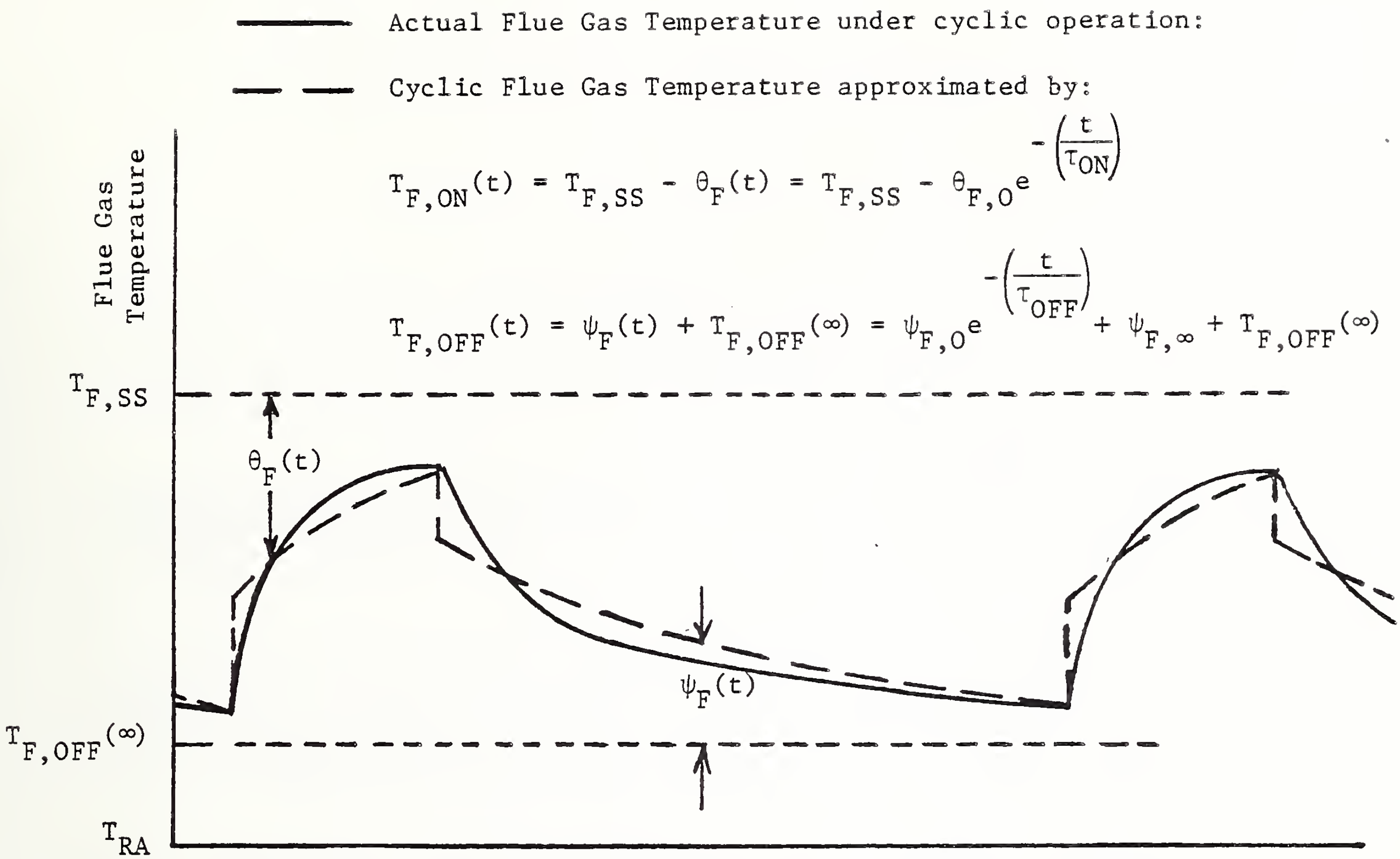
For furnaces, t_1 = 0.5 min and t_2 = 2.5 min. For boilers, t_1 = 1 min and t_2 = 5.5 min. The quantities $\theta_{F,O,X}$ and τ_{ON} are defined in Appendix A and steps 33 and 32 of Section 4.1.

Figure A-1. Heat-up Test and Approximated Flue Gas Temperature Profile Prior to Correcting for the Effect of Cycling and the use of Outdoor Combustion Air.



For furnaces, t_3 = 1.5 min, t_4 = 9 min and $T_{F,OFF}(\infty)$ is the off-period minimum flue gas temperature ($T_{F,OFF}(\infty) = T_{RA}$ for units without continuously operating pilot lights). For boilers, t_3 = 3.75 min, t_4 = 22.5 min and $T_{F,OFF}(\infty)$ is the flue gas temperature measured 45 minutes after the boiler is shut off. The quantities $\psi_{F,O,X}$, $\psi_{F,\infty,X}$ and τ_{OFF} are defined in Appendix A and steps 35, 36 and 34 of Section 4.1.

Figure A-2. Cool-down Test and Approximated Flue Gas Temperature Profile Prior to Correcting for the Effect of Cycling and the Use of Outdoor Combustion Air.



The quantities $\theta_{F,O}$, τ_{ON}, $\psi_{F,O}$, $\psi_{F,\infty}$, and τ_{OFF} are defined in Appendix A and respectively in steps 49, 32, 50, 51 and 34 of Section 4.1.

Figure A-3. Flue Gas Temperature Profile After Correcting for the Effect of Cycling and the Use of Outdoor Combustion Air.

APPENDIX B

Computerized Version of Sections 4.1 and 4.2 in Fortran V

B1. General Program Description

The complete computer program consists of a main program and two subroutines. The main program is labeled NBS Furnace and Boiler Simulation (NBSFBS5) and its subroutines are FUNT4 and sensible heat LOSS (SENLOS). This Fortran V program, NBSFBS5, was designed to be run on a Univac 1108 computer[1/] using either a card deck or interactive terminal techniques. Modification may have to be made to the program when employing it on different types of computers.

NBSFBS5 performs the calculation steps and chooses calculation paths based on the input information when alternatives are presented in the calculation procedure. An example of this is the different treatment given to the calculation of the part-load fuel utilization efficiency for indoor and outdoor units presented in program statements 184 to 188. Other bases for selection of calculation paths to determine on and off-cycle losses are ignition equipment, system number (NSYS), and unit type (Furnace/Boiler/Space Heater). Specific identification of these alternate paths is presented later in a program flow chart and a summary of the different calculation paths.

The NBSFBS5 program closely follows the order of the numbered steps contained in section 4.1. Input and output column number labels are assigned in accordance with those listed in Figure 10. Input line 5 includes step numbers 1 to 8, while input lines 6 and 7 include steps 9 to 16 and 17 to 22, respectively. Program input lines 1, 2, 3, 4, and 8 do not appear in Figure 10. Their input value descriptions are given in the Input Data Code Sheet for NBSFBS5 presented in Figure B1.

Subroutine FUNT4 calculates the F3 through F8 Functions used in determing off cycle sensible and infiltration heat losses (QSOFF & QIOFF) and replaces the plots of the F3 through F8 functions given in Figures 3 through 8. The F3 through F8 functions are determined in pairs using FI and FJ arguments for each call of the FUNT4 subroutine. Depending upon the main program path for a particular test unit the arguments FI and FJ returned by FUNT4 can be either F3 and F4, F5 and F6, or F7 and F8. These three program paths are shown in the main program flow chart section C-C, statement lines 149 to 183.

The SENLOS subroutine sets values which could otherwise be read from Figures 1 and 2A to 2F, and also tests for a possible reset of SFR (stack to flue gas mass flow ratio) for vented heaters with draft diverters. Values returned by this subroutine according to fuel type (TFUEL) are HHV_A, A/F and $L_{L,A}$ (step numbers 24, 25, & 26). $R_{T,F}$, $L_{S,SS,A}$, and η_{SS} are also returned as step numbers 28, 29 and 30. These are calculated for all units based upon appropriate steady-state stack or flue temperature and CO_2 readings and the appropriate coefficients, CF (IFUEL, I), stored for each fuel type.

B2. Program Flow Chart

A flow chart of the NBSFBS5 program is provided in Figure B2 to assist future users in gaining an understanding of the program, to help in trouble shooting, and to help users modify the program in order to be able to operate in other program languages, or on other computers. The NBSFBS5 flow chart has three segments, listed as AA, BB, and CC, charted separately. These three segments, which are presented as subsections of the main program in the same fashion as FUNT4 and SENLOS, are charted in Figures B3 and B4. Figure B5 illustrates the standard data processing flow chart symbols used and their meanings.

[1/] Reference to a specific computer is for illustrative purposes and does not constitute or imply endorsement by NBS.

Flow chart notes written inside the program symbols use input/output step numbers corresponding to those in Figure 10, Work Sheet for Vented Home Heating Equipment.

The left column of numbers on each program sheet indicates the statement numbers found in the left-most column of the program listing. Where statement numbers occur elsewhere in a flow sheet due to program branching, the statement numbers are located on the outside top left corner of a program symbol.

A listing of the major program-directed calculation paths is given in Figure B6. For each test basis, the statement number and type of heating system option is listed. Reference to this summary and the flow charts will enable the user to trace the calculation path for a particular test unit.

B3. Input Data Code

Input data to the NBSFBS5 program must follow the order and form presented in Figure B1, Input Data Code Sheet for NBSFBS5. All input values which are listed as zero or blank in the procedure should have a value of "0." or "0.0" placed in the input field. For example, on units equipped with intermittent ignition devices the use of a plain "0" can result in an error message being printed out because of the mixed real and integer values in input line 5.

This program uses the implicit scheme for processor recognition of integer and real number input variables. The only integer inputs are IFB, INST, NSYS, and IFUEL. All other input variables are real positive numbers. Although the use of real number inputs greater than zero without the decimal is allowed on many processors, each user will need to check the specific requirements for his or her processor.

The freefield inputs used by NBS on the Univac 1108 Fortran V compiler may not be acceptable for use on other systems or with other computer languages. It is not possible to anticipate all future alternate input format needs, so no attempt has been made to prepare alternate input formats. This same situation will arise for the output formats. Thus output format changes may also be necessary for program implementation on other systems. Output formats are written for a carriage 132 characters wide. Use of a 72-character-wide carriage will require modification to the output formats of the initial 67 quantities. The Regional Annual Operating Cost Table should be accommodated on most output devices in its present form.

It is suggested that the following information be included in the input title and subtitle lines:

- SYSTEM TYPE
- FUEL OPTIONS
- STACK DAMPER EQUIP.
- IGNITION TYPE
- DRAFT HOOD, DIVERTER OR BAROMETRIC DAMPER
- MODEL OR IDENTIFICATION NUMBER
- DATE OR RUN
- SOURCE OF INPUT
- HEAT EXCHANGER TYPE

B4. Sample Input/Output Tests

Eleven sample sets of test unit data are presented in Figure B-8 following the program listing in Figure B-7. Table B-1, which assigns an identification number to each test unit, shows that there are six No. 2 oil-fuel units and five natural-gas-fired units. Although the data for the eleven test units are derived from tests of real furnaces, boilers and space heaters, the data have been altered to provide a check on the major program path options. As a result, the output performance is not efficiencies and costs that should be referenced as typical, average, or representative cases for the types of furnaces, boilers or vented heaters presented. The information sources used to assemble the sample sets of test unit data include AGA Laboratories, GAMA, NBS Laboratory data, and field data obtained by a contractor, the Walden Division of Abcor, Inc.

B5. Program Usage

To use the program interactively or by batch run card deck, it is recommended that the user consult the operating procedures for their computer system. When run using interactive techniques, the program does not respond with requests for input, as some operators may prefer, but relies upon a pre-prepared input file according to the input data code sheet.

Table B-1. Identification Number Table for NBSFBS5 Test Unit Data

SYSTEM TYPE	IFB	FUEL TYPE	NSYS (System Number)											
			1	2	3	4	5	6	7	8	9	10	11	12
Furnace	1	Natural Gas	5				6				7			
		No. 2 Oil				1				2				9
Boiler	2	Natural Gas												
		No. 2 Oil				3						8		
Vented Heater	3	Natural Gas	10								11			
		No. 2 Oil			4									

Fig. B-1. INPUT DATA CODE SHEET FOR NBSFBS5

Line 1: NRUN

Enter number of sets of test data to be analyzed as a left justified integer. Set this value equal to the number of sets of data lines 2 through 8 to be analyzed by the NBSFBS program.

FOR DATA OF TEST NO. 1

Line 2: TITLE

May be one to 80 characters.

Line 3: SUBTITLE

May be one to 80 characters.

Line 4: IFB, INST

Use IFB = 1 if the unit is a furnace, 2 if the unit is a boiler, or 3 if the unit is a vented heater.

For central furnaces installed indoors, vented wall furnaces, and vented room heaters use INST = 1. For floor furnaces and central furnaces installed outdoors or in unheated spaces, use INST = 2.

Line 5: SYS#, IFUEL, HHV, Q_{IN}, Q_P, PE, BE, $X_{CO_2,S}$

* SYS# must be an integer as found in tables 1 and 2 for each system being analyzed.
* IFUEL must be an integer as given as TFUEL in Step 2 of section 4.1.
* HHV is the measured higher heating value of the test fuel, in Btu/lb.
* Q_{IN} and Q_P are steady-state and pilot input rates, respectively, in Btu/h.
* PE and BE are power burner and blower (or pump) input powers, respectively, in kW.
* $X_{CO_2,S}$ is the concentration by volume of CO_2 in dry stack gas, in %.

Line 6: $T_{S,SS,X}$, $X_{CO_2,F}$, $T_{F,SS}$, $T_{F,ON}(t_1)$, $T_{F,ON}(t_2)$, $T_{F,OFF}(t_3)$, $T_{F,OFF}(t_4)$, $T_{F,OFF}(t_5)$

Input values of line six to be given in positive real numbers using units of degree F for temperatures, and percent(%) for $X_{CO_2,F}$.

Line 7: T_{RA}, Q_J, S/F, $\cancel{D_V}$ D_F, D_S, Y

* T_{RA} is input as a degree F temperature.
* Q_J is a percent (%).
* S/F, D_F, and D_S are positive real numbers using values found in Table 2. Note: For vented heaters with draft diverters or draft hoods enter value of S/F from Table 2; program automatically claculates S/F = (1.3) $(R_{T,S}/R_{T,F})$, compares it with the entered value, and uses the larger of the two.
* Y - is a positive real number. See step 22 of calculation procedure for value to be entered.

Line 8: FLCOST, ELCOST, K

* FLCOST is given in dollars per unit of fuel.
* ELCOST is given as dollars per kWh.
* K is Btu content per unit of fuel.

TEST DATA No. 2

Test data number two and successive tests are to be input as repeats of lines 2 through 8.

TEST DATA No. 3

Lines 2 through 8.

•

•

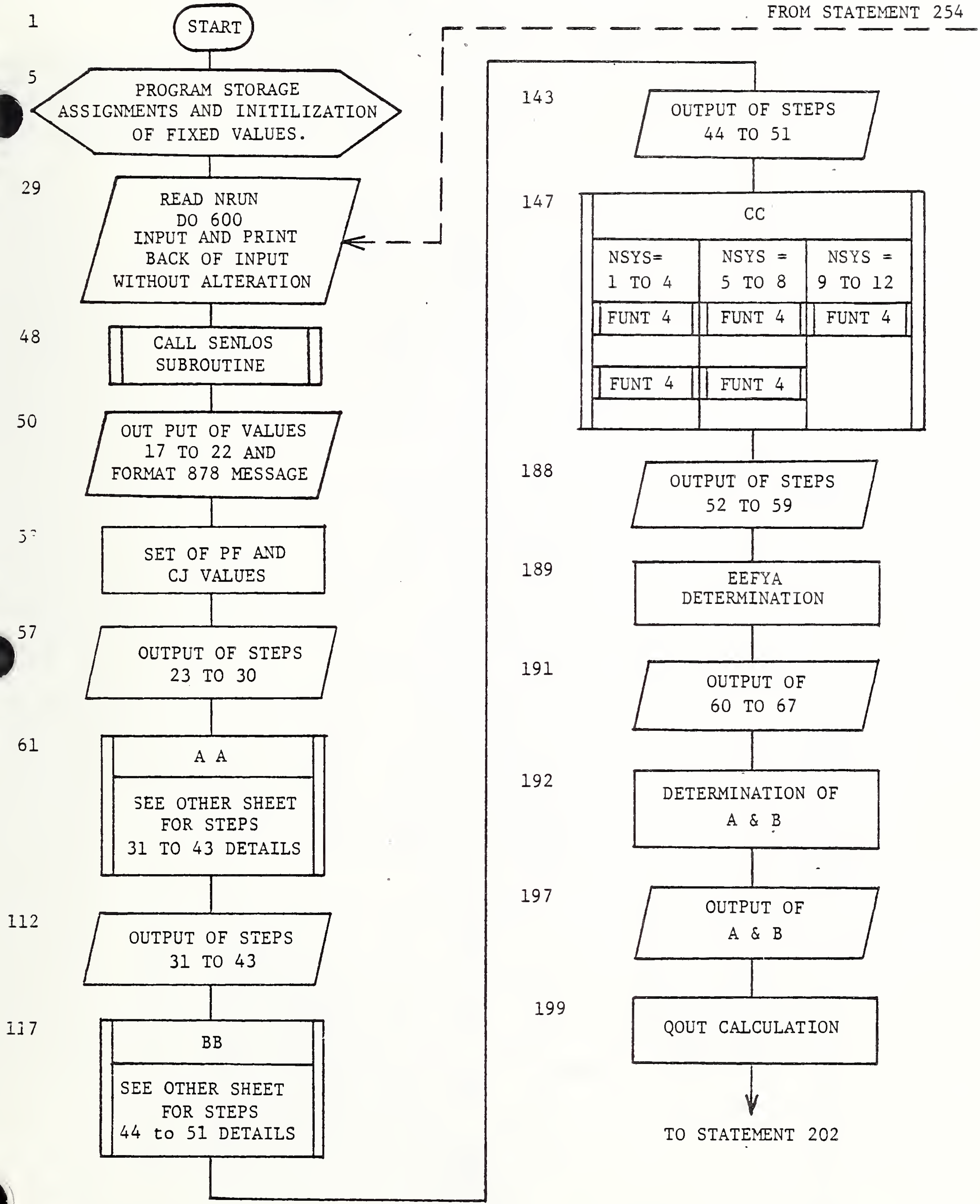
•

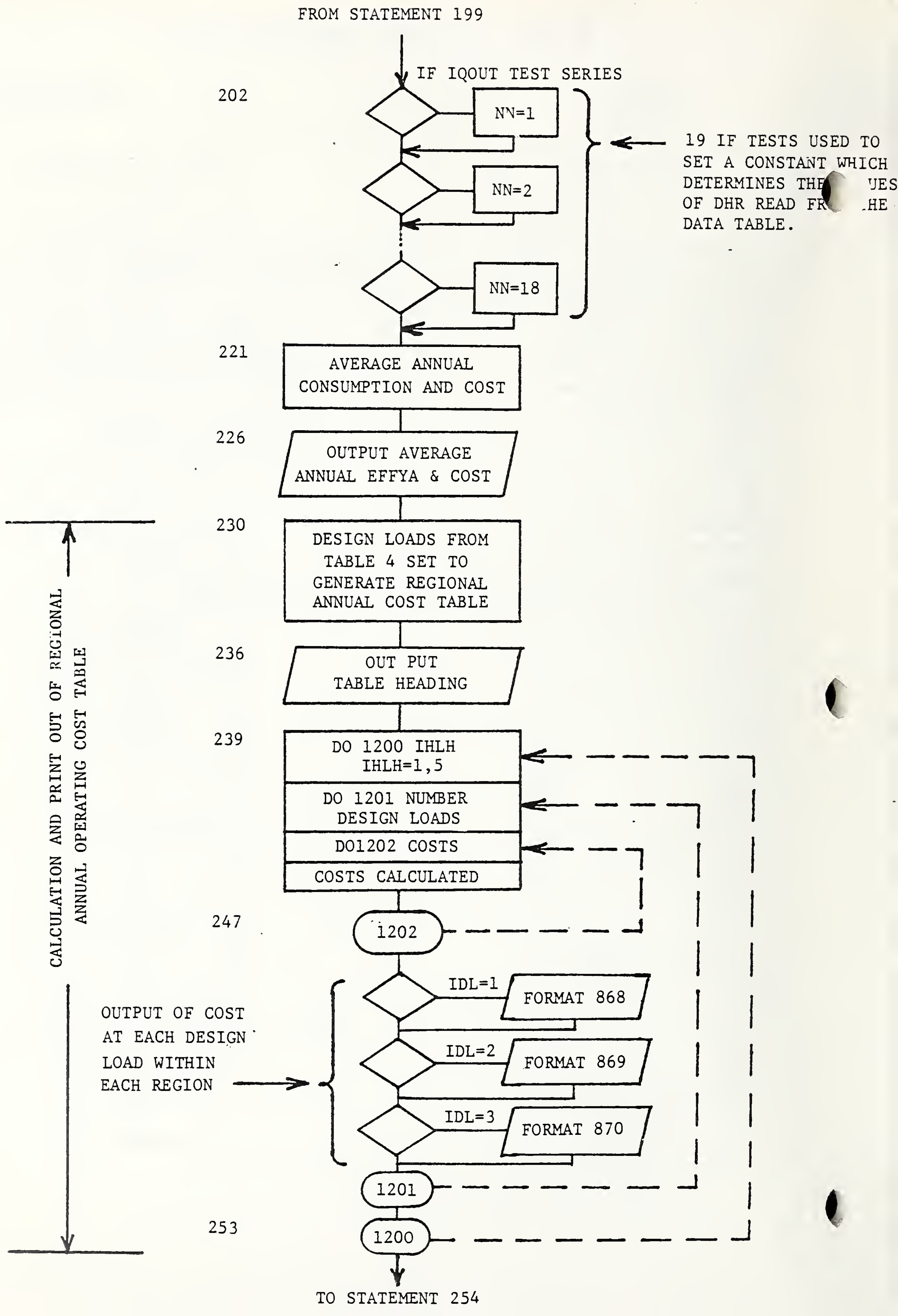
TEST DATA No. (NRUN)

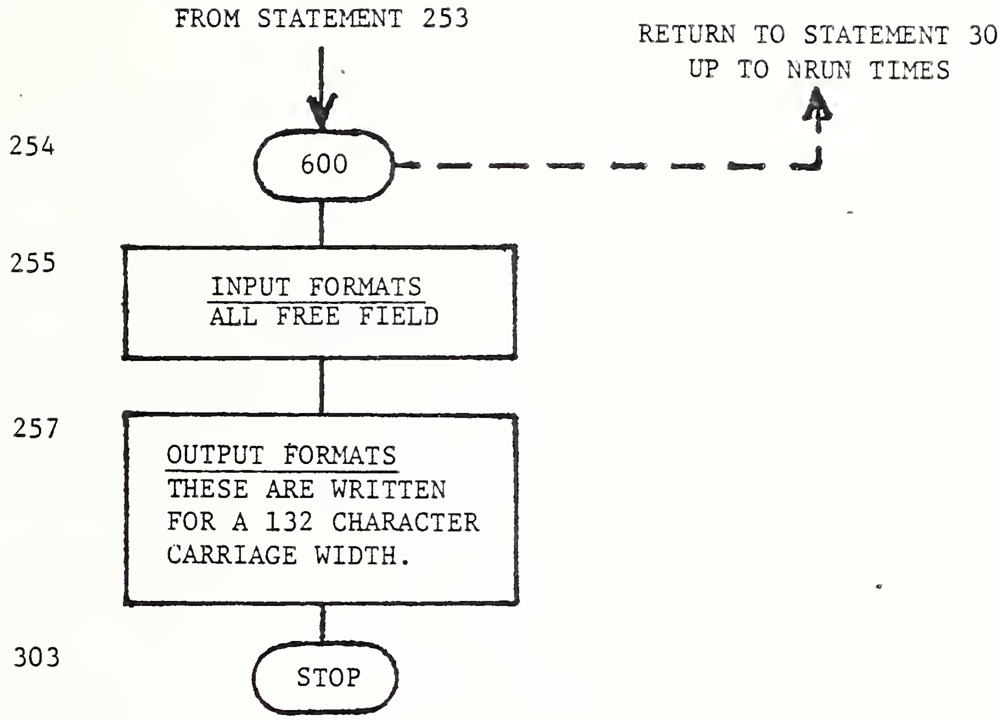
Lines 2 through 8.

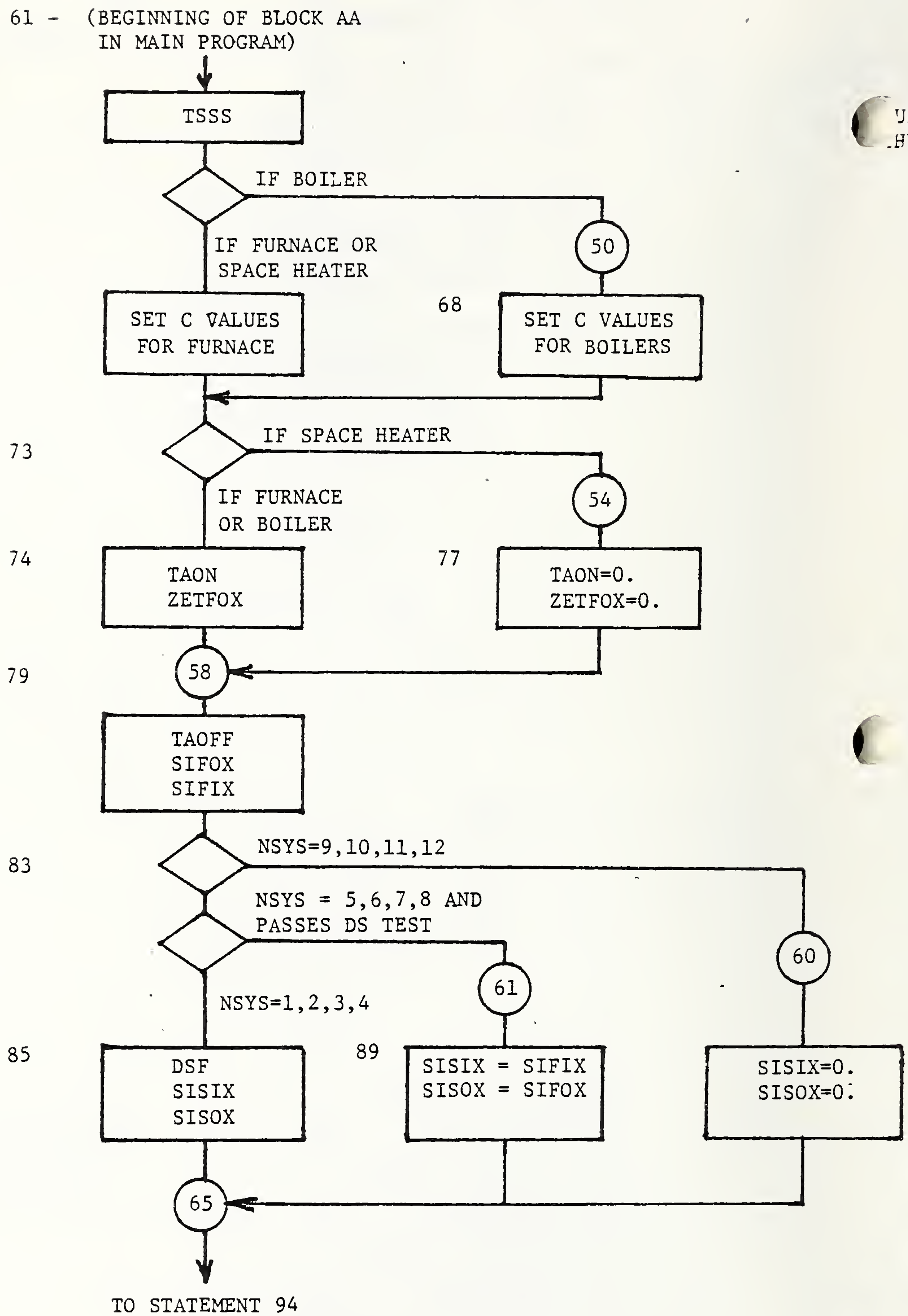
<u>Note</u>: This program is written to use free field format input as given by FORMAT No. 801. All input variables must be separated by commas or spaces as required by the computer processor system used.

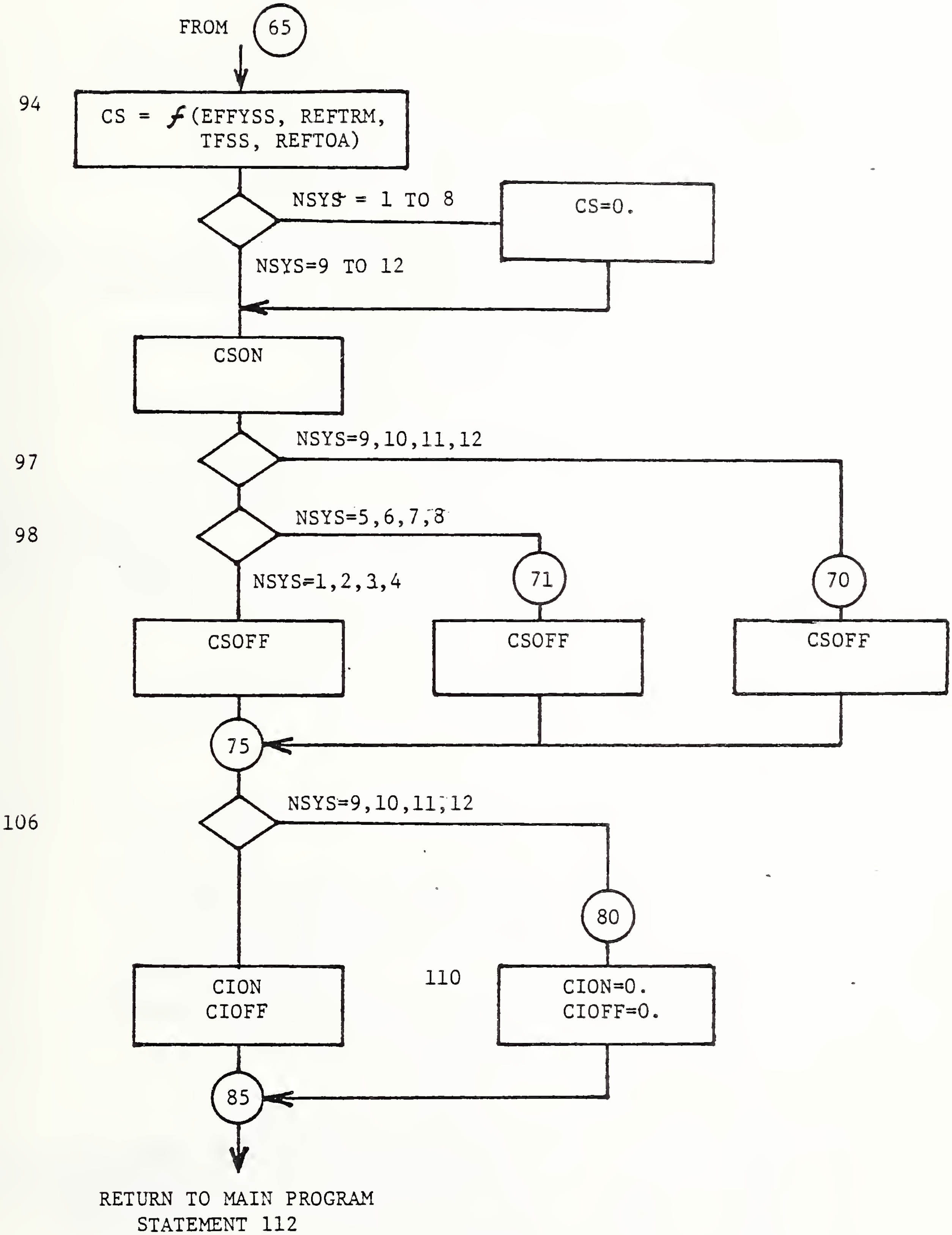
FIG. B-2. MAIN NBSFBS PROGRAM FLOW CHART



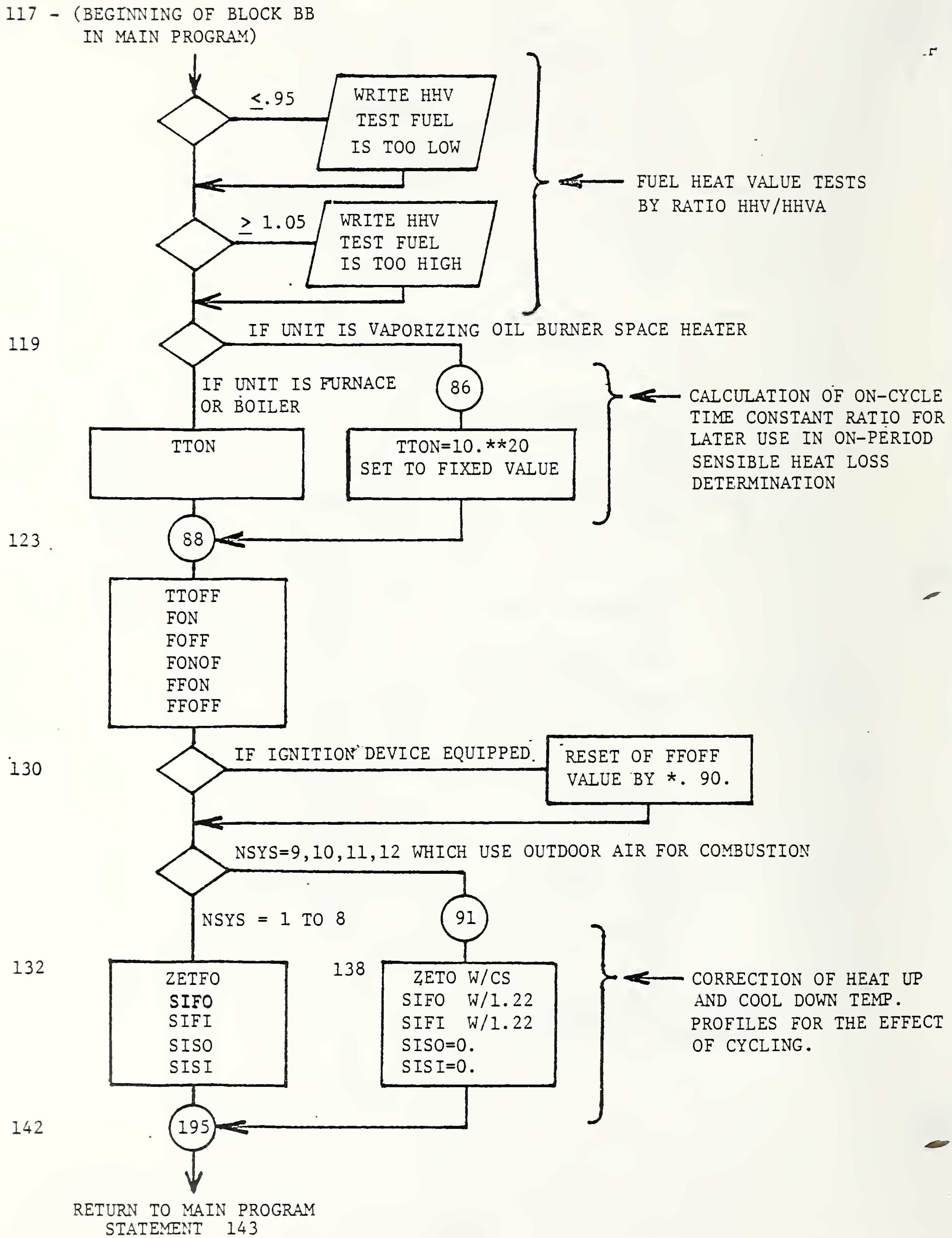

FROM STATEMENT 199
IF IQOUT TEST SERIES
202
NN=1
NN=2
NN=18
19 IF TESTS USED TO SET A CONSTANT WHICH DETERMINES THE UES OF DHR READ FR HE DATA TABLE.
221
AVERAGE ANNUAL CONSUMPTION AND COST
226
OUTPUT AVERAGE ANNUAL EFFYA & COST
230
DESIGN LOADS FROM TABLE 4 SET TO GENERATE REGIONAL ANNUAL COST TABLE
236
OUT PUT TABLE HEADING
239
DO 1200 IHLH IHLH=1,5
DO 1201 NUMBER DESIGN LOADS
DO1202 COSTS
COSTS CALCULATED
247
1202
CALCULATION AND PRINT OUT OF REGIONAL ANNUAL OPERATING COST TABLE
OUTPUT OF COST AT EACH DESIGN LOAD WITHIN EACH REGION
IDL=1
FORMAT 868
IDL=2
FORMAT 869
IDL=3
FORMAT 870
1201
253
1200
TO STATEMENT 254


FROM STATEMENT 253
RETURN TO STATEMENT 30
UP TO NRUN TIMES
254
600
255
INPUT FORMATS
ALL FREE FIELD
257
OUTPUT FORMATS
THESE ARE WRITTEN
FOR A 132 CHARACTER
CARRIAGE WIDTH.
303
STOP


61 - (BEGINNING OF BLOCK AA
IN MAIN PROGRAM)
TSSS
IF BOILER
IF FURNACE OR
SPACE HEATER
50
68
SET C VALUES
FOR FURNACE
SET C VALUES
FOR BOILERS
73
IF SPACE HEATER
IF FURNACE
OR BOILER
54
74
77
TAON
ZETFOX
TAON=0.
ZETFOX=0.
79
58
TAOFF
SIFOX
SIFIX
83
NSYS=9,10,11,12
NSYS = 5,6,7,8 AND
PASSES DS TEST
60
61
NSYS=1,2,3,4
85
89
DSF
SISIX
SISOX
SISIX = SIFIX
SISOX = SIFOX
SISIX=0.
SISOX=0.
65
TO STATEMENT 94


FROM 65
94
CS = f(EFFYSS, REFTRM, TFSS, REFTOA)
NSYS = 1 TO 8
CS=0.
NSYS=9 TO 12
CSON
97
NSYS=9,10,11,12
98
NSYS=5,6,7,8
NSYS=1,2,3,4
71
70
CSOFF
CSOFF
CSOFF
75
106
NSYS=9,10,11,12
80
CION
CIOFF
110
CION=0.
CIOFF=0.
85
RETURN TO MAIN PROGRAM STATEMENT 112

PROGRAM SEGMENT BB



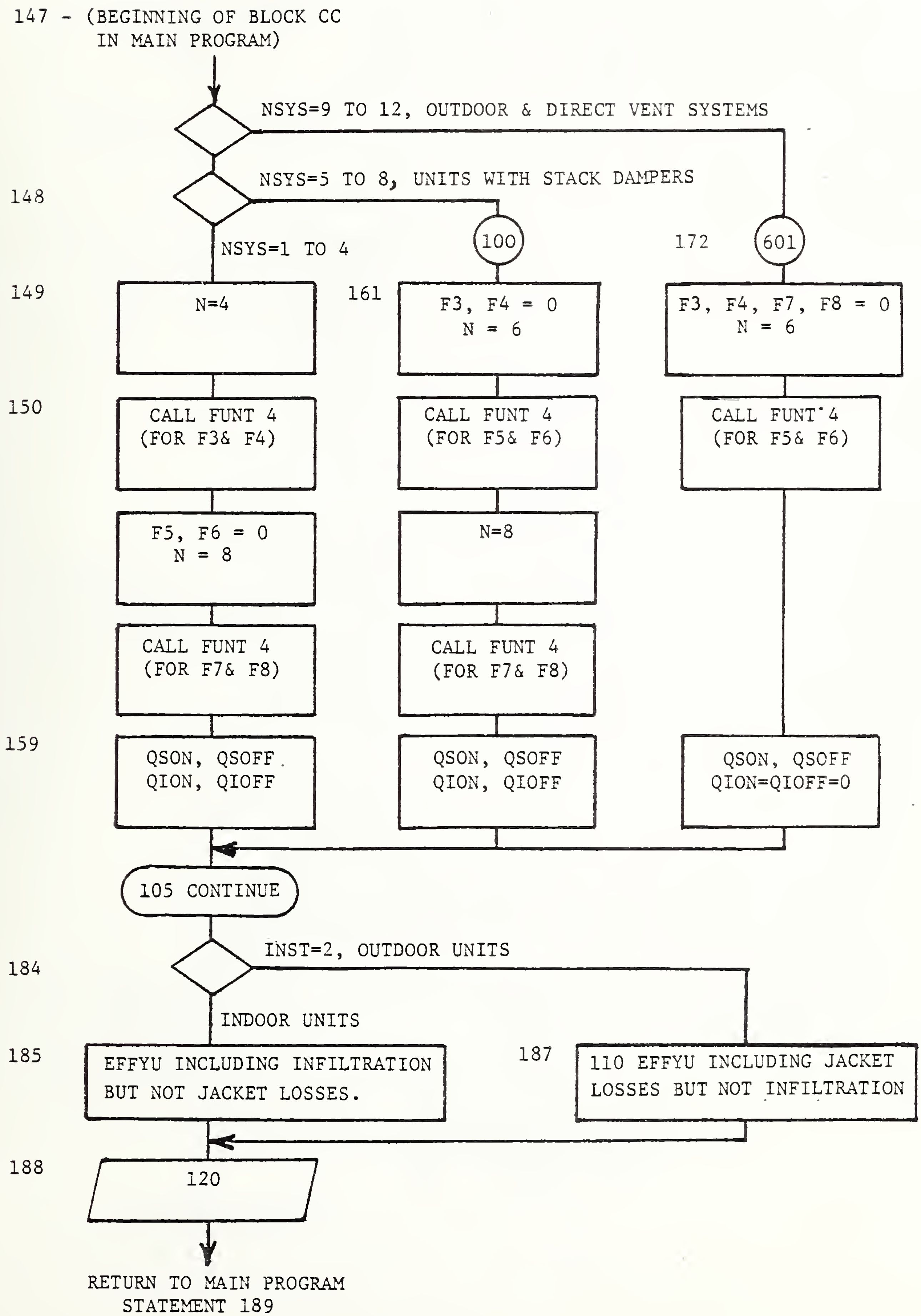

147 - (BEGINNING OF BLOCK CC
IN MAIN PROGRAM)
NSYS=9 TO 12, OUTDOOR & DIRECT VENT SYSTEMS
148
NSYS=5 TO 8, UNITS WITH STACK DAMPERS
NSYS=1 TO 4
100
172
601
149
N=4
161
F3, F4 = 0
N = 6
F3, F4, F7, F8 = 0
N = 6
150
CALL FUNT 4
(FOR F3& F4)
CALL FUNT 4
(FOR F5& F6)
CALL FUNT 4
(FOR F5& F6)
F5, F6 = 0
N = 8
N=8
CALL FUNT 4
(FOR F7& F8)
CALL FUNT 4
(FOR F7& F8)
159
QSON, QSOFF
QION, QIOFF
QSON, QSOFF
QION, QIOFF
QSON, QSOFF
QION=QIOFF=0
105 CONTINUE
184
INST=2, OUTDOOR UNITS
INDOOR UNITS
185
EFFYU INCLUDING INFILTRATION
BUT NOT JACKET LOSSES.
187
110 EFFYU INCLUDING JACKET
LOSSES BUT NOT INFILTRATION
188
120
RETURN TO MAIN PROGRAM
STATEMENT 189

FIG. B-3. SUBROUTINE FUNT 4 FLOW CHART

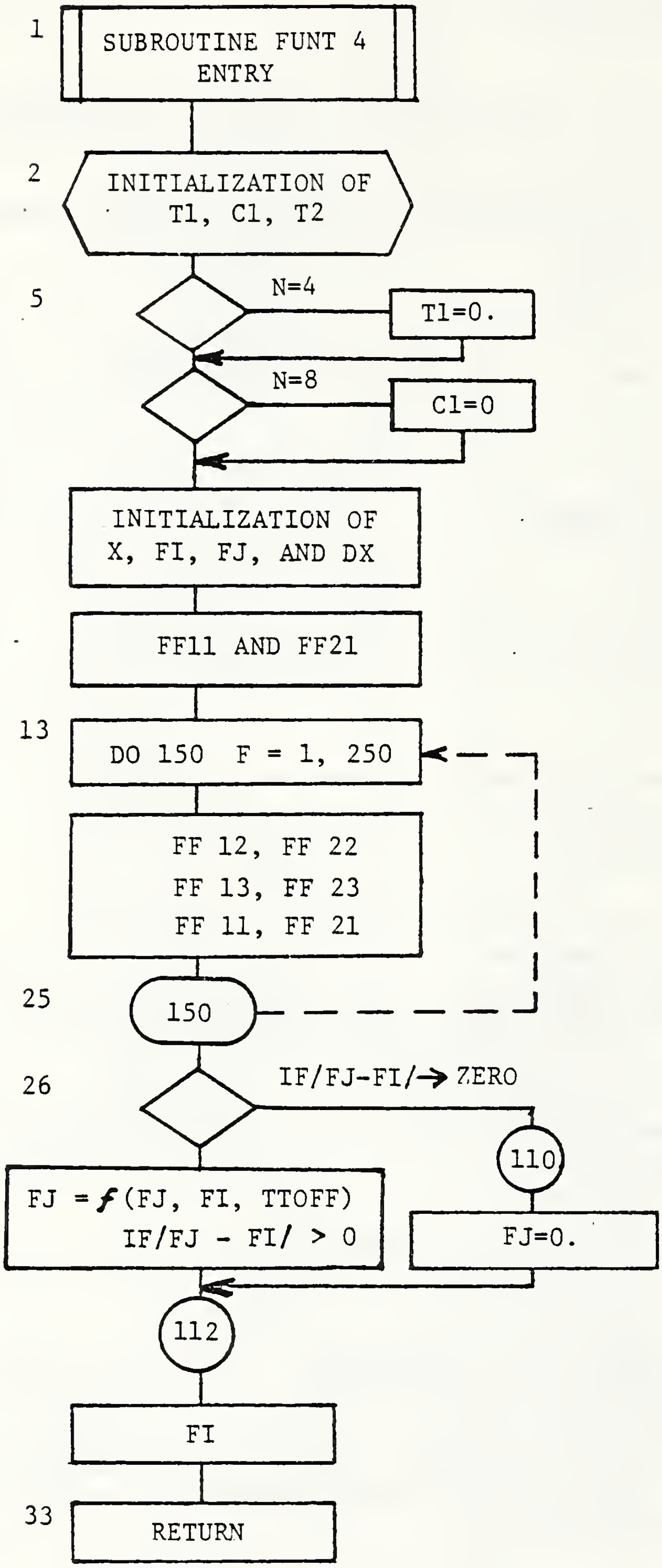
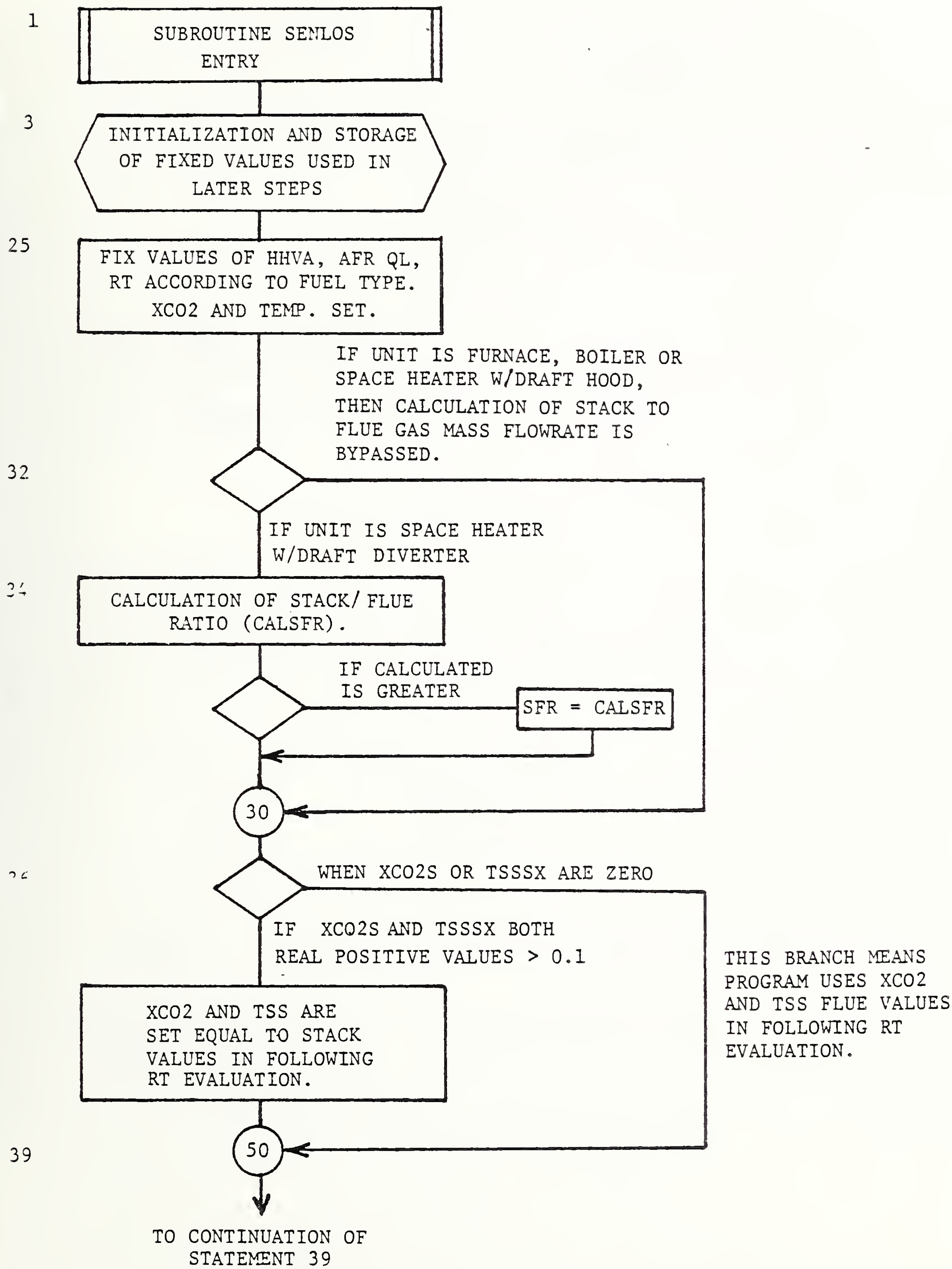


FIG. B-4 SUBROUTINE SENLOS FLOW CHART



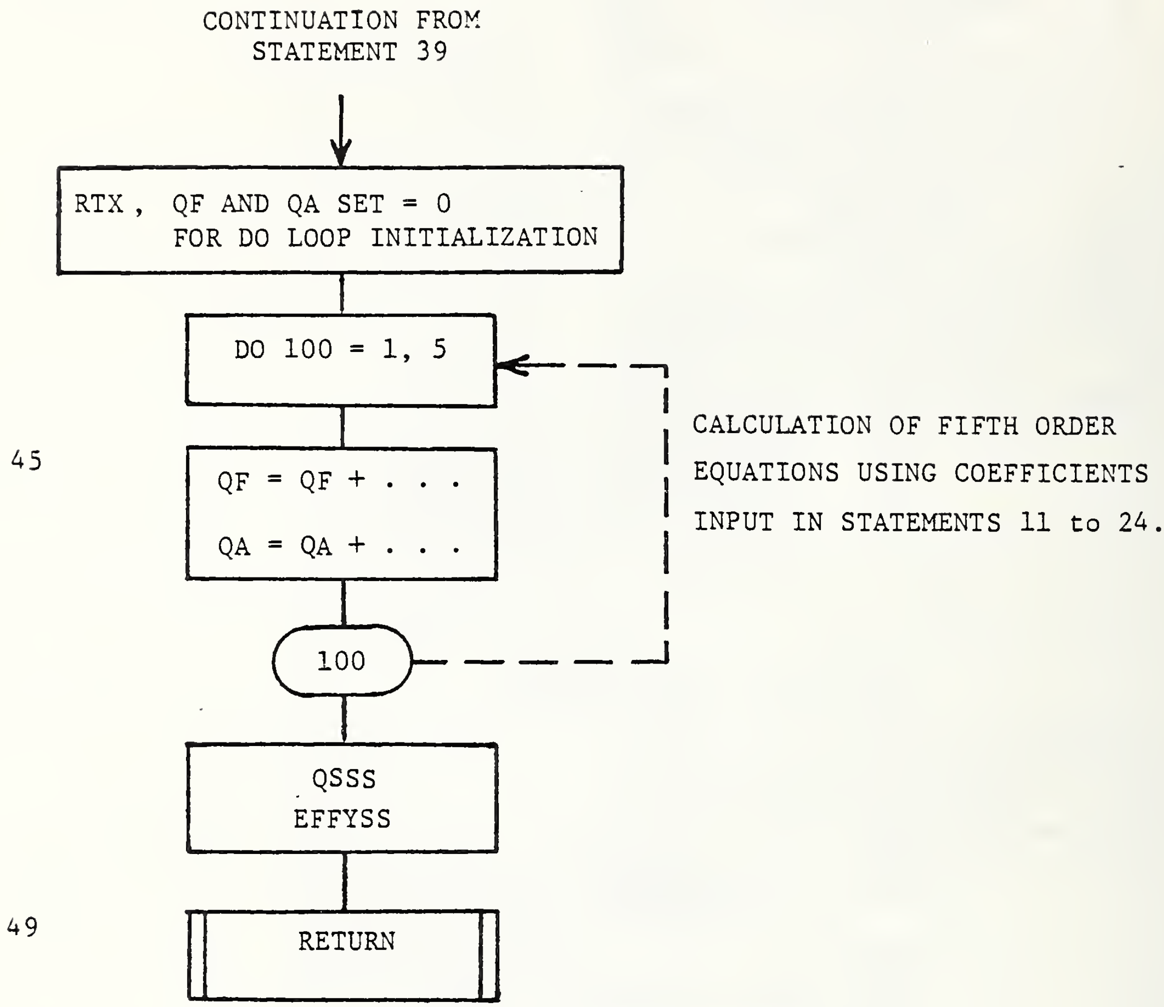
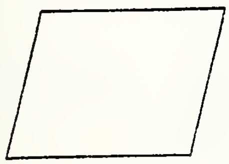
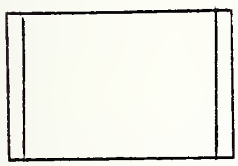
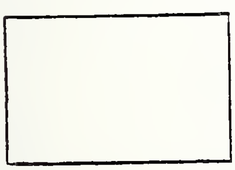
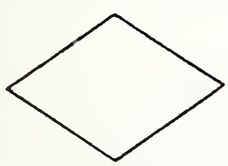
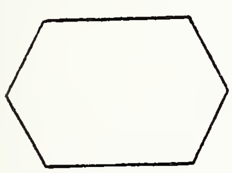

CONTINUATION FROM STATEMENT 39
RTX , QF AND QA SET = 0 FOR DO LOOP INITIALIZATION
DO 100 = 1, 5
45
QF = QF + . . .
QA = QA + . . .
CALCULATION OF FIFTH ORDER EQUATIONS USING COEFFICIENTS INPUT IN STATEMENTS 11 to 24.
100
QSSS
EFFYSS
49
RETURN

Figure B-5. Symbols and Meanings Used in Flow Diagram

SYMBOL[1]	MEANING
	Start and termination of program. also used in these flow charts for do loop terminal statements
	Input of data and output of information
	Used for identification of a subroutine, and to designate segments AA, BB, and CC whose expanded operation are specified elsewhere
	Calculation steps using predefined quantities in defined operations
	If tests for decision of which branch of program calculations should use. Usually a test for type, NSYS number, and other equipment options.
	Main program and subroutine initial assignment of data values
	A junction in program flow referenced by a Fortran statement identification number

[1] Symbols conform to Federal Information Processing Standards (ANSI X 3.5-1970)

Figure B-6 Program Directed Calculation Path Summary by Test Basis[1/] .

Statement Number	Test Basis	Program Path Option Option 1: Option 2: Option η
62 NBSFBS5	Does IFB=1 or 3, or does IFB=2	Furnace and Space Heaters: Boilers
73	Does TFSS=TFON2=TFON2 for test for space heater with oil vaporizing type burner	Furnaces, boilers, and non-vaporizing space heater: oil vaporizing type space heaters
83, 84	NSYS Groups	NSYS of 1 to 4:5 to 8:9 to 12
97, 98	NSYS Groups	NSYS of 1 to 4:5 to 8:9 to 12
106	NSYS Groups	NSYS of 1 to 8:9 to 12
119	Temp test for vaporizing oil space heater	Furnaces, boiler and nonvaporizing heater:oil vaporizing type space heaters
130	Test for pilot input Fuel Value < 0.1	Pilot equipped: ignition device equipped
131	NSYS Groups	NSYS of 1 to 8: NSYS of 9 to 12
147, 148	NSYS Groups	NSYS of 1 to 4:5 to 8:9 to 12
184	Installation (INST)	INST=1, indoor: INST=2, outdoor
32 of SENLOS	Is unit not a space heater or is XCO_2S zero	Space heater w/draft diverter: furnaces, boilers and space heaters without draft diverter
36 of SENLOS	Checks input stack CO_2 and steady state stack temperature to determining if unit has a draft diverter	Diverter equipped systems: all other systems

[1/] This summary does not include the many IF statement tests which only reassign values of specified quantities. (e.g., statements 41 and 42)

NBSFBS5

```
C
C    *** EVALUATION OF FURNACE/BOILER SYSTEMS ***
C    *** NBSFBS 5 *** APRIL   1978 ***MEK ***
C    *** FOR CENTRAL FURNACES AND BOILERS, AND FOR VENTED HEATERS ***
      DIMENSION TITLE(20,2)
      DIMENSION COST(5,5,5),DL(5)
      DIMENSION TABLE(18,6), NNDL(18)
      DATA REFTRM,DD,HR/70.,5200.,4600./
      DATA REFTOA,PHI,TOA,ALPHA/42.,.7,42.,.7/
      DATA (TABLE(1,NN),NN=1,6)/5.0,5.,0.,0.,0.,0./
      DATA (TABLE(2,NN),NN=1,6)/10.0,5.,10.,0.,0.,0./
      DATA (TABLE(3,NN),NN=1,6)/15.,10.,15.,0.,0.,0./
      DATA (TABLE(4,NN),NN=1,6)/20.,15.,20.,0.,0.,0./
      DATA (TABLE(5,NN),NN=1,6)/25.,20.,25.,30.,0.,0./
      DATA (TABLE(6,NN),NN=1,6)/30.,25.,30.,35.,0.,0./
      DATA (TABLE(7,NN),NN=1,6)/35.,30.,35.,40.,45.,0./
      DATA (TABLE(8,NN),NN=1,6)/40.,35.,40.,45.,50.,0./
      DATA (TABLE(9,NN),NN=1,6)/50.,40.,45.,50.,60.,0./
      DATA (TABLE(10,NN),NN=1,6)/60.0,50.,60.,70.,80.,0/
      DATA (TABLE(11,NN),NN=1,6)/70.0,60.,70.,80.,90.,0/
      DATA (TABLE(12,NN),NN=1,6)/80.0,70.,80.,90.,100.,0/
      DATA (TABLE(13,NN),NN=1,6)/90.0,80.,90.,100.,110.,120./
      DATA (TABLE(14,NN),NN=1,6)/100.0,90.,100.,110.,120.,130./
      DATA (TABLE(15,NN),NN=1,6)/110.00,100.,110.,120.,130.,140./
      DATA (TABLE(16,NN),NN=1,6)/130.00,120.,130.,140.,150.,160./
      DATA (TABLE(17,NN),NN=1,6)/150.00,120.,140.,160.,180.,200./
      DATA (TABLE(18,NN),NN=1,6)/170.00,140.,160.,180.,200.,220./
      DATA (NNDL(NN),NN=1,18)/1,2,2,2,3,3,4,4,4,4,4,4,5,5,5,5,5,5/
      READ(5,801),NRUN
      DO 600 I=1,NRUN
      READ(5,800),TITLE
      WRITE(6,850),((TITLE(II,JJ),II=1,20),JJ=1,2)
      READ(5,801),IFB,INST
      IF(IFB.EQ.1) WRITE(6,851)
      IF(IFB.EQ.2) WRITE(6,852)
      IF(IFB.EQ.3) WRITE(6,861)
      IF(INST.EQ.1) WRITE(6,853)
      IF(INST.EQ.2) WRITE(6,854)
      TON =3.87
      TOFF =13.3
      IF(IFB.EQ.2) TON =9.68
      IF(IFB.EQ.2) TOFF =33.26
      READ(5,801),NSYS,IFUEL,HHV,QIN,QP,PE,BE,XCO2S
      WRITE(6,855),NSYS,IFUEL,HHV,QIN,QP,PE,BE,XCO2S
      READ(5,801),TSSSX,XCO2F,TFSS,TFON1,TFON2,TFOFF3,TFOFF4,TFOFF5
      WRITE(6,856),TSSSX,XCO2F,TFSS,TFON1,TFON2,TFOFF3,TFOFF4,TFOFF5
      READ(5,801),TRA,QJ,SFR,DF,DS,Y
      CALL SENLOS(IFUEL,NSYS,XCO2S,TSSSX,XCO2F,TFSS,HHVA,AFR,QL,RT,QSSS,
     1EFFYSS,TRA,IFB,SFR)
      WRITE(6,857),TRA,QJ,SFR,DF,DS,Y
      READ(5,801),FLCOST,ELCOST,FK
      WRITE(6,878)
      PF=QP/QIN
      CJ=4.7
      IF(IFB.EQ.1) CJ= 3.3
      IF(INST.EQ.1) CJ=0.0
      WRITE(6,858),PF,HHVA,AFR,QL,CJ,RT,QSSS,EFFYSS
```

```
C
C      *** COLUMNS 31 THROUGH 43 ***
C
       TSSS=(TFSS-TRA )/SFR+TRA
       IF(IFB.EQ.2) GO TO 50
       C1=2.
       C2=0.5
       C3=7.5
       C4=1.5
       GOTO 51
 50    C1=4.5
       C2=1.
       C3=18.75
       C4=3.75
C      *** STATEMENTS 51 AND54 TO 58 ARE FOR VAPORIZING TYPE OIL BURNERS ***
 51    IF(TFSS.EQ.TFON1.AND.TFSS.EQ.TFON2) GO TO 54
       TAON=C1/ALOG((TFSS-TFON1)/(TFSS-TFON2))
       ZETFOX=(TFSS-TFON1)*EXP(C2/TAON)
       GO TO 58
 54    TAON= 0.
       ZETFOX= 0.
 58    CONTINUE
       TAOFF=C3/ALOG((TFOFF3-TFOFF5)/(TFOFF4-TFOFF5))
       SIFOX=(TFOFF3-TFOFF5)*EXP(C4/TAOFF)
       SIFIX=TFOFF5-TRA
       IF(NSYS.GT.8) GO TO60
       IF(NSYS.GT.4.AND.DS.LE.(DF/SFR)) GO TO 61
       DSF=DF/(SFR*DS)
       SISIX=DSF*SIFIX
       SISOX=DSF*SIFOX
       GOTO 65
 61    SISIX=SIFIX
       SISOX=SIFOX
       GOTO 65
 60     SISIX=0.0
       SISOX=0.0
 65    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 70
       IF(NSYS.GT.4) GO TO 71
       CSOFF=DF*CSON*(TFSS+460.+REFTRM-TRA)**1.19/(TFSS-TRA)**0.56
       GOTO 75
 71    CSOFF=DS*SFR*CSON*(TSSS+460.+REFTRM-TRA)**1.19/(TSSS-TRA+REFTRM-RE
      ,FTOA)**0.56
       GOTO 75
 70    CSOFF=DF*CSON*(TFSS+460.+REFTRM-TRA)**1.19/(TFSS-TRA+REFTRM-REFTOA
      ,)**0.56
 75    IF(NSYS.GT.8) GO TO 80
       CION=PHI*SFR*CSON
       CIOFF=DS*CION*(TSSS-TRA+530.)**1.19/(TSSS-TRA+REFTRM-REFTOA)**0.56
       GOTO 85
 80    CION=0.
       CIOFF=0.
 85    WRITE(6,859),TSSS,TAON,ZETFOX,TAOFF,SIFOX,SIFIX,SISIX,SISOX
       WRITE(6,860),CS,CSON,CSOFF,CION,CIOFF
C
C      *** COLUMNS  44 THROUGH 53
```

```
C
      IF((HHV/HHVA).LE.0.95)WRITE(6,871)
      IF((HHV/HHVA).GE.1.05)WRITE(6,872)
      IF(TFSS.EQ.TFON1.AND.TFSS.EQ.TFON2) GO TO 86
      TTON=TON/TAON
      GO TO 88
86    TTON = 10.**20
88    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      ***C1I=.90 AS IN SEC. 4.     IF IID EQUIPPED UNIT ***
      IF(QP.LT.0.1) FFOFF=FFOFF*.90
      IF(NSYS.GT.8) GO TO 91
      ZETFO=FFON*ZETFOX
      SIFO=FFOFF*SIFOX
      SIFI=SIFIX
      SISO=FFOFF*SISOX
      SISI=SISIX
      GOTO 95
91    ZETFO=CS*FFON*ZETFOX
      SIFO =1.22*SIFOX*FFOFF
      SIFI =1.22*SIFIX
      SISO =0.
      SISI =0.0
95    WRITE(6,862),TOA,TON,TOFF,TTON,TTOFF,ZETFO,SIFO,SIFI
C
C      *** COLUMNS 54 THROUGH  59
C
      IF(NSYS.GT.8) GO TO 601
      IF(NSYS.GT.4) GO TO 100
      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
      QSOFF =CSOFF*(F3+SIFI *F4)*TOFF /TON
      QION =CION*(REFTRM-REFTOA)
      QIOFF=CIOFF*(REFTRM-REFTOA)*(F7+SISI*F8)*TOFF/TON
      GOTO 105
100   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
      GOTO 105
601   CONTINUE
      F3 =0.
```

```
      F4 =0.
      F7 =0.
      F8 =0.
      N=6
      CALL FONT4(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.
105   CONTINUE
      IF(INST.EQ.2) GO TO 110
      EFFYU=100.-QL-TON*(QSON+QSOFF+QION+QIOFF)/(TON+PF*TOFF )
      GO TO 120
110   EFFYU=100.-QL-CJ*QJ-TON*(QSON+QSOFF)/(TON+PF*TOFF)
120   WRITE(6,863),SISO,SISI,F3 ,F4 ,F5 ,F6 ,F7 ,F8
      ETAU =EFFYU
      EFFYA=EFFYSS*ETAU*DD/(EFFYSS*DD+2.5*ETAU*PF*(1.+ALPHA)*HR)
      WRITE(6,864),QSON,QSOFF,QION,QIOFF ,ETAU,DD,HR,EFFYA
      A=100000./(341300.*(PE+Y*BE)+(QIN-QP)*ETAU)
       B=0.
      IF(QP.LT.0.1) GO TO 1250
      B=(.00002)*A*QP*ETAU
1250  CONTINUE
      WRITE(6,874),A,B
C
      QOUT =QIN*EFFYSS/ 100.
      IF(INST.EQ.2) QOUT=(QIN*EFFYSS/ 100.)-(3.3*QJ)   QOUT = QIN *(EFYSS-3.3*QJ)/100.
      IQOUT =((QOUT+500.)/1000.)
      IF(IQOUT.LE.10) NN=1
      IF(IQOUT.GT.10.AND.IQOUT.LE.16) NN=2
      IF(IQOUT.GT.16.AND.IQOUT.LE.25) NN=3
      IF(IQOUT.GT.25.AND.IQOUT.LE.34) NN=4
      IF(IQOUT.GT.34.AND.IQOUT.LE.42) NN=5
      IF(IQOUT.GT.42.AND.IQOUT.LE.51) NN=6
      IF(IQOUT.GT.51.AND.IQOUT.LE.59) NN=7
      IF(IQOUT.GT.59.AND.IQOUT.LE.76) NN= 8
      IF(IQOUT.GT.76.AND.IQOUT.LE.93) NN=  9
      IF(IQOUT.GT.93.AND.IQOUT.LE.110) NN= 10
      IF(IQOUT.GT.110.AND.IQOUT.LE.127) NN= 11
      IF(IQOUT.GT.127.AND.IQOUT.LE.144) NN= 12
      IF(IQOUT.GT.144.AND.IQOUT.LE.161) NN= 13
      IF(IQOUT.GT.161.AND.IQOUT.LE.178) NN= 14
      IF(IQOUT.GT.178.AND.IQOUT.LE.195) NN= 15
      IF(IQOUT.GT.195.AND.IQOUT.LE.237) NN= 16
      IF(IQOUT.GT.237.AND.IQOUT.LE.271) NN= 17
      IF(IQOUT.GT.271.AND.IQOUT.LE.305) NN= 18
      IF(IQOUT.GT.305) NN=18
      DHR= TABLE(NN,1)
      BOH =(A*DHR*2080.*.77)-(B*2080.)
      AFUEL=(QIN-QP)* BOH+8760.*QP
      AELEC=(PE+Y*BE)*BOH
      ACOST=AFUEL*FLCOST/FK+AELEC*ELCOST
      WRITE(6,873),EFFYA
      WRITE(6,865),FLCOST,FK,ELCOST,ACOST,BOH
      WRITE(6,881),DHR
C
      NDL= NNDL(NN)
      DL(1)= TABLE(NN,2)
```

```
      DL(2)= TABLE(NN,3)
      DL(3)= TABLE(NN,4)
      DL(4)= TABLE(NN,5)
      DL(5)= TABLE(NN,6)
      WRITE(6,866)
      WRITE(6,867),ELCOST,FK
      HLH=250.
      DO 1200 IHLH=1,5
      HLH=HLH+500.
      DO 1201 IDL=1,NDL
      BOH = (A*DL(IDL)*.77-B)*HLH
      FUEL=(QIN-QP)*BOH+8760.*QP
      ELEC=(PE+Y*BE)*BOH
      DO 1202 ICOST=1,5
      COST(IHLH,IDL,ICOST)=FUEL*(0.15+0.05*ICOST)/FK+ELEC*ELCOST
1202  CONTINUE
      IF(IDL.EQ.1) WRITE(6,868),HLH,DL(IDL),(COST(IHLH,IDL,K),K=1,5)
      IF(IDL.EQ.2) WRITE(6,869),HLH,DL(IDL),(COST(IHLH,IDL,K),K=1,5)
      IF(IDL.NE.1.AND.IDL.NE.2) WRITE(6,870),DL(IDL),(COST(IHLH,IDL,K),K
     ,=1,5)
1201  CONTINUE
1200  CONTINUE
600   CONTINUE
800   FORMAT(20A4)
801   FORMAT()
850   FORMAT(//2(5X,20A4/))
851   FORMAT(/5X'FURNACE')
852   FORMAT(/5X'BOILER')
853   FORMAT(5X'INSTALLED INDOOR')
854   FORMAT(5X'INSTALLED OUTDOOR')
855   FORMAT(///5X'INPUT VALUES '//5X'1)NSYS'4X'2)IFUEL'3X'3)HHV'
     ,5X'4)QIN'5X'5)QP'6X'6)PE'6X'7)BE'6X'8)XCO2S'/I7,I10,6X,8(1PE10.2))
856   FORMAT(/5X'9)TSSS'4X'10)XCO2F'2X'11)TFSS'3X'12)TFON1'2X'13)TFON2'
     ,2X'14)TFOFF3'1X'15)TFOFF4'1X'16)TFOFF5'/3X,8(1PE10.2))
857   FORMAT(/5X'17)TRA'4X'18)QJ'5X'19)S/F'4X'20)DF'5X'21)DS',
     ,4X'22) Y    '/3X,8(1PE10.2))
858   FORMAT(/5X'23)PF'5X'24)HHVA'3X'25)A/F'4X'26)QL'5X'27)CJ'5X,
     ,'28)RT'5X'29)QSSS'3X'30)EFFYSS'/3X,8(1PE10.2))
859   FORMAT(/5X'31)TSSS'3X'32)TAUON'2X'33)ZETFOX'1X'34)TAUOFF',
     ,1X'35)PSIFOX'1X'36)PSIFIX'1X'37)PSISIX'1X'38)PSISOX'/3X,
     ,8(1PE10.2))
860   FORMAT(/5X'39)CS'5X'40)CSON'3X'41)CSOFF'2X'42)CION'3X,
     ,'43)CIOFF'/3X,5(1PE10.2))
861   FORMAT(/5X'VENTED HEATER')
862   FORMAT(/5X'44)TOA'4X'45)TON'4X'46)TOFF'3X'47)TTON'3X'48)TTOFF',
     ,2X'49)ZETFO'2X'50)PSIFO'2X'51)PSIFI'/3X,8(1PE10.2))
863   FORMAT(/5X'52)PSISO'2X'53)PSISI'2X'54)F3'5X'55)F4'5X,
     ,'56)F5'5X'57)F6'5X'58)F7'5X'59)F8'/3X,8(1PE10.2))
864   FORMAT(/5X'60)QSON'3X'61)QSOFF'2X'62)QION'3X'63)QIOFF'2X'64)EFFYU'
     ,2X'65)DD'5X'66)HR'5X'67)EFFYA'/3X,8(1PE10.2))
865   FORMAT(5X'FUEL RATE $'F5.3,'PER 'F10.0,'BTU'/5X,
     ,'ELEC RATE  $'F5.3,'PER KW-HR'/5X,
     ,'AVERAGE ANNUAL OPERATING COST  $'F7.0,/5X,
     ,'AVERAGE ANNUAL BURNER OPERATING HOURS  'F6.0)
866   FORMAT(///5X'REGIONAL ANNUAL OPERATING COST ')
867   FORMAT(//26X'COST OF ELEC $'F5.3,'  PER KW-HR'/5X,
     ,'REGION'5X'DESIGN'4X'COST OF FUEL $ PER 'F10.0,1X,'BTU'/16X,
     ,'KBTU/HR'3X'0.20'2X'0.25'2X'0.30'2X'0.35'2X'0.40')
```

```
868   FORMAT(//I6,F14.0,F10.0,4F6.0)
869   FORMAT(5X'('F5.0,'HLID)'F5.0,F10.0,4F6.0)
870   FORMAT(F20.0,F10.0,4F6.0)
871   FORMAT(///5X'*** WARNING-HEATING VALUE OF TEST FUEL IS TOO'
     ,' LOW ***',///)
872   FORMAT(///5X'** WARNING-HEATING VALUE OF TEST FUEL IS TOO'
     ,' HIGH ***',///)
873   FORMAT(///5X'AVERAGE ANNUAL PERFORMANCE='//5X,
     ,'AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 'F4.1,' PERCENT')
874   FORMAT(/5X'A'10X,'B'/3X,2(1PE10.2))
876   FORMAT(/5X,'**DESIGN HEATING REQ. IS GREATER THAN 305KBTU/HR**')   Delete MEK 1-25-79
878   FORMAT(///5X'CALCULATED VALUES-'/)
881   FORMAT(5X,'LABELED DHR OF MODEL TO BE ',F5.0,'KBTU/HR')
      STOP
      END
END PRT


      FUNT4
      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 150 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
150    FF21=FF23
      IF((ABS(FJ-FI )).LE.0.0000001) GO TO 110
      FJ =(FJ -FI )/(100.*TTOFF )
       FJ =DX *FJ /3.
       GOTO 112
110   FJ =0.
112   FI =FI *DX /(3.*TTOFF )
      RETURN
       END
```

```
SENLOS
      SUBROUTINE SENLOS(IFUEL,NSYS,XCO2S,TSSSX,XCO2F,TFSS,HHVA,AFR,QL,RT
     *,QSSS,EFFYSS,TRA,IFB,SFR)
C      ***CALCULATION  OF HHVA AFR QL RT QSSS EFFYSS *** WITH SFR CHECK ***
C      ***APRIL 1978*** FOR USE WITH NBSFBS 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)
      IF(CALSFR.GT.SFR) 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
```

Figure B-8. Eleven Sample Sets of Test Data

```
NBSFBS5  TEST UNIT,   DATA SET NUMBER  1
OIL FURNACE NSYS=4    IID   BAROMETRIC DRAFT CONTROL


FURNACE
INSTALLED INDOOR


INPUT VALUES

1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
 4          2          1.96+04    7.00+04    0.00       2.20-01    3.70-01    0.00

9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
 0.00       1.45+01    6.50+02    3.50+02    5.08+02    4.18+02    2.00+02    7.40+01

17)TRA     18)QJ      19)S/F     20)DF      21)DS      22) Y
 7.40+01    0.00       1.40+00    4.00-01    8.50-01    1.38+00


CALCULATED VALUES-

23)PF      24)HHVA    25)A/F     26)QL      27)CJ      28)RT      29)QSSS    30)EFFYSS
 0.00       1.95+04    1.45+01    6.50+00    0.00       1.06+00    1.27+01    8.08+01

31)TSSS    32)TAUON   33)ZETFOX  34)TAUOFF  35)PSIFOX  36)PSIFIX  37)PSISIX  38)PSISOX
 4.85+02    2.67+00    3.62+02    7.47+00    4.21+02    0.00       0.00       1.41+02

39)CS      40)CSON    41)CSOFF   42)CION    43)CIOFF
 0.00       2.01-02    9.56-01    1.97-02    1.91+00

44)TOA     45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
 4.20+01    3.87+00    1.33+01    1.45+00    1.78+00    3.23+02    3.29+02    0.00

52)PSISO   53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
 1.10+02    0.00       1.11+00    9.03-03    0.00       0.00       5.84-03    1.90-05

60)QSON    61)QSOFF   62)QION    63)QIOFF   64)EFFYU   65)DD      66)HR      67)EFFYA
 9.26+00    3.65+00    5.50-01    1.07+00    7.90+01    5.20+03    4.60+03    7.90+01

A          B
 1.73-02    0.00


AVERAGE ANNUAL PERFORMANCE=

ERAGE ANNUAL ENERGY USAGE EFFICIENCY, 79.0 PERCEN
L RATE $ .470PER    140000.BTU
```

ELEC RATE $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 255.
AVERAGE ANNUAL BURNER OPERATING HOURS 970.
LABELED DHR OF MODEL TO BE 35.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .038 PER KW-HR / COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	30.	38.	46.	53.	61.	68.
(750.HLH)	35.	45.	53.	62.	71.	83.
	40.	51.	61.	71.	81.	91.
	45.	57.	69.	80.	91.	102.
2	30.	64.	76.	89.	101.	114.
(1250.HLH)	35.	74.	89.	104.	118.	133.
	40.	85.	102.	118.	135.	152.
	45.	96.	115.	133.	152.	171.
3	30.	89.	107.	124.	142.	159.
(1750.HLH)	35.	104.	125.	145.	166.	186.
	40.	119.	143.	166.	189.	212.
	45.	134.	160.	187.	213.	239.
4	30.	115.	137.	160.	182.	205.
(2250.HLH)	35.	134.	160.	187.	213.	239.
	40.	153.	183.	213.	243.	273.
	45.	172.	206.	240.	274.	307.
5	30.	140.	168.	195.	223.	250.
(2750.HLH)	35.	164.	196.	228.	260.	292.
	40.	187.	224.	261.	297.	334.
	45.	211.	252.	293.	334.	376.

NBSFBS5 TEST UNIT, DATA SET NUMBER 2
OIL FURNACE NSYS=8 IID W/VENT DAMPER BAROMETRIC DRAFT CONTROL

FURNACE
INSTALLED INDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
8	2	1.96+04	7.00+04	0.00	2.20-01	3.70-01	0.00

```
9)TSSS    10)XCO2F  11)TFSS   12)TFON1  13)TFON2  14)TFOFF3 15)TFOFF4 16)TFOFF5
 0.00      1.45+01   6.50+02   3.50+02   5.08+02   4.18+02   2.00+02   7.40+01

17)TRA    18)QJ     19)S/F    20)DF     21)DS     22) Y
 7.40+01   0.00      1.40+00   4.00-01   6.00-02   1.38+00
```

CALCULATED VALUES-

```
23)PF     24)HHVA   25)A/F    26)QL     27)CJ     28)RT     29)QSSS   30)EFFYSS
 0.00      1.95+04   1.45+01   6.50+00   0.00      1.06+00   1.27+01   8.08+01

31)TSSS   32)TAUON  33)ZETFOX 34)TAUOFF 35)PSIFOX 36)PSIFIX 37)PSISIX 38)PSISOX
 4.85+02   2.67+00   3.62+02   7.47+00   4.21+02   0.00      0.00      4.21+02

39)CS     40)CSON   41)CSOFF  42)CION   43)CIOFF
 0.00      2.01-02   1.93-01   1.97-02   1.35-01

44)TOA    45)TON    46)TOFF   47)TTON   48)TTOFF  49)ZETFO  50)PSIFO  51)PSIFI
 4.20+01   3.87+00   1.33+01   1.45+00   1.78+00   3.23+02   3.29+02   0.00

52)PSISO  53)PSISI  54)F3     55)F4     56)F5     57)F6     58)F7     59)F8
 3.29+02   0.00      0.00      0.00      1.21+00   9.27-03   7.51-03   8.42-06

60)QSON   61)QSOFF  62)QION   63)QIOFF  64)EFFYU  65)DD     66)HR     67)EFFYA
 9.26+00   8.03-01   5.50-01   9.76-02   8.28+01   5.20+03   4.60+03   8.28+01

A         B
 1.65-02   0.00
```

AVERAGE ANNUAL PERFORMANCE=

```
AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 82.8 PERCENT
FUEL RATE $ .470PER     140000.BTU
ELEC RATE  $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   244.
AVERAGE ANNUAL BURNER OPERATING HOURS    927.
LABELED DHR OF MODEL TO BE   35.KBTU/HR
```

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .038 PER KW-HR COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	30.	37.	44.	51.	58.	65.
(750.HLID)	35.	43.	51.	59.	68.	76.
	40.	49.	58.	68.	77.	87.
	45.	55.	66.	76.	87.	98.

2	30.	61.	73.	85.	97.	109.
(1250.HLH)	35.	71.	85.	99.	113.	127.
	40.	81.	97.	113.	129.	145.
	45.	92.	109.	127.	145.	163.
3	30.	85.	102.	119.	136.	152.
(1750.HLH)	35.	100.	119.	139.	158.	178.
	40.	114.	136.	159.	181.	203.
	45.	128.	153.	178.	203.	228.
4	30.	110.	131.	153.	174.	196.
(2250.HLH)	35.	128.	153.	178.	203.	228.
	40.	146.	175.	204.	232.	261.
	45.	165.	197.	229.	262.	294.
5	30.	134.	161.	187.	213.	239.
(2750.HLH)	35.	157.	187.	218.	249.	279.
	40.	179.	214.	249.	284.	319.
	45.	201.	241.	280.	320.	359.

NBSFBS5 TEST UNIT, DATA SET NUMBER 3
OIL BOILER NSYS=4 IID BAROMETRIC DRAFT

BOILER
INSTALLED INDOOR

INPUT VALUES

1) NSYS	2) IFUEL	3) HHV	4) QIN	5) QP	6) PE	7) BE	8) XCO2S
4	2	1.96+04	2.12+05	0.00	2.75-01	1.30-01	0.00
9) TSSS	10) XCO2F	11) TFSS	12) TFON1	13) TFON2	14) TFOFF3	15) TFOFF4	16) TFOFF5
0.00	1.21+01	5.72+02	4.98+02	5.45+02	3.15+02	1.62+02	1.44+02
17) TRA	18) QJ	19) S/F	20) DF	21) DS	22) Y		
6.80+01	0.00	1.40+00	4.00-01	8.50-01	1.00+00		

CALCULATED VALUES-

23) PF	24) HHVA	25) A/F	26) QL	27) CJ	28) KT	29) QSSS	30) EFFYSS
0.00	1.95+04	1.45+01	6.50+00	0.00	1.25+00	1.28+01	8.07+01
31) TSSS	32) TAUON	33) ZETFOX	34) TAUOFF	35) PSIFOX	36) PSIFIX	37) PSISIX	38) PSISOX
4.28+02	4.46+00	9.26+01	8.33+00	2.68+02	7.60+01	2.55+01	9.02+01
39) CS	40) CSON	41) CSOFF	42) CION	43) CIOFF			

0.00	2.36-02	1.12+00	2.31-02	2.25+00			
44) TOA	45) TON	46) TOFF	47) TTON	48) TTOFF	49) ZETFO	50) PSIFO	51) PSIFI
4.20+01	9.68+00	3.33+01	2.17+00	3.99+00	9.15+01	2.36+02	7.60+01
52) PSISO	53) PSISI	54) F3	55) F4	56) F5	57) F6	58) F7	59) F8
7.92+01	2.55+01	3.50-01	7.88-03	0.00	0.00	4.64-03	2.71-05
60) QSON	61) QSOFF	62) QION	63) QIOFF	64) EFFYU	65) DD	66) HR	67) EFFYA
1.20+01	3.64+00	6.46-01	1.16+00	7.61+01	5.20+03	4.60+03	7.61+01
A	B						
6.15-03	0.00						

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 76.1 PERCENT
FUEL RATE $ .470PER 140000.BTU
ELEC RATE $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 716.
AVERAGE ANNUAL BURNER OPERATING HOURS 984.
LABELED DHR OF MODEL TO BE 100.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .038 PER KW-HR / COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	90.	102.	126.	150.	174.	198.
(750.HLH)	100.	113.	140.	167.	194.	220.
	110.	124.	154.	183.	213.	242.
	120.	136.	168.	200.	232.	265.
	130.	147.	182.	217.	252.	287.
2	90.	169.	210.	250.	290.	331.
(1250.HLH)	100.	188.	233.	278.	323.	367.
	110.	207.	256.	306.	355.	404.
	120.	226.	280.	333.	387.	441.
	130.	245.	303.	361.	419.	478.
3	90.	237.	294.	350.	406.	463.
(1750.HLH)	100.	264.	326.	389.	452.	514.
	110.	290.	359.	428.	497.	566.
	120.	316.	391.	467.	542.	617.
	130.	343.	424.	506.	587.	669.
	90.	305.	377.	450.	523.	595.
50.HLH)	100.	339.	419.	500.	581.	661.

```
           110.     373.  461.  550.  639.  727.
           120.     407.  503.  600.  697.  794.
           130.     440.  545.  650.  755.  860.


5           90.     373.  461.  550.  639.  727.
(2750.HLH) 100.     414.  513.  611.  710.  808.
           110.     456.  564.  672.  781.  889.
           120.     497.  615.  733.  852.  970.
           130.     538.  666.  795.  923. 1051.
```

NBSFBS5 TEST UNIT, DATA SET NUMBER 4
OIL VENTED HEATER NSYS=3 SIMULATED UNIT, ATM. BURNER W/BAROMETRIC DRAFT

VENTED HEATER
INSTALLED INDOOR

INPUT VALUES

```
1)NSYS    2)IFUEL   3)HHV     4)QIN     5)QP      6)PE      7)BE      8)XCO2S
 3         2         1.96+04   7.00+04   0.00      0.00      1.00-01   0.00

9)TSSS    10)XCO2F  11)TFSS   12)TFON1  13)TFON2  14)TFOFF3 15)TFOFF4 16)TFOFF5
 0.00      1.45+01   6.25+02   6.25+02   6.25+02   4.08+02   2.00+02   7.40+01

17)TRA    18)QJ     19)S/F    20)DF     21)DS     22) Y
 7.40+01   0.00      1.40+00   1.00+00   1.00+00   1.38+00
```

CALCULATED VALUES-

```
23)PF     24)HHVA   25)A/F    26)QL     27)CJ     28)RT     29)QSSS   30)EFFYSS
 0.00      1.95+04   1.45+01   6.50+00   0.00      1.06+00   1.21+01   8.14+01

31)TSSS   32)TAUON  33)ZETFOX 34)TAUOFF 35)PSIFOX 36)PSIFIX 37)PSISIX 38)PSISOX
 4.68+02   0.00      0.00      7.69+00   4.06+02   0.00      0.00      2.90+02

39)CS     40)CSON   41)CSOFF  42)CION   43)CIOFF
 0.00      2.01-02   2.38+00   1.97-02   2.25+00

44)TOA    45)TON    46)TOFF   47)TTON   48)TTOFF  49)ZETFO  50)PSIFO  51)PSIFI
 4.20+01   3.87+00   1.33+01   1.00+20   1.73+00   0.00      3.65+02   0.00

52)PSISO  53)PSISI  54)F3     55)F4     56)F5     57)F6     58)F7     59)F8
 2.61+02   0.00      1.29+00   9.12-03   0.00      0.00      7.20-03   1.04-05

60)QSON   61)QSOFF  62)QION   63)QIOFF  64)EFFYU  65)DD     66)HR     67)EFFYA
 1.21+01   1.06+01   5.50-01   1.56+00   6.87+01   5.20+03   4.60+03   6.87+01

A         B
 2.06-02   0.00
```

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 68.7 PERCENT
FUEL RATE $ .470PER 140000.BTU
ELEC RATE $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 277.
AVERAGE ANNUAL BURNER OPERATING HOURS 1155.
LABELED DHR OF MODEL TO BE 35.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .038 PER KW-HR / COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	30.	38.	46.	55.	64.	73.
(750.HLH)	35.	44.	54.	65.	75.	85.
	40.	50.	62.	74.	86.	98.
	45.	56.	70.	83.	96.	110.
2	30.	63.	77.	92.	107.	122.
(1250.HLH)	35.	73.	90.	108.	125.	142.
	40.	83.	103.	123.	143.	163.
	45.	94.	116.	138.	161.	183.
3	30.	88.	108.	129.	150.	171.
(1750.HLH)	35.	102.	127.	151.	175.	199.
	40.	117.	145.	172.	200.	228.
	45.	131.	163.	194.	225.	256.
4	30.	113.	139.	166.	193.	220.
(2250.HLH)	35.	131.	163.	194.	225.	256.
	40.	150.	186.	222.	257.	293.
	45.	169.	209.	249.	289.	330.
5	30.	138.	170.	203.	236.	269.
(2750.HLH)	35.	161.	199.	237.	275.	313.
	40.	184.	227.	271.	314.	358.
	45.	207.	256.	305.	354.	403.

NBSFBS5 TEST UNIT, DATA SET NUMBER 5
GAS FIRED UPFLOW FURNACE,CLAMSHELL HX, PILOT W/DRAFT HOOD NSYS=1

FURNACE
INSTALLED INDOOR

INPUT VALUES

1) NSYS	2) IFUEL	3) HHV	4) QIN	5) QP	6) PE	7) BE	8) XCO2S
1	3	2.18+04	1.27+05	7.06+02	0.00	6.10-01	0.00
9) TSSS	10) XCO2F	11) TFSS	12) TFON1	13) TFON2	14) TFOFF3	15) TFOFF4	16) TFOFF5
0.00	7.30+00	5.12+02	2.98+02	4.49+02	2.81+02	1.41+02	9.80+01
17) TRA	18) QJ	19) S/F	20) DF	21) DS	22) Y		
7.00+01	0.00	2.40+00	1.00+00	1.00+00	1.38+00		

CALCULATED VALUES-

23) PF	24) HHVA	25) A/F	26) QL	27) CJ	28) RT	29) QSSS	30) EFFYSS
5.56-03	2.01+04	1.45+01	9.55+00	0.00	1.59+00	1.38+01	7.66+01
31) TSSS	32) TAUON	33) ZETFOX	34) TAUOFF	35) PSIFOX	36) PSIFIX	37) PSISIX	38) PSISOX
2.54+02	1.64+00	2.91+02	5.18+00	2.44+02	2.80+01	1.17+01	1.02+02
39) CS	40) CSON	41) CSOFF	42) CION	43) CIOFF			
0.00	2.87-02	3.40+00	4.81-02	5.96+00			

** WARNING-HEATING VALUE OF TEST FUEL IS TOO HIGH ***

44) TOA	45) TON	46) TOFF	47) TTON	48) TTOFF	49) ZETFO	50) PSIFO	51) PSIFI
4.20+01	3.87+00	1.33+01	2.37+00	2.57+00	2.78+02	2.29+02	2.80+01
52) PSISO	53) PSISI	54) F3	55) F4	56) F5	57) F6	58) F7	59) F8
9.54+01	1.17+01	5.13-01	8.47-03	0.00	0.00	5.24-03	2.30-05
60) QSON	61) QSOFF	62) QION	63) QIOFF	64) EFFYU	65) DD	66) HR	67) EFFYA
1.08+01	8.76+00	1.35+00	3.16+00	6.69+01	5.20+03	4.60+03	6.57+01
A	B						
1.15-02	1.08-02						

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 65.7 PERCENT
FUEL RATE $ .207PER 100000.BTU
ELEC RATE $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 329.
AVERAGE ANNUAL BURNER OPERATING HOURS 1078.
LABELED DHR OF MODEL TO BE 60.KBTU/HR

REGIONAL ANNUAL OPERATING COST

COST OF ELEC $ .038 PER KW-HR

REGION	DESIGN KBTU/HR	COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1 (750.HLH)	50.	104.	128.	151.	175.	198.
	60.	123.	151.	178.	206.	234.
	70.	142.	174.	205.	237.	269.
	80.	161.	197.	233.	269.	305.
2 (1250.HLH)	50.	165.	202.	239.	276.	314.
	60.	197.	241.	285.	329.	373.
	70.	228.	279.	330.	381.	432.
	80.	259.	317.	375.	433.	491.
3 (1750.HLH)	50.	227.	277.	328.	378.	429.
	60.	270.	331.	391.	452.	512.
	70.	314.	384.	455.	525.	595.
	80.	358.	438.	518.	598.	678.
4 (2250.HLH)	50.	288.	352.	416.	480.	545.
	60.	344.	421.	498.	574.	651.
	70.	401.	490.	579.	668.	758.
	80.	457.	559.	661.	762.	864.
5 (2750.HLH)	50.	349.	427.	505.	582.	660.
	60.	418.	511.	604.	697.	790.
	70.	487.	595.	704.	812.	921.
	80.	556.	680.	803.	927.	1051.

NBSFBS5 TEST UNIT, DATA SET NUMBER 6
GAS FIRED UPFLOW FURNACE, CLAMSHELL HX, IID W/VENT DAMPER

FURNACE
INSTALLED INDOOR

INPUT VALUES

1) NSYS	2) IFUEL	3) HHV	4) QIN	5) QP	6) PE	7) BE	8) XCO2S
5	3	2.18+04	1.27+05	0.00	0.00	6.10-01	0.00
9) TSSS	10) XCO2F	11) TFSS	12) TFON1	13) TFON2	14) TFOFF3	15) TFOFF4	16) TFOFF5
0.00	7.40+00	5.10+02	2.88+02	4.45+02	2.82+02	1.37+02	7.00+01
17) TRA	18) QJ	19) S/F	20) DF	21) DS	22)		
+01	0.00	2.40+00	1.00+00	1.70-01	1 0		

```
CALCULATED VALUES-

23)PF       24)HHVA     25)A/F      26)QL       27)CJ       28)RT       29)QSSS     30)EFFYSS
 0.00        2.01+04     1.45+01     9.55+00     0.00        1.57+00     1.36+01     7.69+01

31)TSSS     32)TAUON    33)ZETFOX 34)TAUOFF 35)PSIFOX 36)PSIFIX 37)PSISIX 38)PSISOX
 2.53+02     1.63+00     3.02+02     6.51+00     2.67+02     0.00        0.00        2.67+02

39)CS       40)CSON     41)CSOFF    42)CION     43)CIOFF
 0.00        2.83-02     1.43+00     4.76-02     1.00+00


** WARNING-HEATING VALUE OF TEST FUEL IS TOO HIGH ***


44)TOA      45)TON      46)TOFF     47)TTON     48)TTOFF    49)ZETFO    50)PSIFO    51)PSIFI
 4.20+01     3.87+00     1.33+01     2.38+00     2.04+00     2.79+02     2.26+02     0.00

52)PSISO    53)PSISI    54)F3       55)F4       56)F5       57)F6       58)F7       59)F8
 2.26+02     0.00        0.00        0.00        6.99-01     9.04-03     6.73-03     1.34-05

60)QSON     61)QSOFF    62)QION     63)QIOFF    64)EFFYU    65)DD       66)HR       67)EFFYA
 1.06+01     3.44+00     1.33+00     6.49-01     7.45+01     5.20+03     4.60+03     7.45+01

A           B
 1.03-02     0.00


AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 74.5 PERCENT
FUEL RATE $ .207PER    100000.BTU
ELEC RATE  $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   291.
AVERAGE ANNUAL BURNER OPERATING HOURS     986.
LABELED DHR OF MODEL TO BE   60.KBTU/HR


REGIONAL ANNUAL OPERATING COST

                        COST OF ELEC $ .038  PER KW-HR
REGION       DESIGN     COST OF FUEL $ PER    100000. BTU
             KBTU/HR    0.20  0.25  0.30  0.35  0.40


1             50.        85.  104.  122.  141.  160.
( 750.HLH)    60.       102.  124.  147.  169.  192.
              70.       119.  145.  171.  198.  224.
```

	80.	136.	166.	196.	226.	256.
2	50.	141.	173.	204.	235.	267.
(1250.HLH)	60.	170.	207.	245.	282.	320.
	70.	198.	242.	286.	329.	373.
	80.	226.	276.	326.	377.	427.
3	50.	198.	242.	286.	329.	373.
(1750.HLH)	60.	237.	290.	343.	395.	448.
	70.	277.	338.	400.	461.	523.
	80.	316.	387.	457.	527.	597.
4	50.	254.	311.	367.	424.	480.
(2250.HLH)	60.	305.	373.	441.	508.	576.
	70.	356.	435.	514.	593.	672.
	80.	407.	497.	587.	678.	768.
5	50.	311.	380.	449.	518.	587.
(2750.HLH)	60.	373.	456.	539.	621.	704.
	70.	435.	532.	628.	725.	821.
	80.	497.	608.	718.	828.	939.

NBSFBS5 TEST UNIT, DATA SET NUMBER 7
GAS FIRED OUT-DOOR FURNACE WITH ATMOSPHERE TYPE BURNER

FURNACE
INSTALLED OUTDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
9	3	2.18+04	1.01+05	7.25+02	0.00	3.89-01	0.00
9)TSSS	10)XCO2F	11)TFSS	12)TFON1	13)TFON2	14)TFOFF3	15)TFOFF4	16)TFOFF5
0.00	9.80+00	6.28+02	3.40+02	4.86+02	3.50+02	1.97+02	1.18+02
17)TRA	18)QJ	19)S/F	20)DF	21)DS	22) Y		
7.00+01	7.70-01	1.00+00	1.00+00	0.00	1.38+00		

CALCULATED VALUES-

23)PF	24)HHVA	25)A/F	26)QL	27)CJ	28)RT	29)QSSS	30)EFFYSS
7.18-03	2.01+04	1.45+01	9.55+00	3.30+00	1.21+00	1.38+01	7.67+01
31)TSSS	32)TAUON	33)ZETFOX	34)TAUOFF	35)PSIFOX	36)PSIFIX	37)PSISIX	38)PSISOX
[illegible].28+02	2.83+00	3.44+02	6.96+00	2.88+02	[illegible]9+01	0.00	0.00

```
  )CS       40)CSON    41)CSOFF   42)CION    43)CIOFF
 1.04+00    2.21-02    2.55+00    0.00       0.00


** WARNING-HEATING VALUE OF TEST FUEL IS TOO HIGH ***



44)TOA      45)TON     46)TOFF    47)TTON    48)TTOFF   49)ZETFO   50)PSIFO   51)PSIFI
 4.20+01    3.87+00    1.33+01    1.37+00    1.91+00    3.32+02    2.95+02    5.86+01

52)PSISO    53)PSISI   54)F3      55)F4      56)F5      57)F6      58)F7      59)F8
 0.00       0.00       0.00       0.00       1.01+00    9.21-03    0.00       0.00

60)QSON     61)QSOFF   62)QION    63)QIOFF   64)EFFYU   65)DD      66)HR      67)EFFYA
 1.03+01    1.36+01    0.00       0.00       6.45+01    5.20+03    4.60+03    6.31+01

A           B
 1.50-02    1.41-02


AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 63.1 PERCENT
FUEL RATE $ .207PER    100000.BTU
ELEC RATE  $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   281.
AVERAGE ANNUAL BURNER OPERATING HOURS    1174.
LABELED DHR OF MODEL TO BE   50.KBTU/HR


REGIONAL ANNUAL OPERATING COST                                WILL CHANGE IF STATEMENT 200 REVISED
                                                                        1-25-79 [illegible]

                     COST OF ELEC $ .038  PER KW-HR
REGION      DESIGN   COST OF FUEL $ PER    100000. BTU
            KBTU/HR  0.20  0.25  0.30  0.35  0.40


1            40.      87.  107.  127.  147.  167.
( 750.HLH)   45.      97.  119.  141.  163.  186.
             50.     106.  131.  155.  179.  204.
             60.     125.  154.  183.  212.  240.


2            40.     137.  168.  199.  231.  262.
(1250.HLH)   45.     153.  188.  222.  257.  292.
             50.     169.  207.  246.  284.  323.
             60.     201.  246.  292.  338.  384.


3            40.     186.  229.  271.  314.  356.
(1750.HLH)   45.     209.  256.  304.  351.  399.
             50.     231.  284.  336.  389.  442.
```

	60.	276.	339.	401.	464.	527.
4	40.	236.	290.	343.	397.	451.
(2250.HLH)	45.	265.	325.	385.	446.	506.
	50.	293.	360.	427.	494.	561.
	60.	351.	431.	511.	591.	670.
5	40.	285.	350.	415.	481.	546.
(2750.HLH)	45.	321.	394.	467.	540.	613.
	50.	356.	437.	518.	599.	680.
	60.	426.	523.	620.	717.	814.

NBSFBS5 TEST UNIT, DATA SET NUMBER 8
OIL FIRED BOILER, INSTALLED INDOOR, DIRECT VENTED, POWER BURNER

BOILER
INSTALLED INDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
10	2	1.95+04	1.70+05	0.00	5.00-01	4.00-01	0.00
9)TSSS	10)XCO2F	11)TFSS	12)TFON1	13)TFON2	14)TFOFF3	15)TFOFF4	16)TFOFF5
0.00	9.80+00	7.40+02	5.55+02	7.35+02	3.20+02	1.10+02	8.80+01
17)TRA	18)QJ	19)S/F	20)DF	21)DS	22) Y		
6.60+01	0.00	1.40+00	4.00-01	0.00	1.00+00		

CALCULATED VALUES-

23)PF	24)HHVA	25)A/F	26)QL	27)CJ	28)RT	29)QSSS	30)EFFYSS
0.00	1.95+04	1.45+01	6.50+00	0.00	1.53+00	2.08+01	7.27+01
31)TSSS	32)TAUON	33)ZETFOX	34)TAUOFF	35)PSIFOX	36)PSIFIX	37)PSISIX	38)PSISOX
5.47+02	1.25+00	4.13+02	7.96+00	3.72+02	2.20+01	0.00	0.00
39)CS	40)CSON	41)CSOFF	42)CION	43)CIOFF			
1.03+00	2.85-02	1.35+00	0.00	0.00			
44)TOA	45)TON	46)TOFF	47)TTON	48)TTOFF	49)ZETFO	50)PSIFO	51)PSIFI
4.20+01	9.68+00	3.33+01	7.77+00	4.18+00	4.22+02	4.08+02	2.68+01
52)PSISO	53)PSISI	54)F3	55)F4	56)F5	57)F6	58)F7	59)F8
0.00	0.00	0.00	0.00	7.42-01	8.54-03	0.00	0.00
60)QSON	61)QSOFF	62)QION	63)QIOFF	64)EFFYU	65)DD	66)HR	67)EFFYA
[illegible]99+01	4.49+00	0.00	0.00	6.91+01	[illegible]0+03	4.60+03	6.91+01

	B
8.29-03	0.00

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 69.1 PERCENT
FUEL RATE $ .470PER 140000.BTU
ELEC RATE $ .038PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 563.
AVERAGE ANNUAL BURNER OPERATING HOURS 930.
LABELED DHR OF MODEL TO BE 70.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .038 PER KW-HR COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	60.	80.	97.	115.	132.	149.
(750.HLH)	70.	93.	113.	134.	154.	174.
	80.	106.	129.	153.	176.	199.
	90.	119.	146.	172.	198.	224.
2	60.	133.	162.	191.	220.	249.
(1250.HLH)	70.	155.	189.	223.	257.	291.
	80.	177.	216.	255.	293.	332.
	90.	199.	243.	286.	330.	374.
3	60.	186.	227.	267.	308.	349.
(1750.HLH)	70.	217.	264.	312.	359.	407.
	80.	248.	302.	356.	411.	465.
	90.	279.	340.	401.	462.	523.
4	60.	239.	291.	344.	396.	448.
(2250.HLH)	70.	279.	340.	401.	462.	523.
	80.	319.	388.	458.	528.	598.
	90.	358.	437.	515.	594.	672.
5	60.	292.	356.	420.	484.	548.
(2750.HLH)	70.	341.	415.	490.	565.	639.
	80.	389.	475.	560.	645.	731.
	90.	438.	534.	630.	726.	822.

NBSFBS5 TEST UNIT, DATA SET NUMBER 9 (OUTPUT EFFYA HIGHER THAN NORMAL.)
OIL FIRED FORCED WARM AIR FURNACE HYPOTHETICAL DIRECT VENT W/STACK DAMPER

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FURNACE
INSTALLED INDOOR


INPUT VALUES

1)NSYS    2)IFUEL   3)HHV     4)QIN     5)QP      6)PE      7)BE      8)XCO2S
12         2         1.95+04   1.16+05   0.00      5.00-01   4.00-01   0.00

9)TSSS    10)XCO2F  11)TFSS   12)TFON1  13)TFON2  14)TFOFF3 15)TFOFF4 16)TFOFF5
 0.00      8.90+00   4.55+02   1.78+02   3.20+02   3.13+02   1.60+02   6.10+01

17)TRA    18)QJ     19)S/F    20)DF     21)DS     22) Y
 6.10+01   0.00      2.40+00   3.50-02   0.00      1.38+00


CALCULATED VALUES-

23)PF     24)HHVA   25)A/F    26)QL     27)CJ     28)RT     29)QSSS   30)EFFYSS
 0.00      1.95+04   1.45+01   6.50+00   0.00      1.68+00   1.30+01   8.05+01

31)TSSS   32)TAUON  33)ZETFOX 34)TAUOFF 35)PSIFOX 36)PSIFIX 37)PSISIX 38)PSISOX
 2.25+02   2.78+00   3.32+02   8.03+00   3.04+02   0.00      0.00      0.00

39)CS     40)CSON   41)CSOFF  42)CION   43)CIOFF
 1.06+00   3.12-02   1.25-01   0.00      0.00

44)TOA    45)TON    46)TOFF   47)TTON   48)TTOFF  49)ZETFO  50)PSIFO  51)PSIFI
 4.20+01   3.87+00   1.33+01   1.39+00   1.66+00   3.09+02   2.72+02   0.00

52)PSISO  53)PSISI  54)F3     55)F4     56)F5     57)F6     58)F7     59)F8
 0.00      0.00      0.00      0.00      1.02+00   9.27-03   0.00      0.00

60)QSON   61)QSOFF  62)QION   63)QIOFF  64)EFFYU  65)DD     66)HR     67)EFFYA
 8.56+00   4.38-01   0.00      0.00      8.45+01   5.20+03   4.60+03   8.45+01

A         B
 9.84-03   0.00


AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 84.5 PERCENT
FUEL RATE $ .470PER     140000.BTU
ELEC RATE  $ .040PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   340.
AVERAGE ANNUAL BURNER OPERATING HOURS     788.
LABELED DHR OF MODEL TO BE    50.KBTU/HR


REGIONAL ANNUAL OPERATING COST
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Note: Hypothetical temperature data
may result in higher than
normal EFFYA.

REGION	DESIGN KBTU/HR	COST OF ELEC $ .040 PER KW-HR COST OF FUEL $ PER 140000. BTU 0.20	0.25	0.30	0.35	0.40
1	40.	47.	57.	66.	75.	85.
(750.HLH)	45.	53.	64.	74.	85.	96.
	50.	59.	71.	83.	94.	106.
	60.	71.	85.	99.	113.	127.
2	40.	79.	94.	110.	126.	142.
(1250.HLH)	45.	89.	106.	124.	142.	159.
	50.	98.	118.	138.	157.	177.
	60.	118.	142.	165.	189.	212.
3	40.	110.	132.	154.	176.	198.
(1750.HLH)	45.	124.	149.	173.	198.	223.
	50.	138.	165.	193.	220.	248.
	60.	165.	198.	231.	264.	297.
4	40.	142.	170.	198.	226.	255.
(2250.HLH)	45.	159.	191.	223.	255.	287.
	50.	177.	212.	248.	283.	318.
	60.	213.	255.	297.	340.	382.
5	40.	173.	208.	242.	277.	311.
(2750.HLH)	45.	195.	234.	273.	311.	350.
	50.	217.	260.	303.	346.	389.
	60.	260.	312.	363.	415.	467.

NBSFBS5 TEST UNIT, DATA SET 10 NOTE 19)S/F INPUT AS 2.48 AND RESET
SPACE HEATER, FREE STANDING, GAS FIRED WITH A DRAFT DIVERTER

VENTED HEATER
INSTALLED INDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
1	3	2.01+04	3.28+04	9.69+02	0.00	0.00	2.60+00
9)TSSS	10)XCO2F	11)TFSS	12)TFON1	13)TFON2	14)TFOFF3	15)TFOFF4	16)TFOFF5
3.76+02	6.70+00	7.66+02	4.24+02	6.01+02	4.75+02	2.08+02	1.27+02
17)TRA	18)QJ	19)S/F	20)DF	21)DS	22) Y		
7.50+01	0.00	3.24+00	1.00+00	1.00+00	1.38+00		

CALCULATED VALUES-

23) PF	24) HHVA	25) A/F	26) QL	27) CJ	28) RT	29) QSSS	30) EFFYSS
2.95-02	2.01+04	1.45+01	9.55+00	0.00	1.73+00	2.36+01	6.68+01
31) TSSS	32) TAUON	33) ZETFOX	34) TAUOFF	35) PSIFOX	36) PSIFIX	37) PSISIX	38) PSISOX
2.88+02	2.74+00	4.10+02	5.14+00	4.66+02	5.20+01	1.60+01	1.44+02
39) CS	40) CSON	41) CSOFF	42) CION	43) CIOFF			
0.00	3.10-02	3.75+00	7.03-02	8.50+00			
44) TOA	45) TON	46) TOFF	47) TTON	48) TTOFF	49) ZETFO	50) PSIFO	51) PSIFI
4.20+01	3.87+00	1.33+01	1.41+00	2.59+00	3.91+02	3.96+02	5.20+01
52) PSISO	53) PSISI	54) F3	55) F4	56) F5	57) F6	58) F7	59) F8
1.22+02	1.60+01	1.02+00	8.80-03	0.00	0.00	5.52-03	2.11-05
60) QSON	61) QSOFF	62) QION	63) QIOFF	64) EFFYU	65) DD	66) HR	67) EFFYA
1.71+01	1.91+01	1.97+00	4.79+00	5.14+01	5.20+03	4.60+03	4.74+01
A	B						
6.11-02	6.09-02						

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 47.4 PERCENT
FUEL RATE $ .220PER 100000.BTU
ELEC RATE $ .040PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 113.
AVERAGE ANNUAL BURNER OPERATING HOURS 1341.
LABELED DHR OF MODEL TO BE 15.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .040 PER KW-HR COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1	10.	37.	46.	55.	64.	73.
(750.HLH)	15.	48.	60.	72.	84.	96.
2	10.	50.	62.	74.	87.	99.
(1250.HLH)	15.	68.	85.	102.	120.	137.
3	10.	63.	78.	94.	110.	125.
(1750.HLH)	15.	89.	111.	133.	155.	178.
4	10.	76.	95.	113.	132.	151.
(225[illegible])	15.	109.	137.	164.	191.	219.

5	10.	89.	111.	133.	155.	177.
(2750.HLH)	15.	130.	162.	195.	227.	260.

NBSFBS5 TEST UNIT, DATA SET 11
FLOOR FURNACE, GAS FIRED, RATED 45 000 BTU/HR

VENTED HEATER
INSTALLED INDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
9	3	2.01+04	4.44+04	1.02+03	0.00	0.00	0.00
9)TSSS	10)XCO2F	11)TFSS	12)TFON1	13)TFON2	14)TFOFF3	15)TFOFF4	16)TFOFF5
0.00	9.20+00	5.63+02	1.35+02	2.19+02	5.04+02	3.29+02	9.70+01
17)TRA	18)QJ	19)S/F	20)DF	21)DS	22) Y		
7.50+01	4.64+00	2.60+00	1.00+00	1.00+00	1.38+00		

CALCULATED VALUES-

23)PF	24)HHVA	25)A/F	26)QL	27)CJ	28)RT	29)QSSS	30)EFFYSS
2.30-02	2.01+04	1.45+01	9.55+00	0.00	1.28+00	1.26+01	7.78+01
31)TSSS	32)TAUON	33)ZETFOX	34)TAUOFF	35)PSIFOX	36)PSIFIX	37)PSISIX	38)PSISOX
2.63+02	9.15+00	4.52+02	1.33+01	4.55+02	2.20+01	0.00	0.00
39)CS	40)CSON	41)CSOFF	42)CION	43)CIOFF			
1.04+00	2.33-02	2.68+00	0.00	0.00			
44)TOA	45)TON	46)TOFF	47)TTON	48)TTOFF	49)ZETFO	50)PSIFO	51)PSIFI
4.20+01	3.87+00	1.33+01	4.23-01	9.97-01	3.92+02	2.63+02	2.68+01
52)PSISO	53)PSISI	54)F3	55)F4	56)F5	57)F6	58)F7	59)F8
0.00	0.00	0.00	0.00	1.32+00	9.43-03	0.00	0.00
60)QSON	61)QSOFF	62)QION	63)QIOFF	64)EFFYU	65)DD	66)HR	67)EFFYA
5.75+00	1.45+01	0.00	0.00	7.17+01	5.20+03	4.60+03	6.64+01
A	B						
3.22-02	4.70-02						

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 66.4 PERCENT
FUEL RATE @ .220PER 100000.BTU

ELEC RATE $ .040PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 133.
AVERAGE ANNUAL BURNER OPERATING HOURS 1190.
LABELED DHR OF MODEL TO BE 25.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .040 PER KW-HR COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1	20.	47.	59.	71.	82.	94.
(750.HLH)	25.	55.	69.	83.	96.	110.
	30.	63.	79.	95.	110.	126.
2	20.	66.	83.	100.	116.	133.
(1250.HLH)	25.	80.	100.	120.	140.	160.
	30.	93.	117.	140.	163.	187.
3	20.	86.	107.	129.	150.	172.
(1750.HLH)	25.	105.	131.	157.	183.	209.
	30.	123.	154.	185.	216.	247.
4	20.	105.	132.	158.	184.	211.
(2250.HLH)	25.	130.	162.	194.	227.	259.
	30.	154.	192.	231.	269.	307.
5	20.	125.	156.	187.	218.	250.
(2750.HLH)	25.	154.	193.	231.	270.	309.
	30.	184.	230.	276.	322.	368.