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Recommended Testing and Calculation Procedures for Estimating the Seasonal Performance of Residential Condensing Furnaces and Boilers

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RECOMMENDED TESTING AND CALCULATION PROCEDURES FOR ESTIMATING THE SEASONAL PERFORMANCE OF RESIDENTIAL CONDENSING FURNACES AND BOILERS

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

ABSTRACT

Procedures are developed for testing and rating the performance of residential central furnaces and boilers of the condensing type. A condensing furnace or boiler is a unit designed to condense part of the water vapor generated by the burning of hydrogen in the fuel and equipped with a means of draining this condensate. The test procedure is similar to one developed by the National Bureau of Standards for the Department of Energy covering non-condensing central heating equipment, except that it requires slightly tighter control of the laboratory temperature, a return water temperature of 120°F (48.9°C) with a 20 degree Fahrenheit (11.1 degree celsius) water temperature rise for hot water boilers, and offers an optional test procedure for condensing units having no off-period losses. The rating procedure provides a method for estimating the steady-state, part-load and annual fuel utilization efficiencies of condensing furnaces and boilers. It accounts for the fact that the latent heat loss for a condensing unit is smaller than for a conventional furnace or boiler, since some of the water vapor generated from burning hydrogen in the fuel is condensed and thereby gives up part of its latent heat to the heat exchanger and jacket.

Key Words: Annual fuel utilization efficiency; annual operating costs; central heating equipment; condensing boilers; condensing furnaces; part-load performance; rating procedure; seasonal efficiency.

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Note: Based largely upon the recommendations in this report, the Department of Energy (DOE) published a "Final Rulemaking Regarding Amendments to Test Procedures for Furnaces" in the Federal Register; Volume 45, No. 157, August 12, 1980, page 53714 through 53728. This DOE rulemaking covers test procedures for condensing furnaces and boilers and is the official legally binding version of the test procedure which manufacturers of the covered products are required to follow.

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1. INTRODUCTION

The test and calculation procedures recommended herein apply to residential central furnaces and boilers of the condensing type. A condensing furnace or boiler is a unit which is designed to condense part of the water vapor generated by the burning of hydrogen in the fuel and is equipped with a means of draining this condensate. For the purposes of this test procedure, a furnace or boiler shall be considered to be of the condensing type if the latent heat loss coefficient C_L, defined in step 68 of the calculation procedure, in section 4.1 is less than 1 when the unit is evaluated in a hypothetical test cycle having a percent on-time of 22.5% and, if the unit is a boiler, the return water temperature is 120°F (48.9°C).

1.1 DESCRIPTION OF RECOMMENDED TEST PROCEDURES

The testing procedure for condensing furnaces and boilers is almost identical to the procedure that has been developed for non-condensing units [1,2]. It consists of a steady-state performance test and cool-down and heat-up tests to determine the flue gas temperature vs. time profiles during the off-and on-periods. It differs from the conventional furnace and boiler test procedure in that it requires control of laboratory temperature between 65°F and 85°F, a return water temperature of 120°F (48.9°C) with a 20 degree Fahrenheit (11.1 degree Celsius) water temperature rise for hot water boilers, and offers an optional test procedure (section 3.7) for condensing units whose design is such that there is absolutely no chance of air flow through the combustion chamber during the off-period. This optional procedure allows a manufacturer to test and rate his unit using only the steady-state test, thereby neglecting the slight gain in performance that his unit is likely to experience during the on-period when operating in a cyclic manner. This effect is not expected to be very large and allowing the manufacturer to eliminate the cool-down and heat-up test greatly simplifies the test and calculation procedures.

The requirements that the boiler be tested with a return water temperature of 120°F (48.9°C) and a water temperature rise of 20 degrees Fahrenheit (11.1 degrees Celsius) should result in an average distribution system water temperature, $\overline{T_{AV}}$, of approximately 130°F (54.4°C). This value was selected using the assumption that the average boiler water temperature used to meet the building load at an outdoor design temperature of 5°F (-15°C) might typically be 190°F (87.8°C) and that the heat transfer from baseboard convectors to the room air was proportional to $(\overline{T_{AV}} - T_A)^{1.5}$, where T_A is the room air temperature [3]. Assuming a typical residential zero-load temperature of 65°F (18.3°C) and continuous water circulation, it can then be shown that an average boiler water temperature of approximately 130°F (54.4°C) would be required to meet the house's heating load at an outdoor temperature of 42°F (5.56°C), which is the average heating season temperature used to rate non-condensing furnaces and boilers in NBSIR 78-1543 [1]. While cyclic operation of the pump will tend to raise the temperature of the water required during the on-period to meet the building load, its exact effect depends on factors outside the control of the boiler manufacture (i.e. the mass of and water content in distribution system, the type of distribution system, the size of the house, etc.) and has been ignored in the present version of this test procedure. The average boiler water temperature rise of 20 degrees Fahrenheit (11.1 degrees Celsius) was selected because it is believed to be typical of temperature rises found in the field and results in uniform heating of a house without the designer of the distribution system having to be concerned about excessive temperature drops throughout the system.

1.2 DESCRIPTION OF RECOMMENDED CALCULATION PROCEDURE FOR DETERMINING THE FUEL UTILIZATION EFFICIENCY AND THE ANNUAL OPERATING COST

Condensing furnaces and boilers are extremely complex heating devices. Their efficiency, as measured by the input/output method, is dependent on the return water (or air) temperature, the temperature and moisture content of the incoming combustion air, and even the barometric pressure. These effects would tend to make it extremely difficult to devise a test and rating procedure which yielded consistent and repeatable results if it were not for the fact that a preliminary test of a pulse combustion, condensing boiler at the National Bureau of Standards tended to show that the flue gas temperature was primarily a function of the return water temperature. Large changes in the temperature and absolute humidity of the incoming combustion air (and also, by implication, the barometric pressure) had an almost negligible effect on the measured flue gas temperature. These findings indicated than an acceptable procedure for rating a condensing boiler/furnace would be to determine its flue gas temperature at a typical return water/air temperature and then to calculate its flue losses assuming dry combustion air having an average (heating season) temperature of 42°F (5.56°C). This assumes that most of these condensing units will be of the direct-vent type which uses outdoor air for combustion, and that this combustion air would typically have a very low water vapor content (be nearly dry). To keep the calculation procedure as close as possible to that given for non-condensing units in section 4.1 of NBSIR 78-1543 and to avoid confusion, it was decided that all condensing furnaces and boilers (including direct exhaust units using indoor combustion air) should be rated as direct-vent devices. This is expected to result in an insignificant error for condensing units using indoor combustion air for the following reasons: the combustion air must be heated up regardless of whether it comes from inside or outside the residence; direct vent and direct exhaust units do not use dilution air for draft control (S/F=1); and condensing furnaces and boilers have very low flue gas temperatures (and thus very low losses).

As a result of the observations and assumptions described above, the calculation procedure for determining the steady-state (η_{SS}) and part-load (η_u) efficiencies of condensing furnaces and boilers is only slightly changed from the procedure specified in section 4.1 of NBSIR 78-1543 for non-condensing units [1]. The major difference is that, for condensing boilers, the steady-state efficiency is the value measured in the steady-state test corrected to a return water temperature of 180°F (82.2°C), and, for condensing furnaces and boilers, a procedure is provided (in steps 68 and 69) to account for the fact that the latent heat loss, $L_{L,A}$, is reduced, since some of the water vapor (generated from the burning of hydrogen in the fuel) is condensed and gives up part of its latent heat to the heat exchanger and jacket. In addition, a procedure is given to calculate η_u using only steady-state operating losses, if the optional test procedure in section 3.7 is employed for a pulse combustion unit whose design is such that there is absolutely no chance of air flow through the unit during the off-period.

As in the case of non-condensing units, the part-load efficiency, η_u, is found for a single cycle having a percent on-time of 22.5% and then corrected for the effect of the pilot light during the non-heating season, if applicable, to arrive at the annual fuel utilization efficiency, $EFFY_A$. The procedure for calculating the annual cost of operation of condensing furnaces and boilers is unchanged from that specified in section 4.2 of NBSIR 78-1543 [1].

2. TEST INSTALLATION AND INSTRUMENTATION

The test requirements for gas and oil-fired condensing furnaces and boilers are, in general, identical to those described in NBSIR 78-1543 for forced air furnaces and hot water boilers, except that:

a) tighter room temperature control is required during the condensing furnace test, and

b) different supply and return water temperatures are employed in testing condensing boilers, and a means must be provided to maintain these water temperatures within strict limits.

2.1 INSTALLATION OF TEST PLENUM, DUCT WORK, AND PIPING

2.1.1 Condensing Furnaces

For gas-fueled condensing furnaces, the plenum and test duct requirements are the same as those specified for gas-fueled, forced-air furnaces in sections 2.1.9 and 2.1.10 of ANSI Standard Z21.47-1973. For oil-fueled condensing furnaces, the plenum and test duct requirements are identical to those specified in section 6.2 of ANSI Standard Z91.1-1972.

2.1.2 Condensing Boilers

Piping requirements are identical to those described in section 2.9 of ANSI Standard Z21.13-1974 for gas-fueled condensing boilers and those described in sections 7.0 and 8.1.1 through 8.1.3 of the Hydronic Institute's Testing and Rating for Cast Iron and Steel Heating Boilers, January 1977 edition, for oil-fueled condensing boilers, except that a means shall be provided to supply 120°F (48.9°C) return water, at a constant rate, to the test boiler during both the steady-state and heat-up tests described below. This will typically, although not necessarily, require the use of a large water tank, an auxiliary boiler, and two pumps.

2.2 FLUE REQURIEMENTS

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. 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 ($°F\text{-}h\text{-}ft^2/Btu$) and an outer layer of aluminum foil. Care should be taken to not block the air intake with insulation, where appropriate.

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 $\pm$ 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 $\pm$ 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 A21.47-1973. 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 $\pm$ 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

The burners on gas- or oil-fueled, condensing furnaces and boilers shall be adjusted to give, during the steady-state performance test described below, the CO_2 reading recommended by the manufacturer (if applicable) and an hourly Btu input rate which is within $\pm$ 2% of the manufacturer's specified nominal hourly Btu input rating (nameplate rating). During the steady-state performance test, the concentration of carbon monoxide present in dry flue gas shall not exceed 0.04 percent by volume. For oil-fired condensing units, the smoke in the flue gases shall not exceed No. 1 smoke during the steady-state performance test as measured by the procedure in ANSI Standard Z11.182 - 1965 (R 1971) (ASTM D2156-65 (1970)). If the carbon monoxide or smoke exceeds these specified limits during the steady-state test, the burner shall be readjusted to give a lower CO_2 reading and all tests shall be started over. Once the burner is properly adjusted, no additional adjustments shall be made to it during the required series of performance tests.

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

2.5 CIRCULATING AIR AND WATER FLOW REQUIREMENTS

2.5.1 Condensing Furnaces

For gas-fueled, condensing furnaces, the external static pressure and air throughout shall be adjusted as specified in sections 2.1.11, 2.1.12 and 2.1.13 of ANSI Standard Z21.47-1973, except that the temperature rise during the steady-state test described below shall be the maximum temperature rise specified by the manufacturer.

For oil-fueled, condensing furnaces, the external static pressure and air throughput shall be adjusted as specified in Table 5 and section 6.2 of ANSI Standard Z91.1-1972, except that the temperature rise during the steady-state test described below shall be the maximum temperature rise specified by the manufacturer.

During the steady-state and heat-up tests described below, the return air temperature to the gas-or oil-fueled, condensing furnace shall remain within ± 5 degrees Fahrenheit (± 2.8 degrees Celsius) of the value of the room temperatures, T_{RA} measured during the steady-state performance test.

2.5.2 Condensing Boilers

The water flow rate through the condensing boiler shall be adjusted to produce a water temperature rise, during the steady-state test described below, which is between 19.5 and 20.5 degrees Fahrenheit (10.8 and 11.4 degrees Celsius). During the steady-state test and the heat-up test, the condensing boiler shall be supplied with return water having a temperature of 120°F (48.9°C). The maximum permissible variation of the return water temperature from the required value, during the steady-state and heat-up tests, shall not exceed plus or minus 2 degrees Fahrenheit (1.1 degrees Celsius), except during the first 30 seconds after start up it shall not exceed plus or minus 10 degrees Fahrenheit (5.56 degrees Celsius) and between 30 and 60 seconds after start up it shall not exceed plus or minus 5 degrees Fahrenheit (2.78 degrees Celsius).

2.6 LOCATION OF TEMPERATURE MEASURING INSTRUMENTATION

A grid of thermocouples shall be installed in a test plane parallel to and located within 12 inches (30.5 cm) of the furnace or boiler outlet. The grid shall consist of either 9 or 17 thermocouples (manufacturer's option) if the nominal inside diameter of the flue pipe is greater than 2 inches (5.1 cm) and 5 thermocouples if the nominal inside diameter of the flue pipe is less than or equal to 2 inches (5.1 cm). The thermocouples making up the grid shall be wired in parallel and the length of all thermocouple leads shall be equal before paralleling. Locate one thermocouple in the center of the vent pipe and eight (sixteen) [four] thermocouples along imaginary lines intersecting at right (45 degree) [right] angles in this test plane at points 1/3 and 2/3 (1/3 and 2/3) [half] the distance between the center of the flue pipe and the pipe wall.

Bead-type thermocouples shall be used 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, radiation shields shall be installed on the fire-side of the thermocouples only and the shields positioned so that they do not touch the thermocouple junctions.

The location 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 location in the center of the plane of each inlet air opening.

The inlet and outlet water temperatures on both gas-fueled and oil-fueled hot water boilers shall be measured using sheathed thermocouples inserted through pipe plugs that are located within 12 inches (30.5 cm) of the inlet and outlet of the boiler. A minimum of 6 inches (15.3 cm) of thermocouple lead, immediately upstream of the thermocouple junction, shall be immersed in the water between the pipe plug and the boiler inlet/outlet. The remainder of the thermocouple lead shall be run along the surface of the pipe (and under any insulation) for a distance of not less than 3 feet (183 cm). The three feet of pipe immediately before the boiler inlet and the three feet immediately after the boiler outlet 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.

2.7 COMBUSTION MEASUREMENT INSTRUMENTATION

The flue gases for condensing furnaces and boilers shall be analyzed to determine the concentration by volume of carbon dioxide (CO_2) present in the dry flue gas, with instrumentation which will result in a determination of the CO_2 concentration with an error no larger than $\pm$ 0.1 percentage points.

2.8 ENERGY FLOW INSTRUMENTATION

Install one or more instruments which measure the quantity of electrical energy and gas or fuel oil supplied to the furnace or boiler during the steady-state and heat-up tests with an error no larger 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 laboratory room temperature shall remain within $\pm$ 5 degrees Fahrenheit ($\pm$ 2.8 degrees Celsius) of the value T_{RA} measured during the steady-state performance test. At no time during these tests shall the room temperature exceed 85°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 OF AIR THROUGH THE FURNACE OR BOILER DURING THE OFF-PERIOD

The tracer gas chosen for this task should have a density which is less than or approximately equal to the density or air. It shall be of different chemical species or significantly larger 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 MEASUREMENT

3.1 STEADY-STATE TESTING

The furnace or boiler shall be set up as specified in sections 2.1, 2.2, 2.3 and 2.6. Begin the test by operating the burner and circulating air blower or water pump, with the adjustments specified in 2.4 and 2.5, until steady-state conditions are obtained, as indicated by a temperature variation in three successive readings taken 15 minutes apart of not more than 1 degree Fahrenheit (0.56 degrees Celsius) in the flue gas temperature and the supply (outlet) water temperature, for hot water boilers.

Measure the room temperature (T_{RA}) as described in section 2.9, and measure the steady-state flue gas temperature ($T_{F,SS}$) using the thermocouple grid described in section 2.6. A sample of the flue gas shall be secured in the plane of temperature measurement or within 3 1/2 feet (107 cm) of this plane on the downstream side and analyzed to determine the concentration by volume of CO_2 ($X_{CO_2,F}$) present in the dry flue gas. If the location of sampling the CO_2 differs from the temperature measurement plane, care should be taken to assure that there are no air leaks in the flue pipe between these two locations.

The steady-state heat input rate (Q_{in}), including pilot light gas input if appropriate, shall be determined by multiplying the measured higher heating value of the test fuel by the measured steady-state input rate. If gas is the fuel used, correct the input rate to standard conditions of 60°F (15.6°C) and 30 inches of mercury (762 mm of measuring) using measured values of gas temperature and pressure at the meter and the measured barometric pressure.

Measure the steady-state electric power to the burner (PE), if appropriate. 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.

Record all measured values.

3.2 COOL-DOWN TEST

3.2.1 Gas-and Oil-Fueled Condensing Furnaces

After steady-state testing is completed and all required measurements made, the burner shall be turned off and the flue gas temperature measured, ($T_{f,off}$) by means of the thermocouple grid described in 2.6, at 1.5 minutes (t_3) and 9.0 minutes (t_4) after the burner shuts off. Units employing flue dampers or a stack damper in conjunction with a barometric damper shall have their flue or stack dampers closed 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 1.5 minutes or until the supply air temperature drops to a value of 40 degrees Fahrenheit (22.2 degrees Celsius) above the inlet air temperature, whichever results in the longer blower on-time. An exception to this is that if the furnace employs a single motor drive a power burner and an indoor air circulating blower, the blower and the burner shall be shut off together. If the blower delay time exceeds 1.5 minutes, the time between burner shut-off and blower shut-off shall be measured using a stop watch and the quantity t^+ shall be set equal to this measured delay time or 13.30 minutes, whichever is smaller. For units equipped with a continuously burning pilot light, 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 0.5 degrees Fahrenheit (0.28 degrees Celsius) in three sucessive readings taken 15 minutes apart, and then a third flue gas temperature measurement shall be made to determine the off-period minimum flue gas temperature ($T_{F,off}(\infty)$). For units not equipped with a continuously operating pilot light, $T_{F,off}(\infty)$ shall be set equal to the measured room temperature T_{RA} and the unit shall remain off for a minimum time period of 20 minutes.

During the cool-down test, the energy input rate to the pilot light (Q_P), if the unit is so equipped, shall be measured to within an accuracy of $\pm$ 3%. Record all measured values.

3.2.2 Gas- and Oil-Fueled Condensing Boilers

After steady-state testing is completed, the main burner(s) shall be turned off and the flue gas temperature, $T_{F,off}$ measured at 3.75 (t_3) and 22.5 (t_4) minutes after the burner(s) shuts off, using the thermocouple grid described in section 2.6. During this off-period, no water shall be allowed to circulate through the boiler. A third flue gas temperature shall be made 45 minutes after the burner(s) 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%. For units equipped with flue dampers, the damper shall be closed during the cool-down test. Record all measured values.

3.3 HEAT-UP TEST

3.3.1 Gas- and Oil-Fueled Condensing Furnaces

After the cool-down test is completed, the furnace shall be turned on and the flue gas temperature measured, ($T_{f,on}$) using the thermocouple grid described in section 2.6, at 0.5 (t_1) and 2.5 (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 that, 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 values.

3.3.2 Gas- and Oil-Fueled Condensing Boilers

Fifty minutes after the main burner(s) is turned off for the cool-down test, the condensing boiler shall be turned on and the flue gas temperature measured, ($T_{f,on}$) using the thermocouple grid described in section 2.6 at 1.0 minute (t_1)

and 5.5 minutes (t_2) after the main burner comes on. The pump circulating the water through the boiler shall be started simultaneously with the main burner(s), the water flow rate shall be the same as that maintained during the steady state test described in 3.1, and the return water temperature shall be within the limits specified in section 2.5.2.

3.4 JACKET LOSS MEASUREMENT

A jacket loss test is specified only for units intended to be installed out of doors. 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) Gas-fueled forced-air condensing furnaces - ANSI Z21.47-1973, section 2.9.1 and Appendix F.

(b) Gas- or oil-fueled hot water condensing boilers - ANSI Z21.47-1973, section 2.9.1 and Appendix F.

(c) Oil-fueled forced-air condensing 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), on 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 AND D_F

On furnaces or boilers where design is such that there is absolutely no chance of air flow through the combustion chamber and heat exchanger when the unit is off, D_F and D_P may be set equal to 0.0.

For other units using pulse combustion or power burners, the values of D_F and D_P may be obtained as described below. On 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 1°F (0.56°C) in the flue gas temperature and 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 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 thatn $\pm$ 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 (T_T) of the tracer gas entering the flow meter 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 section 4.4.

3.7 OPTIONAL PROCEDURES FOR CONDENSING FURNACES AND BOILERS WHICH HAVE NO OFF-PERIOD FLUE LOSSES

At the discretion of the manufacturer, the cool-down and heat-up tests specified in 3.2 and 3.3 may be omitted on condensing units whose design is such that there is absolutely no chance of air flow through the combustion chamber and heat exchanger when the burner(s) is off. This type of unit has no off-period heat losses up the flue and the above option (in conjunction with the calculation procedure in section 4.1) allows the manufacturer to give up the slight gain in efficiency that his unit would typically experience during the on-period (due to a lower average, on-period, flue gas temperature) and use the efficiency achieved during the steady state test described in 3.1 in place of the part-load efficiency η_u.

4. CALCULATION OF DERIVED RESULTS FROM TEST MEASUREMENTS

4.1 RECOMMENDED PROCEDURE FOR CALCULATING THE ANNUAL FUEL UTILIZATION EFFICIENCY FOR CONDENSING FURNACES AND BOILERS

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

- Collecting measured quantities from the tests and the assignment of characterisitc constants associated with the system under evaluation.

- Calculation of losses (i.e., latent heat loss, $L_{L,A}$, on-cycle sensible heat loss, $L_{S,on}$, and off-cycle sensible heat loss, $L_{S,off}$) and the annual fuel utilization efficiency, $EFFY_A$.

The calculation procedure involves carrying out each of the following numbered steps and entering the result, in the column having the same number, on the worksheet given in Figure 10 of NBSIR 78-1543 [1]. In order to facilitate a comparison with the calculation procedure for non-condensing furnaces and boilers, these steps are presented, whenever possible, as modifications to the corresponding steps in section 4 of NBSIR 78-1543 [1]. The list of nomenclature, section 4, the figures, and the tables from NBSIR 78-1543 [1] are reproduced in Appendix A for the benefit of those readers who do not have a copy of [1].

Numbered Steps and Columns in Figure 10 of NBSIR 78-1543 (Refer to Appendix A):

1. Select the appropriate system number SYS# from Table 2 of NBSIR 78-1543. This table shall apply to both direct vent and direct exhaust, condensing units.

2-7. Same as steps 2 through 7 in 4.1 of NBSIR 78-1543.

8-9. Enter 0.0.

10,11. Same as steps 10 and 11 in 4.1 of NBSIR 78-1543.

12-16. Same as steps 12 through 16 in 4.1 of NBSIR 78-1543 except enter 0.0 if optional procedure described in section 3.7 is employed.

17-18. Same as steps 17 and 18 in 4.1 of NBSIR 78-1543.

19. Enter S/F = 1.0.

20. Enter the off-period flue gas factor, D_F, selected from Table 2 of NBSIR 78-1543 for SYS# (column 1) under consideration or obtained in accordance with section 3.6.

21. Enter $D_S = D_F$ (col. 20) in column 21.

22-28. Same as steps 22 through 28 in 4.1 of NBSIR 78-1543.

29. Using the value of $R_{T,F}$ (column 28) and $\Delta T_{F,SS} = [T_{F,SS}(\text{column } 11) - T_{RA}(\text{column } 17)]$ read from Figure 2 of NBSIR 78-1543 the average sensible heat loss during the steady-state test, $L_{S,SS,A}$, and enter in column 29.

30. Calculate and enter the steady-state efficiency (excluding jacket losses and corresponding to a return water temperature of 180°F (82.2°C) for boilers) using:

$$\eta_{SS} = 100 - C_L' \; L_{L,A}(\text{col. } 26) - L_{S,SS,A}(\text{col. } 29) - L_C', \text{ for furnaces}$$

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

$$- \frac{(100)(.24)(180 - 120)\ (1 + (R_{T,F}(\text{col. } 28))(A/F(\text{col. } 25)))}{HHV_A(\text{col. } 24)}, \text{ for boilers}$$

where C_L' and L_c' are found in steps 68 and 69 respectively, and, if the optional procedure described in section 3.7 was employed, proceed directly to step 64 skipping all intermediate steps. If optional procedure in section 3.7 is not employed, continue with step 31.

31-38. Same as steps 31 through 38 in 4.1 of NBSIR 78-1543.

39. Enter $C_S = \dfrac{T_{F,SS}(\text{col. } 11) - 42}{T_{F,SS}(\text{col. } 11) - 70}$ in column 39

40-48. Same as steps 40 through 48 in 4.1 of NBSIR 78-1543.

49. Calculate and enter: $\theta_{F,O} = C_{t,on} \times \theta_{F,O,X}(\text{col. } 33)$ using the definition of $C_{t,on}$ in step 49 of 4.1, NBSIR 78-1543.

50-63. Same as steps 50 through 63 in 4.1 of NBSIR 78-1543.

64. If optional procedure described in 3.7 was employed, calculate and enter:

$$\eta_u = 100 - C_L\, L_{L,A}(\text{col. } 26) - L_C - C_J(\text{col. } 27) L_J(\text{col. } 18)$$

$$- \frac{t_{on}(\text{col. } 45)}{t_{on}(\text{col. } 45) + PF\ (\text{col. } 23)\ t_{off}(\text{col. } 46)} \times C_s(\text{col. } 39)$$

$$\times L_{S,SS,A}(\text{col. } 29)$$

where C_L is found using the procedure described in step 68, L_C is found in step 69

and $C_S = \dfrac{T_{F,SS}(\text{col. } 11) - 42}{T_{F,SS}(\text{col. } 11) - 70}$.

If optional procedure described in 3.7 was NOT employed, calculate and enter:

$$\eta_u = 100 - C_L\, L_{L,A}(\text{col. } 26) - L_c - C_J(\text{col. } 27) \times L_J(\text{col. } 18)$$

$$- \frac{t_{on}(\text{col. } 45)}{t_{on}(\text{col. } 45) + PF\ (\text{col. } 23)\ t_{off}(\text{col. } 46)} \times [L_{S,on}(\text{col. } 60)$$

$$+ L_{S,off}(\text{col. } 61)],$$

where C_L is found using the procedure described in step 68 and L_C is found in step 69.

65-67. Same as steps 65 through 67 in 4.1 of NBSIR 78-1543.

68. Calculate and enter the latent heat loss coefficient, C_L, using the following four-step procedure:

(a) Calculate what the partial pressure, p_V, of water vapor would be in the flue gases if there were no condensation and the atmospheric pressure was equal to 14.7 psia:

$$p_V = \frac{m_V}{m_{FG}} \times \frac{M_{FG}}{M_V} \times (14.7)$$

where $m_V = \dfrac{HHV_A(\text{col. } 24) \times L_{L,A}(\text{col. } 26)}{(100) \times (1053.3)}$ is the weight of water vapor

generated per unit weight of fuel burnt.

$m_{FG} = 1 + A/F(\text{col. } 25) \times R_{T,F}(\text{col. } 28)$ is the weight of flue gases generated per unit weight of fuel burnt.

$M_V = 18$ is the approximate molecular weight of water

$$M_{FG} = \begin{cases} 29.0 & \text{No. 1 and No. 2 fuel oil} \\ 28.0 & \text{natural gas} \\ 27.5 & \text{manufactured gas} \\ 28.5 & \text{butane and propane} \end{cases}$$ are the approximate apparent molecular weights of flue gases for different fuels.

1053.3 is the assumed latent heat/lb of water.

(b) Calculate the average flue gas temperature, $\overline{T_{F,on}}$, during the on-period using:

$$\overline{T_{F,on}} = T_{F,SS}(\text{col. } 11) + \frac{\theta_{F,0}(\text{col. } 49)\left(e^{-\left(\frac{t_{on}}{\tau_{on}}\right)(\text{col. } 47)} - 1\right)}{\left(\frac{t_{on}}{\tau_{on}}\right)(\text{col } 47)},$$

if the optional procedure described in 3.7 was NOT employed.

Use $\overline{T_{F,on}} = T_{F,SS}$ (col. 11), if optional procedure described in 3.7 was employed.

(c) From Table 1 find the saturated vapor pressure, $p_v{}^s$, at temperature $\overline{T_{F,on}}$ and the saturated vapor pressure $Pv^{s'}$ at $T_{F,ss}$.

(d) If $p_v < p_v{}^s$, $C_L = 1$ and the unit does not meet the definition given in the Introduction for a condensing furnace or boiler and the furnace or boiler should be re-tested using the procedures specified in NBSIR 78-1543. If $Pv < Pv^{s'}$, $C_L' = 1$.

If $p_v \geq p_v{}^s$, calculate the latent heat loss coefficient, C_L, using:

$$C_L = \left(\frac{p_v{}^s}{p_v}\right)\left(\frac{14.7 - p_v}{14.7 - p_v{}^s}\right)$$

If $Pv \geq Pv^{s'}$, calculate the latent heat loss coefficient, C_L', using:

$$C_L' = \left(\frac{Pv^{s'}}{Pv}\right)\left(\frac{14.7 - Pv}{14.7 - p_v^{s'}}\right)$$

69. Calculate the loss L_C and L_C', in percent, due to hot condensate going down the drain and correct for the fact that this condensate did not go up the flue as heated vapor (as was assumed in determining $L_{S,SS,A}$).

$$L_C = \frac{L_{L,A}(\text{col. } 26)(1 - C_L(\text{col. } 68\text{d}))}{1053.3} \times$$

$$(1.0\ (T_{F,SS}(\text{col. } 11) - 70) - 0.45\ (T_{F,SS}(\text{col. } 11) - 42))$$

$$L_C' = \frac{L_{L,A}\ (\text{col. } 26)(1 - C_L'\ (\text{col. } 68\text{d}))}{1053.3} \times$$

$$(1.0(T_{F,ss}(\text{col.}11) - 70) - 0.45\ (T_{F,SS}\ (\text{col. } 11)-42))$$

4.2 RECOMMENDED PROCEDURES FOR CALCULATING THE ANNUAL COST OF OPERATION OF A CONDENSING FURNACE OR BOILER LOCATED IN DIFFERENT CLIMATIC REGIONS OF THE COUNTRY AND IN BUILDINGS WITH DIFFERENT DESIGN HEATING REQUIREMENTS

These procedures are the same as those in section 4.2 of NBSIR 78-1543.

4.3 ADDITIONAL CALCULATIONS FOR CONDENSING FURNACES OR BOILERS UTILIZING AUTOMATIC FLUE DAMPERS

These calculations are identical to those given in section 4.3 of NBSIR 78-1543.

4.4 ADDITIONAL CALCULATION PROCEDURES FOR FURNACES OR BOILERS EQUIPPED WITH POWER BURNERS

These procedures are the same as the procedures given in section 4.4 of NBSIR 78-1543.

REFERENCES

1. Kelly, G. E., CHI, J., and Kuklewicz, M. E., "Recommended Testing and Calculation Procedures for Determining the Seasonal Performance of Residential Central Furnaces and Boilers," NBSIR 78-1543, October 1978.

2. Department of Energy, "Test Procedure for Furnaces and Vented House Heating Equipment," Federal Register, Vol. 43, No. 91, Wednesday, May 10, 1978, pages 20108 through 20205.

3. American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Handbook and Product Directory - 1979 Equipment Volume, New York, New York, 1979, page 284.

Table 1. Saturated Vapor Pressure of Water at Different Temperatures

Temp. (°F)	Pressure (psia)
700.0	3094.3
600.0	1543.2
500.0	680.86
400.0	247.26
300.0	67.005
200.0	11.526
180.0	7.5110
179.0	7.3460
178.0	7.1840
177.0	7.0250
176.0	6.8690
175.0	6.7159
174.0	6.5656
173.0	6.4182
172.0	6.2736
171.0	6.1318
170.0	5.9926
169.0	5.8562
168.0	5.7223
167.0	5.5911
166.0	5.4623
165.0	5.3361
164.0	5.2124
163.0	5.0911
162.0	4.9722
161.0	4.8556
160.0	4.7414
159.0	4.6294
158.0	4.5197
157.0	4.4122
156.0	4.3068
155.0	4.2036
154.0	4.1025
153.0	4.0035
152.0	3.9065
151.0	3.8114
150.0	3.7184
149.0	3.6273
148.0	3.5381
147.0	3.4508
146.0	3.3653
145.0	3.2816
144.0	3.1997
143.0	3.1195
142.0	3.0411
141.0	2.9642

Temp. (°F)	Pressure (psia)
140.0	2.8892
139.0	2.8157
138.0	2.7438
137.0	2.6735
136.0	2.6047
135.0	2.5375
134.0	2.4717
133.0	2.4074
132.0	2.3445
131.0	2.2830
130.0	2.2230
129.0	2.1642
128.0	2.1068
127.0	2.0507
126.0	1.9959
125.0	1.9424
124.0	1.8901
123.0	1.8390
122.0	1.7891
121.0	1.7403
120.0	1.6927
119.0	1.6463
118.0	1.6009
117.0	1.5566
116.0	1.5133
115.0	1.4711
114.0	1.4299
113.0	1.3898
112.0	1.3505
111.0	1.3123
110.0	1.2750
109.0	1.2385
108.0	1.2030
107.0	1.1684
106.0	1.1347
105.0	1.10174
104.0	1.06965
103.0	1.03838
102.0	1.00789
101.0	0.97818
100.0	0.94924
99.0	0.92103
98.0	0.89356
97.0	0.86679
96.0	0.84072

Table 1. Saturated Vapor Pressure of Water at Different Temperatures (con't)

Temp. (°F)	Pressure (psia)
95.0	0.81534
94.0	0.79062
93.0	0.76655
92.0	0.74313
91.0	0.72032
90.0	0.69813
89.0	0.67653
88.0	0.65551
87.0	0.63507
86.0	0.61518
85.0	0.59583
84.0	0.57702
83.0	0.55872
82.0	0.54093
81.0	0.52364
80.0	0.50683
79.0	0.49049
78.0	0.47461
77.0	0.45919
76.0	0.44420
75.0	0.42964
74.0	0.41550
73.0	0.40177
72.0	0.38844
71.0	0.37549
70.0	0.36292
69.0	0.35073
68.0	0.33889
67.0	0.32740
66.0	0.31626
65.0	0.30545
64.0	0.29497
63.0	0.28480
62.0	0.27494
61.0	0.26538

APPENDIX A. CALCULATION PROCEDURE FOR NON-CONDENSING FURNACES AND BOILERS

In order to assist readers who do not have a copy of NBSIR 78-1543 [1], the following items from [1] are reproduced in this appendix: the list of nomenclature, section 4 (which gives the calculation procedure for non-condensing furnaces and boilers), Tables 1 through 5, and Figures 1 through 10.

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 square inches
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	ratio of Q_P to Q_{IN}, Q_P/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 minutes

t_{OFF}	off-time per cycle, in minutes
t_{ON}	on-time per cycle, in minutes
t_1, t_2, t_3, t_4	different times at which flue and/or stack gas temeprature are measured, in minutes
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 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 minutes
τ_{OFF}	cool-down time constant defined in step 34 of section 4.2, in minutes
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

4. CALCULATION OF DERIVED RESULTS FROM TEST MEASUREMENT (FOR NON-CONDENSING FURNACES AND BOILERS)

The test procedures for furnaces and boilers were 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 in 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-

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* i.e., sections 2 and 3 of NBSIR78-1543 [1].

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 temperature 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 temperture.

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 $1 + \left(\frac{t^+ - t^-}{3.87}\right)$ 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 fuel (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 $0.95 \leq \frac{HHV \text{ (col. 3)}}{HHV_A \text{ (col. 24)}} \leq 1.05$.

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 $X_{CO2,F}$ (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

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

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:

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

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)(col. 19) x D_S(col. 21) > D_F(col. 20), calculate and enter in column 37:

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

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 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:

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

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:

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

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

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

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:

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

$$\times D_F(\text{col. } 20) \times K_{S,ON}(\text{col. } 40)$$

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

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

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

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

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

$$\times K_{S,ON}(\text{col. } 40)$$

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

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

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:

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

$$\times D_S(\text{col. } 21)$$

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}(col. 45)/τ_{ON}(col. 32) and t_{OFF}(col. 46)/τ_{OFF}(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:

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

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

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

where $C_S' = 1.22$

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

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

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

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

    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: $F4[\psi_{F,O}(\text{col. }50), (t_{OFF}/\tau_{OFF})(\text{col. }48)]$.

    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: $F5[\psi_{S,O}(\text{col. }52), (t_{OFF}/\tau_{OFF})(\text{col. }48)]$.

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

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: $F6[\psi_{S,O}(\text{col. }52), (t_{OFF}/\tau_{OFF})(\text{col. }48)]$.

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

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

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

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

$$L_{S,ON} = C_S(\text{col. } 39) \times L_{S,SS,A}(\text{col. } 29) - K_{S,ON}(\text{col. } 40) \times \theta_{F,O}(\text{col. } 49) \times \frac{1}{(t_{ON}/\tau_{ON})(\text{col. } 47)} \times \left(1 - e^{-\frac{t_{ON}}{\tau_{ON}}(\text{col. } 47)}\right).$$

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

$$L_{S,OFF} = K_{S,OFF}(\text{col. } 41) \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}(\text{col. } 45)} \times [\text{F3 (col. } 54) + \psi_{F,\infty}(\text{col. } 51) \times \text{F4 (col. } 55)].$$

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

$$L_{S,OFF} = K_{S,OFF}(\text{col. } 41) \times \frac{t_{OFF}(\text{col. } 46)}{t_{ON}(\text{col. } 45)} \times [\text{F5 (col. } 56) + \psi_{S,\infty}(\text{col. } 53) \times \text{F6 (col. } 57)].$$

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:

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

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

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)

$$\eta_u = 100 - L_{L,A}(\text{col. }26) - C_J(\text{col. }27) \times L_J(\text{col. }18)$$

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

$$+ L_{S,OFF}(\text{col. }61)].$$

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:

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

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:

Burner Operating Hours = A (HLH) (C) (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. 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:

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

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

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

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

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

Annual Electricity Consumption = (PE + yBE)(Burner Operating Hours)

Step 3. The annual cost of operation is then:

Annual Cost of Operation = (Annual Fuel Consumption)$(\frac{1}{K})$($ per unit of fuel)

+ (Annual Electricity Consumption)($ 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:

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

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

and C ≡ 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 $Q_{OUT} \equiv \frac{(E_{IN})(3.413)}{100}$ x $(100 - 3.3\ L_J)$ 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 user 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:

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

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:

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

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

$\dot{V}_T$ = 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:

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

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:

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

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	$(D_o)(D_p')$

$$\text{where } D_P' = \begin{cases} 0.4, & D_o \leq \dfrac{1}{(S/F)} \\[2ex] 0.4 + \dfrac{(0.85 - (0.40)(D_o))\left(D_o - \dfrac{1}{(S/F)}\right)}{D_o\left(1 - \dfrac{1}{(S/F)}\right)}, & D_o > \dfrac{1}{(S/F)} \end{cases}$$

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 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/F
	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}	$-7.4253321 \times 10^{-12}$	$6.4307377 \times 10^{-16}$

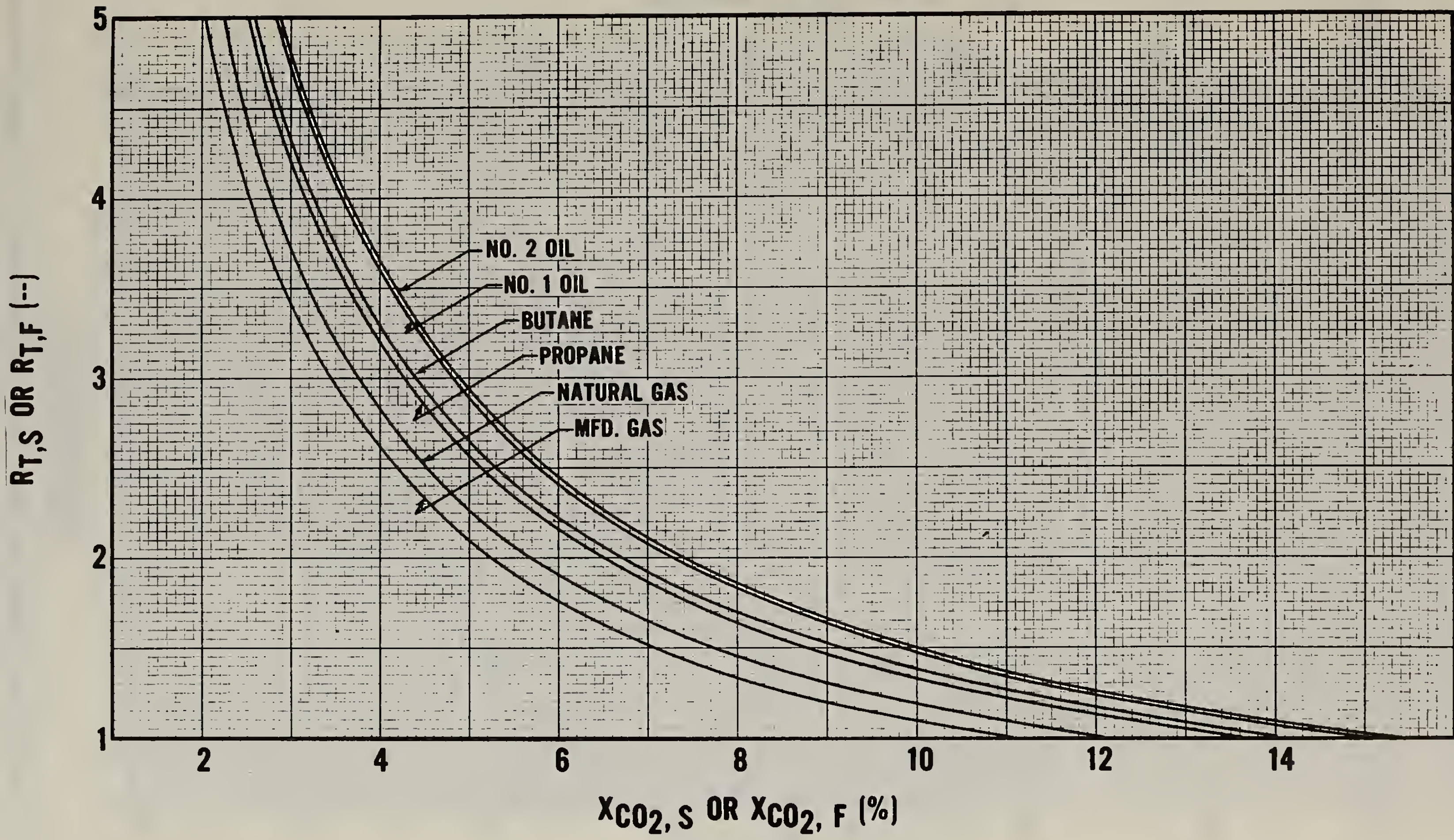


Fig. 1. Ratio of Total Combustion to Stoichiometric Air Versus Carbon Dioxide Concentration

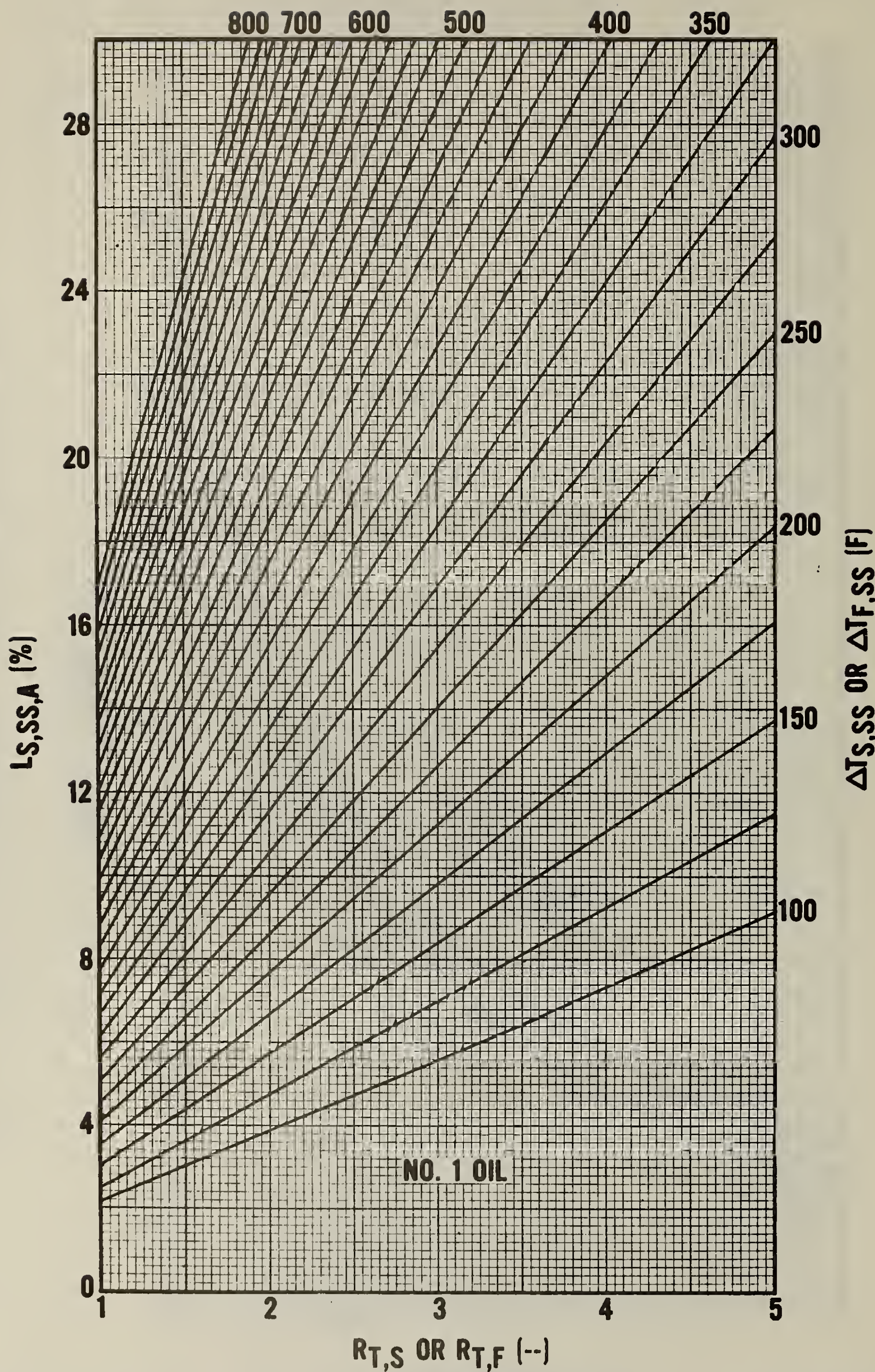


Fig. 2A. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For No. 1 Oil)

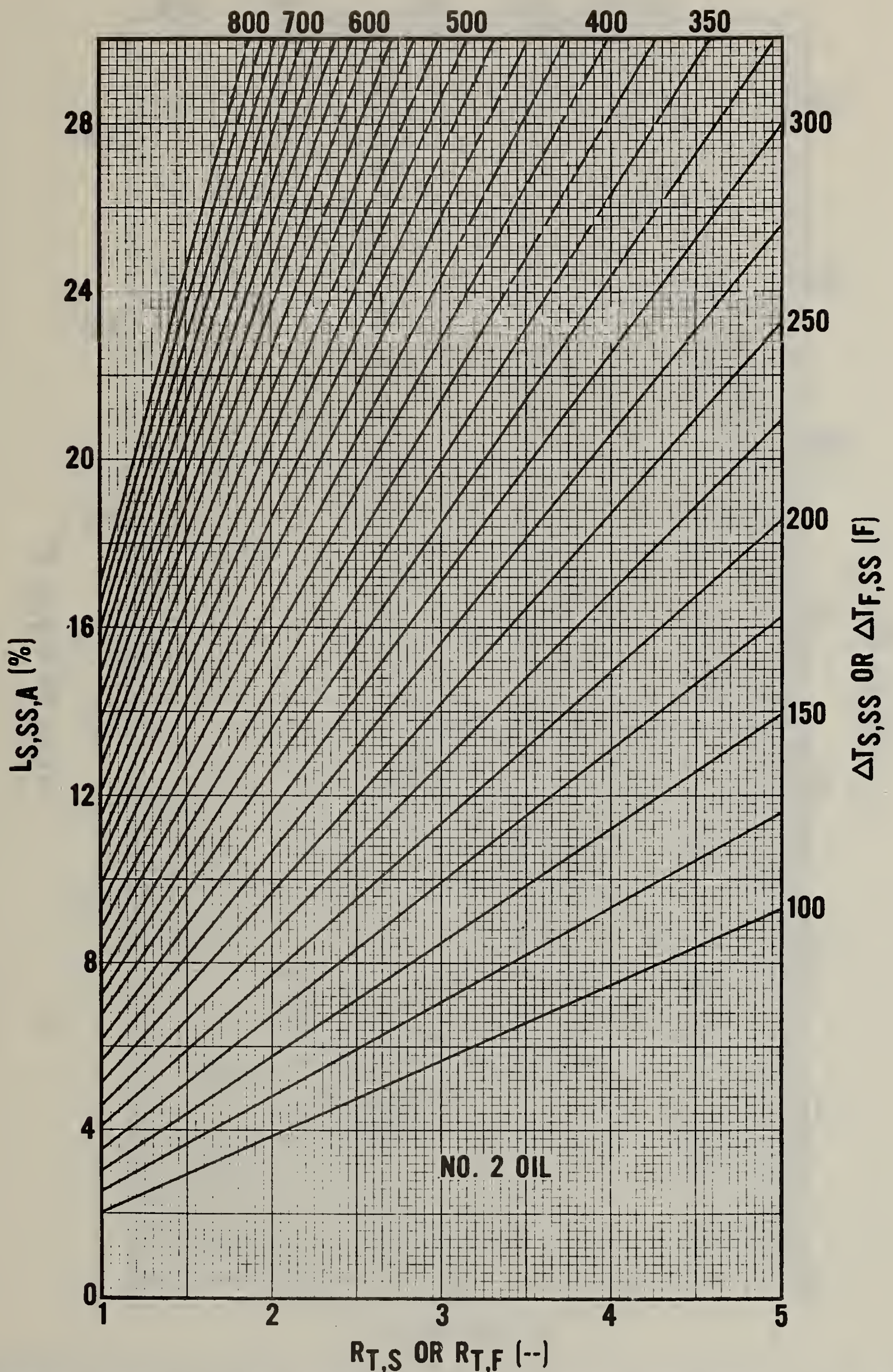


Fig. 2B. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For No. 2 Oil)

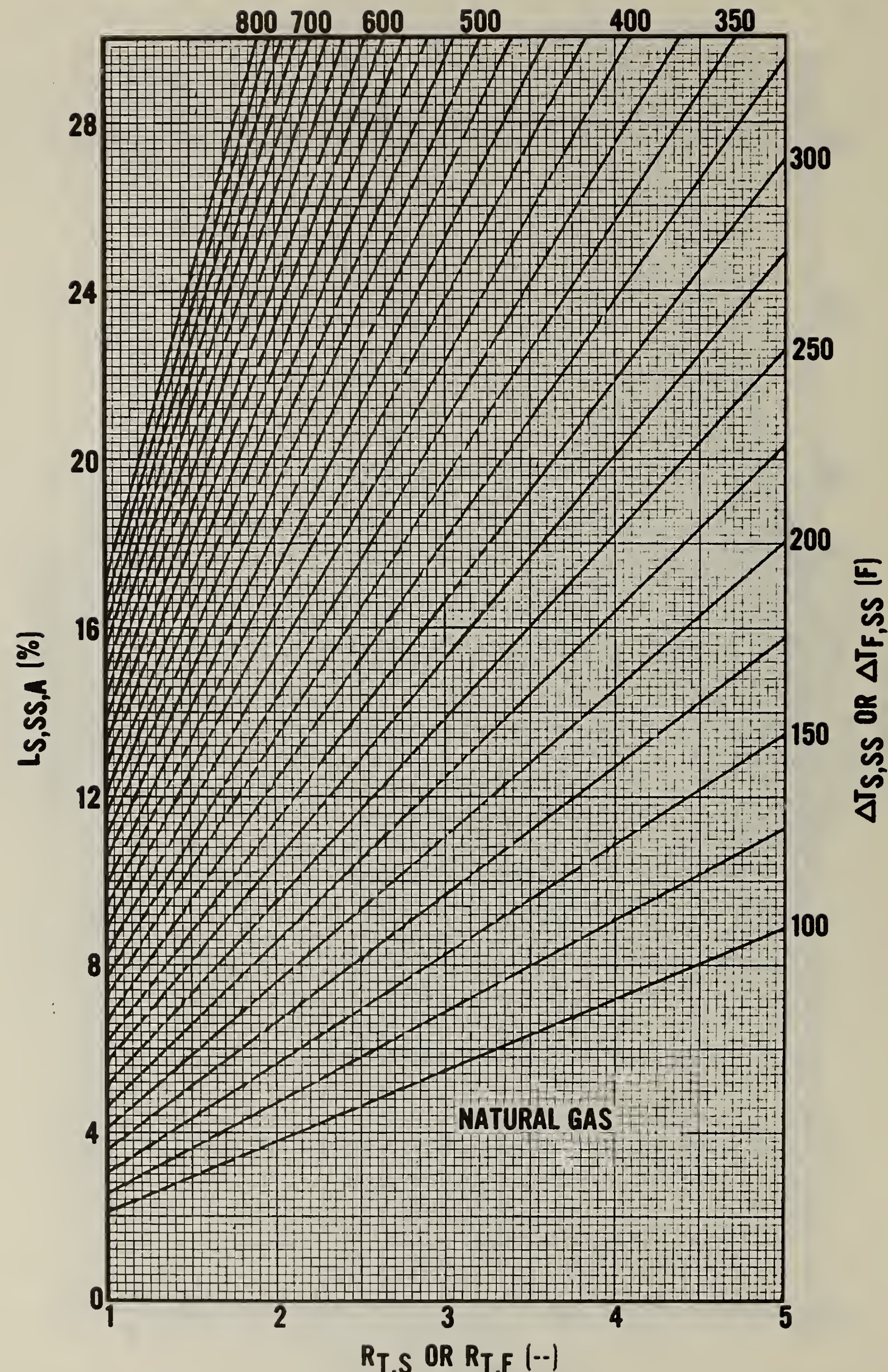


Fig. 2C. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Natural Gas)

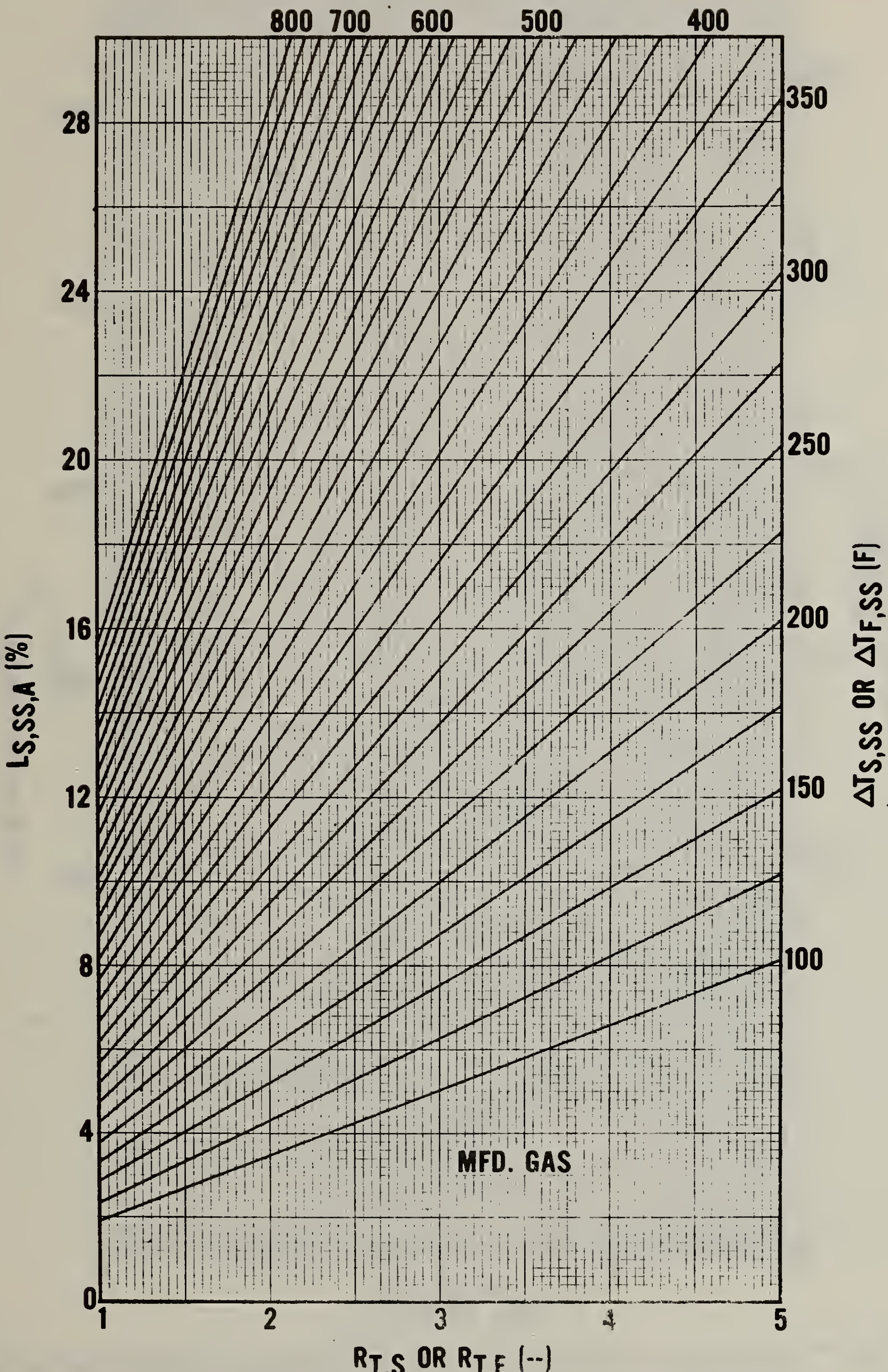


Fig. 2D. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Manufactured Gas)

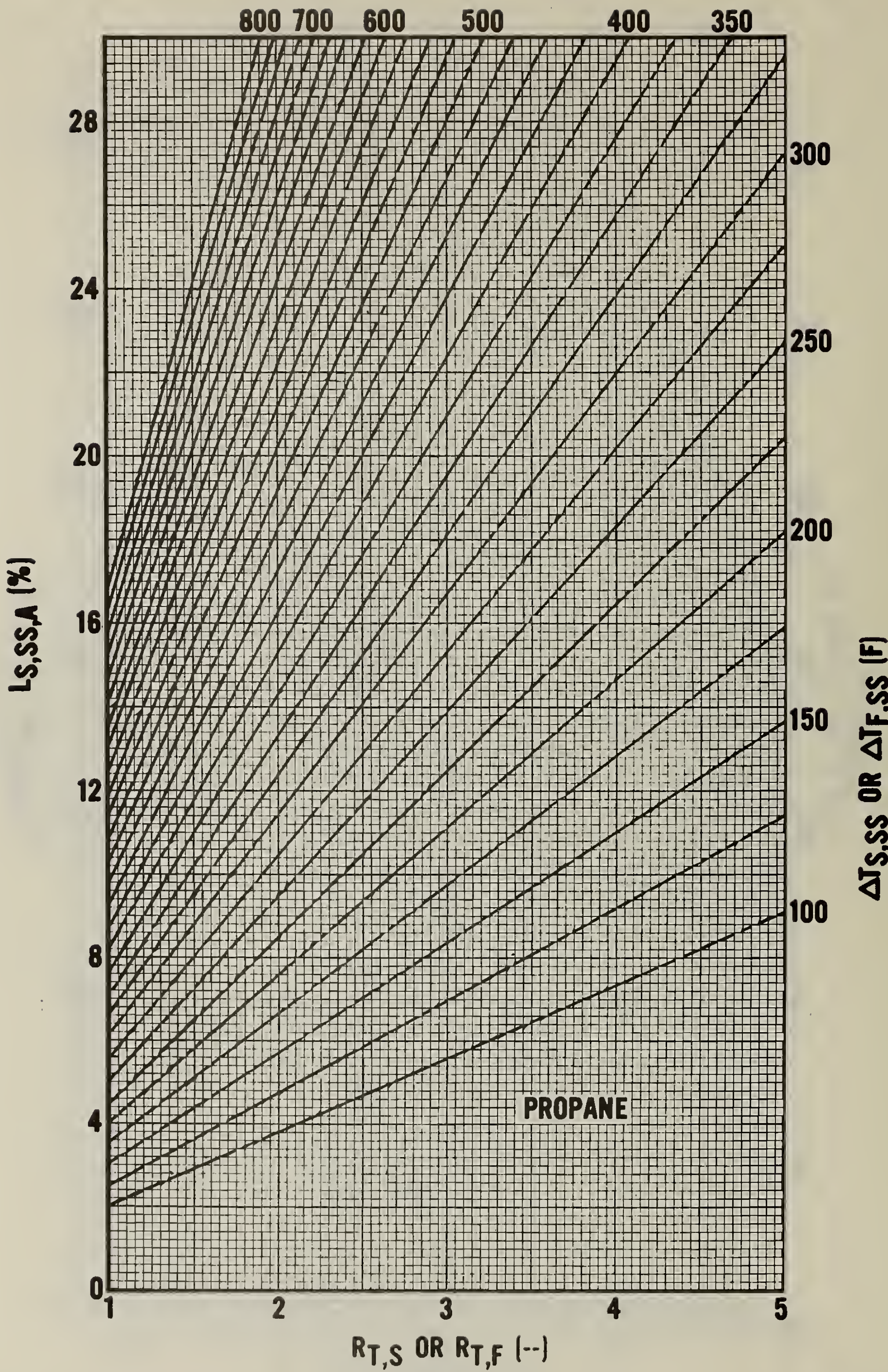


Fig. 2E. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Propane)

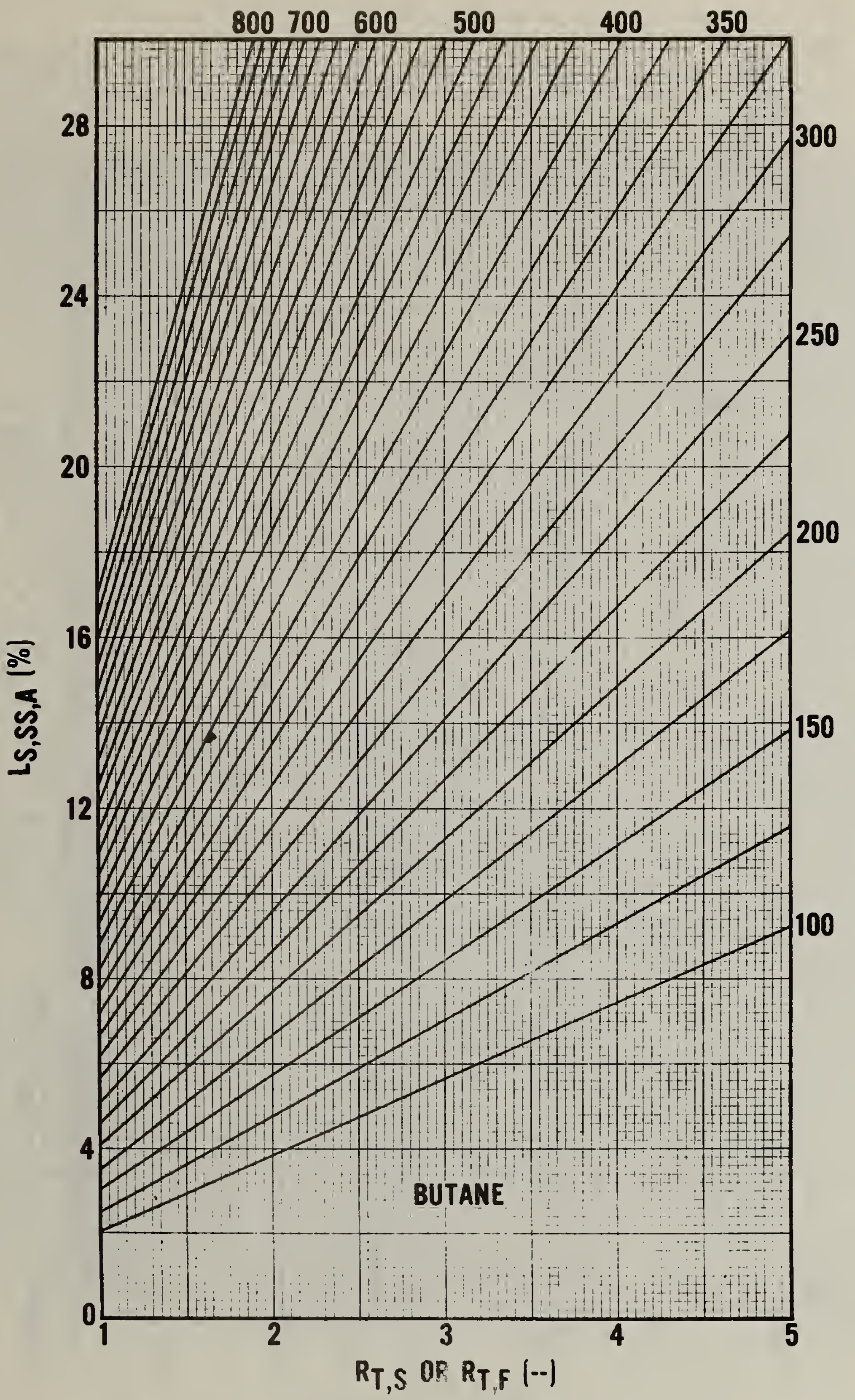


Fig. 2F. Steady-State Sensible Heat Loss Versus Ratio of Total Combustion to Stoichiometric Air (For Butane)

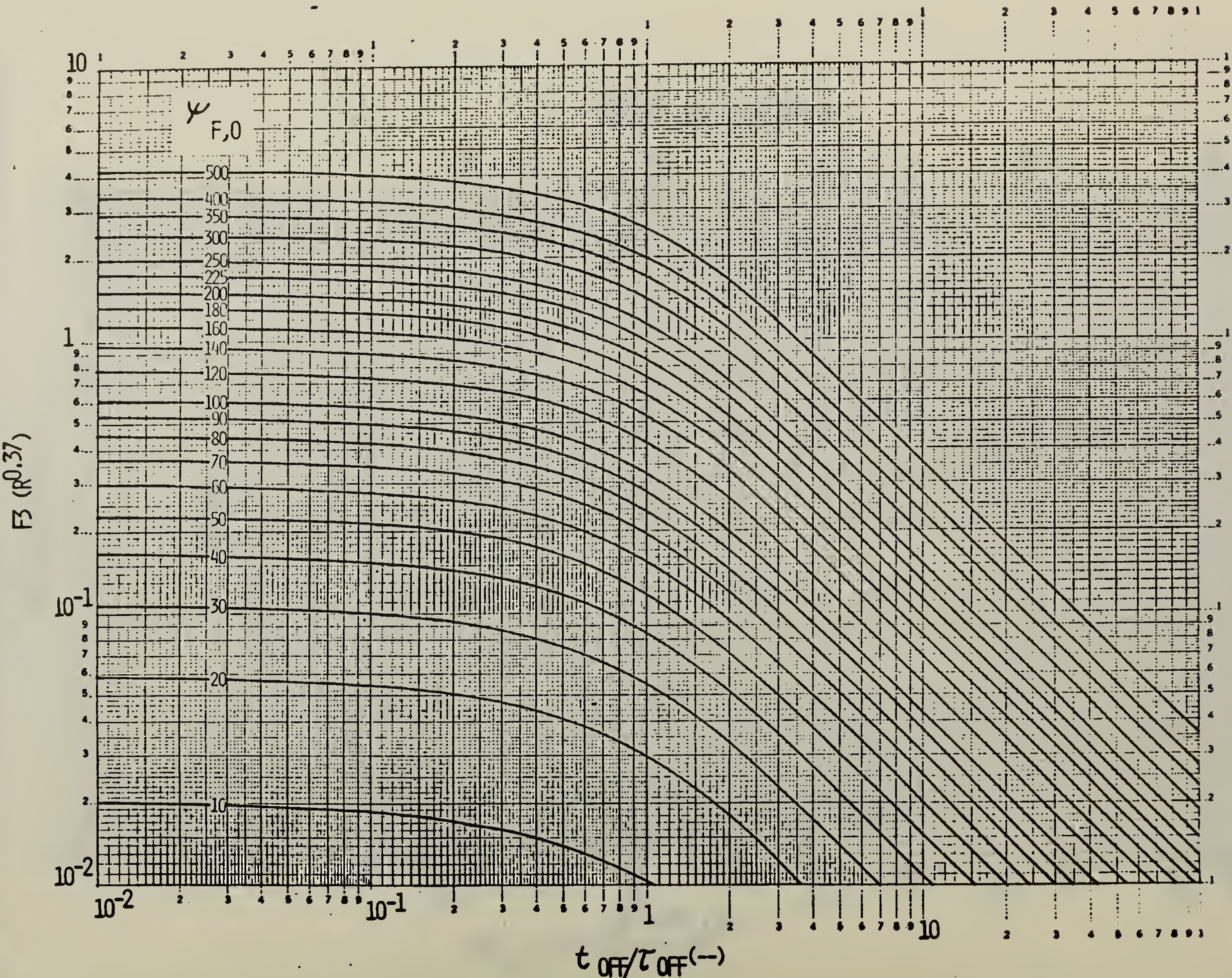


Fig. 3. Values of the F3 Function

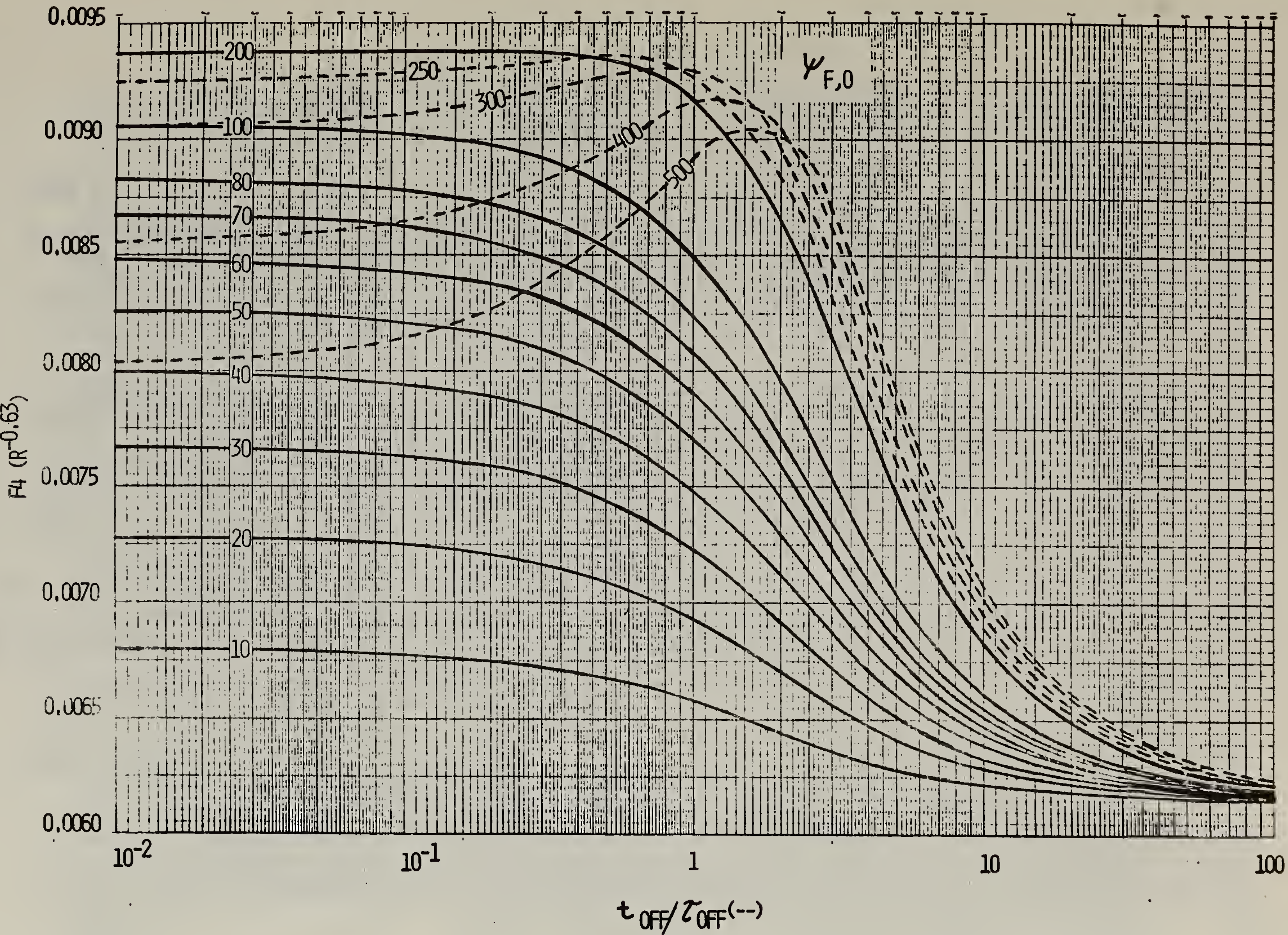


Fig. 4. Values of the F4 Function

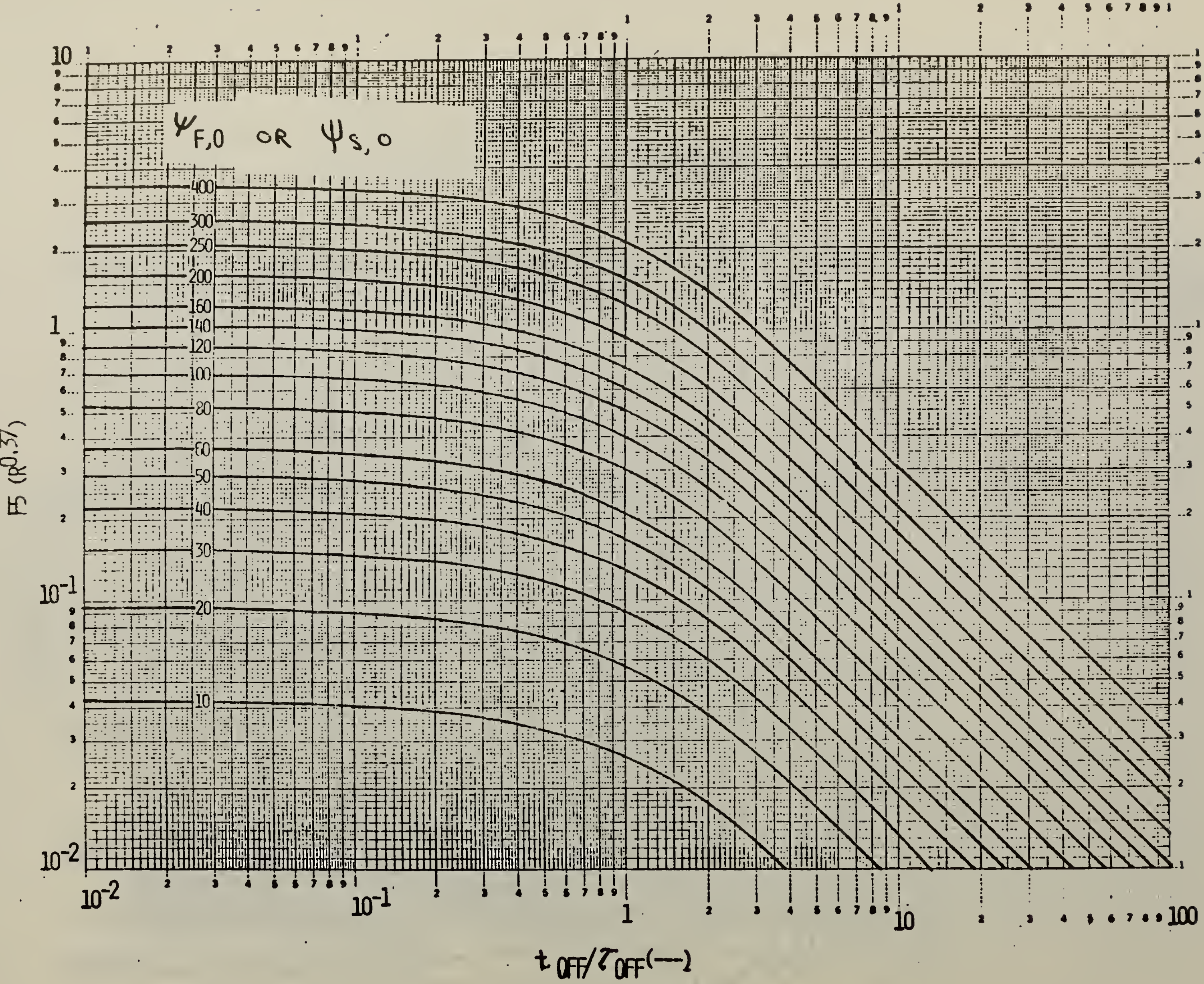


Fig. 5. Values of the F5 Function

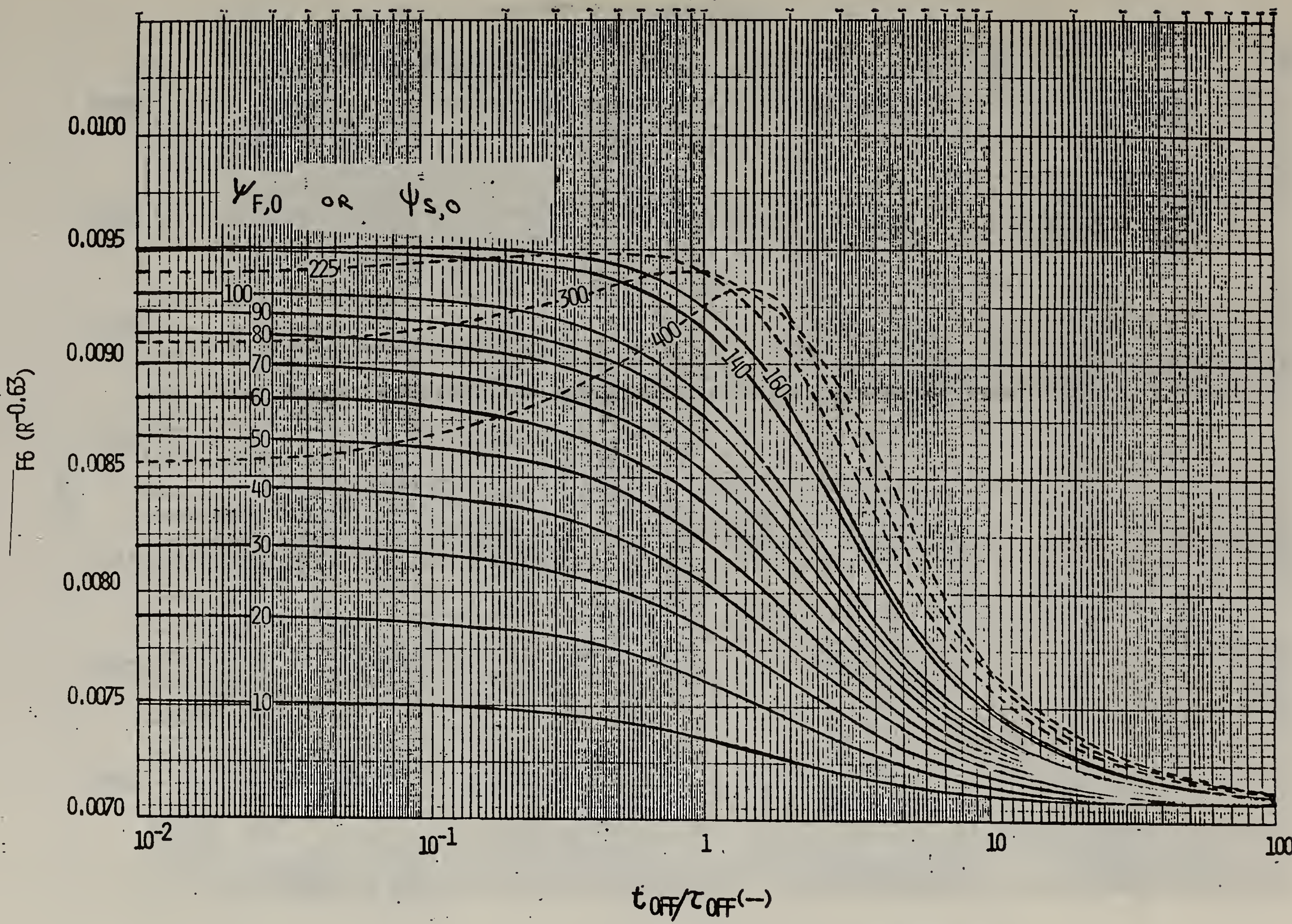


Fig. 6. Values of the F6 Function

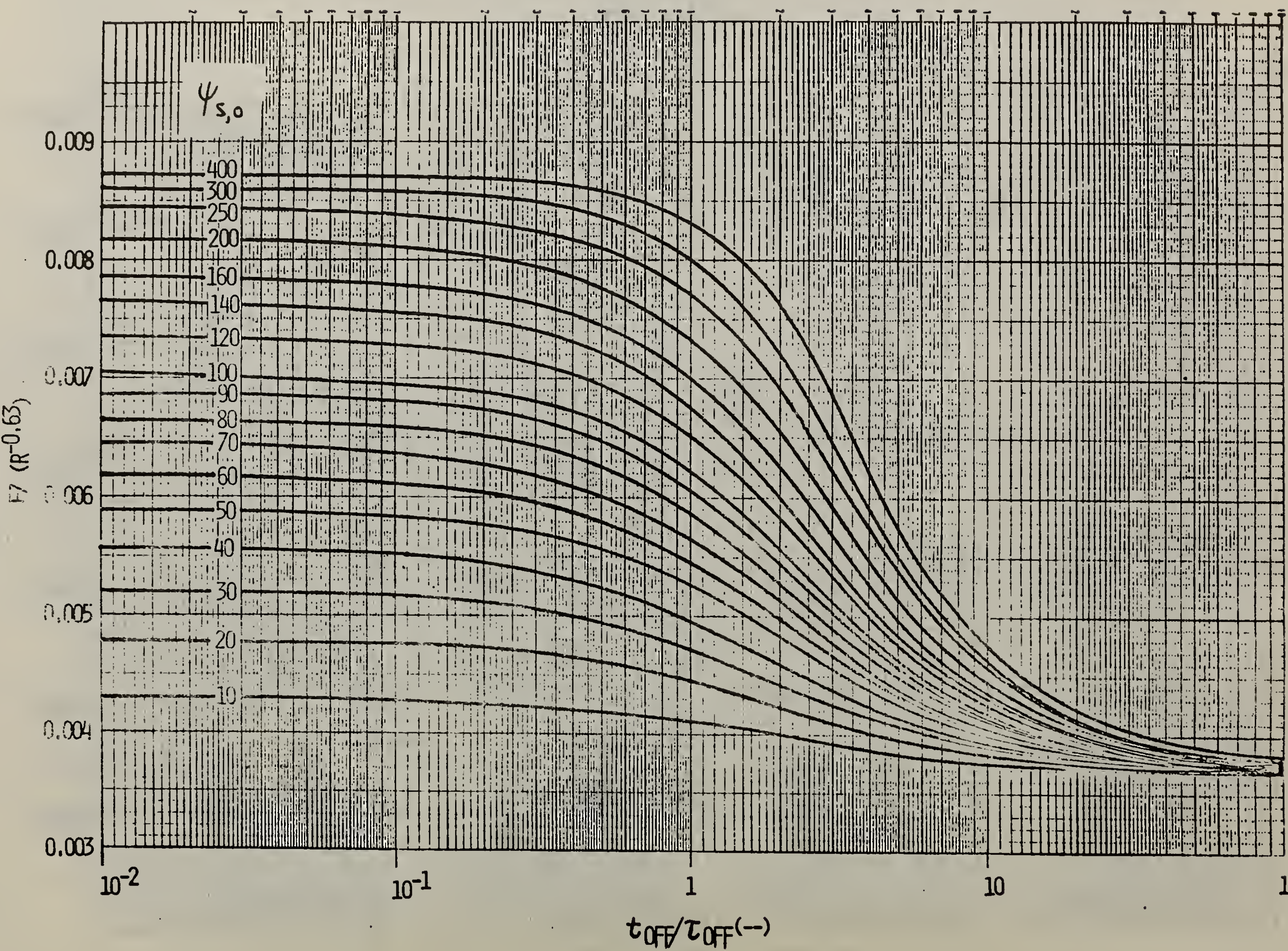


Fig. 7. Values of the F7 Function

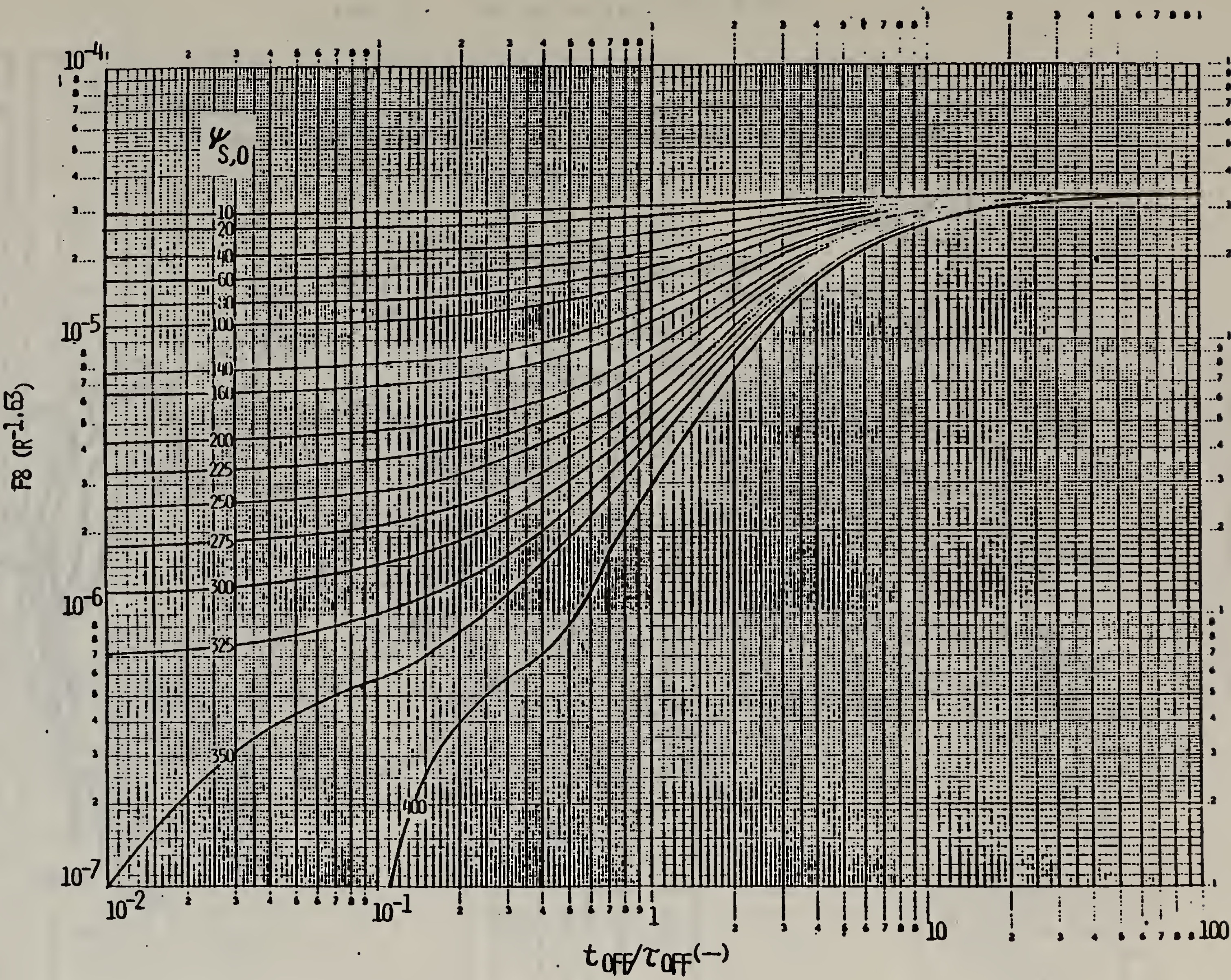
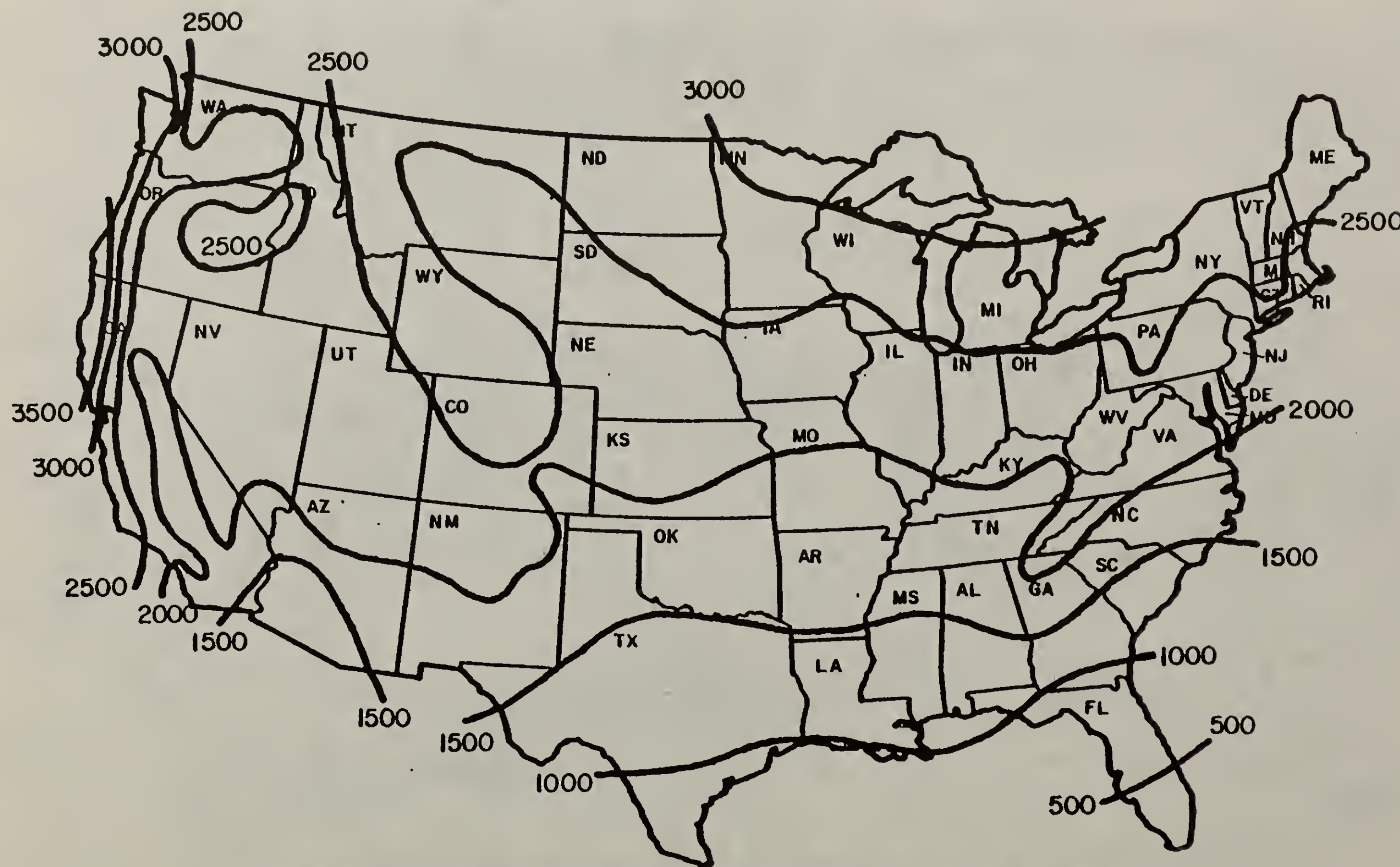


Fig. 8. Values of the F8 Function



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	$\theta_{F,0,X}$ °F	τ_{OFF} minutes	$\psi_{F,0,X}$ °F	$\psi_{F,\infty,X}$ °F	$\psi_{S,\infty,X}$ °F	$\psi_{S,0,X}$ °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} (-)	$\theta_{F,0}$ °F	$\psi_{F,0}$ °F	$\psi_{F,\infty}$ °F

52	53	54	55	56	57	58	59
$\psi_{S,0}$ °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 B

Computerized Calculation Procedure for Condensing and Non-Condensing Furnaces and Boilers

The computerized calculation procedure consists of a main program and three subroutines. The fortran program is listed in Figure B-1, and may require modifications when used on some computer systems. The subroutines FUNT 4 and SENLOS5 perform the functions described in Appendix B of NBSIR 78-1543 [1]. The newer CLFTR2 subroutine calculates the latent heat loss coefficient, C_L, and condensate loss correction factor, L_c, used in steps 68 and 69 of the calculation procedure for condensing furnaces and boilers.

Three sample sets of data given in Figure B-2 are supplied to exercise the program calculation paths for condensing units. The previous eleven sample sets in reference [1] can also be used to check this program, which is why the three sets are assigned numbers 12 through 14. These three sets of input data are supplied to check the condensing type unit calculation paths, but do not represent specific tests of condensing units. Consequently, these output performances should not be referenced as typical or representative values for condensing heating units.

The program and subroutine flow charts, Figures B-3 through B-6, are provided to assist future users in understanding or revising the program. Numbers in the left column of the flow chart indicate corresponding program statements in Figure B-1.

Input to the program must follow the order presented in Figure B-7 entitled Input Data Code Sheet for NBSFBS7. All input values which are listed as zero or blank in the written procedure should have a value of "0.0" placed in their input field.

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 our Fortran V compiler may not be acceptable for use on other systems. It is not possible to anticipate all future alternate input or output format needs, so no attempt has been made to prepare alternate formats. Thus format changes may be necessary for program implementation on other systems. Use of a 72-character-wide output format will require modification to the output formats of the initial 67 quantities which are written for a carriage 132 characters wide.

The fuel cost rates printed out in the regional annual operating cost table are not likely to agree with current Federal Trade Commission fact sheet requirements for specific fuels. Adjustment of CBFBS7 program statements 270 and 313 through 315 is necessary for the desired fuel price ranges.

Figure B-1. Computer Program

```
       CBFBS7
C
C       *** EVALUATION OF FURNACE/BOILER SYSTEMS: CONDENSING 8 NONCONDENSING
C       ** NBSFBS 7 ** APR  1980 ** USE W/ SENLOS,FUNT4,CLFTR SUBROUTINES
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.,25.,0.,0./
       DATA (TABLE(6,NN),NN=1,6)/30.,25.,30.,35.,40.,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 (NNDL(NN),NN=1,16)/1,2,2,3,0,4,0,4,4,4,4,4,5,5,5,5/
       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.LE.3) GO TO 991
       ICOND = 1
       WRITE(6,848)
       GO TO 992
991    ICOND = 0
       WRITE(6,849)
992    CONTINUE
       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.OR.IFB.EQ.5) TON =9.68
       IF(IFB.EQ.2.OR.IFB.EQ.5) 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
       IOPTN = 0
       IF((TFON1.EQ.0.0).AND.(TFON2.EQ.0.0).AND.(IFB.GE.4)) IOPTN = 1
       READ(5,801),TRA,QJ,SFR,DF,DS,Y,QNP
       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,QNP
       READ(5,801),FLCOST,ELCOST,FK
       WRITE(6,878)
```

```
      PF=QP/QNP
      CJ=4.7
      IF(IFB.EQ.1.OR.IFB.EQ.4) CJ= 3.3
      IF(INST.EQ.1) CJ=0.0
      IF(IOPTN.EQ.1)GO TO 994
C
C      *** COLUMNS 31 THROUGH 43 ***
C
      TSSS=(TFSS-TRA )/SFR+TRA
      IF(IFB.EQ.2.OR.IFB.EQ.5) 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-TRA))
      IF(IFB.GE.4) CS = (TFSS-42.)/(TFSS-70.)
      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    CONTINUE
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      ***CII=.90 AS IN SEC. 4.2.23 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
      IF(IFB.GE.4) ZETFO = FFON*ZETFOX
      SIFO =1.22*SIFOX*FFOFF
      SIFI =1.22*SIFIX
      SISO =0.
      SISI =0.0
95    CONTINUE
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 FUNT4(N,SIFO,TTOFF,REFTOA,REFTRM,F5,F6)
      QSON=CS*QSSS-CSON*ZETFO*(1.-EXP(-TTON))/TTON
      QSOFF=CSOFF*(F5+SIFI*F6)*TOFF/TON
      QION =0.
      QIOFF =0.
105   CONTINUE
994   IF(IOPTN.NE.1) GO TO 995
      CALL CLFTR(CLP,QLCP,IFUEL,AFR,RT,HHVA,QL,IOPTN,ZETFO,TFSS,TTON)
      IF(IFB.EQ.4) EFFYSS = 100.-CLP*QL-QSSS-QLCP
      IF(IFB.EQ.5) EFFYSS = 100.-QL-QSSS-24.*60.*(1.+RT*AFR)/HHVA
      CS = (TFSS-42.)/(TFSS-70.)
      EFFYU = 100.-CLP*QL-QLCP-CJ*QJ-(TON*CS*QSSS)/(TON+PF*TOFF)
      EFFYA = EFFYSS*EFFYU*DD/(EFFYSS*DD+2.5*EFFYU*PF*(1.+ALPHA)*HR)
      WRITE(6,858),PF,HHVA,AFR,QL,CJ,RT,QSSS,EFFYSS
      WRITE(6,882),EFFYU,DD,HR,EFFYA
      GO TO 997
995   CONTINUE
      IF(IFB.LE.3) GO TO 996
      CALL CLFTR(CLP,QLCP,IFUEL,AFR,RT,HHVA,QL,1,ZETFO,TFSS,TTON)
      IF(IFB.EQ.4) EFFYSS = 100.-CLP*QL-QSSS-QLCP
      IF(IFB.EQ.5) EFFYSS = 100.-QL-QSSS-24.*60.*(1.+RT*AFR)/HHVA
      CALL CLFTR(CL,QLC,IFUEL,AFR,RT,HHVA,QL,IOPTN,ZETFO,TFSS,TTON)
      EFFYU = 100.-CL*QL-QLC-CJ*QJ-(TON*(QSON+QSOFF)/(TON+PF*TOFF))
      GO TO 120
996   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(6,858),PF,HHVA,AFR,QL,CJ,RT,QSSS,EFFYSS
      WRITE(6,859),TSSS,TAON,ZETFOX,TAOFF,SIFOX,SIFIX,SISIX,SISOX
      WRITE(6,860),CS,CSON,CSOFF,CION,CIOFF
      WRITE(6,862),TOA,TON,TOFF,TTON,TTOFF,ZETFO,SIFO,SIFI
      WRITE(6,863),SISO,SISI,F3 ,F4 ,F5 ,F6 ,F7 ,F8
      EFFYA=EFFYSS*EFFYU*DD/(EFFYSS*DD+2.5*EFFYU*PF*(1.+ALPHA)*HR)
      WRITE(6,864),QSON,QSOFF,QION,QIOFF ,EFFYU,DD,HR,EFFYA
997   CONTINUE
      A=100000./(341300.*(PE+Y*BE)+(QNP-QP)*EFFYU)
       B=0.
      IF(QP.LT.0.1) GO TO 1250
      B=(.00002)*A*QP*EFFYU
1250  CONTINUE
      WRITE(6,874),A,B
C
      QOUT =QNP*EFFYSS/ 100.
      IF(INST.EQ.2) QOUT=QNP*(EFFYSS-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.42) NN=4
      IF(IQOUT.GT.42.AND.IQOUT.LE.59) NN=6
      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) NN= 16
      DHR= TABLE(NN,1)
      BOH =(A*DHR*2080.*.77)-(B*2080.)
      AFUEL=(QNP-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=(QNP-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),IHLH,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()
 848  FORMAT(/5X'CONDENSING')
 849  FORMAT(/5X'NONCONDENSING')
 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(4X,F6.2))
857   FORMAT(/5X'17)TRA'4X'18)QJ'5X'19)S/F'4X'20)DF'5X'21)DS',
     ,4X'22) Y'6X'00)QNP   '/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,'HLH)'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))
878   FORMAT(//5X'CALCULATED VALUES-'/)
881   FORMAT(5X,'LABELED DHR OF MODEL TO BE ',F5.0,'KBTU/HR')
882   FORMAT(/5X'64)EFFYU'2X'65)DD'5X'66)HR'5X'67)EFFYA'/3X,4(1PE10.2))
      STOP
      END
END PRT
```

```
      SENLOS5
      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
END PRT
```

```
          CLFTR2
          SUBROUTINE CLFTR(CL,QLC,IFUEL,AFR,RT,HHVA,QL,IOPTN,ZETFO
         *,TFSS,TTON)
C
C          ***CALCULATION OF CL AND QLC***
C          ***APRIL 1980***FOR USE WITH QLC***
          DIMENSION FGMW(6)
          DATA (FGMW(J), J=1,6)/29.,29.,28.,27.5,28.5,28.5/
          FGM = 1.+AFR*RT
          VM = HHVA*QL/(100.*1053.3)
          PV = VM*FGMW(IFUEL)*14.7/(FGM*18.)
          IF(IOPTN.NE.1) GO TO 100
          AVTFON = TFSS
          GO TO 101
  100     AVTFON = TFSS - ZETFO*(1.-EXP(-TTON))/TTON
  101     PVS = .4912*EXP(15.4638-7284./(AVTFON+392.))
          IF(PV.GT.PVS) GO TO 110
          CL = 1.
          WRITE(6,990)
          GO TO 120
  110     CL = PVS*(14.7-PV)/(PV*(14.7-PVS))
  120     QLC = QL*(1.-CL)*(1.*(TFSS-70.)-.45*(TFSS-42.))/1053.3
  990     FORMAT(///15X'**WARNING**CL=1**'/5X'**UNIT SHOULD BE TESTED AND
         ,RATED AS A NONCONDENSING HEATING SYSTEM**'/5X'**ALL CALCULATED
         ,RESULTS WHICH FOLLOW ARE INVALID**')
          RETURN
          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
END PRT
```

Figure B-2. Three Sample Sets of Test Data

```
FURNACE.ABS

GAS CONDENSING BOILER TEST WITHOUT HEAT-UP/COOLDOWN SET12
USE WITH OPTION 3.7 CALCULATION PROCEDURE, IOPTN WILL=1

CONDENSING
INSTALLED OUTDOOR
```

Note: Input line No. 4 was 5, 2 for set 12.

```
INPUT VALUES

1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
11         3          2.01+04    8.35+04    0.00       0.00       1.30-01    0.00

9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
     .00     10.90     121.60        .00        .00        .00        .00        .00

17)TRA     18)QJ      19)S/F     20)DF      21)DS      22) Y      00)QNP
 7.74+01    0.00      1.00+00    0.00       0.00       1.00+00    8.00+04

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    4.70+00    1.10+00    9.74-01    8.83+01

64)EFFYU   65)DD      66)HR      67)EFFYA
 9.20+01    5.20+03    4.60+03    9.20+01

A          B
 1.35-02    0.00

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 92.0 PERCENT
FUEL RATE $ .350PER    100000.BTU
ELEC RATE  $ .050PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   248.
AVERAGE ANNUAL BURNER OPERATING HOURS    865.
LABELED DHR OF MODEL TO BE    40.KBTU/HR
```

REGIONAL ANNUAL OPERATING COST

COST OF ELEC $ .050 PER KW-HR

REGION	DESIGN KBTU/HR	COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1	35.	45.	56.	67.	78.	89.
(750.HLH)	40.	52.	64.	77.	89.	102.
	45.	58.	72.	87.	101.	115.
	50.	65.	81.	96.	112.	127.
2	35.	76.	94.	112.	130.	149.
(1250.HLH)	40.	87.	107.	128.	149.	170.
	45.	97.	121.	144.	168.	191.
	50.	108.	134.	160.	186.	212.
3	35.	106.	132.	157.	182.	208.
(1750.HLH)	40.	121.	150.	179.	209.	238.
	45.	136.	169.	202.	235.	267.
	50.	152.	188.	224.	261.	297.
4	35.	136.	169.	202.	235.	267.
(2250.HLH)	40.	156.	193.	231.	268.	306.
	45.	175.	217.	260.	302.	344.
	50.	195.	242.	288.	335.	382.
5	35.	167.	207.	247.	287.	327.
(2750.HLH)	40.	190.	236.	282.	328.	374.
	45.	214.	266.	317.	369.	420.
	50.	238.	295.	352.	410.	467.

CONDENSING FURNACE TEST SAMPLE INPUT SET 13
DIRECT VENT WITH HEAT-UP/COOLDOWN IOPTN=0

CONDENSING
INSTALLED OUTDOOR

INPUT VALUES

1)NSYS	2)IFUEL	3)HHV	4)QIN	5)QP	6)PE	7)BE	8)XCO2S
11	3	2.01+04	1.00+05	0.00	0.00	5.00-01	0.00
9)TSSS	10)XCO2F	11)TFSS	12)TFON1	13)TFON2	14)TFOFF3	15)TFOFF4	16)TFOFF5
.00	10.00	130.00	120.00	128.00	120.30	105.00	76.00
17)TRA	18)QJ	19)S/F	20)DF	21)DS	22) Y	00)QNP	
7.60+01	0.00	1.00+00	0.00	0.00	1.39+00	1.00+05	

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	3.30+00	1.19+00	1.28+00	8.95+01
31)TSSS	32)TAUON	33)ZETFOX	34)TAUOFF	35)PSIFOX	36)PSIFIX	37)PSISIX	38)PSISOX
1.30+02	1.24+00	1.50+01	1.77+01	4.82+01	0.00	0.00	0.00
39)CS	40)CSON	41)CSOFF	42)CION	43)CIOFF			
1.47+00	2.17-02	0.00	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	3.11+00	7.51-01	8.70+00	5.26+01	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	2.04-01	8.38-03	0.00	0.00
60)QSON	61)QSOFF	62)QION	63)QIOFF	64)EFFYU	65)DD	66)HR	67)EFFYA
1.81+00	0.00	0.00	0.00	8.97+01	5.20+03	4.60+03	8.97+01
A	B						
1.09-02	0.00						

AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 89.7 PERCENT
FUEL RATE $ .350PER 100000.BTU
ELEC RATE $ .050PER KW-HR
AVERAGE ANNUAL OPERATING COST $ 335.
AVERAGE ANNUAL BURNER OPERATING HOURS 870.
LABELED DHR OF MODEL TO BE 50.KBTU/HR

REGIONAL ANNUAL OPERATING COST

REGION	DESIGN KBTU/HR	COST OF ELEC $ .050 PER KW-HR COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1	40.	59.	71.	84.	97.	109.
(750.HLH)	45.	66.	80.	94.	109.	123.
	50.	74.	89.	105.	121.	136.
	60.	88.	107.	126.	145.	164.
2	40.	98.	119.	140.	161.	182.
(1250.HLH)	45.	110.	134.	157.	181.	204.
	50.	123.	149.	175.	201.	227.
	60.	147.	179.	210.	241.	273.
3	40.	137.	167.	196.	225.	254.

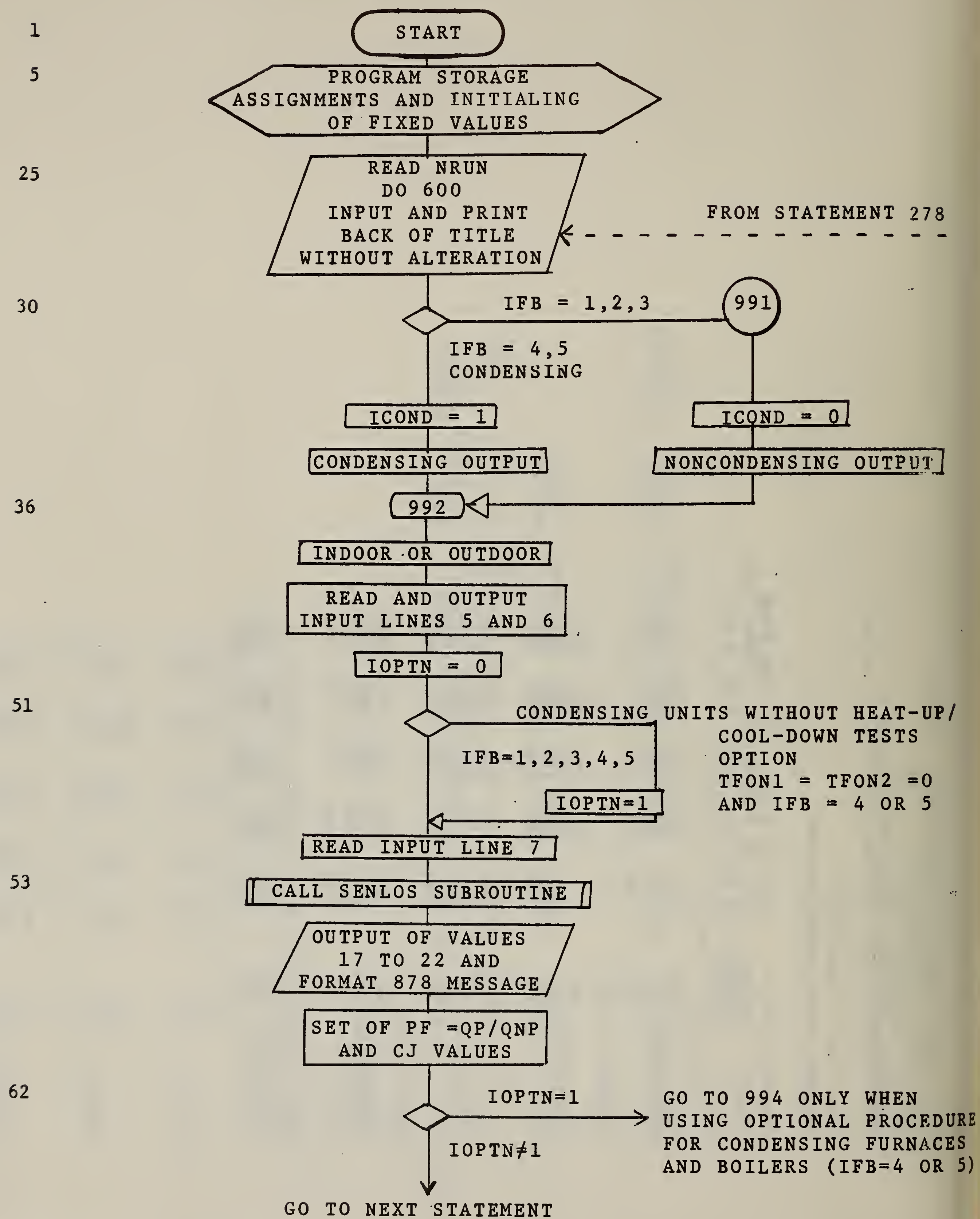
```
(1750.HLH)   45.      155.  188.  220.  253.  286.
             50.      172.  208.  245.  282.  318.
             60.      206.  250.  294.  333.  382.


4            40.      177.  214.  252.  290.  327.
(2250.HLH)   45.      199.  241.  283.  326.  368.
             50.      221.  268.  315.  362.  409.
             60.      265.  321.  378.  434.  491.


5            40.      216.  262.  308.  354.  400.
(2750.HLH)   45.      243.  295.  346.  398.  450.
             50.      270.  327.  385.  442.  500.
             60.      324.  393.  462.  531.  600.

CONDENSING FURNACE TEST SAMPLE INPUT     SET 14
DIRECT VENT USING OPTION 3.7  IOPTN=1    SET 14


CONDENSING
INSTALLED OUTDOOR


INPUT VALUES

1)NSYS     2)IFUEL    3)HHV      4)QIN      5)QP       6)PE       7)BE       8)XCO2S
11          3          2.01+04    1.00+05    0.00       0.00       5.00-01    0.00

9)TSSS     10)XCO2F   11)TFSS    12)TFON1   13)TFON2   14)TFOFF3  15)TFOFF4  16)TFOFF5
     .00     10.00     130.00        .00        .00        .00        .00        .00

17)TRA     18)QJ      19)S/F     20)DF      21)DS      22) Y      00)QNP
 7.60+01    0.00       1.00+00    0.00       0.00       1.39+00    1.00+05

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    3.30+00    1.19+00    1.28+00    8.95+01

64)EFFYU   65)DD      66)HR      67)EFFYA
 8.89+01    5.20+03    4.60+03    8.89+01

A          B
 1.10-02    0.00


AVERAGE ANNUAL PERFORMANCE=

AVERAGE ANNUAL ENERGY USAGE EFFICIENCY, 88.9 PERCENT
FUEL RATE $ .350PER    100000.BTU
ELEC RATE  $ .050PER KW-HR
AVERAGE ANNUAL OPERATING COST  $   337.
AVERAGE ANNUAL BURNER OPERATING HOURS     877.
```

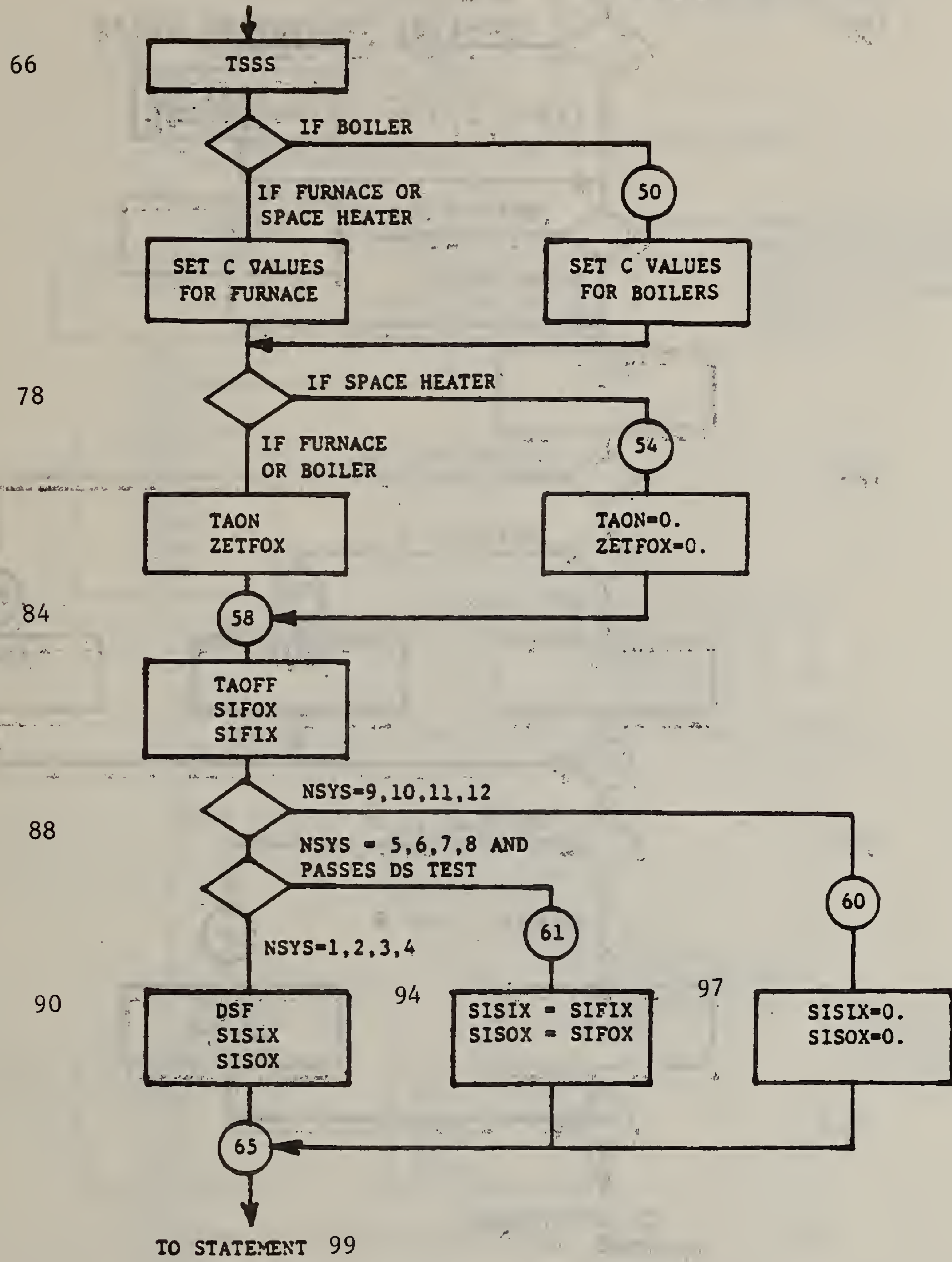
LABELED DHR OF MODEL TO BE 50.KBTU/HR

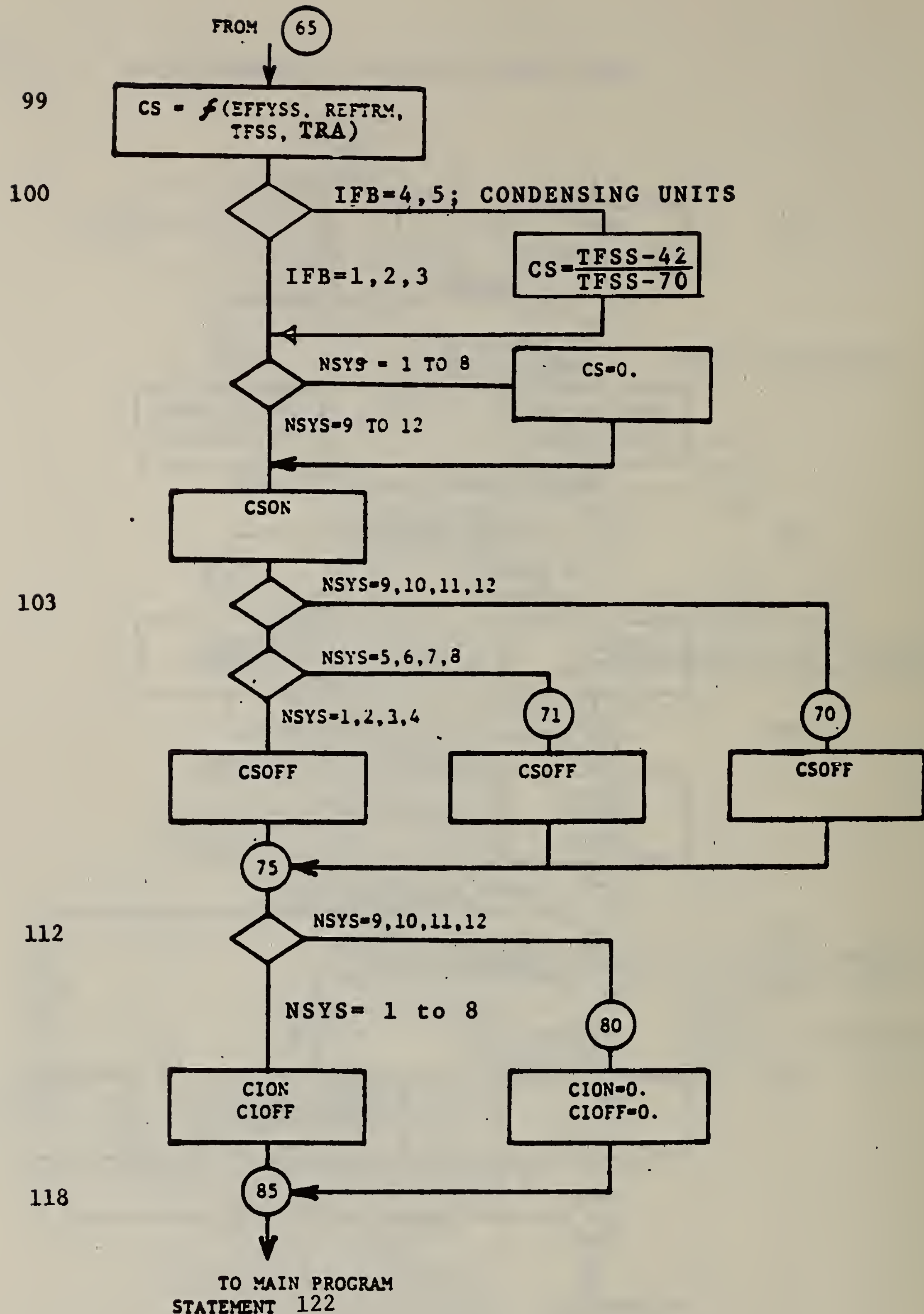
REGIONAL ANNUAL OPERATING COST

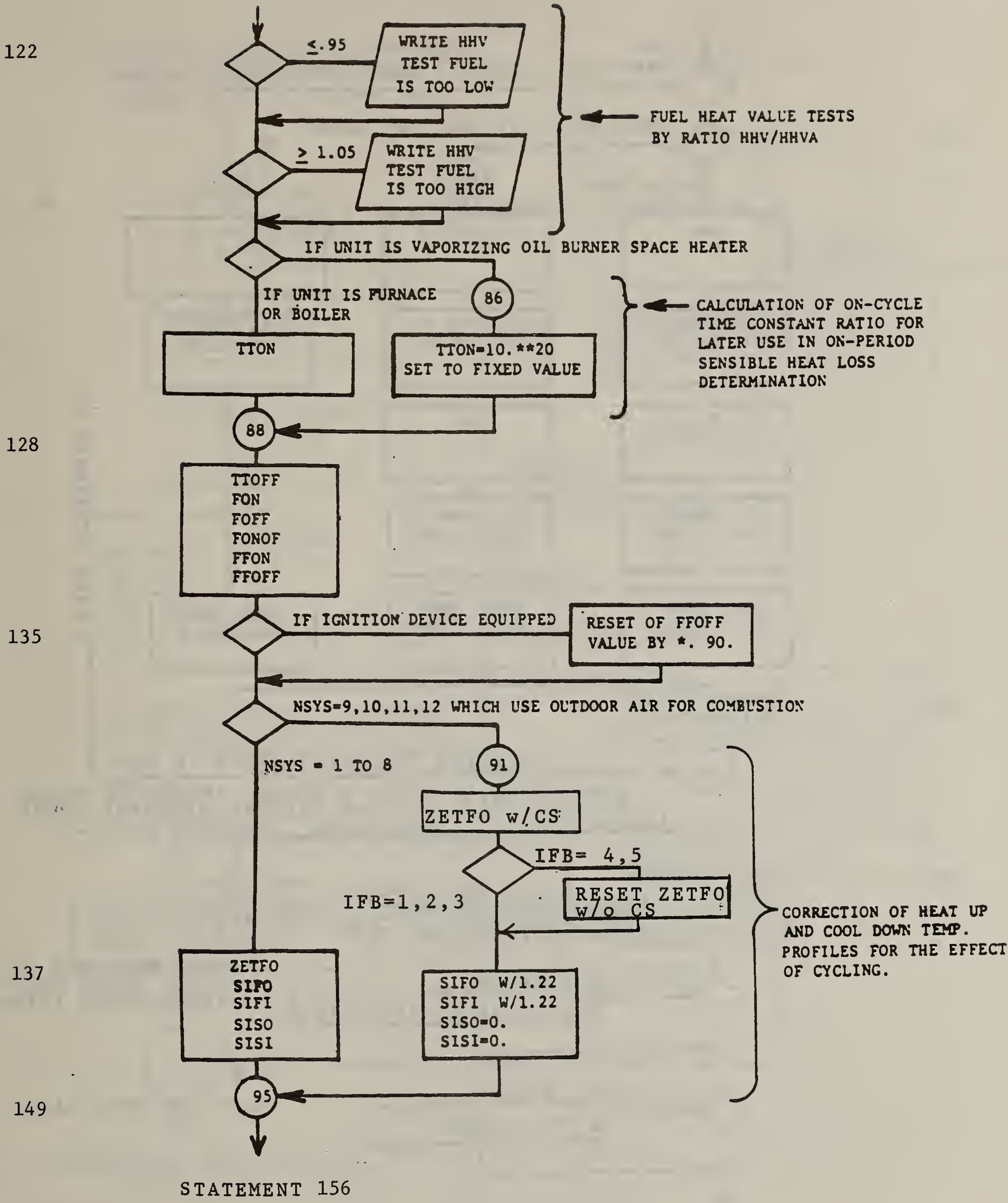
REGION	DESIGN KBTU/HR	COST OF ELEC $ .050 PER KW-HR COST OF FUEL $ PER 100000. BTU 0.20	0.25	0.30	0.35	0.40
1	40.	59.	72.	85.	97.	110.
(750.HLH)	45.	67.	81.	95.	110.	124.
	50.	74.	90.	106.	122.	137.
	60.	89.	108.	127.	146.	165.
2	40.	99.	120.	141.	162.	183.
(1250.HLH)	45.	111.	135.	159.	183.	206.
	50.	124.	150.	176.	203.	229.
	60.	148.	180.	212.	243.	275.
3	40.	139.	168.	198.	227.	257.
(1750.HLH)	45.	156.	189.	222.	256.	289.
	50.	173.	210.	247.	284.	321.
	60.	208.	252.	296.	341.	385.
4	40.	178.	216.	254.	292.	330.
(2250.HLH)	45.	200.	243.	286.	329.	371.
	50.	223.	270.	318.	365.	412.
	60.	267.	324.	381.	433.	495.
5	40.	218.	264.	311.	357.	403.
(2750.HLH)	45.	245.	297.	349.	402.	454.
	50.	272.	330.	388.	446.	504.
	60.	327.	396.	466.	535.	605.

FIG. B-3. MAIN NBSFBS7 PROGRAM FLOW CHART




66
TSSS
IF BOILER
IF FURNACE OR SPACE HEATER
50
SET C VALUES FOR FURNACE
SET C VALUES FOR BOILERS
78
IF SPACE HEATER
IF FURNACE OR BOILER
54
TAON ZETFOX
TAON=0. ZETFOX=0.
84
58
TAOFF SIFOX SIFIX
NSYS=9,10,11,12
88
NSYS = 5,6,7,8 AND PASSES DS TEST
60
61
NSYS=1,2,3,4
90
DSF SISIX SISOX
94
SISIX = SIFIX SISOX = SIFOX
97
SISIX=0. SISOX=0.
65
TO STATEMENT 99

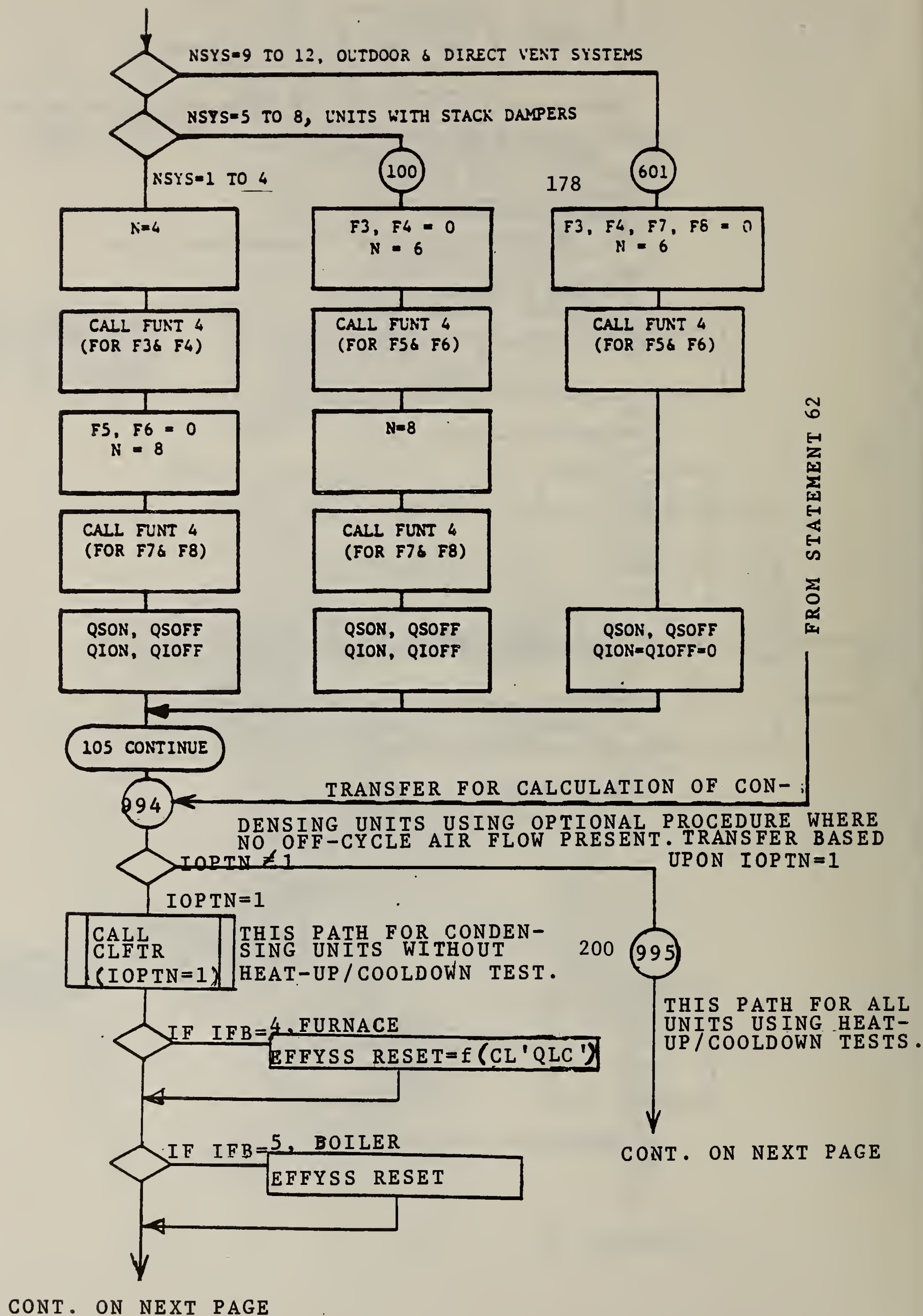

FROM 65
99
CS = ƒ(EFFYSS, REFTRM, TFSS, TRA)
100
IFB=4,5; CONDENSING UNITS
CS=(TFSS-42)/(TFSS-70)
IFB=1,2,3
NSYS = 1 TO 8
CS=0.
NSYS=9 TO 12
CSON
103
NSYS=9,10,11,12
NSYS=5,6,7,8
NSYS=1,2,3,4
71
70
CSOFF
CSOFF
CSOFF
75
112
NSYS=9,10,11,12
NSYS= 1 to 8
80
CION
CIOFF
CION=0.
CIOFF=0.
118
85
TO MAIN PROGRAM
STATEMENT 122


122
≤.95
WRITE HHV TEST FUEL IS TOO LOW
≥ 1.05
WRITE HHV TEST FUEL IS TOO HIGH
FUEL HEAT VALUE TESTS BY RATIO HHV/HHVA
IF UNIT IS VAPORIZING OIL BURNER SPACE HEATER
IF UNIT IS FURNACE OR BOILER
86
TTON
TTON=10.**20 SET TO FIXED VALUE
CALCULATION OF ON-CYCLE TIME CONSTANT RATIO FOR LATER USE IN ON-PERIOD SENSIBLE HEAT LOSS DETERMINATION
128
88
TTOFF
FON
FOFF
FONOF
FFON
FFOFF
135
IF IGNITION DEVICE EQUIPPED
RESET OF FFOFF VALUE BY *. 90.
NSYS=9,10,11,12 WHICH USE OUTDOOR AIR FOR COMBUSTION
NSYS = 1 TO 8
91
ZETFO w/CS
IFB= 4,5
IFB=1,2,3
RESET ZETFO w/o CS
CORRECTION OF HEAT UP AND COOL DOWN TEMP. PROFILES FOR THE EFFECT OF CYCLING.
137
ZETFO
SIFO
SIFI
SISO
SISI
SIFO W/1.22
SIFI W/1.22
SISO=0.
SISI=0.
149
95
STATEMENT 156

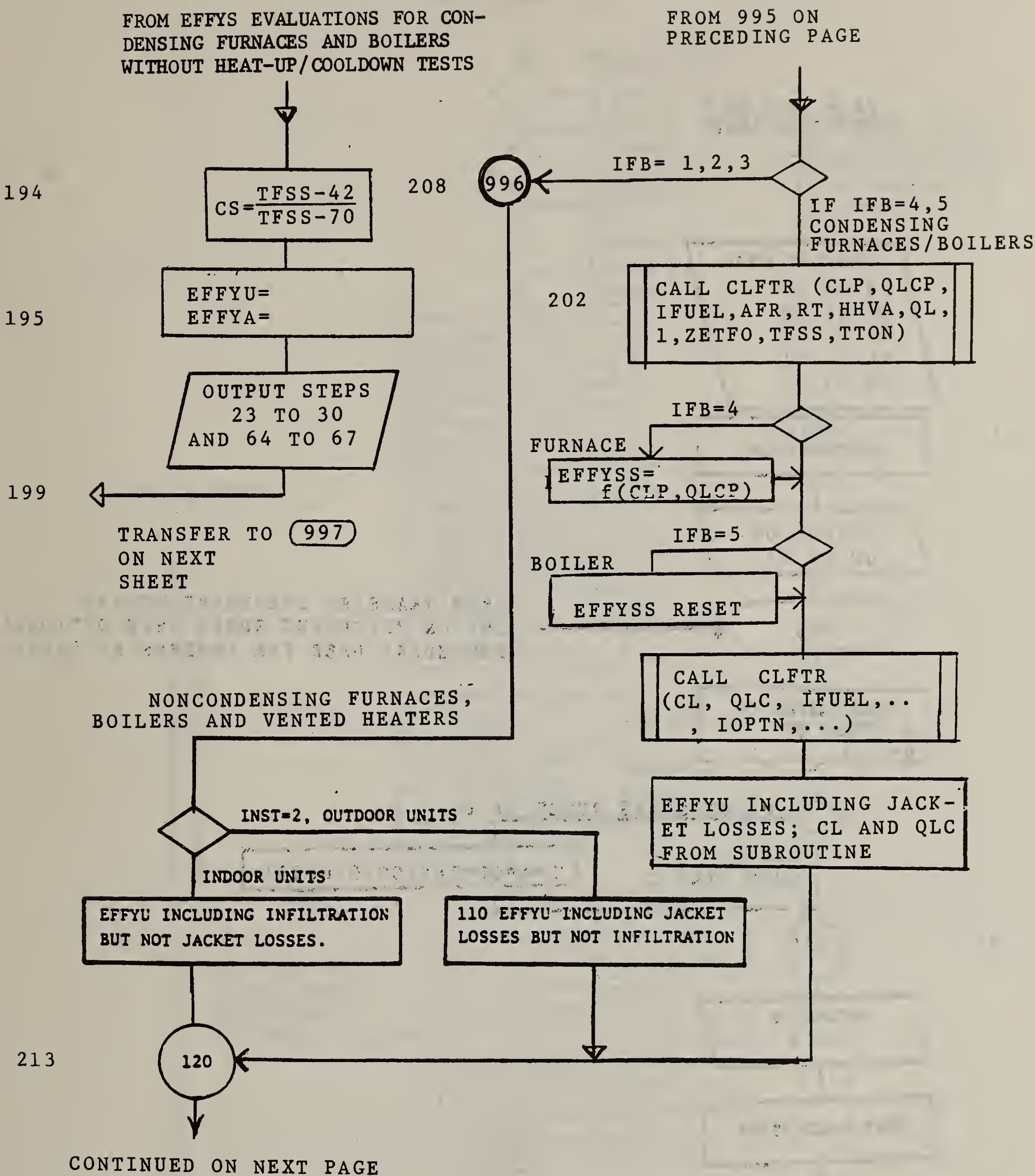
154

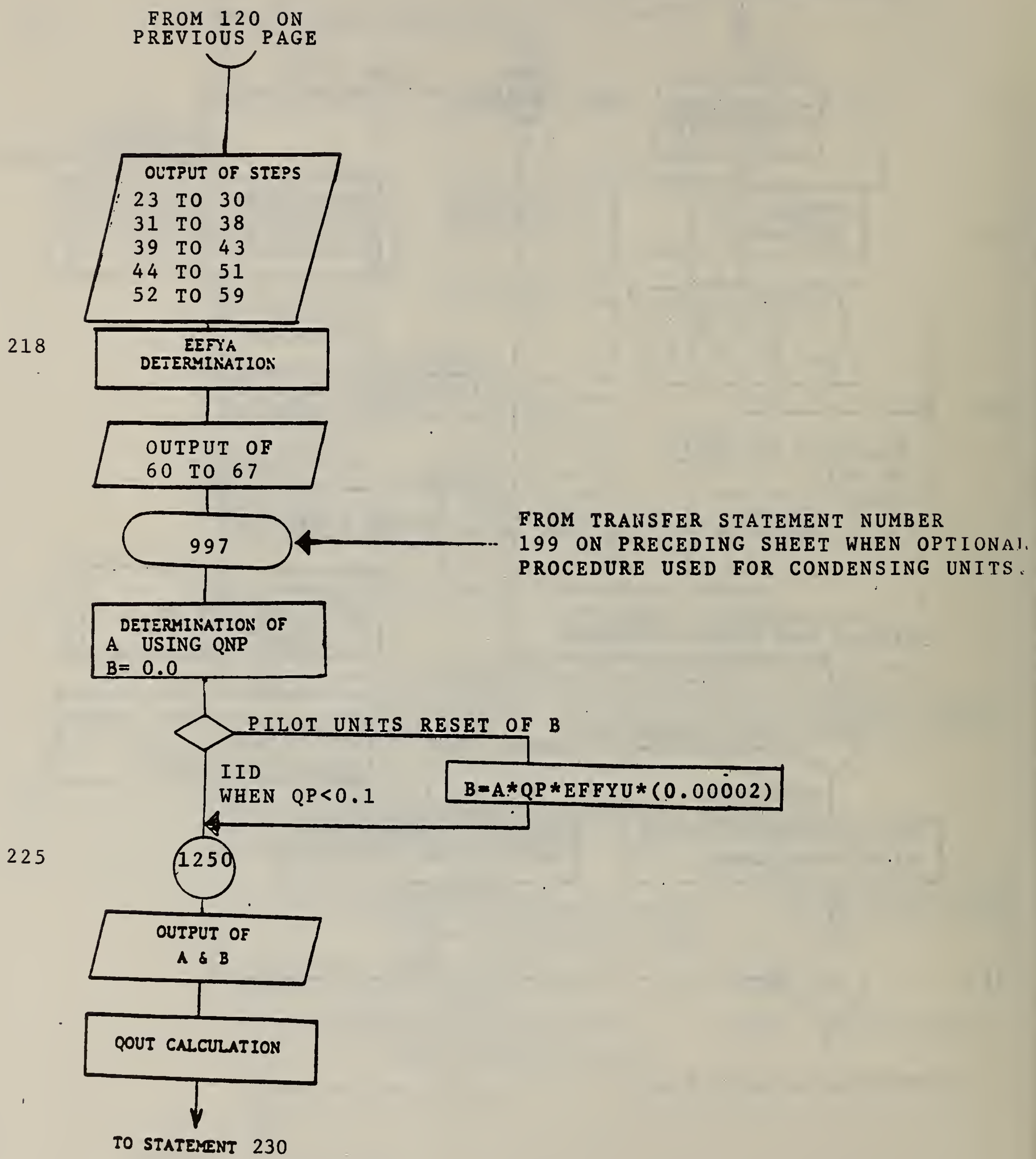
189

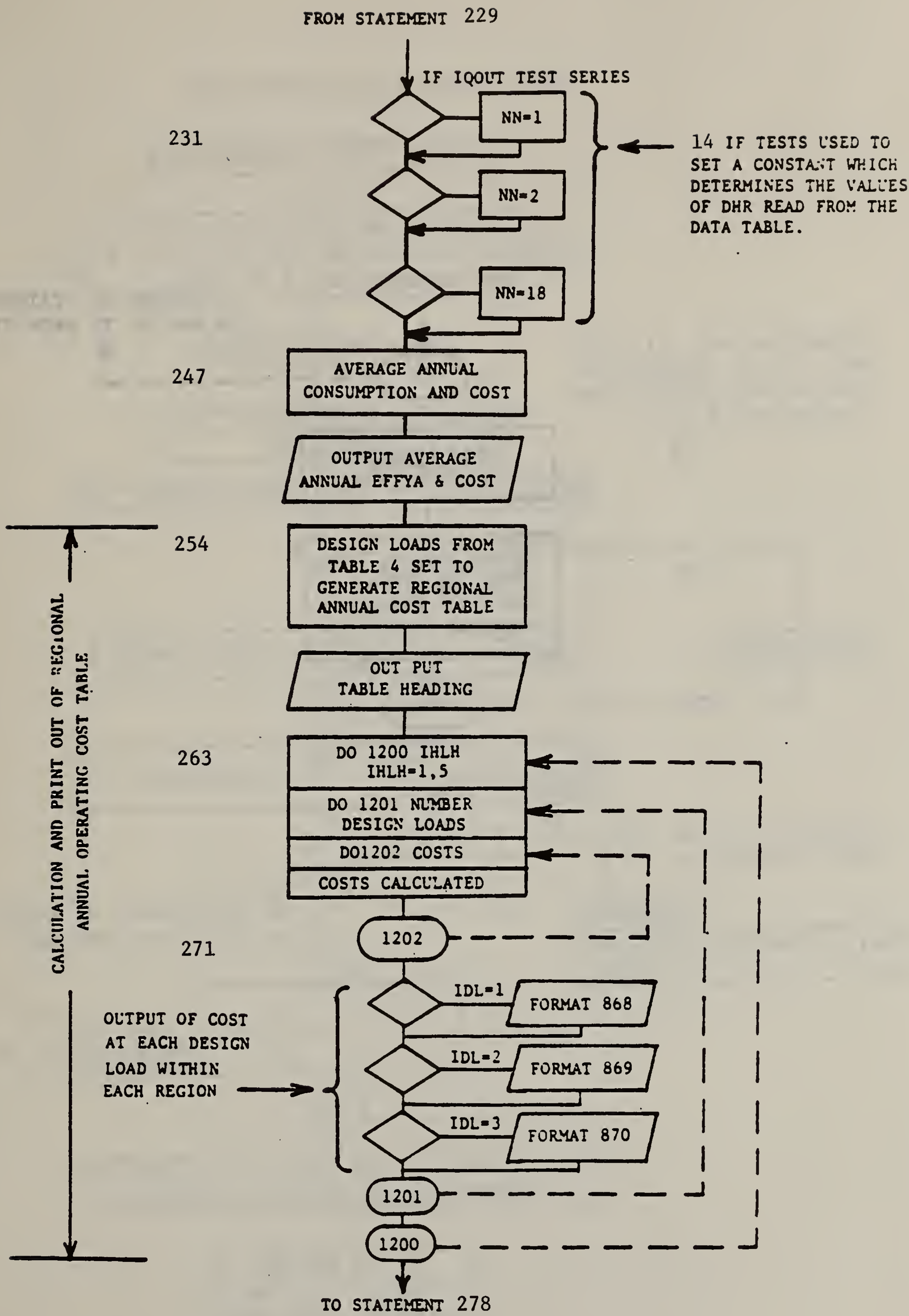
191



NSYS=9 TO 12, OUTDOOR & DIRECT VENT SYSTEMS
NSYS=5 TO 8, UNITS WITH STACK DAMPERS
NSYS=1 TO 4
100
601
178
N=4
F3, F4 = 0
N = 6
F3, F4, F7, F8 = 0
N = 6
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)
QSON, QSOFF
QION, QIOFF
QSON, QSOFF
QION, QIOFF
QSON, QSOFF
QION=QIOFF=0
FROM STATEMENT 62
105 CONTINUE
994
TRANSFER FOR CALCULATION OF CONDENSING UNITS USING OPTIONAL PROCEDURE WHERE NO OFF-CYCLE AIR FLOW PRESENT. TRANSFER BASED UPON IOPTN=1
IOPTN ≠ 1
IOPTN=1
CALL CLFTR (IOPTN=1)
THIS PATH FOR CONDENSING UNITS WITHOUT HEAT-UP/COOLDOWN TEST.
200
995
THIS PATH FOR ALL UNITS USING HEAT-UP/COOLDOWN TESTS.
IF IFB=4, FURNACE
EFFYSS RESET=f(CL'QLC')
IF IFB=5, BOILER
EFFYSS RESET
CONT. ON NEXT PAGE
CONT. ON NEXT PAGE


FROM EFFYS EVALUATIONS FOR CONDENSING FURNACES AND BOILERS WITHOUT HEAT-UP/COOLDOWN TESTS
FROM 995 ON PRECEDING PAGE
194
CS= TFSS-42 / TFSS-70
208
996
IFB= 1,2,3
IF IFB=4,5 CONDENSING FURNACES/BOILERS
195
EFFYU=
EFFYA=
202
CALL CLFTR (CLP,QLCP, IFUEL,AFR,RT,HHVA,QL, 1,ZETFO,TFSS,TTON)
OUTPUT STEPS 23 TO 30 AND 64 TO 67
IFB=4
FURNACE
EFFYSS= f(CLP,QLCP)
199
TRANSFER TO 997 ON NEXT SHEET
IFB=5
BOILER
EFFYSS RESET
CALL CLFTR (CL, QLC, IFUEL,.. , IOPTN,...)
NONCONDENSING FURNACES, BOILERS AND VENTED HEATERS
EFFYU INCLUDING JACKET LOSSES; CL AND QLC FROM SUBROUTINE
INST=2, OUTDOOR UNITS
INDOOR UNITS
EFFYU INCLUDING INFILTRATION BUT NOT JACKET LOSSES.
110 EFFYU INCLUDING JACKET LOSSES BUT NOT INFILTRATION
213
120
CONTINUED ON NEXT PAGE


FROM 120 ON PREVIOUS PAGE
OUTPUT OF STEPS
23 TO 30
31 TO 38
39 TO 43
44 TO 51
52 TO 59
218
EEFYA DETERMINATION
OUTPUT OF 60 TO 67
997
FROM TRANSFER STATEMENT NUMBER 199 ON PRECEDING SHEET WHEN OPTIONAL PROCEDURE USED FOR CONDENSING UNITS.
DETERMINATION OF A USING QNP B= 0.0
PILOT UNITS RESET OF B
B=A*QP*EFFYU*(0.00002)
IID WHEN QP<0.1
225
1250
OUTPUT OF A & B
QOUT CALCULATION
TO STATEMENT 230


FROM STATEMENT 229
IF IQOUT TEST SERIES
231
NN=1
NN=2
NN=18
14 IF TESTS USED TO SET A CONSTANT WHICH DETERMINES THE VALUES OF DHR READ FROM THE DATA TABLE.
247
AVERAGE ANNUAL CONSUMPTION AND COST
OUTPUT AVERAGE ANNUAL EFFYA & COST
254
DESIGN LOADS FROM TABLE 4 SET TO GENERATE REGIONAL ANNUAL COST TABLE
OUT PUT TABLE HEADING
263
DO 1200 IHLH IHLH=1,5
DO 1201 NUMBER DESIGN LOADS
DO1202 COSTS
COSTS CALCULATED
1202
271
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
1200
TO STATEMENT 278

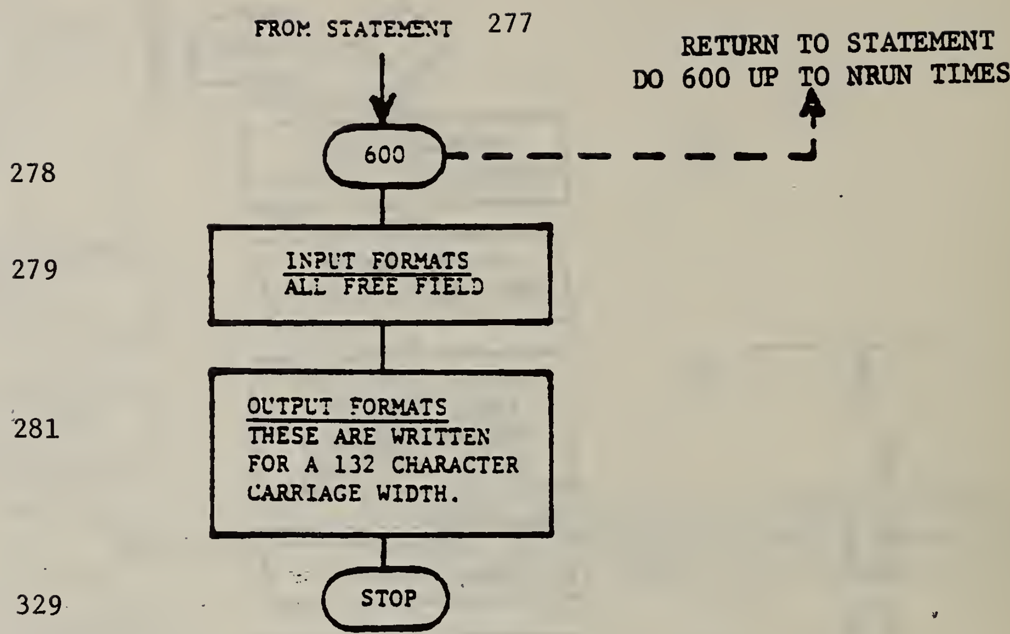

FROM STATEMENT 277
RETURN TO STATEMENT
DO 600 UP TO NRUN TIMES
278
600
279
INPUT FORMATS
ALL FREE FIELD
281
OUTPUT FORMATS
THESE ARE WRITTEN
FOR A 132 CHARACTER
CARRIAGE WIDTH.
329
STOP

FIG. B-4. SUBROUTINE CLFTR FLOW CHART

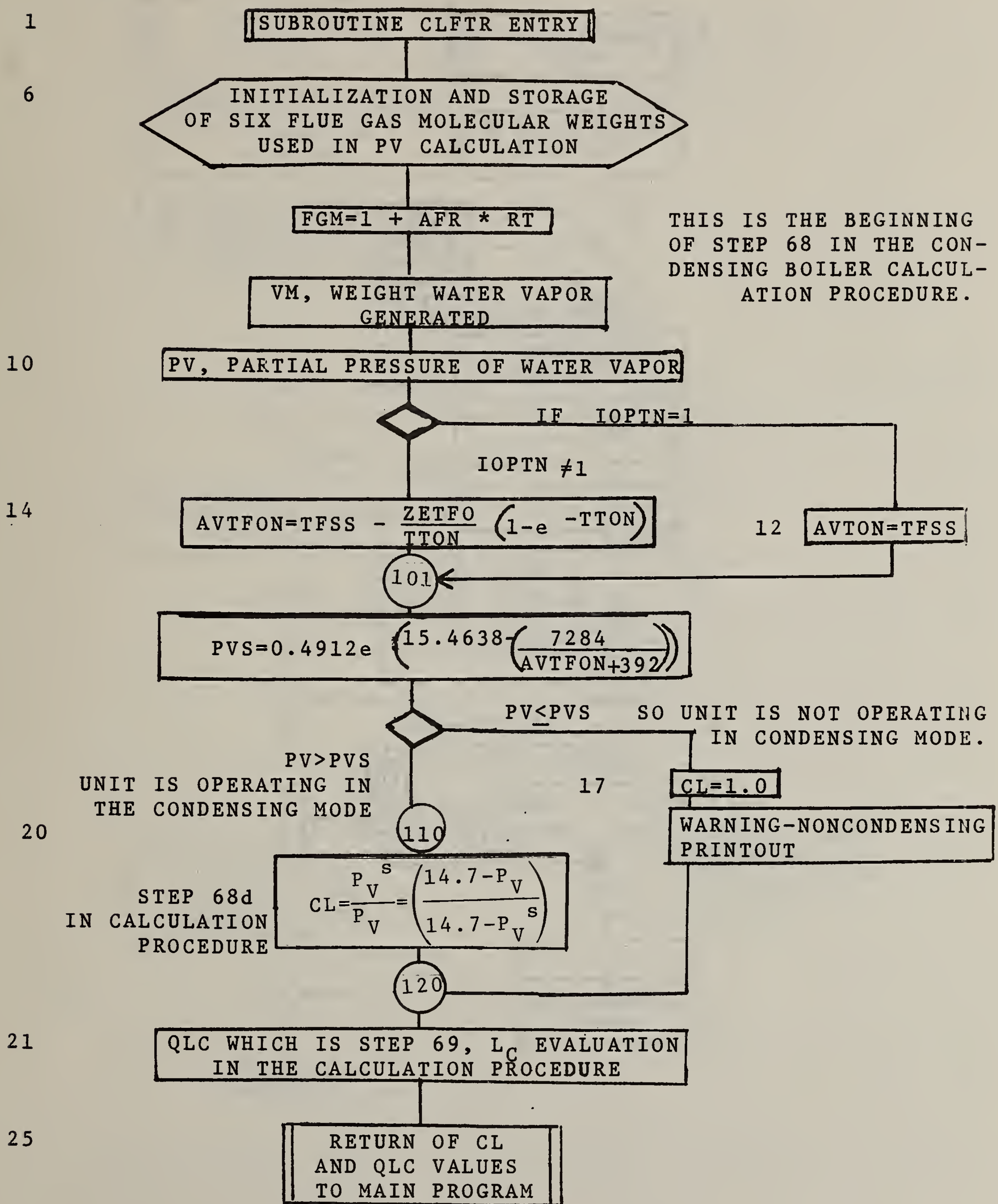


FIG. B-5. SUBROUTINE FUNT 4 FLOW CHART

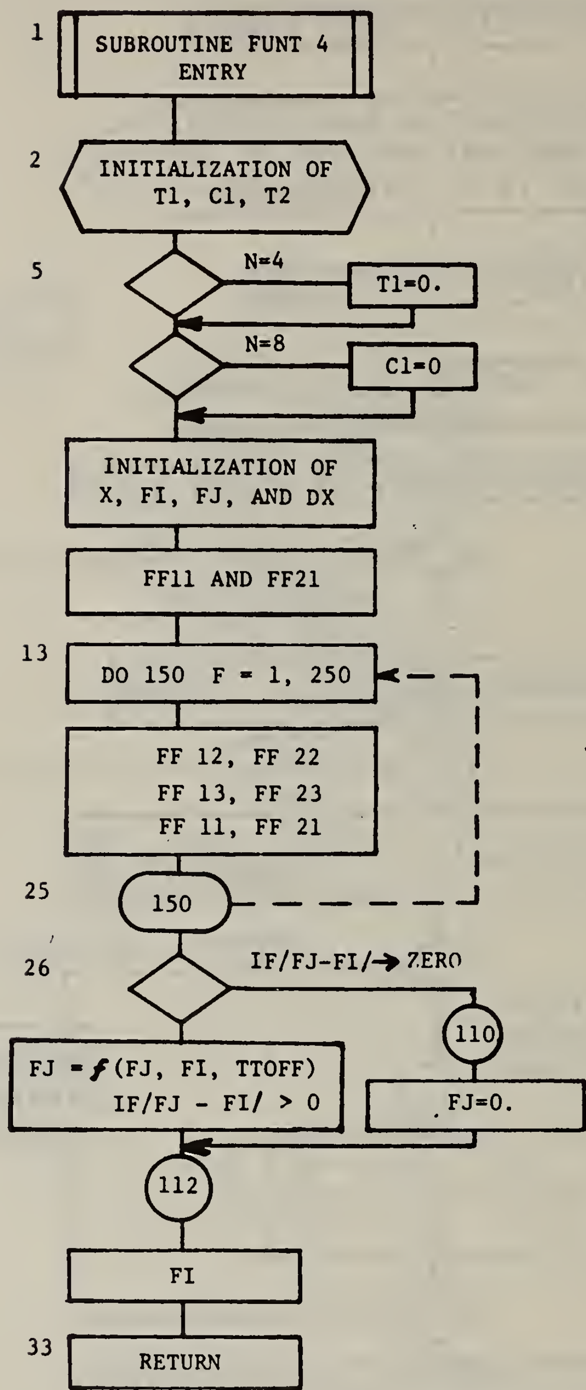
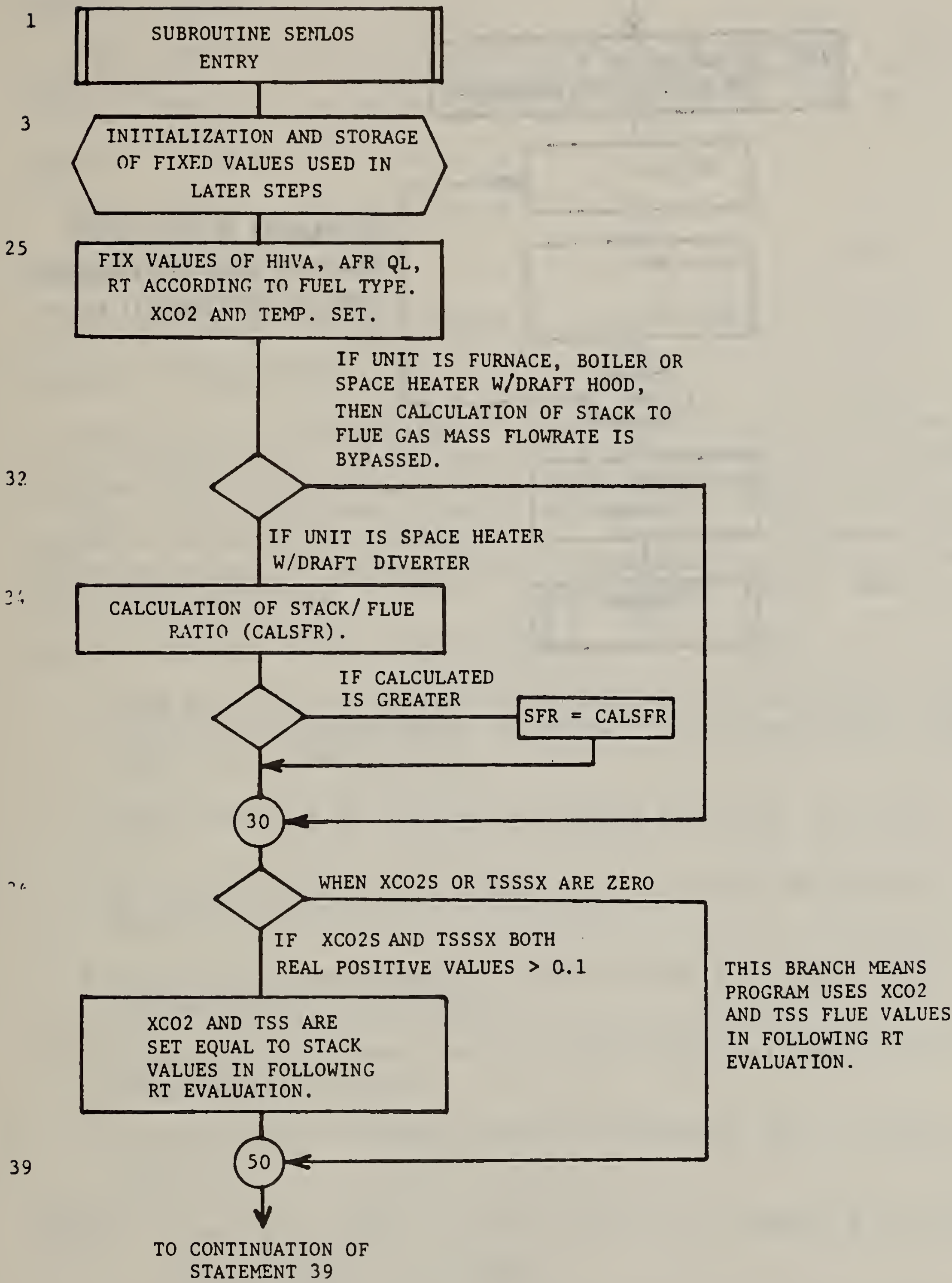


FIG. B-6 SUBROUTINE SENLOS FLOW CHART



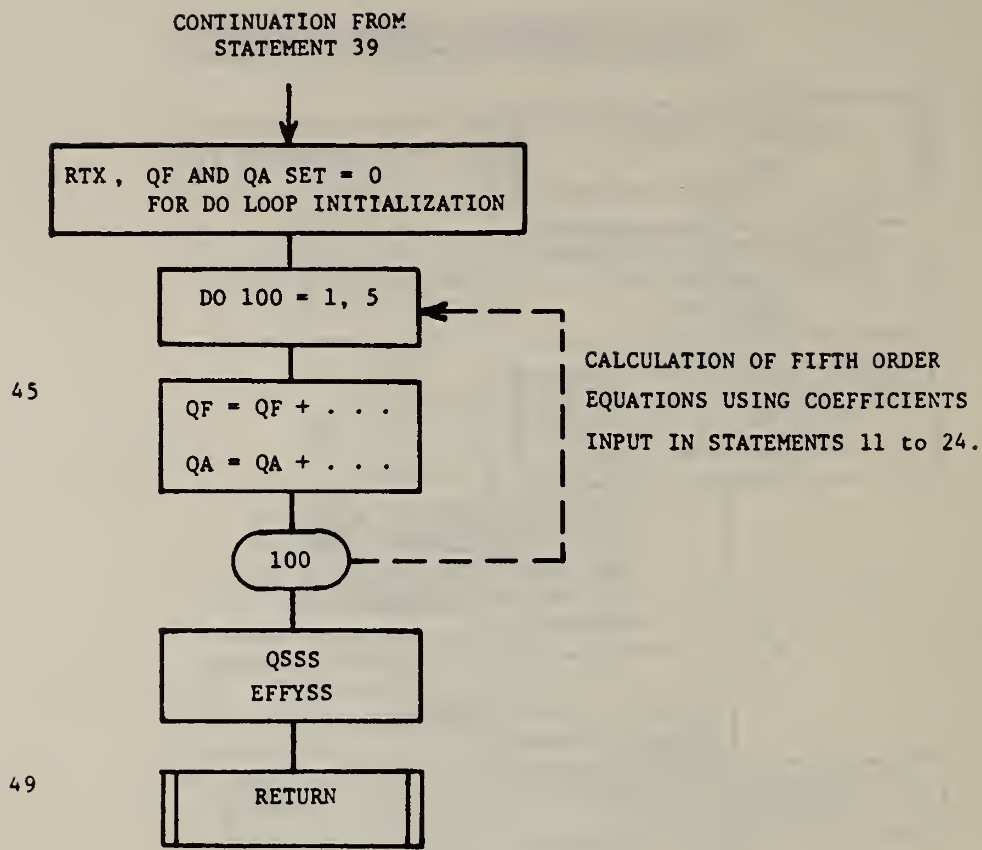

CONTINUATION FROM STATEMENT 39
RTX, QF AND QA SET = 0 FOR DO LOOP INITIALIZATION
DO 100 = 1, 5
45
QF = QF + . . .
QA = QA + . . .
CALCULATION OF FIFTH ORDER EQUATIONS USING COEFFICIENTS INPUT IN STATEMENTS 11 to 24.
100
QSSS
EFFYSS
49
RETURN

FIG. B-7. INPUT DATA CODE SHEET FOR NBSFS7

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, 3 if the unit is a vented heater, 4 if the unit is a condensing furnace, or 5 if the unit is a condensing boiler.

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. When using IFB equal to 4 or 5, INST should always be set equal to 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. Condensing systems should always be input as 9 through 12.

* IFUEL must be an integer as given as IFUEL 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 measured steady-state and pilot input rates, respectfully, in Btu/hr.

* PE and BE are power burner and blower (or pump) input powers, respectfully, in kW.

* X_{CO_2S} is the concentration by volume of CO_2 in dry stack gas, in %.

Line 6: $T_{S,SS,X}$, X_{CO_2F}, $T_{F,SS}$, $T_{F,ON}(t_1)$, $T_{F,ON}(t_2)$, $T_{F,OFF}(t_3)$, $T_{F,OFF}(t_4)$, $T_{F,OFF}(t_5)$

Input values of line six to be given in positive real numbers using units of degree F for temperatures, and percent (%) for X_{CO_2F}.

Input values for condensing units tested using optional procedure given in section 3.7 requiring no heat-up/cooldown test must have the values of $T_{F,ON}(t_1)$ through $T_{F,OFF}(t_4)$ equal to zero (0.) and IFB must be 4 or 5.

Vaporizing type oil burners must have input values of $T_{F,SS}$ equal to $T_{F,ON}(t_1)$ and $T_{F,ON}(t_2)$.

Line 7: T_{RA}, Q_J, S/F, D_F, D_S, Y, QNP

* 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 calculates 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.

* QNP is the nameplate input rate in Btu/h.

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.

Note: 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.

APPENDIX C

Using Condensate Measurement for Calculation of Annual Fuel Utilization Efficiency of Condensing Furnaces and Boilers

C1. Background

An alternative test and calculation procedure to that presented in the main body of this report is discussed within this Appendix. This condensate collection procedure is considered to be a viable evaluation method for distinguishing the relative efficiency of one unit to another only if great care is taken to be consistent in the design and operation of the test setup in which each unit is evaluated. Therefore, it is a procedure that might best be conducted on a single test rig with the same experienced personnel.

Condensate collection can be used in conjunction with the test procedures for non-condensing heating systems to estimate the efficiencies of condensing furnaces and boilers[1]. The steady-state, cool-down, and heat-up tests are required. Condensate is collected during a cyclic operation test. The quantity of collected condensate is used to determine the latent heat gain due to flue gas water vapor condensation as it is recovered within the confines of the furnace or boiler and not the flue or stack. The percent heat gain is then added to the non-condensing Annual Fuel Utilization Efficiency (AFUE) to estimate the condensing Annual Fuel Utilization Efficiency. Details of test procedures for condensate collection and evaluation are given in the following sub-sections.

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[1] Federal Register, Volume 45, No. 252, Wednesday, December 31, 1980, pp. 86526.

C2. Condensate Collection Instrumentation

The test unit shall be installed according to the requirements given in section 2. Control devices shall be installed to allow cyclic operation of the unit and return water or air flows as described in sections 3.2 and 3.3 of this recommended procedure. The test unit shall be leveled prior to test. Operation times and beginning and end of condensate collection shall be determined by a clock or timer with a minimum resolution to one second. Control of on and off operation actions shall be within ±6 seconds of the scheduled time. Condensate drain lines shall be attached to the unit as recommended by the manufacturer.

The flue pipe installation must not allow condensate formed in the flue pipe to flow back into the unit. An initial downward slope from the unit's exit, an offset with a drip leg, annular collection rings, or drain holes must be included in the flue pipe installation without disturbing normal flue gas flow (as given in section 2.2), and temperature measurement instrumentation (as given in section 2.6). Flue gases shall not flow out of the drain with the condensate.

Collection-containers must be glass or polished stainless steel, so removal of interior deposits can be easily made. The collection-container shall have a vent opening to the atmosphere.

The scale for measuring the containers and condensate sample mass shall be calibrated with an error no larger than ±0.5 percent over the range of interest.

C3. Cyclic Test Method for Condensate Collection

The condensing furnace or boiler is to have steady-state, cool-down, and heat-up tests conducted by the procedures for non-condensing units given in NBSIR 78-1543 section 3, using the flue gas, air or water flow, and room ambient conditions given in section 2 of the condensing furnace and boiler test procedure. The condensate collection containers shall be dried prior to each use and be at room ambient temperature prior to a sample collection. Tare weight of the collection-container must be measured and recorded prior to each sample collection.

Operating times for on and off cycles at 22.5% on time schedule shall be 9 minutes 41 seconds on and 33 minutes 16 seconds off for boilers and 3 minutes 52 seconds on and 13 minutes 20 seconds off for furnaces.

The unit should be operated in a cyclic manner until flue gas temperatures at the end of each on-cycle are within 5°F (2.8°C) of each other for two consecutive cycles. Then begin the three test cycles. Return water temperature for boilers or return air temperature for furnaces shall be equal to those required for steady-state test periods, and shall remain within the limits given in sections 2.5.1 and 2.5.2 of this procedure. Operation of the furnace blower or boiler pump shall conform to time delay requirements given in sections 3.2 and 3.3 for cool-down and heat-up tests.

Begin condensate collection at one minute before start up of the first test on-period. Three cycles later, the container shall be removed at the end of the cool down cycle one minute prior to the beginning of what would be the fourth cycle period. Condensate mass shall be measured immediately at the end of collection period to prevent evaporation loss from the sample.

Fuel input shall be recorded during the entire test period starting at the beginning of the on-time of the first cycle to the beginning of the on-time of the second cycle, etc., for each of the three test cycles. Fuel Higher Heating Value (HHV), temperature and pressures necessary for determining fuel energy input, Q_c, will be observed and recorded. The fuel quantity and HHV shall be measured with errors no greater than one percent.

C4. Recommended Procedure for Calculating Annual Fuel Utilization Efficiency Using Collected Condensate Techniques

Using the conditions for a condensing furnace or boiler, and the procedure for the steady-state, cool-down, heat-up of the non-condensing furnace or boiler; calculations shall be performed to determine the Annual Fuel Utilization Efficiency (AFUE) (Col. 67). The calculation steps for the non-condensing procedure are presented in section 4 of NBSIR 78-1543 [1] using a direct vent system number.

To determine the AFUE for the condensing units, use the following steps:

(1) Determine the mass of condensate for three cycles, m_c, by subtracting the tare container weight from the total container and condensate weight at end of three cycles of operation.

(2) Calculate the fuel energy input during the three cycles, Q_c, in Btu/(3 cycles).

(3) Calculate the heat gain due to condensation, L_G, in percent by the following equation:

$$L_G = \frac{m_c \text{ (lbm/(3 cycle))} \times 1053.3 \text{ (Btu/lbm)} \times 100}{Q_c \text{ (Btu/(3 cycle)}}$$

(4) Calculate the loss L_c due to hot condensate going down the drain correcting for the fact that this condensate did not go up the flue as heated vapor.

$$L_c = \frac{L_G}{1053.3} \times (1.0\ (T_{F,SS}\ \text{(Col. 11)} - 70) - 0.45\ (T_{F,SS}\ \text{(col. 11)} - 42))$$

(5) Calculate the condensing AFUE by adding the percent heat gain due to condensation, L_G, to the previously calculated non-condensing AFUE (col. 67), and by subtracting the loss L_c.

Condensing AFUE = non-condensing AFUE (col. 67) + L_G - L_c.

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15. SUPPLEMENTARY NOTES

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

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

Procedures are developed for testing and rating the performance of residential central furnaces and boilers of the condensing type. A condensing furnace or boiler is a unit designed to condense part of the water vapor generated by the burning of hydrogen in the fuel and equipped with a means of draining this condensate. The test procedure is similar to one developed by the National Bureau of Standards for the Department of Energy covering non-condensing central heating equipment, except that it requires slightly tighter control of the laboratory temperature, a return water temperature of 120°F (48.9°C) with a 20 degree Fahrenheit (11.1 degree celsius) water temperature rise for hot water boilers, and offers an optional test procedure for condensing units having no off-period losses. The rating procedure provides a method for estimating the steady-state, part-load and annual fuel utilization efficiencies of condensing furnaces and boilers. It accounts for the fact that the latent heat loss for a condensing unit is smaller than for a conventional furnace or boiler, since some of the water vapor generated from burning hydrogen in the fuel is condensed and thereby gives up part of its latent heat to the heat exchanger and jacket.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*
Annual fuel utilization efficiency; annual operating costs; central heating equipment; condensing boilers; condensing furnaces; part-load performance; rating procedure; seasonal efficiency.

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