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*College of Engineering and Applied Sciences, State University of New York, Stony Brook, N.Y. 11794

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Abstract

The seasonal operating cost of a small oil or gas-fired boiler or furnace depends upon the intrinsic merits of the device itself, the appropriateness of its capacity and cycle characteristics to the imposed load conditions, the weather characteristics and heat loss characteristics of the building being heated, and the control philosophy employed. The current study provides the bases for comparing quantitatively the seasonal operating costs of various specific space heating and/or domestic hot water systems, as influenced by the device specifics and device interaction with the space conditioned system that it serves. The resulting formalism is applied to various space heating systems. Quantitative cost comparisons are presented.

I. INTRODUCTION AND BACKGROUND

The cost effective performance of an oil or gas-fired boiler or furnace depends upon a number of factors. Some of these factors are characteristics solely of the boiler/furnace under consideration.[1] Other factors pertain to the coupling mechanisms (e.g., water lines, air ducts, etc.) between energy conversion device and the conditioned space it serves. Still other factors pertain to the merits of the "sizing" of the energy conversion device and its appropriateness when measured against the enthalpy flow demands imposed by the structure it is required to serve.[2,3]

One may assess the effectiveness of a structure's design and operating strategy in making optimum use of a given boiler/furnace system. Analyses with these emphases are given elsewhere.[1,3] The purpose of this analysis is to provide the bases for comparing the seasonal operating costs of various specific space heating and/or domestic hot water systems, as influenced by the device specifics <u>and</u> device interaction with the space conditioned system it serves.

A given space conditioning device can have its intrinsic merits evaluated in a laboratory. Thus, for example, an oil-fired boiler's efficiency is generally characterized in terms of its steady state efficiency, η_s, and its cycle efficiency <u>curve</u>. Studies have shown η_s to be a function of a number of operating parameters. It is generally found that η_s increases with reduced firing rate and that η_s increases with reduced boiler temperature (Figures 1 and 2). The cycle efficiency curve (cycle efficiency vs. fractional burner "<u>ON TIME</u>") is found to be well defined, once the various operating parameters (including the ON/OFF control philosophy and a characteristic ON TIME) are fixed. Cycle efficiency curves shown for three different oil-fired boilers, subject to an operating philosophy and a characteristic ON TIME which is typical for (frame construction) residential dwellings (Figure 3). We have previously shown[3] that high mass (masonry construction) structures, insulated exterior to the high mass shell, will provide very long ON TIMES and cycle efficiency values very close to unity.

Accordingly, devices which display very high η_s values and η_c curves which stay close to unity, even as the fractional ON TIME falls are considered to be of high merit (high efficiency). Based on laboratory measurements, then, the intrinsic figures of merit of the space heating device (boiler) are determinable.

The seasonal performance of such a well-studied device is not determinable on the basis of laboratory measurements alone. Seasonal performance is ultimately measured, by the consumer, in terms of operating costs for the installed device, serving a specific house, in a specific city, during a specific heating season, subject to the infinitude of house variables (house size, shape, degree of insulation, wind exposure, solar exposure, airtightness, internal heat sources, venting, sight topography, landscaping effects, etc.) as well as variables pertaining to the wisdom of the heating systems' installation (line losses, design firing rate, use/nonuse of conditioned air for combustion, etc.) and servicing (cleanliness of boiler, fuel nozzle cleanliness, etc.). One can assess the performance of a laboratory tested device (as well as a nontested one) in a specific situation (specific house, installation, city, heating season, subject to the vagaries of a specific family's operation of their home) by recording the total seasonal energy usage (and the associated costs) for space heating. A knowledge of the boiler's efficiency characteristics is not needed to make such an in the field determination.

In this work we apply laboratory derived efficiency measurements to

1. estimate the expected seasonal performance (cost) of a properly installed (and serviced) space heating device--when coupled to a structure whose standard thermal features are to be characterized.
2. compare the effects of device efficiencies (η_s and η_c) on the expected seasonal performace (cost).

As noted earlier, the expected in-the-field seasonal performance can be influenced by a very large number of factors.

In-the-field determination of seasonal costs vary from installation-to-installation and require total energy usage (and cost) data, not necessarily efficiency data. The intrinsic efficiencies of a given oil-fired boiler may be central to the seasonal performance of a given installation, but seasonal performance pertains to the entire system properties (house with all its subsystems and interactions) and not to the space-heating source alone.

It is thus clear that any analytic model designed to evaluate the seasonal performance of a space-heating system must include certain features. Without these features adequately specified, the system itself will be found to be inadequately specified. These are found to be the system (house) characteristics necessary to specify the seasonal operational history (and energy usage history) of the space heating device. It is the space heating device's seasonal operating (and energy usage) history which determines seasonal cost. In this work, we include only those system (house plus subsystem plus interactions) characteristics which are "necessary." Our definition of "necessary" embraces the following:

1. A specified design heat load for a frame structure.
2. An hourly temperature history (and heating load) for the structure.
3. Specifics of the domestic hot water load that the system (house) is to require.
4. The intrinsic merits and the operating characteristics of the oil-fired device that serves the overall system (the structure).

The above four features are "necessary" to any adequate analytic model. One may also consider one or more of the very many constraints which (in an in-the-field installation) may serve to degrade "seasonal performance." As detailed earlier, these include duct/line losses, unwise house venting, unwise boiler installation (e.g., use of conditioned air for combustion and off-cycle stack venting), etc.... If we were to include these features, however, we would be including unnecessary features. Their inclusion would obfuscate the purposes of the analysis. Our purpose is to provide an assessment of the seasonal performance of a specific system (house) employing a wisely installed and properly operated, specific oil-fired boiler under specified seasonal load conditions.

Thus, the myriad additional interactions which are capable of degrading a system's performance are taken to be "unnecessary." Wise installation and proper maintenance and operation would eliminate them. Their inclusion would detract from our central purposes--to rationally evaluate and compare the seasonal performances of a specific characteristic system (house), as determined by necessary feature 4, the intrinsic merits of the device--properly and wisely installed, operated and maintained.

Before proceeding with this analysis, we recognize the existence and importance of other studies[4,5] whose purposes are to identify and evaluate the many ways in which unwise installations and operational constraints can (unnecessarily) degrade seasonal performance. Those studies have helped us understand the costs incurred by unnecessarily degraded systems.

II. ENTHALPY BALANCES AND SEASONAL USAGE OF FUEL

The seasonal performance of a given boiler/furnace-heated system (structure with all its subsystems) is measured in terms of the seasonal heating energy costs for the system. We may use this seasonal performance (cost) as an installed figure of merit for the boiler/furnace subsystem if the installation is fully comparable to that which applies to the determination of an installed figure of merit for some competitive system (boiler, furnace, heat pump, etc.). Without standardization of this kind, comparison of two figures of merit (e.g., for two competing space heating devices) would have little meaning.

To derive such a figure of merit, we consider first the energy delivery rate of a boiler/furnace of interest--as it interacts with the hourly demands of the heated structure it is designed to serve.

$$\dot{m}_f \eta_c \eta_s \Delta_c + \sum_{\mu} S_\mu = L + H_o \quad , \quad \text{for } T_c < T^* \tag{1}$$

Symbol definitions appear in a nomenclature section.

In equation (1), the hourly load, L, does not include all the source and sink terms that may be other than linear functions of the dimensionless temperature difference, T. These terms appear in the summation, $\sum S_\mu$, and may include such diverse sources as the heating output of kitchen appliances, electric lighting, the energy output of living occupants, etc. $\sum S_\mu$ may also include such diverse sinks as venting of conditioned air by unwisely installed boilers/furnaces, by externally vented clothes dryers, bathroom and kitchen vents, etc.

In order to provide a figure of merit for a given <u>installed</u> piece of equipment, unencumbered by unnecessary building characteristics, we consider the heating device of interest to interact with a building system for which $\sum S_\mu \equiv 0$. Equation (1) may then be rewritten:

$$\dot{m}_f \eta_c \eta_s \Delta_c = \mathcal{X}_d T + H_o \quad , \quad \text{for } T_c < T^* \tag{2a}$$

Corresponding steady state conditions give

$$\dot{m}_{f,d} \eta_s \Delta_c = \left(\mathcal{X}_d + H_o\right)\alpha \tag{2b}$$

The "overfiring ratio" generally has a value, $\alpha > 1$, reflecting considerations of domestic hot water supply. It has been shown elsewhere[2,4] that α should be taken as small as possible, in order to assure optimum overall efficiency ($\bar{\eta}$) values.

Note that for commonly encountered[2,3] operating cycles (frame structures) one can correlate η_c as a function of the ratio ($\dot{m}_f/\dot{m}_{f,d}$). Thus, for a given characteristic ON TIME (cycle characteristic)

$$\eta_c = \phi(\dot{m}_f/\dot{m}_{f,d}) \tag{3}$$

where the functional dependence of equation (3) is determined in the laboratory for any given piece of apparatus. Inasmuch as[2,3]

$$\bar{\eta} = \eta_c \eta_s \tag{4}$$

it follows that $\dot{m}_f$ enters equation (1) in a nonlinear fashion. Combining (2a) and (2b) gives for ($T_c < T^*$):

$$\dot{m}_f = \left[\frac{\dot{m}_{f,d}}{\alpha \eta_c} - \frac{H_o}{\Delta_c \bar{\eta}} \right] \left[\frac{T^* - T_c}{T^* - T_d} \right] + \frac{H_o}{\Delta_c \bar{\eta}} \tag{5}$$

Thus, during any given hour characterized by $T_{c,i}$, the actual fuel mass flow rate is

$$\dot{m}_{f,i} = \left[\frac{\dot{m}_{f,d}}{\alpha \eta_{c,i}} - \frac{H_o}{\Delta_c \bar{\eta}_i} \right] \left[\frac{T^* - T_{c,i}}{T^* - T_d} \right] + \frac{H_o}{\Delta_c \bar{\eta}_i} \tag{6}$$

Given n_i hours per season which have a characteristic temperature, $T_{c,i}$ (where $T_{c,i} < T^*$ for all i) we may write the resulting total fuel usage

$$\dot{m}_{f,i}n_i = \left[\frac{\dot{m}_{f,d}}{\alpha\eta_{c,i}} - \frac{H_o}{\Delta_c\bar{\eta}_i}\right]\left[\frac{T^*-T_{c,i}}{T^*-T_d}\right] n_i + (H_o n_i)/(\Delta_c\bar{\eta}_i) \tag{7}$$

Then, summing over $T_{c,i} < T^*$ values, the total annual heating season fuel usage is obtained

$$M_1 = \sum_i \dot{m}_{f,i}n_i = \sum_i \left\{\left[\frac{\dot{m}_{f,d}}{\alpha\eta_{c,i}} - \frac{H_o}{\Delta_c\bar{\eta}_i}\right]\left[\frac{T^*-T_{c,i}}{T^*-T_d}\right] n_i\right\} + \sum_i (H_o n_i)/(\Delta_c\bar{\eta}_i) \tag{8}$$

In order to obtain the corresponding total annual fuel usage M_2, for the nonheating season, we note that for $T_c \geq T^*$

$$\dot{m}_f^* \bar{\eta}^*\Delta_c = H_o \tag{9}$$

where $\bar{\eta}^*$ is a nonlinear function of $\dot{m}_f$. Thus, the total mass of fuel used for domestic hot water (nonheating season) is given by

$$M_2 = \frac{H_o n^*}{\eta_c^*\eta_s\Delta_c} \tag{10}$$

Correspondingly, for a "perfect" system ($\eta_c = \eta_s = 1$)

$$(M_2)_p = \frac{H_o n^*}{\Delta_c} = M_2\eta_c^*\eta_s \tag{11}$$

The total mass of fuel used during the year is given by

$$M = M_1 + M_2 \tag{12}$$

where the specific cost data may be used to calculate (from equation (12)) the seasonal cost for fuel oil. To this cost must be added the seasonal costs of all electrically energized auxiliary equipment (oil pump, air fan, water circulator).

We may also define a Seasonal Performance Factor (SPF) in terms of (M/M_p), where M_p is the fuel mass that would have been consumed by a (physically unobtainable) "perfect" system ($\bar{\eta} = 1$). To find the value of

$$M_p = (M_1)_p + (M_2)_p \tag{13}$$

We note that $(M_1)_p$ and $(M_2)_p$ are obtained from equations (8), (10), and (11).

The Seasonal Performance Factor may be taken as a "figure of merit." We may then choose to define it as follows:

$$(SPF) \equiv \frac{M_p}{M} \tag{14}$$

We will find that the (SPF) so defined is <u>not needed</u> in order to calculate seasonal operating costs for energy usage. Rather, the (SPF) so defined may be used as a measure of the direct fossil fuel usage efficiency--not including the costs that derive from the use of electrically energized components.

III. MODE OF APPLICATION

Seasonal performance (cost) is calculated directly from a knowledge of the fossil fuel (and electrical) energy consumed by the installed space heating device, interacting with the characteristic structure it serves. Laboratory-determined values of (η_s) and (η_c) are employed in the calculation of seasonal performance of several oil-fired boiler systems. Such application may proceed, calculationally, in a number of ways. Consider, for example, that equation (6) can be rewritten as

$$(\eta_{c,i})\left(\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}\right) = \left[\left(\frac{1}{\alpha}\right) - \frac{H_o}{\Delta_c \eta_s \dot{m}_{f,d}}\right]\left[\frac{T^* - T_{c,i}}{T^* - T_d}\right] + \left[\frac{H_o}{\Delta_c \eta_s \dot{m}_{f,d}}\right] \quad (15)$$

or

$$\Lambda_i = \mathfrak{A}_i$$

where (Λ_i) is the left-hand side of equation (15). $(\mathfrak{A}_i)$ is the right-hand side of equation (15). For an installed piece of equipment, we generally have the following information: The design heat load, $\mathcal{X}_d$; the average hourly domestic hot water to be provided, H_o; the heat of combustion of the fuel, Δ_c; the (laboratory ascertained) value of the steady state efficiency, η_s; and the firing rate ("nozzle size" in hourly mass flow rate), $\dot{m}_{f,d}$. Accordingly, we calculate the "overfiring ratio," α, from equation (2).

For a given outside temperature, $T_{c,i}$, a given (design) interior temperature T^* and a given (design) outside temperature, T_d, we find that the right-hand side of equation (15), $\mathfrak{A}_i$, is fully specified and calculable. The cycle efficiency, η_c, is found to be a simple monotonic function of the burner fractional on time $(\dot{m}_f/\dot{m}_{f,d})$. Accordingly, one may use laboratory determined curves (such as those shown in Figure 3) of (η_c) vs. $(\dot{m}_f/\dot{m}_{f,d})$ to determine the unique product $(\eta_{c,i})(\dot{m}_{f,i}/\dot{m}_{f,d})$ which satisfies the left-hand side of equation (15),

$$\Lambda_i = (\eta_{c,i})(\dot{m}_{f,i}/\dot{m}_{f,d})$$

Thus, for any given exterior hourly temperature, T_i, the corresponding cycle efficiency, $(\eta_{c,i})$, <u>and</u> the hourly mass flow rate, $(\dot{m}_{f,i})$ are easily found.

Equation (15) is similarly applied for each possible hourly temperature of interest, $T_{c,i} = (T_d), (T_d+1), (T_d+2), \ldots (T^*-1)$. This yields a table of values of $(\eta_{c,i})$ and $(\dot{m}_{f,i}/\dot{m}_{f,d})$ as a function of outside temperature.

Examination of the weather data for any given locality, during any given heating season, permits the tabulation of a chart of (n_i) values--the number of seasonal heating hours that correspond to each value of the outside temperature, $T_{c,i}$. Thus, all necessary hourly data are available for calculation of the summation given by equation (8)--the total mass of fuel used during the heating season, M_1. To find the total mass of fuel used over a twelve-month period (for both heating and domestic hot water) one adds the total mass of fuel used for domestic hot water during the nonheating season, M_2. Thus equation (12) yields the total twelve-month usage of fossil fuel for heating and domestic hot water.

The total annual energy costs for the system are given by

$$C_t = MC_m + C_e\left\{\left[\sum_i \left(\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}\right) n_i \omega_H\right] + \left[\left(\frac{\dot{m}_f^*}{\dot{m}_{f,d}}\right) n^* \omega_S\right]\right\} \qquad (16)$$

where the first term on the right-hand side of (16) gives the annual fossil fuel costs and the final cluster of terms gives the annual electrical costs (pumps, fans, circulators, etc.).

IV. SOME APPLICATIONS TO OIL-FIRED BOILERS

The seasonal performance formulation may be applied to any fossil fuel-fired system, once we specify

- hourly (design) firing rate
- design heat load for the structure (conditioned space)
- the structure's weather experience during the period of interest (n_i vs. $T_{c,i}$)
- the design domestic hot water load
- design indoor temperature
- the (laboratory determined value of) steady state efficiency
- the (laboratory determined curve of) cycle efficiency vs. fractional on time, for a given operational mode.

The formulation has been applied to the cases of three different boiler systems, each serving a structure for which χ_d = 50,000 Btuh. Hourly weather data were taken[6] for a ten-year (hour-by-hour) average for the Metropolitan New York City area. In all cases, propper installation, service and maintenance are assumed to apply. Further discussion of these calculations is given in the Appendix.

The three boiler systems studied are each commercially available units. In order of decreasing performance, they are designated to be boilers [A], [B], and [C], respectively. Figures (2) and (3) give the steady state and cycle efficiency data employed in this calculation. Data for Figures (2) and (3) were determined in the laboratories of Brookhaven National Laboratory.

Tables (1)-(3) give the total annual fossil fuel usage (in gallons of number 2 fuel oil per year) for a number of overfiring ratios and domestic hot water loads. We note that $\alpha = 1$ usage corresponds to number 2 fuel oil firing rates which are lower than 0.75 gals/hr. Rates below 0.75 gals/hr are smaller than those characteristically encountered in the field, although equipment currently under test at BNL can be utilized at these low firing rates. All cases of $\alpha = 2$ or $\alpha = 3$ correspond to firing rates greater than 0.75 gals/hr.

It is clear that Boiler [A] is better than Boiler [B], which is in turn better than Boiler [C]. One may assess the seasonal efficiency of each of these boilers (based on the efficiency in the direct use of fossil fuel energy alone) by determining the appropriate Seasonal Performance Factors. As noted earlier, such SPF values are not needed in order to calculate seasonal costs (from equation (16)), which must include electrical energy costs as well. Nevertheless, such SPF values are useful bases for comparison of the installed seasonal efficiencies (based on oil usage only) of oil-fired boilers. Seasonal Performance Factors for Boilers [A], [B], and [C] are shown in Tables (4)-(6). Summer only SPF values are distressingly low. Nevertheless, these low (summer only) values have only a modest effect on the annual SPF (overall twelve-month period). This result derived directly from the fact that summer, highly inefficient fuel oil usage consumes only a small fraction of the (overall) annual fuel oil usage.

One may also compare the possible range of seasonal direct fossil fuel usage rates by normalizing the values of Tables (1)-(3) in terms of the minimum value (993 gals of number 2 fuel oil) obtained. Table 7 gives the Direct Annual Fossil Fuel Usage Ratios for Boilers [A], [B], and [C].

Examination of the tabulated results, Tables (1)-(7), shows that the performance of Boiler [A] benefits both from its very fine (η_s) value as well as from its very desirable (η_c) vs. ($\dot{m}_f/\dot{m}_{f,d}$) curve (Figure 3). Also, for currently available firing rates Boiler [A] can provide seasonal efficiencies in the range of (76.6% to 78.5%).

Contrasting to the best performance of [A], we find that Boiler [C] may have seasonal efficiencies that are substantially lower.

It is important to recall that all calculations presented are based on the assumption of wise and proper installation, maintenance, servicing, and cleaning of all equipment.

As has been noted elsewhere,[1,2,4,5] improper/unwise installation, sizing, operation, maintenance and servicing can degrade the performance of any space conditioning system--including the ones studied here.

In order to calculate the annual energy operating costs for each of these boilers, one must know

1. the number of kilowatt-hours of electrical energy used by each device; when its oil pump, circulator, fan, etc. is operating
2. the annual number of hours during which each such component operates, for each device

3. the cost of electrical energy, per killowatt hour

4. the cost of number 2 fuel oil, per gallon.

Item (2) is derivable from the analysis previously presented. Consequently, item (1) is directly calculable. Items (3) and (4) may vary, according to locale, customer usage pattern, and with the other numerous factors which affect the pricing of electrical energy. Tables (8)-(10) show the electrical energy usage patterns for Boilers [A], [B], and [C] respectively. Although variations in installations may be expected, the following typical power consumption rates are assumed. A circulator is assumed to operate at 0.200 Kwatts. The air fan plus oil pump are taken to operate at 0.200 Kwatts. Calculated results are shown in Tables (8)-(10).

Total annual operating costs (number 2 fuel oil plus electrical energy) are directly calculable from the data of Tables (1)-(3) and (8)-(10), inclusive. Cost data for oil and electrical energy are required. In recent years, such cost data hve changed rapidly. Nevertheless, using figures that appear to be currently applicable to central and eastern Long Island, New York, we derive the cost data of Figure (11)-(13) inclusive. It is seen that Boiler [A] sustains very modest cost increases due to increased overfiring ratios. This is largely due to the excellent (η_c) characteristics of this boiler (Figure 3). Boilers [B] and [C] annually use about the same electrical energy as does [A]. These latter two boilers, due to their lower (η_c) and (η_s) values are more costly to operate.

V. COMPARISON WITH AN AIR-TO-AIR HEAT PUMP

The application of the seasonal performance formulation for oil-fired boilers (previous section) was made for a 50,000 Btuh space heating load. The formulation is easily applicable to other constraints of fuel type, firing rate, heating load, weather, and climate. Such applications are currently under way and will be reported at a later time.

Recent in situ tests of a given high quality air-to-air heat pump have been carried out by the National Bureau of Standards[5] for a 50,000 Btuh space heating load. The heat pump in question was sized to meet the design heating load (an unusual feature), thereby permitting only minimal use of ordinary resistance heating for heat pump output augmentation at temperatures below the balance point. This strategy does increase cycle losses at high operating temperatures, however.

NBS measured performance data are shown in Table 14 (from reference 5).

The data of reference (5) may be used directly with the weather data for Metropolitan New York (see previous sections) to deduce a seasonal performance for a 50,000 Btuh heat load. In order that the so-calculated results be comparable to those previously obtained for oil-fired boilers, we again assume proper installation, maintenance, and operation. Thus, for example, duct losses, etc. are considered not to exist. Results of this calculation are shown in Table 15. Further discussion of these calculations is given in the Appendix. It is assumed that resistance heat (COP of unity) is employed to supply domestic hot water. Costs are illustrated for $0.03 per kwt-hr to $0.05 per kwt-hr. Costs per kwt-hr may vary substantially with regional conditions. At this writing, costs for heat pump users in central and eastern Long Island, New York are approximately $0.035 per kwt-hr.

It is hoped that more extensive heat pump operating data will be forthcoming from the various national laboratories at an early date, thereby permitting a more comprehensive characterization of estimated annual performances.

Comparison of these limited data for oil-fired boilers and the specific heat pump installation examined indicates that

1. Resistance heated domestic hot water degrades the seasonal COP for an air-to-air heat pump (Tables 14 and 15).
2. An oil-fired boiler employed to also furnish domestic hot water has its seasonal performance less strikingly effected (Tables 1-13).
3. The best of the three oil-fired units (Boiler [A]) providing 120 gals/day of domestic hot water has seasonal energy costs of $682 (for an overfiring ratio of α = 2).
4. The heat pump system studied, providing 120 gals/day of domestic hot water (same hour-by-hour heating load as Boiler [A]) and using electrical energy at $0.035 per kwt-hr has seasonal heating energy costs of $1092. Kwt-hr costs of electrical energy have been found to vary substantially with regional location, with time, and with the "user class" of the electric utility customer. This appears to be less true for users of oil.

VI. CONCLUDING REMARKS

All space conditioning devices have intrinsic merits/deficiencies which govern their operating ability to deliver heating/cooling services efficiently to the conditioned spaces that they are asked to serve. Over and above the intrinsic merits of a space conditioning device, seasonal performance analyses must include the essential characteristics of the conditioned space so served. These essential characteristics include the structure's design heating load, the detailed weather (exterior) conditions of interest, and the operating (control) philosophy for the overall system. Taken together with the energy conversion capacity of the device, as well as its steady state and cyclic figures of merit, these systems characteristics permit the calculation of the seasonal performance of the overall system.

In order to assure an equitable basis for comparison of the performance of various competing devices, it is found useful to omit consideration of the myriad performance degradations that derive from improper/unwise installation, maintenance, servicing, and operation of any device of interest.

For the case of oil or gas-fired boilers (or furnaces), the formulation given in this report can be employed, in conjunction with laboratory-determined boiler/furnace efficiency data to determine seasonal performance (seasonal energy usage) and seasonal costs. For the case of a given boiler, (η_s) and (η_c) values can be determined in the laboratory. Once the other parametric variables are specified (e.g., design firing rate, seasonal weather history, domestic hot water usage, design heat load, etc.) the calculation is straightforward. Some details of such calculations are given in the Appendix.

Application of the formulation is illustrated for three oil-fired boiler systems of varying intrinsic merits. The basic efficiency data for the calculation were obtained at Brookhaven National Laboratory. For purposes of an equitable comparison with another space heating device, National Bureau of Standards data on the Coefficient of Performance of a high quality air-to-air heat pump were employed (together with the identical assumptions regarding the conditioned space and weather conditions). Results of the comparison of the four systems studied (the oil-fired boilers plus one heat pump) are presented.

The formulation is being currently utilized in a more extensive study of a range of devices and operating conditions.

VII. NOMENCLATURE

C_e - Hourly operating costs of the electrical components of a fossil-fuel-fired space heating (and domestic hot water) system (dollars/hour).

C_m - Specific fossil fuel costs (dollars per pound of fuel).

C_t - Annual energy costs for the system (dollars per year).

H_o - Domestic hot water load (Btu/hr).

L - Heat loss (load) for conditioned space of a characteristic structure (Btu/hr).

d - Design heat loss (load) for conditioned space of a characteristic structure (Btu/hr).

$\dot{m}_f$ - Mass flow rate of fuel, <u>actual</u> (lbs/hr).

$\dot{m}_{f,d}$ - Mass flow rate of fuel, <u>design</u> (lbs/hr).

$\dot{m}_f^*$ - Mass flow rate of fuel during the nonheating season, actual (lbs/hr).

M - Total mass of fuel used during the year (lbs).

M_1 - Total mass of fuel used during the heating season (lbs).

M_2 - Total mass of fuel used during the nonheating season (lbs).

M_{1p} - Total mass of fuel that would be used during the heating season by a (perfect) system for which all η values are unity (lbs).

M_{2p} - Total mass of fuel that would be used during the nonheating season by a (perfect) system for which all η values are unity (lbs).

n_i - Number of hours in the year having a characteristic outdoor temperature, T_{ci}, during the heating season ($T_{c,i} < T^*$).

n^* - Total number of hours in the nonheating season ($T_c \geq T^*$)

S_μ - Heat source or sink, of the μ^{th} kind, in the conditioned space (Btu/hr).

T = Temperature (^oF).

T_c - Characteristic outside temperature (^oR).

$T_{c,i}$ - Characteristic outside temperature of the i^{th} value (^oR).

T_d - Outside temperature used for design heat loss calculations for the conditioned space (^oR).

T^* - Temperature of the conditioned space (^oR).

α - The overfiring ratio.

Δ_c - Heat of combustion of fuel (Btu/lb)

$\bar{\eta}$ - Overall efficiency of the boiler/furnace

$\bar{\eta}^*$ - Overall efficiency during the nonheating season

η_c^* - Cycle efficiency

$\bar{\eta}_i$ - Cycle efficiency during the nonheating season.

η_s - Overall efficiency when the outside characteristic temperature has a value $T_{c,i}$.

τ - Dimensionless temperature difference for the conditioned space, $[(T^* - T_c)/(T^* - T_d)]$

ϕ - An experimentally determined function that relates the cycle efficiency to the actual (and design) firing rates of a boiler/furnace, for a given characteristic cycle.

ω_H - Heating season electrical power requirements for fossil-fuel-fired system during ON mode.

ω_S - Summer season electrical power requirements for fossil-fuel-fired system during ON mode.

Table 1, Boiler [A]

Annual Usage of Number 2 Fuel Oil Per Year (gallons/year). N.Y. Metropolitan Area. Ten-year hourly weather data; 8-month heating plus 12 month domestic hot water. For $\alpha = 1$, $\dot{m}_{f,d} < 0.75$ gal/hr. For $\alpha = 2$ and $\alpha = 3$, $\dot{m}_{f,d} > 0.75$ gal/hr.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day
1	993	1127	1224	1328
2	1021	1214	1292	1380
3	1064	1317	1399	1480

Table 2, Boiler [B]

Annual Usage of Number 2 Fuel Oil Per Year (gallons/year). N.Y. Metropolitan Area. Ten year hourly weather data; 8 month heating plus 12 month domestic hot water. For $\alpha = 1$, $\dot{m}_{f,d} < 0.75$ gal/hr. For $\alpha = 2$ and $\alpha = 3$, $\dot{m}_{f,d} > 0.75$ gal/hr.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day
1	1105	1307	1401	1522
2	1209	1493	1620	1723
3	1326	1670	1834	1960

Table 3, Boiler [C]

Annual Usage of Number 2 Fuel Oil Per Year (gallons/year). N.Y. Metropolitan Area. Ten year hourly weather data; 8 month heating plus 12 month domestic hot water. For $\alpha = 1$, $\dot{m}_{f,d} < 0.75$ gal/hr. For $\alpha = 2$ and $\alpha = 3$, $\dot{m}_{f,d} > 0.75$ gal/hr.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day
1	1192	1399	1508	1611
2	1283	1557	1704	1822
3	1399	1722	1902	2047

Table 4, Boiler [A]

Seasonal Performance Factor (SPF) for Boiler [A]. N.Y. Metropolitan Area. Ten year hourly weather data.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day	Season
1	.8069	.7869	.7938	.7963	12 months
	---	.4513	.6213	.6787	Summer Only
2	.7845	.7302	.7522	.7663	12 months
	---	.2372	.4406	.5749	Summer Only
3	.7529	.6729	.6948	.7146	12 months
	---	.1607	.3035	.4304	Summer Only

Table 5, Boiler [B]

Seasonal Performance Factor (SPF) for Boiler [B].

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day	Season
1	.7247	.6785	.6939	.7069	12 months
	---	.2308	.3999	.5181	Summer Only
2	.6435	.5937	.5999	.6138	12 months
	---	.1415	.2261	.3063	Summer Only
3	.6043	.5308	.5298	.5394	12 months
	---	.1118	.1682	.2216	Summer Only

Table 6, Boiler [C]

Seasonal Performance Factor (SPF) for Boiler [C].

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day	Season
1	.6723	.6338	.6447	.6565	12 months
	---	.2315	.3787	.4906	Summer Only
2	.6242	.5695	.5704	.5803	12 months
	---	.1538	.2274	.2972	Summer Only
3	.5725	.5147	.5111	.5166	12 months
	---	.1247	.1769	.2235	Summer Only

Table 7

Normalized Annual Consumption of Number 2 Fuel Oil for Various Conditions

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day	Boiler
1	1.000	1.135	1.233	1.337	A
1	1.113	1.316	1.411	1.533	B
1	1.200	1.409	1.518	1.622	C
2	1.029	1.223	1.301	1.390	A
2	1.218	1.504	1.632	1.735	B
2	1.293	1.568	1.716	1.835	C
3	1.072	1.327	1.409	1.491	A
3	1.335	1.682	1.848	1.975	B
3	1.409	1.735	1.916	2.062	C

Table 8, Boiler [A]

Annual Electrical Usage (kwt-hr).

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day
1	895	942	969	1000
2	677	713	723	734
3	601	640	647	653

Table 9, Boiler [B]

Annual Electrical Usage (kwt-hr)

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day
1	913	981	1005	1037
2	706	757	774	785
3	639	680	696	706

Table 10, Boiler [C]

Annual Electrical Usage (kwt-hr)

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day
1	915	980	1005	1027
2	704	748	767	780
3	637	672	688	699

Table 11, Boiler [A]

Annual Operating Costs. N.Y. Metropolitan Area. Cost bases: (1) Number 2 fuel oil @ $0.47/gal, (2) electrical energy @ $0.045/kwt-hr. Energy usage based on Tables 1 and 8.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day	
1	$467	$530	$575	$624	Oil
	40	42	44	45	Elec.
	$507	$572	$619	$669	Total
2	$480	$571	$607	$649	Oil
	30	32	33	33	Elec.
	$510	$603	$640	$682	Total
3	$500	$619	$657	$696	Oil
	27	29	29	29	Elec.
	$527	$648	$686	$725	Total

Table 12, Boiler [B]

Annual Operating Costs. Metropolitan N.Y. Area. Cost bases: (1) Number 2 fuel oil @ $0.47/gal, (2) electrical energy @ $0.045/kwt-hr. Energy usage based on data of Tables 2 and 9.

α \ H_o	0	40 gal/day	80 gal/day	120 gal/day	
1	$519	$614	$658	$715	Oil
	41	44	45	46	Elec.
	$560	$658	$703	$761	Total
2	$568	$702	$761	$810	Oil
	32	34	35	35	Elec.
	$600	$736	$796	$845	Total
3	$623	$785	$862	$921	Oil
	29	31	31	32	Elec.
	$652	$816	$893	$953	Total

Table 13, Boiler [C]

<u>Annual Operating Costs</u>. N.Y. Metropolitan Area. Cost bases: (1) Number 2 fuel oil @ $0.47/gal, (2) electrical energy @ $0.045/kwt-hr. Energy usage based on data of Tables 3 and 10.

H_o \ α	0	40 gal/day	80 gal/day	120 gal/day	
1	$560 41 $601	$657 44 $701	$709 45 $754	$757 46 $803	Oil Elec. Total
2	$603 32 $635	$732 34 $766	$801 35 $836	$856 35 $891	Oil Elec. Total
3	$658 29 $687	$809 30 $839	$894 31 $925	$962 31 $993	Oil Elec. Total

Table 14

<u>Measured COP (Overall) for a High Quality Air-to-Air Heat Pump Sized to Heat a 50,000 Btuh Design Load</u>. (NBS data, reference 5). Return air of 66°F; 1680 CFM fan. (Heating only)

Measured (COP)	Outdoor Temp.
1.05	2°F
1.22	12°F
1.42	22°F
1.60	32°F
2.12	42°F
2.17	52°F
2.18	62°F

Table 15

Annual Performance of an Air-to-Air Heat Pump (operating COP of Table 14) serving a 50,000 Btuh design heat load in a N.Y. Metropolitan winter (10 year hourly weather data). Heating plus domestic hot water only)

H_o	0	40 gal/day	80 gal/day	120 gal/day	
Annual kwt-hrs used	20,400	24,005	27,609	31,214	
Annual Costs of Electrical Energy (Heat Plus Domestic h.w)	$612	$720	$828	$936	@ $0.03/kwt-hr
	$816	$960	$1104	$1249	@ $0.04/kwt-hr
	$1020	$1200	$1380	$1561	@ $0.05/kwt-hr
Overall (Seasonal) COP	1.72	1.61	1.53	1.47	

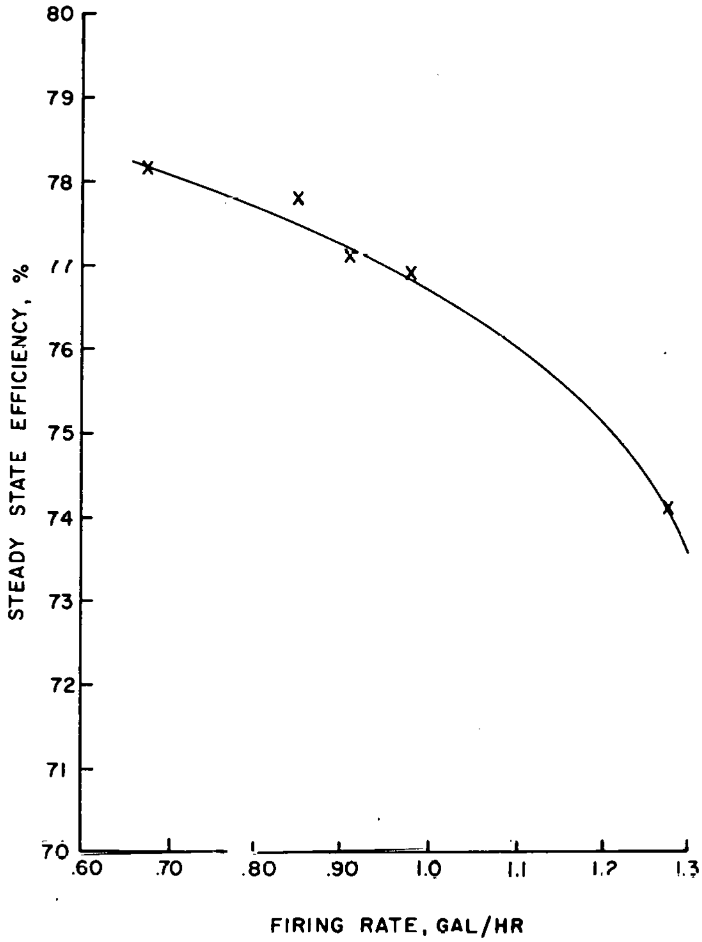

Figure 1. Steady state efficiency vs. firing rate for a steel fire-tube boiler.

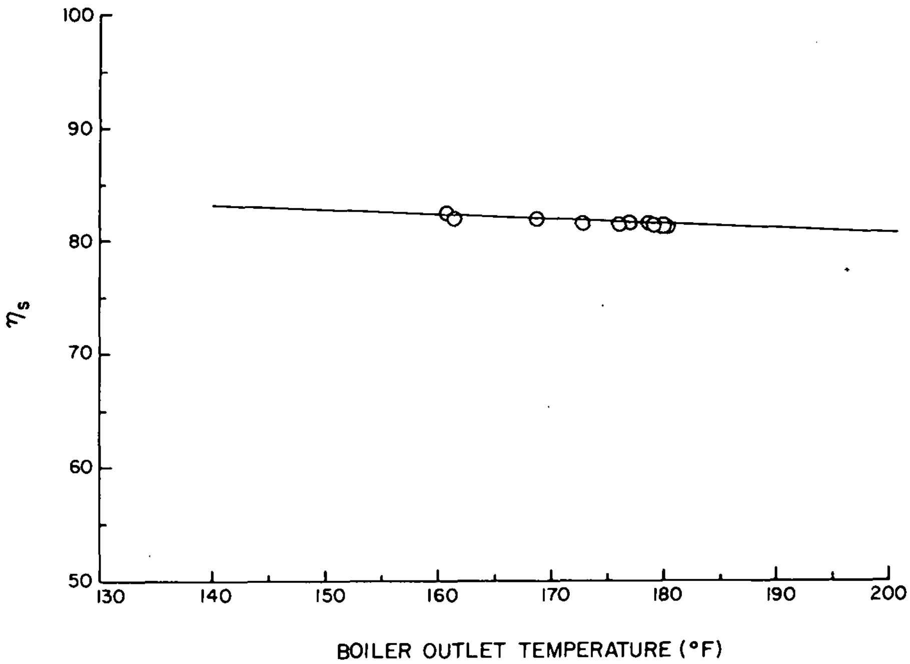

Figure 2a. Steady state efficiency (%) vs. boiler outlet temperature (°F) for boiler [A].

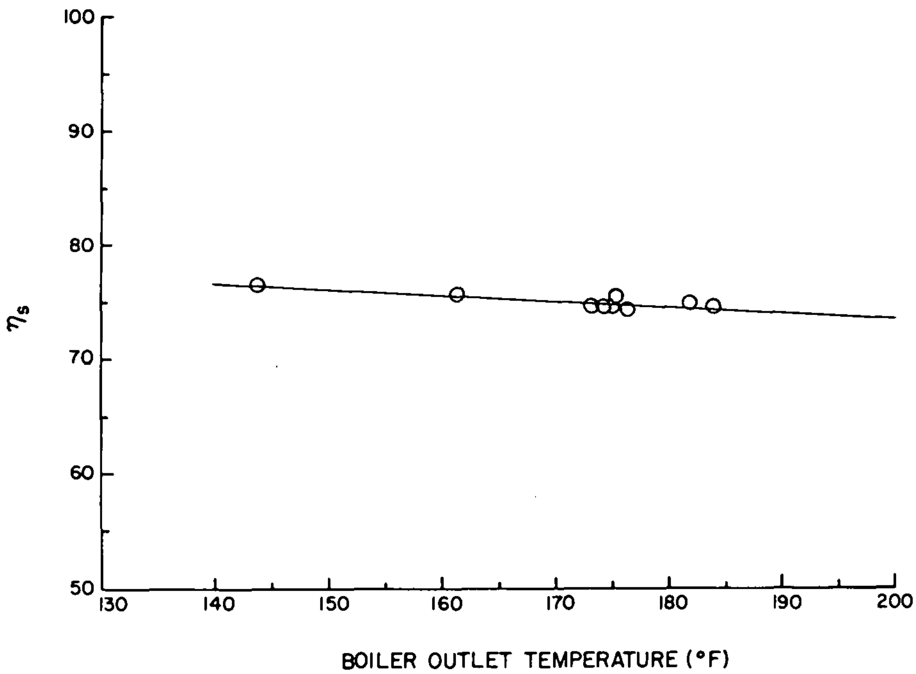

Figure 2b. Steady state efficiency (%) vs. boiler outlet temperature (°F) for boiler [B].

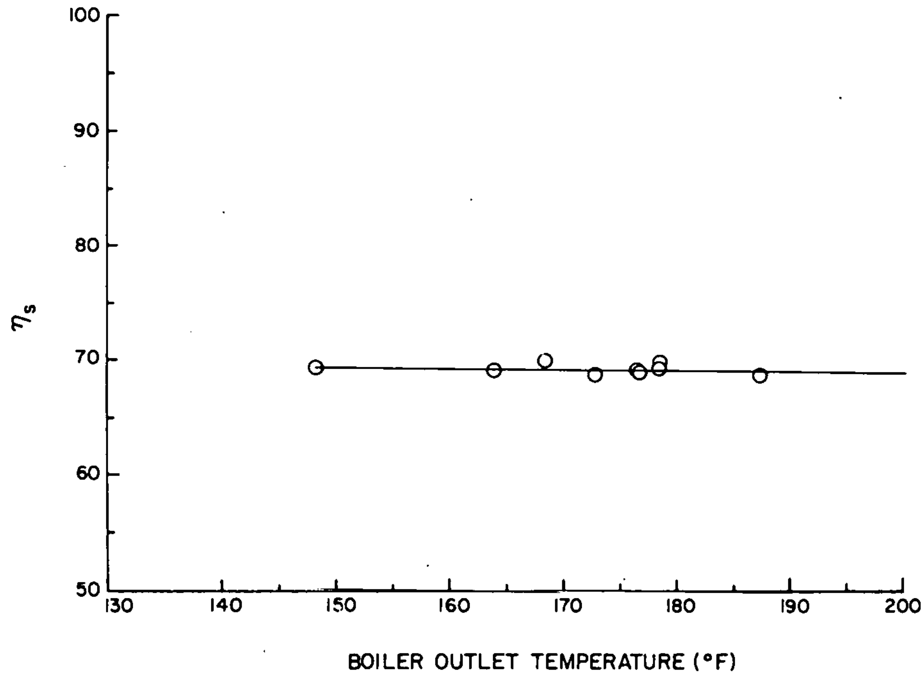

Figure 2c. Steady state efficiency (%) vs. boiler outlet temperature (°F) for boiler [C].

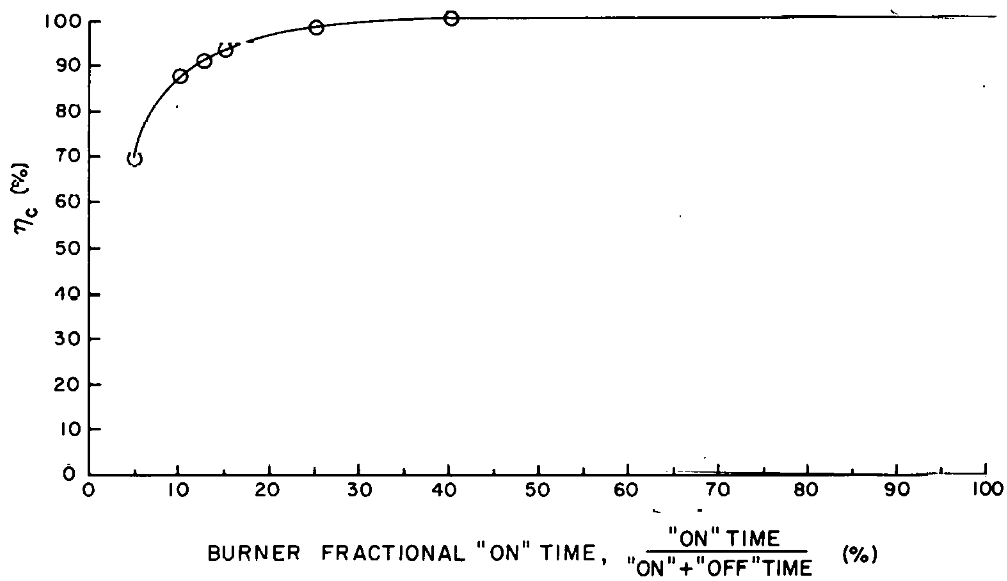

Figure 3a. Cycle efficiency (η_c) vs. burner fractional "on" time (%) for boiler [A].

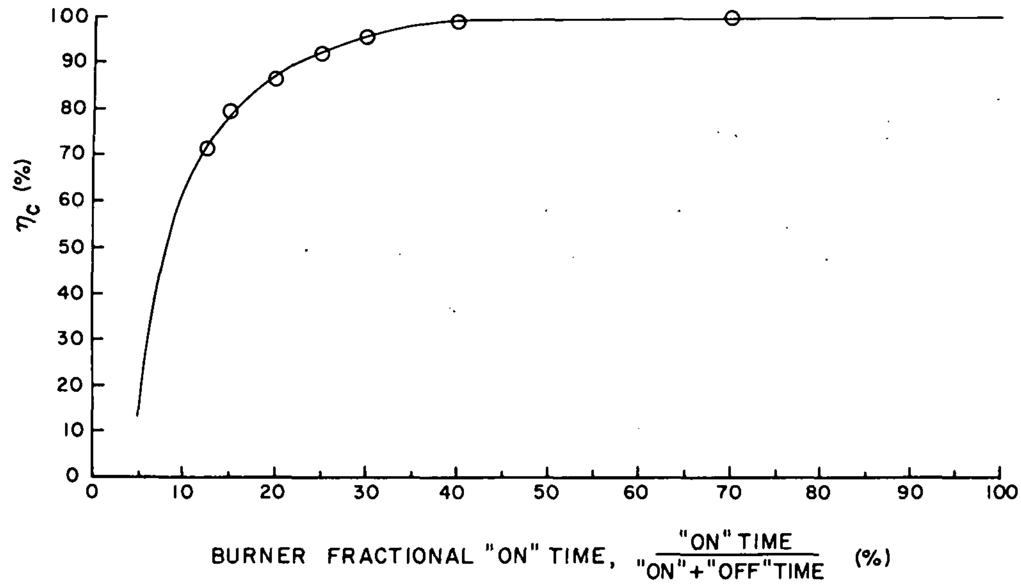

Figure 3b. Cycle efficiency (η_c) vs. burner fractional "on" time (%) for boiler [B].

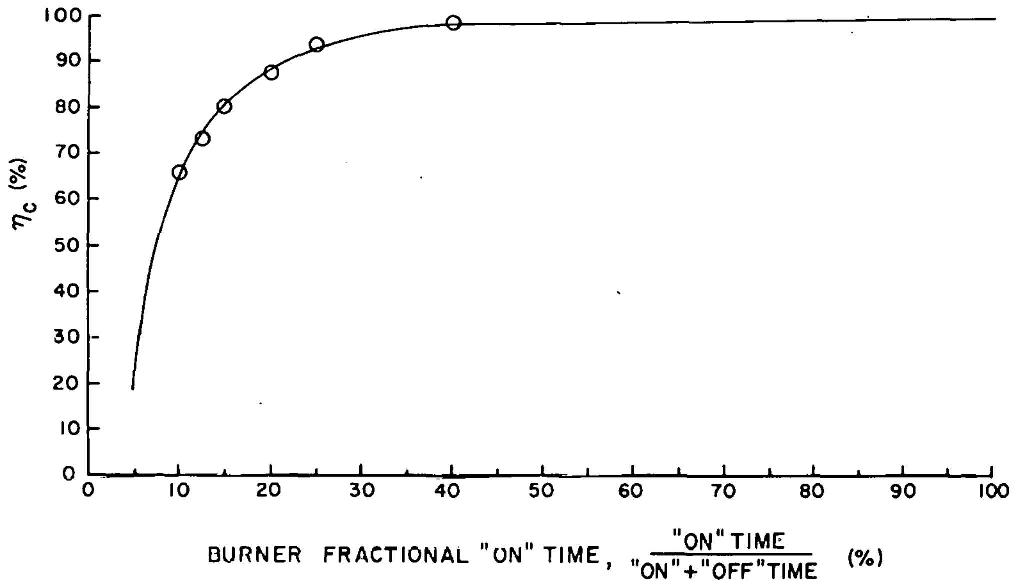

Figure 3c. Cycle efficiency (η_c) vs. burner fractional "on" time (%) for boiler [C].

References

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3. Berlad, A. L., Lin, H. C., Salzano, F. J., and Batey, J. Comfort Range Thermal Storage. ENERGY - The International Journal (In Press). BNL 21591. July 1976.

4. Bonne, U., Johnson, A. E., Glatzel, J., and Torbor, R. Analysis of New England Oil Burner Data. Effect of Reducing Excess Firing Rate on Seasonal Efficiency. Final Report by Honeywell Corporate Research Center on NBS Contract 514736, August 1975.

5. Kelley, G. E., and Bean, J. Dynamic Performance of a Residential Air-to-Air Heat Pump. National Bureau of Standards Report BSS-93, 1976.

6. E CUBE Weather Data, American Gas Association, Arlington, Virginia, 1975.

APPENDIX

Part A Evaluation of Seasonal Performance of an Oil or Gas-Fired Boiler/Furnace

For the heating season:

Eq. (2a) can be rewritten as

$$\dot{m}_{f,i}\ \eta_{c,i}\ \eta_s\ \Delta_c = \mathcal{L}_d \left[\frac{T^*-T_{c,i}}{T^*-T_d}\right] + H_o\ ,\ \text{where } T_{c,i} < T^* \quad \text{(A-1)}$$

Eq. (2b) yields

$$\dot{m}_{f,d}\ \eta_s\ \Delta_c = (\mathcal{L}_d + H_o)\ \alpha \quad \text{(A-2)}$$

(A-1/A-2) yields

$$\eta_{c,i}\left(\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}\right) = \left\{\mathcal{L}_d \left[\frac{T^*-T_{c,i}}{T^*-T_d}\right] + H_o\right\} \Big/ (\dot{m}_{f,d}\ \Delta_c\ \eta_s) \quad \text{(A-3)}$$

or

$$\Lambda_i = \mathcal{R}_i$$

Laboratory tests will provide $\eta_{c,i}$ vs. $\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}$. Thus $\mathcal{R}$HS is known once all the parameters are given. We then construct a relation between Λ_i and $\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}$. Therefore, once $\mathcal{R}_i$ is known, Λ_i is obtained automatically. By interpolation, we find the corresponding $\frac{\dot{m}_{f,i}}{\dot{m}_{f,d}}$; this in turn gives $\dot{m}_{f,i}$

and

$$M_1 = \sum \dot{m}_{f,i}\ n_i$$

For the nonheating season:

$$\dot{m}_f^* = \frac{H_o \ \dot{m}_{f,d}}{\eta_c^* \ (\mathcal{L}_d + H_o)\alpha} = \frac{H_o}{\eta_c^* \ \eta_s \ \Delta_c} \qquad \text{(A-4)}$$

$$\eta_c^* \ \frac{\dot{m}_f^*}{\dot{m}_{f,d}} = \frac{H_o}{(H_o + \mathcal{L}_d)\alpha} \qquad \text{(A-5)}$$

Again, by interpolation, we get $\frac{\dot{m}_f^*}{\dot{m}_{f,d}}$ and thus obtain $\dot{m}_f^*$.

$$M_2 = \dot{m}_f^* \ n^* \qquad \text{(A-6)}$$

For a perfect unit (efficiency of unity)

$$\dot{m}_{f,i}{}^p = \mathcal{L}_d \left\{ \left[\frac{T^* - T_{c,i}}{T^* - T_d} \right] + H_o \right\} \Big/ H_c \qquad \text{(A-7)}$$

$$M_1{}^p = \sum \dot{m}_{f,i}{}^p \ n_i$$

$$\dot{m}_f^*{}^p = \frac{H_o}{\Delta_c} \qquad \text{(A-8)}$$

$$M_2{}^p = \frac{H_o}{\Delta_c} n^*$$

$$SPF = \frac{M_1{}^p + M_2{}^p}{M_1 + M_2} \qquad \text{(A-9}$$

A printout of the Program SPE is attached as Part D.

Part B Evaluation of Seasonal Performance of an Air-to-Air Heat Pump

SPF of a heat pump can be defined as

$$SPF = \frac{TPH + TRH + TDH}{\sum \frac{(TPH_i)(n_i)}{(COP_H)_i} + \frac{(TRH + TDH)}{COP_R}} \qquad \text{(A-10)}$$

where

TPH_i = thermal energy delivered by heat pump at the i^{th} temperature,

$TPH = \sum TPH_i \ (n_i)$

n_i = Number of hours associated with the i^{th} temperature;

TPH = Total thermal energy delivered by heat pump

TRH = Total thermal energy delivered by resistance heater for heating;

TDH = Total thermal energy delivered by resistance heater for domestic hot water;

$(COP)_{h,i}$ = Coeff. of Performance of heat pump at i^{th} temperature.

$\sum \frac{THP_i \ (n_i)}{(COP)H_i}$ = Total electrical energy delivered to heat pump

COP_R = Coeff. of Performance for resistance heaters for heater, (=1).

$\frac{TRH}{COP_R}$ = Total electrical energy delivered to the resistance heaters for heating;

$\frac{TDH}{COP_R}$ = Total electrical energy delivered to the resistance heaters for hot water.

To compute SPF, we have to first find T_B, the balance point of heat pump operation; for $T_i < T_B$, supplementary (resistance) heat is required.

Ref. 5 gives performance information of a heat pump designed to meet a 50,000 Btuh heating load. COP, heating requirement and supplementary heat (if any) at each temperature are given.

Starting from the lowest temperature encountered, we can find the heat requirement, COP, and the supplementary heat requirement at each temperature.

Inasmuch as

$$TRH = \sum TRH_i \ (n_i)$$

$$TDH = Q \ (DT) n_i$$

where

TRH_i = Thermal energy delivered by the heat pump at i^{th} temp.,

n_1 = Total number of hours corresponding to the domestic hot water usage period.

SPF of (A-10) is readily calculable.

Part C Ten-Year Hourly Average Weather Data[6] for Three Representative Climates. Eight-Month Heating Season and Twelve-Month Heating Season

Tabulated below are the number of hours per heating season for metropolitan New York City, Minneapolis and Washington, D.C. Column (A) gives the number of hours for an eight-month season. Column (B) gives the number of hours for a twelve-month season.

Temp. (°F)	New York		Minneapolis		Washington, D.C.	
	(A)	(B)	(A)	(B)	(A)	(B)
-20	0	0	0	0	0	0
-19	0	0	0	0	0	0
-18	0	0	2	2	0	0

-continued-

Temp. (°F)	New York		Minneapolis		Washington, D.C.	
	(A)	(B)	(A)	(B)	(A)	(B)
-17	0	0	3	3	0	0
-16	0	0	6	6	0	0
-15	0	0	10	10	0	0
-14	0	0	5	5	0	0
-13	0	0	8	8	0	0
-12	0	0	11	11	0	0
-11	0	0	16	16	0	0
-10	0	0	16	16	0	0
- 9	0	0	8	8	0	0
- 8	0	0	19	19	0	0
- 7	0	0	19	19	0	0
- 6	0	0	16	16	0	0
- 5	0	0	25	25	0	0
- 4	0	0	29	29	0	0
- 3	0	0	30	30	0	0
- 2	0	0	37	37	0	0
- 1	0	0	41	41	0	0
0	0	0	67	67	0	0
1	0	0	54	54	0	0
2	0	0	56	56	0	0
3	3	3	80	80	0	0
4	2	2	51	51	0	0
5	0	0	63	63	0	0
6	2	2	60	60	0	0
7	2	2	64	64	0	0

Temp. (^{O}F)	New York		Minneapolis		Washington, D.C.	
	(A)	(B)	(A)	(B)	(A)	(B)
8	2	2	60	60	0	0
9	6	6	78	78	0	0
10	4	4	67	67	0	0
11	5	5	65	65	7	7
12	6	6	61	61	5	5
13	9	9	80	80	3	3
14	12	12	64	64	5	5
15	14	14	84	84	14	14
16	16	16	62	62	9	9
17	23	23	67	67	12	12
18	32	32	75	75	17	17
19	42	42	70	70	33	33
20	57	57	76	76	46	46
21	43	43	68	68	55	55
22	53	53	66	66	48	48
23	47	47	95	95	70	70
24	49	49	110	110	68	68
25	63	63	119	119	65	65
26	69	69	82	82	81	81
27	57	57	123	123	95	95
28	45	45	110	110	108	108
29	71	71	101	101	64	64
30	120	120	123	123	103	103
31	97	97	88	88	125	125

Temp. (°F)	New York		Minneapolis		Washington, D.C.	
	(A)	(B)	(A)	(B)	(A)	(B)
32	131	131	130	130	156	156
33	124	124	109	109	151	151
34	156	156	99	99	122	122
35	173	173	101	101	124	124
36	171	171	106	106	143	143
37	192	192	89	89	130	130
38	187	187	100	100	162	162
39	194	194	90	94	132	132
40	171	171	92	97	136	136
41	180	180	109	112	120	120
42	160	161	107	117	109	109
43	160	162	96	103	144	144
44	159	161	96	107	145	145
45	148	149	107	117	101	101
46	179	180	88	100	94	94
47	128	131	102	120	103	103
48	126	129	101	124	104	104
49	117	119	110	146	96	96
50	101	104	98	142	123	123
51	98	102	80	120	121	121
52	90	101	86	144	120	123
53	118	125	76	114	118	118
54	124	138	63	104	101	103
55	111	126	75	128	122	125

Temp. (^{O}F)	New York		Minneapolis		Washington, D.C.	
	(A)	(B)	(A)	(B)	(A)	(B)
56	114	136	81	128	110	114
57	113	142	72	130	99	108
58	124	158	55	144	99	110
59	91	134	52	129	117	132
60	83	123	54	146	85	100
61	80	136	30	114	106	124
62	47	135	43	139	119	149
63	62	137	32	156	119	153
64	93	172	43	148	94	155
65	62	162	38	157	110	161
66	54	172	28	135	79	139
67	59	170	22	130	67	152
68	65	190	29	153	64	144
69	51	208	16	142	53	168

Part D Program Printout

A typical calculation and printout is appended. The illustrated calculation is for Boiler [A], overfired at $\alpha = 2$, operating under typical metropolitan New York weather conditions, providing 40 gallons of domestic hot water per day. An 8-month heating season and a 12-month domestic hot water usage is considered.

BNL

SEASONAL PERFORMANCE

SPE00G3

METROPOLITAN NEW YORK CALCULATION

BOILER A

8 MONTH HEATING SEASON

α = 2

$\dot{Q}$ = 40 GAL/DAY FOR 12 MONTHS

1

```
      PROGRAM SPL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     THE PURPOSE OF THIS PROGRAM IS TO EVALUATE SEASONAL PERFORMANCE
C
C     FOR AN OIL OR GAS-FIRED BOILER/FURNACE WITH KNOWN CYCLE EFFICIENCY
C
C     AT ANY LOCATION WITH GIVEN WEATHER INFORMATION.
C
C     THIS PROGRAM HAS BEEN TESTED AT BROOKHAVEN NATIONAL LABORATORY
C
C     COMPUTING CENTER.
C
C
      REAL M1,M2,M1P,M2P
      REAL NT,NTC
      REAL NTR,NDT
      DIMENSION UNAME(10),LOWETH(10)
      DIMENSION B(21,1),R(21),E(21),G(22),TS(22),XR1(1)
      DIMENSION NT(90),NTC(90)
      DIMENSION XR(90),FR(90,1),EMFI(90),EMFIP(90)
      READ(5,10) (UNAME(I),I=1,10)
      READ(5,15) FTAS,NTR,HC,DT,ELO,Q,ALPHA,NDT
      READ (5,10) (LOWETH(I),I=1,10)
      READ(5,20) MODE
      READ(5,30) (B(I,1), I=1,21)
      READ (5,35) (E(I),I=1,21)
      READ(5,30) (R(I),I=1,21)
      READ(5,40) (NT(I),I=1,90)
      READ(5,45) (NTC(I),I=1,90)
      READ(5,35) E1
      READ(5,35) E2
C     NS1 IS THE TOTAL NO OF HOURS IN 4 MONTH PERIOD OF NONHEATING
C     SEASON
      NS1=2920
      WRITE(6,5)
      WRITE(6,6)
      WRITE(6,7)
      WRITE(6,8)
      WRITE(6,9)
      WRITE(6,12)
      WRITE(6,13)
      WRITE(6,14)
      WRITE(6,13)
      WRITE(6,12)
      WRITE(6,11)
      WRITE(6,10) (UNAME(I),I=1,10)
      PRINT(6,11)
      WRITE(6,10) (LOWETH(I),I=1,10)
      WRITE(6,11)
      WRITE(6,16)FTAS
      WRITE(6,17) NTR
      WRITE(6,24) HC
      WRITE(6,18)DT
      WRITE(6,19) ELO
      WRITE(6,21) Q
      WRITE(6,22)ALPHA
      WRITE(6,23) NDT
      WRITE(6,25)
```

2

```
      WRITE(6,30) (Q(I,1), I=1,21)
      WRITE(6,26)
      WRITE(6,35) (F(I),I=1,21)
      WRITE(6,27)
      WRITE(6,30) (R(I),I=1,21)
      WRITE(6,80) MODE
      WRITE(6,50)
      WRITE(6,55) (NT(I),NTC(I),I=1,90)
      WRITE(6,87) E1
      WRITE(6,88) E2
      WRITE(6,5)
      WRITE(6,60)
      WRITE(6,12)
      WRITE(6,13)
      WRITE(6,28)
      WRITE(6,13)
      WRITE(6,12)
C     HC IS THE DOMESTIC HOTWATER USAGE IN TERMS OF BTU/HP
      HC=8.335*DT/24*Q
C     EMFD IS THE DESIGN FLOWRATE
      EMFD=(ELO+HO)*ALPHA/ETAS/HC
      EM=EMFD/7.11
      PRINT 999,EMFD,EM
      K=3
      N=21
      N1=1
      DO 70 I=1,90
      IF(NTC(I) .LT.1.) GO TO 70
      J=NT(I)
      GO TO 75
   70 CONTINUE
   75 J=J+20
      L=90
C     XR(M) EQUALS TO THE PRODUCT OF CYCLE EFFICIENCY AND BFOT.
      DO 300 M=1,90
      XR(M)=(ELO*(NTR-NT(M))/(NTR-NDT)+HO)/HC/ETAS/EMFD
      IF(XR(M) .GE. 1.) XR(M)=1.
  300 CONTINUE
      CALL LTAINT(R,Q,N,N1,XR,FR,L,G,IS,K)
C     EMFI IS THE I TH TEMP FLOW RATE.
C     M1 IS THE TOTAL MASS OF FUEL USED IN THE HEATING SEASON.
      M1=0.
      DO 400 M=1,90
      IF(FR(M,1) .GT. 1.) FR(M,1)=1.
      EMFI(M)=FR(M,1)*EMFD
      M1=M1+EMFI(M)*NTC(M)
  400 CONTINUE
C     TO COMPUTE THE NONHEATING SEASON FUEL USUAGE
      XR1(1)=HO/(ELO+HO)/ALPHA
      IF(XR1(1) .NE.0.) GO TO 440
      M2=0.
      GO TO 550
  440 CONTINUE
      L1=1
      CALL LTAINT(R,Q, N,N1,XR1,FR,L1,G,IS,K)
      X=FR(L1,1)
      PRINT 450,X
```

3

```
           IF(X .LE.B(3)) K=2
           CALL LTAINT(B,E,N,N1,X,FR,L1,G,IS,K)
           EMFN=XR1(1)*LMFD/FR(L1,1)
           PRINT 500,FR(L1,1)
           M2=EMFN*NSI
    550    CONTINUE
           TF1=M1+M2
           M1P=0.
C     DESIGN CONDITION CORRESPONDS TO THE MAXIMUM FUEL USAGE
C      CHANGE TEMPERAURE TO THE BASE OF - 20F.
           MDT=NDT+21
           DO 600 I=MDT,90
           EMFIP(I)=(FLD*(NTR-NT(I))/(NTR-NDT)+HD)/HC
            M1P=M1P+EMFIP(I)*NTC(I)
    600    CONTINUE
           NDDT=MDT-1
           DO 651 I=1,NDDT
           EMFIP(I)=EMFIP(MDT)
           M1P=M1P+EMFIP(I)*NTC(I)
    651    CONTINUE
           M2P=M2*ETAS*FR(L1,1)
           IF(XR1(1) .EQ.0.) FR(L1,1)=0.
           TF2=M1P+M2P
           SSPF=TF2/TF1
           F1=M1/7.11
           F2=M2/7.11
           F1P=M1P/7.11
           F2P=M2P/7.11
           PRINT 650 ,M1,M2
           PRINT 655,F1,F2
           PRINT 660, M1P,M2P
           PRINT 665,F1P,F2P
           PRINT 1003,SSPF
           IF(MODE .EQ. 12) GO TO 690
           IF(HD.EQ. 0.) GO TO 610
           SPF4H=M2P/M2
           PRINT 1160,SPF4H
    610    CONTINUE
           SPF8=M1P/M1
           PRINT 1150,SPF8
C          COMPUTE TOTAL ELECTRICITY USAGE:
    690    IF(Q) 700,703,750
    700    ECIRC=M1/EMFD*E1/1000
           WRITE(6,701) ECIRC
           GO TO 800
    750    WRITE(6,751)
           WRITE(9,752)
    800    EMOTOR=M1/EMFD*F2/1000
           WRITE(6,801) EMOTOR
    1000   CONTINUE
    5      FORMAT(1H1)
    6      FORMAT(// 5X,*PROGRAM SPE IS TO EVALUATE SEASONAL PERFORMANCE
          1OF AN OIL OR GAS-FIRED BOILER/FURNACE*//)
    7      FORMAT(/ 5X,*SPE CAN HANDLE SEASONAL PERFORMANCE EVALUATION FOR *)
    8      FORMAT(/ 5X,*(1) 12 MONTH HEATING SEASON (HEATING AND HOT WATER)*)
    9      FORMAT(/ 5X,*(2) 8 MONTH HEATING SEASON 7 12 MONTH HOT WATER*/)
    10     FORMAT(10A8)
```

4

```
11    FORMAT(/ *==============================================================*/)
12    FORMAT(1X,*.  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .*)
13    FORMAT(1X,*.                                                          .*)
14    FORMAT(1X,*.    INPUT    RETURN                                       .*)
15    FORMAT(8F9.3)
16    FORMAT(// 5X,*STEADY STATE EFFICIENCY ETAS=*,F9.3)
17    FORMAT(//5X,*INDOOR ROOM TEMPERATURE NTR=*,F9.3)
18    FORMAT(// 5X,*TEMPERATURE RISE IN DOMESTIC HOT WATER DT=*,F9.3)
19    FORMAT(// 5X,*DESIGN HEATING LOAD IN BTU/HR FLD=*,F9.3)
20    FORMAT(I2)
21    FORMAT(// 5X,*DOMESTIC HOT WATER USAGE IN GALLONS/DAY Q=*,F9.3)
22    FORMAT(// 5X,*OVERFIRING RATIO ALPHA=*,F9.3)
23    FORMAT(// 5X,*DESIGN OUTDOOR TEMPERATURE NTD=*,F9.3)
24    FORMAT(// 5X,*HEAT OF COMBUSTION FOR FUEL NO. 2 IN BTU/LB HC=*,F9.
     13)
25    FORMAT(// 20X,*INPUT BURNER FRACTIONAL ON TIME*)
26    FORMAT(// 20X,*INPUT BOILER/FURNACE CYCLE EFFICIENCIES AT THE
     1GIVEN FRACTIONAL ON TIME*)
27    FORMAT(// 20X,*PRODUCTS OF THE BFOT AND CYCLE EFFICIENCY*)
28    FORMAT(1X,*.     OUTPUT                                           .*)
30    FORMAT(15F5.3)
35    FORMAT(1X,15F5.3)
40    FORMAT(20F4.0)
45    FORMAT(20F4.0)
50    FORMAT(1H1,40X,*TEMPERATURE*,10X,*NO OF HOURS*)
55    FORMAT(45X,F5.0,15X,F5.0)
60    FORMAT(// 40X*THOROUGHLY CHECK ALL YOUR INPUT DATA*//)
80    FORMAT(// 20X,*OPERATION MODE IS=*,I*,*MONTH HEATING SEASON*)
85    FORMAT(F5.1)
87    FORMAT(// 25X,*CIRCULATOR ELECTRICITY USAGE=*,F5.1,*WATTS*)
88    FORMAT(// 25X,*FAN AND IGNITION ELECTRICITY USAGE=*,F5.1,*WATTS*)
450    FORMAT(25X,*BOILER FRACTIONAL ON TIME IN THE NONHEATING
     1SEASON=*,F6.4//)
500   FORMAT(25X,*CYCLE EFFICIENCY IN THE NONHEATING SEASON =*,F6.4//)
650   FORMAT(25X,*TOTAL MASS FOR THE HEATING SEASON M1=*,F10.2,*LBS*,10X
     1,*FOR 4 MONTH HOT WATER M2=*,F10.2,*LBS*//)
655   FORMAT(25X,*TOTAL FUEL USED INTHE HEATING SEASON=*,F8.2,*GALLONS*,
     110X,*FOR 4 MONTH HOT WATER =*,F8.2,*GALLONS*//)
660   FORMAT(25X,*FOR A PERFECT UNIT M1P=*,F10.2,*LBS*,10X,*M2P=*,F10.2
     1,*LBS*//)
665   FORMAT(25X,*FOR PERFECT UNIT F1P=*,F8.2,*GALLONS*,10X,*F2P=*,
     1F8.2,*GALLONS*//)
700   FORMAT(// 25X,*APPROXIMATE TOTAL CIRCULATOR ELECTRICITY USAGE=*,
     1F8.2,*KW-HR*)
751   FORMAT(// 25X,*THIS WONT GIVE YOU CIRCULATOR USAGE*)
752   FORMAT(// 25X,*TO GET CIRCULATOR USAGE, SET Q=0. AND RESUBMIT THE
     1 PROGRAM*)
801   FORMAT(// 25X,*TOTAL MOTOR AND IGNITION USAGE=*,F8.2,*KW-HR*)
999   FORMAT(// 25X,*DESIGN FLOW RATE=*,F6.2,*LB/HR*,*=*,F6.3,*GAL/HR*/)
1003    FORMAT(25X,*SEASONAL PERFOMANCE FACTOR SPF=*,F8.4//)
1150  FORMAT(// 25X,*SPF FOR 8 MONTH HEATING ALONE IS=*,F6.4)
1160   FORMAT(/ 25X,*SPF FOR 4 MONTH HOT WATER IS =*,F6.4)
      END
```

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```
SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
 4111  SPE

VARIABLES        SN  TYPE          RELOCATION
 5732  ALPHA         REAL                               6300  D        REAL       ARRAY
 5727  DT            REAL                               6352  E        REAL       ARRAY
 5766  ECIRC         REAL                               5730  ELD      REAL
 5741  EM            REAL                               5740  EMFD     REAL
 6740  EMFI          REAL          ARRAY                7072  EMFIF    REAL       ARRAY
 5752  EMFN          REAL                               5767  EMOTOR   REAL
 5725  ETAS          REAL                               5734  E1       REAL
 5735  E2            REAL                               6606  FR       REAL       ARRAY
 5760  F1            REAL                               5762  F1P      REAL
 5761  F2            REAL                               5763  F2P      REAL
 6377  G             REAL          ARRAY                5726  HC       REAL
 5737  H0            REAL                               5724  I        INTEGER
 6425  IS            INTEGER       ARRAY                5745  J        INTEGER
 5742  K             INTEGER                            5746  L        INTEGER
 6266  LONETH        INTEGER       ARRAY                5750  L1       INTEGER
 5747  M             INTEGER                            5754  MDT      INTEGER
 5733  MODE          INTEGER                            5716  M1       REAL
 5720  M1P           REAL                               5717  M2       REAL
 5721  M2P           REAL                               5743  N        INTEGER
 5755  NDOT          INTEGER                            5723  NDT      REAL
 5736  NS1           INTEGER                            5770  NT       REAL       ARRAY
 6122  NTC           REAL          ARRAY                5722  NTR      REAL
 5744  N1            INTEGER                            5731  O        REAL
 6325  R             REAL          ARRAY                5764  SPF4H    REAL
 5765  SPF8          REAL                               5757  SSPF     REAL
 5753  TF1           REAL                               5756  TF2      REAL
 6254  UNAME         REAL          ARRAY                5751  X        REAL
 6454  XR            REAL          ARRAY                6453  XR1      REAL       ARRAY

FILE NAMES       MODE
    0  INPUT              2041  OUTPUT   FMT          0  TAPE5    FMT        2041  TAPE6   FMT

EXTERNALS           TYPE    ARGS
       LTAINT               10

STATEMENT LABELS
 5217   5      FMT               5221   6      FMT               5235   7      FMT
 5244   8      FMT               5253   9      FMT               5262  10      FMT
 5264  11      FMT               5274  12      FMT               5304  13      FMT
 5313  14      FMT               5322  15      FMT               5324  16      FMT
 5332  17      FMT               5340  18      FMT               5347  19      FMT
 5355  20      FMT               5357  21      FMT               5366  22      FMT
 5373  23      FMT               5401  24      FMT               5411  25      FMT
 5417  26      FMT               5431  27      FMT               5440  28      FMT
 5447  30      FMT               5451  35      FMT               5453  40      FMT
 5455  45      FMT               5457  50      FMT               5465  55      FMT
 5470  60      FMT               4320  70                        4323  75
 5476  80      FMT               5505  85      FMT               5507  87      FMT
 5516  88      FMT                  0 300                           0 400
 4373 440                        5525 450      FMT               5536 500      FMT
 4421 550                           0 600                        4526 610
```

```
STATEMENT LABELS
 5545  650     FMT                    0  651                                 5561  655    FMT
 5575  660     FMT                 5606  665     FMT                            0  700         INACTIVE
 5617  701     FMT                 4532  750                                 5630  751    FMT
 5636  752     FMT                 4536  800                                 5646  801    FMT
 5655  999     FMT                 4543  1000                                5665  1003   FMT
 5673  1150    FMT                 5701  1160    FMT

LOOPS  LABEL    INDEX    FROM-TO    LENGTH   PROPERTIES
 4242           * I       65  65     10B                 EXT REFS
 4313  70       * I       84  88     13B         OPT       EXITS
 4336  300        M       92  95     10B         OPT
 4355  400        M      100 104     10B         OPT
 4433  600        I      126 129     10B         OPT
 4451  651        I      131 134     5B     INSTACK

STATISTICS
  PROGRAM LENGTH               31210    1617
  BUFFER LENGTH                41030    2115
```

6

SUBROUTINE AITKEN   74/74   OPT=1 TRACE   FTN 4.5+414   03/23/77 14.55.20   PAGE 1

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```
      SUBROUTINE AITKEN(X,G,N,K,XR,FR,IS)
      DIMENSION X(N),G(N),IS(N)
      IF(K.LT.2)GO TO 2
      KL1=K-1
      DO 1 J=1,KL1
      IT=J+1
      DO 1 I=IT,K
      JJ=IS(J)
      II=IS(I)
    1 G(II)=((XR-X(JJ))*G(II)-(XR-X(II))*G(JJ))/(X(II)-X(JJ))
      II=IS(K)
      FR=G(II)
      RETURN
    2 II=IS(1)
      FR=G(II)
      RETURN
      END
```

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 AITKEN

VARIABLES

SN	TYPE		RELOCATION		SN	TYPE		
0 FR	REAL		F.P.		0 G	REAL	ARRAY	F.P.
67 I	INTEGER				71 II	INTEGER		
0 IS	INTEGER	ARRAY	F.P.		66 IT	INTEGER		
65 J	INTEGER				70 JJ	INTEGER		
0 K	INTEGER		F.P.		64 KL1	INTEGER		
0 N	INTEGER		F.P.		0 X	REAL	ARRAY	F.P.
0 XR	REAL		F.P.					

STATEMENT LABELS
0 1   54 2

LOOPS	LABEL	INDEX	FROM-TO	LENGTH	PROPERTIES
21	1	J	5 10	25B	NOT INNER
33	1	I	7 10	13B	OPT

STATISTICS
PROGRAM LENGTH   114B   76

8

```
            SUBROUTINE LTAINT(X,F,N,M,XR,FR,L,G,IS,K)
            DIMENSION X(N),F(N,M),XR(L),FR(L,M),G(N),IS(N)
            IF(K.LT.1)K=1
            IF(K.GT.N)K=N
            DO 2 LL=1,L
            CALL ORDER(X,N,XR(LL),G,IS)
            DO 2 J=1,M
            DO 1 I=1,K
            II=IS(I)
          1 G(II)=F(II,J)
            CALL AITKEN(X,G,N,K,XR(LL),FR(LL,J),IS)
          2 CONTINUE
            RETURN
            END
```

```
        SYMBOLIC REFERENCE MAP (R=1)

 ENTRY POINTS
     3   LTAINT

 VARIABLES      SN   TYPE            RELOCATION
     0   F           REAL        ARRAY     F.P.             0   FR          REAL       ARRAY     F.P.
     0   G           REAL        ARRAY     F.P.           117   I           INTEGER
   120   II          INTEGER                                0   IS          INTEGER    ARRAY     F.P.
   116   J           INTEGER                                0   K           INTEGER              F.P.
     0   L           INTEGER               F.P.           115   LL          INTEGER
     0   M           INTEGER               F.P.             0   N           INTEGER              F.P.
     0   X           REAL        ARRAY     F.P.             0   XR          REAL       ARRAY     F.P.

 EXTERNALS           TYPE    ARGS
         AITKEN               7                                 ORDER                5

 STATEMENT LABELS
     0   1                                         0   2

 LOCPS  LABEL     INDEX      FROM-TO     LENGTH    PROPERTIES
    30   2        * LL          5  12       43B                 EXT REFS  NOT INNER
    40   2        * J           7  12       31B                 EXT REFS  NOT INNER
    45   1          I           8  10        5B      INSTACK

 STATISTICS
   PROGRAM LENGTH                   155B      109
```

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```
      SUBROUTINE ORDER(X,NN,XR,G,IS)
      DIMENSION X(1),G(1),IS(1),MSAV(20),NSAV(20)
      DATA N/0/
      KEYLOC(M,N)=(M+N)/2
C     CHECK THAT ARRAY =IS= HAS THE PROPER FILLED LENGTH
      IF(N.NE.NN)GO TO 103
C     CHECK FOR PROPER DOWNSHIFTED SORT BEFORE SORTING
      DO 100 I=1,NN
      G(I+1)=ABS(XR-X(I))
  100 CONTINUE
      NNLU=NN-1
      DO 102 I=1,NNLU
      M=IS(I)
      N=IS(I+1)
      IF(G(N+1).LT.G(M+1))GO TO 103
  102 CONTINUE
C  99 SET N TO THE LENGTH OF ARRAY =IS= AND RETURN
   99 N=NN
      RETURN
C 103 SETUP TABLE OF ABSOLUTE VALUES TO BE SORTED IN ASCENDING ORDER
  103 N=NN+1
      G(1)=0.
      DO 104 I=1,N
      IS(I)=I-1
  104 G(I+1)=ABS(XR-X(I))
C     THE FOLLOWING IS ADAPTED FROM THE LIBRARY ROUTINE -QIKS-.
      I=0
      J=0
      LEVEL=0
      M=2
    1 CONTINUE
      IF(N-M-1)5,4,11
C  11 PARTITION ENTRY, BELOW, RETURNS TO 2
C   2 PUSH DOWN
    2 LEVEL=LEVEL+1
C     CHOOSE SMALLEST PORTION OF LIST
      IF((J-M).GT.(N-I))GO TO 3
      MSAV(LEVEL)=I
      NSAV(LEVEL)=N
      N=J
      GO TO 1
    3 MSAV(LEVEL)=M
      NSAV(LEVEL)=J
      M=I
      GO TO 1
C   4 CHECK FOR PROPER ORDER OF TWO-ELEMENT LIST
    4 IF(G(M).LE.G(N))GO TO 5
      G(1)=G(M)
      IS(1)=IS(M)
      G(M)=G(N)
      IS(M)=IS(N)
      G(N)=G(1)
      IS(N)=IS(1)
    5 IF(LEVEL.EQ.0)GO TO 31
C  31 BELOW, DOWNSHIFTS ARRAY -IS- TO FIT AITKEN
      M=MSAV(LEVEL)
      N=NSAV(LEVEL)
```

10

```
C      LIFT UP
       LEVEL=LEVEL-1
       GO TO 1
C      END OF MAIN SORT
C      PARTITION; PASSES EVENTUALLY TO 21
    11 I=M
       J=N
       KEY=KEYLOC(M,N)
       G(1)=G(KEY)
       IS(1)=IS(KEY)
       IF(N.EQ.KEY)GO TO 12
       G(KEY)=G(N)
       IS(KEY)=IS(N)
    12 IF(G(1).GE.G(I))GO TO 16
       G(J)=G(I)
       IS(J)=IS(I)
       GO TO 14
    13 IF(G(1).GE.G(J))GO TO 15
    14 J=J-1
       IF(I.EQ.J)21,13
C   21 BELOW; SPREADER ENTRY
    15 G(I)=G(J)
       IS(I)=IS(J)
    16 I=I+1
       IF(I.NE.J)GO TO 12
C      END PARTITION
C   21 SPREADER
    21 G(I)=G(1)
       IS(I)=IS(1)
    22 IF(I.EQ.N)GO TO 23
       I=I+1
       IF(G(1).EQ.G(I))GO TO 22
    23 IF(J.EQ.M)GO TO 2
       J=J-1
       IF(G(1).EQ.G(J))23,2
C      END SPREADER.  STATEMENT 2 IS IN PUSHDOWN
C      END OF QIKS ADAPTATION
C   31 DOWNSHIFT ARRAY -IS- BEFORE CHECKING AND RETURNING
    31 DO 32 I=1,NN
       IS(I)=IS(I+1)
    32 CONTINUE
       GO TO 99
       END
```

SYMBOLIC REFERENCE MAP (R=1)

ENTRY POINTS
3 ORDER

VARIABLES		SN	TYPE		RELOCATION			
0	G		REAL	ARRAY	F.P.	233	I	INTEGER
0	IS		INTEGER	ARRAY	F.P.	236	J	INTEGER
240	KEY		INTEGER			237	LEVEL	INTEGER

```
      SUBROUTINE ORDER      74/74   OPT=1 TRACE                            FTN 4.5+414       03/23/77  14.55.20        PAGE      3

 VARIABLES       SN  TYPE            RELOCATION
     235  M          INTEGER                              241  MSAV        INTEGER    ARRAY
     232  N          INTEGER                                0  NN          INTEGER                 F.P.
     234  NMLU       INTEGER                              265  NSAV        INTEGER    ARRAY
       0  X          REAL          ARRAY     F.P.           0  XR          REAL                    F.P.

 INLINE FUNCTIONS     TYPE    ARGS
          ABS         REAL       1   INTRIN                    KEYLOC      INTEGER     2    SF

 STATEMENT LABELS
      70  1                                 74  2                                   105  3
     112  4                                126  5                                   133  11
     147  12                               157  13                                  162  14
     166  15                               174  16                                  177  21
     203  22                               211  23                                  220  31
       0  32                                44  99                                    0  100
       0  102                               46  103                                   0  104

 LOOPS  LABEL     INDEX      FROM-TO     LENGTH     PROPERTIES
     25  100        I           8 10         3B       INSTACK
     34  102     *  I          12 16        10B         OPT       EXITS
     60  104        I          23 25         4B       INSTACK
    224  32         I          96 98         2B       INSTACK

 STATISTICS
   PROGRAM LENGTH              325B      213
```

11

PROGRAM SPE IS TO EVALUATE SEASONAL PERFORMANCE FOR AN OIL OR GAS-FIRED BOILER/FURNACE

SPE CAN HANDLE SEASONAL PERFORMANCE EVALUATION FOR
(1) 12 MONTH HEATING SEASON (HEATING AND HOT WATER)
(2) 8 MONTH HEATING SEASON & 12 MONTH HOT WATER

12

INPUT RETURN

UNIT NAME [redacted]- BOILER [A]

LOCATION-METROPOLITAN NEW YORK AREA; 10 YEAR AVERAGE HOURLY WEATHER DATA;

STEADY STATE EFFICIENCY FTAS= .812

INDOOR ROOM TEMPERATURE NTR= 70.000

HEAT OF COMBUSTION FOR FUEL NO. 2 IN BTU/LB HC=19530.000

TEMPERATURE RISE IN DOMESTIC HOT WATER DT= 100.000

DESIGN HEATING LOAD IN BTU/HR ELD=50000.000

DOMESTIC HOT WATER USAGE IN GALLONS/DAY Q= 40.000

OVERFIRING RATIO ALPHA= 2.000

DESIGN OUTDOOR TEMPERATURE NTD= 3.000

```
.000 .050 .100 .150 .200 .250 .300 .350 .400 .450 .500 .550 .600 .650 .700
.750 .800 .850 .900 .9501.000

                INPUT BOILER/FURNACE CYCLE EFFICIENCIES AT THE     GIVEN FRACTIONAL ON TIME
0.000 .691 .870 .930 .960 .978 .990 .997 .998 .9991.0001.0001.0001.0001.000
1.0001.0001.0001.0001.0001.000

                PRODUCTS OF THE RFOT AND CYCLE EFFICIENCY

.000 .034 .087 .140 .192 .245 .300 .350 .400 .450 .500 .550 .600 .650 .700
.750 .800 .850 .900 .9501.000

                OPERATION MODE IS=   8MONTH HEATING SEASON
```

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