MONITORING OF RESIDENCES WITH MODIFIED OIL HEATING SYSTEMS*

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ABSTRACT

An energy conservation study of residential fuel oil savings obtained by the refit of existing boilers and furnaces was made by a one-year field test of 250 detached houses in a 5500 annual heating degree day climate. Retention-head burners properly installed on boilers produced savings of 19%; the addition of vent dampers or boiler temperature programmers to these systems yielded little increase in savings. With boilers using conventional burners, a controls package consisting of a double setback clock thermostat plus a boiler temperature programmer produced fuel savings of 19% in homes unoccupied during the day. With conventional burners the use of vent dampers, flue heat exchangers, or double setback thermostats produced typical savings of 10%.

Retention-head burners yielded 11% fuel savings with furnaces. The addition of vent dampers produced no further savings.

For use in this project, a low-cost method of calculating the annual fuel use in a building was developed that corrected for annual weather changes and for fuel use in heating domestic hot water. The data required were daily mean temperatures and fuel delivery dates and quantities; no instrumentation was installed in the buildings.

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1. BACKGROUND

This evaluation (REFOIL) of refit equipment for residential oil burners supported the multi-state Fuel Oil Conservation Marketing Program of the U.S. Department of Energy (DOE) (1). Its purpose was to provide an unbiased assessment of the relative performance of several classes of equipment offered commercially for the improvement of residential oil burner efficiency.

The monitoring of oil-heated buildings must consider the several situations commonly encountered with oil heat:

- hydronic systems in which both space heat and domestic hot water are delivered by one boiler on demand all year round;
- hydronic systems in which space heat and domestic hot water are delivered by separate boilers; only one of two boilers then operates in the summer;
- warm-air systems in houses whose domestic hot water is heated by another fuel; and
- warm-air systems in houses whose hot water is heated by an oil-fired water heater.

The first and third of these cases are covered by this report. In both cases a correction must be applied to compensate for weather variables; in the first case an additional correction for domestic water heating use must be accommodated by the analysis.

Unlike utility fuel deliveries, fuel oil is delivered in varying quantities at irregular intervals. A typical schedule in a small house having a 275-gallon storage tank would be comprised of seven deliveries per year of 100 to 200 gallons each, at intervals of from three weeks in January to three months over the summer. Anniversary delivery dates are not generally observed, so the analysis must compensate for the varying periods of time covered.

1.1 Previous Testing

Testing of refit equipment has increased since 1973 as a result of the severe economic impact of the rapid rise in cost of No. 2 fuel oil. In addition to the many proprietary tests by manufacturers of burners, boilers (i.e. hot-water systems), furnaces (i.e. warm-air systems), and controls, the U.S. DOE has supported a series of laboratory tests by Krajewski (5), McDonald (4,7), Batey (3,6) et al. at Brookhaven National Laboratory (BNL). Private testing of boilers has been done by the Hydronic Institute (9). Field testing of domestic hydronic systems has been done by Katzman (8) in collaboration with the National Bureau of Standards. The DOE Office of Building and Community Systems and the Office of Weatherization Assistance Programs completed a field test (10) of retention-head burners to demonstrate the feasibility and cost effectiveness of using energy assistance monies to pay for furnace retrofits.

1.2 Rationale for Field Testing

Field testing and laboratory testing of heating equipment supplement one another: laboratory testing yields precise results under closely controlled conditions; field testing is a much closer approximation to actual service conditions. Field testing gains in realism what it gives up in precision, and it also validates laboratory testing. In addition to measuring fuel savings, field tests assess the effects of installation procedures, identify installation and service problems, and reflect the level of homeowner competence and involvement in energy conservation.

This field test also traced the changes in consumption patterns over three consecutive heating seasons in a period of rapid price increases.

2. OBJECTIVES

The purposes of the REFOIL program were to measure the fuel savings of several refit options and combinations of options being widely merchandised to retail fuel oil dealers, and to identify service problems associated with their use. The results were to be used in guiding the selection of equipment used in the multi-state Fuel Oil Conservation Marketing Program.

Secondary objectives of REFOIL were:

- to develop a low-cost method of evaluating the fuel consumption of a given building without the expense of instrumentation and without repeated intrusions into the buildings,
- to examine the variation in fuel savings of a given type of equipment over a number of similar houses,
- to examine the change in fuel consumption of a set of houses during rapid price increases,
- to validate the laboratory tests done at BNL, and
- to provide the public with realistic estimates of fuel savings produced by commercially available equipment.

3. PROCEDURE

The REFOIL field test procedure involved the installation of the energy conservative equipment under test in a number of homes whose fuel delivery history over the past several years was known, monitoring fuel use for a year after installation, and comparing fuel use after installation, corrected for weather differences, i.e., daily mean temperature as expressed in heating degree days, with fuel use in previous years. The tests on hydronic equipment were done in houses of known design, construction, and number of occupants located in a single tract. Tests on warm-air equipment were done in randomly selected houses using oil warm-air heat. All tests were done in owner-occupied houses where no changes affecting fuel use were made within a year prior to or following the installation dates.

3.1 Selection of Equipment Tested

The selection of equipment and their combinations has been reported in detail by Hoppe et al. (2) and is briefly reviewed here. The testing of new designs of high-efficiency boilers and furnaces was addressed by other programs and, therefore, was not covered by REFOIL. The combinations in which the equipment was installed are shown in Table II. The "routine installation" of a retention-head burner noted in the table refers to the common commercial practice of minimum maintenance, whereas the "optimized installation" refers to a full maintenance installation.

- Retention-head burner--a widely used high efficiency replacement burner generating an intensely mixed stable flame with minimum excess combustion air and restricted off-cycle air flow.
- Vent damper--an automatic damper in the flue that closes three minutes after firing stops and opens when firing begins, thus reducing off-cycle losses in boilers.
- Boiler temperature programmer--a control device that modulates boiler water temperature to match the load.

- o Flue heat exchanger--a flue gas-to-boiler water heat exchanger mounted in the flue.
- o Double setback thermostats--an owner-operated control permitting separate day and night setback of room temperature, typically from 68°F to 55°F. Installed only in houses unoccupied during the work day.

3.2 Selection of Test Sites

The general criteria for test houses were that they be readily accessible single-family homes typical of the mass housing market, utilize oil fuel for space heating, be located near a meteorological station, and be located in an area utilizing oil heat intensively and having an average of at least 5000 heating degree days per year. For expediency all houses selected were located in Suffolk County, Long Island, New York, were owner-occupied, and were serviced by a single oil dealer who operated a large installation and maintenance department.

Suffolk County has a moderate marine climate averaging about 5500 heating degree days per year.

Tests on boilers were made in 199 houses in a single housing tract. All houses were constructed between 1965 and 1967 in seven models ranging from 1,560 to 2,530 square feet in size, having design heating loads of 42,000 to 53,000 Btu per hour, and being of one- and two-story traditional designs. Construction was conventional frame, slab on grade, with R-11 wall and ceiling insulation. Foundation insulation and storm windows and doors were used. Distribution of heat was through perimeter loops with fin-tube baseboard units. The boilers used tankless coils for heating domestic water and initially were equipped with conventional burners.

House thermostat settings were left to the discretion of homeowners.

Furnace tests were run on homes scattered around Suffolk County, New York, and of varying construction. All were owner occupied and oil heated. They did not use oil-fired water heaters and initially used conventional burners except where vent dampers were installed. In these cases retention-head burners had been installed by others two or more years prior to testing.

3.3 Field Test Operation

Field testing of boiler equipment was done in a single tract of over 1,000 homes. Letters were sent to each household requesting information to aid in the selection of field test participants. Replies were received from over 800 homes. It was found that one oil dealer supplied over half the houses in the tract and had an adequate service department.

As a result, all installations and monitoring were done by him under contract to BNL. Responsive homeowners using the chosen oil dealer were screened: nonowners, owners with less than 18 months occupancy, and owners who had made substantial house modifications (e.g., wood and coal stoves, solar heating systems) were eliminated. Recipients of the equipment discussed in Section 3 were chosen at random from the remainder. The selected recipients then signed agreements with the oil dealer allowing access to the house, installation of the equipment, and monitoring of fuel delivery data. The homeowners agreed to make no changes for the one-year duration of the experiment and in return were given free service and the option of either having the house restored to its original condition or taking title to the equipment at the conclusion of the experiment.

Generic specifications of equipment installed were made by BNL. Selection of specific models was delegated to the oil dealer.

Oil-fired furnaces were more difficult to find locally. The same oil dealer was able to locate 50 scattered houses that were owner occupied, did not use oil for domestic water heating, and relied solely on oil for space heating. Agreements as previously described were made with these homeowners.

Installations were made in the spring and summer of 1980, and monitoring continued until the fall of 1981. Fuel delivery data were obtained for 1978 through 1981. Records were kept of service calls and complaints.

4. ANALYTICAL METHOD

4.1 Background

The analytical method used in the BNL field test is constrained by the overall thrust of the project: no instrumentation in test homes, commercial rather than laboratory standards of installation, maintenance, and fuel delivery, and accommodation to the wide range of behavior expected of homeowners. An additional problem is the use in the houses chosen for the boiler tests of oil for both space heating and domestic water heating. The former load is highly dependent on weather conditions, while water heating tends to be uniform all year. However, the fuel use is highly nonlinear to DHW use because of the very low burner fractional on-time (and efficiency) in the summer as compared to the heating season.

It is also desirable to use a method related to the current commercial practice to aid in transfer of the technology to industry.

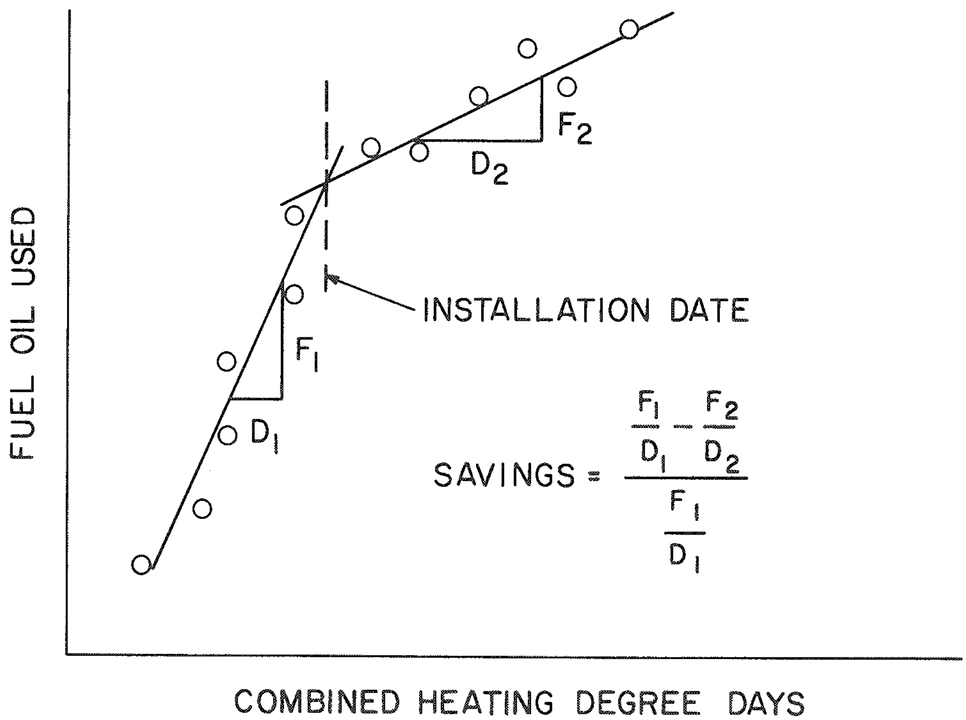

Figure 1. Calculation of Fuel Savings.

4.2 Calculation Method

The method of calculation characterizes the fuel consumption of each house over periods of about one year before and after the refit equipment is installed. A plot of fuel consumed versus cumulative combined heating degree days is typically linear, as shown in Figure 1, with a correlation coefficient greater than 0.95. The concept is validated by a study of fuel use at a single, well-understood house and by a study of 22 houses in one sample which were refitted with retention-head burners. For the single house the plot of fuel use versus heating degree days over several years yielded a correlation coefficient of 0.99. Of the 22 house sample, 20 had correlation coefficients greater that 0.98 and only 1 less than 0.90. The fuel use in gallons per heating degree day is given by the slope of the regression line. The savings are then given by the change in slope divided by the original slope as illustrated in Figure 1. A sample calculation is given in the appendix.

The use of "combined heating degree days" rather than heating degree days accommodates an allowance for domestic hot water. It is commonly used by oil distributors to calculate delivery dates for houses with tankless coils. Combined heating degree days are calculated from the daily mean temperature by adding the correction shown in Table 1 to the heating degree days (base 65°F).

TABLE 1. CORRECTION FOR DOMESTIC WATER HEATING

Daily Mean Temperature, °F	Correction
greater than 61	6 HDD
58 to 61	5
54 to 57	4
50 to 53	3
46 to 49	2
less than 46	0

4.3 Statistical Analysis

The purpose of the field test is to provide quantitative estimates of typical fuel savings and of the range of savings obtained by refitting certain options to existing residential oil burners. The sizes of test samples are from 17 to 28 houses. The effect of extraneous variables in field tests is expected to be large, yielding a broad range of savings. Very high and low outlying values of savings occur repeatedly and in all probability represent cases where occupant behavior distorts fuel use. However, physical reasons justifying the discard of such values are not known.

Common statistical practice is followed in analyzing such data. In characterizing central tendencies, both arithmetic mean and median are given. The use of the median as the "typical savings" is suggested for use in consumer information because of its insensitivity to outliers. In characterizing the spread of the findings, the range and the 95%

confidence interval are given. The latter values are preferred because they reduce the effects of outliers. The t-distribution rather than a normal distribution is used because of the small sample sizes. The t-distribution and its 95% confidence limits are used not only for analysis of data within samples and combined groups but also in calculating the significance of differences between sample means.

4.4 Data Processing

The data base management system selected for the project is the hierarchial case-oriented Scientific Information Retrieval system (available from SIR, Inc., P. O. Box 1404, Evanston, Illinois 60204). It is linked in the CDC 6600 computer in the BNL Computer Center to the Statistical Package for the Social Sciences (SPSS Inc., Suite 3300, 444 North Michigan Ave., Chicago, Illinois 60611). Interactive software for the weather and fuel delivery data inputs was prepared in the Applied Mathematics Department, BNL.

The SIR data base provides several levels of security to protect its integrity and the privacy of homeowners, and to permit read-only access by possible alternate users of the system. It is also nationally available in format compatible with several widely used computing systems.

4.5 Errors

Sources of error are extrinsic in the acquisition of fuel delivery data and in the application of BNL meterological data to a site 12 miles distant, and intrinsic in the algorithm used to calculate the rate of fuel use.

Fuel delivery data are obtained from a single fuel dealer. The volume delivered is measured by state-certified meters accurate to within less than one gallon. Underfills of up to 20 gallons are common, but that value is only about 2% of typical annual usage. Overfills are small and rare because of consumer reaction. An occasional partial fill may be made as a tank truck is emptied. Such an error is significant only if it is the first or last delivery of the test period. In such a case, it would significantly lower the correlation coefficient of the regression line, which has not occurred. We conclude that fuel delivery errors are insignificant.

Meterological data are taken at BNL by its Meterology Office. Instrumentation is traceable to the National Bureau of Standards. Its application to a site 12 miles away may introduce a slight error, but an examination of regional data over several years indicates that the magnitude of such an error is probably less than 3% and would tend to cancel out over the time periods involved. ASHRAE investigations have shown little error deriving from use of an average of maximum and minimum daily temperatures as compared to a true mean in calculating heating degree days.

The inaccuracy intrinsic in the algorithm appears to be the most significant source of error. The excellent correlation of fuel use to combined heating degree days is consonant with a small rather than large error. Seasonal effects are known to exist; they are minimized by selecting equivalent time periods before and after equipment installation. Additional investigation of improved algorithms is needed. Effects of wind, insolation, and breakeven building temperatures to replace the 65°F value should be investigated.

Consideration was given to the use of a commercially available heating degree day meter which senses temperature, wind, and insolation effects, but it was not used because of its proprietary nature and a lack of experience in its use. The concept appeared useful in obtaining a more precise characterization of heating loads.

5. RESULTS AND CONCLUSIONS

5.1 Equipment Performance

Fuel savings obtained from the tests of boiler and furnace refit equipment and combinations of equipment are summarized in Table 2 , from which the principal conclusions of this study are drawn. The typical values shown are medians; the maxima and minima are the 95% confidence limits.

o Retention-Head Burner. The retention-head burner performance as shown for boilers and for furnaces is the benchmark of this study. It shows typical savings of 18% with a narrow range of 16% to 22% for boilers, and a typical savings of 11% on furnaces with a range from 0% to 15%. The optimization procedure as described in Section 3.1 increases fuel savings by 6%. Subsequent discussion in this report is based on the optimized installation. It should be noted that some savings are obtainable by downfiring, cleaning the heat exchanger, and repairing insulation alone. Savings with furnaces are lower than those with boilers because the low thermal mass of furnaces and their purging mode of operation reduces their stack and jacket losses while not firing.

o Boiler Temperature Programmer. The BTP performance is shown with a retention-head burner and with a double setback thermostat. With the retention-head burner the BTP produced no significant reduction in fuel use. After inspecting several of such installations, the manufacturer of the BTP stated that the boiler temperature sensor mounted on

TABLE 2. SUMMARY OF FUEL SAVINGS

Description of Refit	Boiler Min.	Boiler Typical	Boiler Max.	Furnace Min.	Furnace Typical	Furnace Max.
Retention Head-Burner Alone						
with Routine Installation	7	12	15			
with Optimized Installation	16	18	22	0	11	15
Optimized Retention Head Burner In Combination with Either						
Boiler Temperature Programmer	15	21	24			
or Vent Damper[1]	16	20	27	0	11	20
Conventional Burner Refitted with						
Vent Damper	6	9	23			
or Flue Heat Exchanger	4	10	17			
or Double Setback Thermostat	4	11	14			
or Double Setback Thermostat plus Boiler Temperature Programmer	10	19	32			

Percentage Savings

[1]Vent dampers installed in houses which had been equipped with a retention head burner at least one year earlier.

the supply pipe (i.e., boiler-to-load pipe) was too far from the boiler, thus reducing the performance of the unit. With the double setback thermostat and a conventional burner the BTP produced high savings of 19%, an increase of 8% from the savings produced by the double setback thermostat alone. The cold start option of the BTP as described in Section 3.4 was not tested in REFOIL because the boilers used were susceptible to leaks at the domestic water heating coil gaskets if repeatedly thermally cycled to low temperatures.

o Vent Damper. Vent damper performance on boilers is shown with a retention-head burner and with a conventional burner. The addition of a vent damper to a retention-head burner increased typical savings by only 2%. Adding a vent damper to a conventional burner produced typical savings of 9%, while replacing the conventional burner with a retention-head burner (optimized refit) produced savings of 18%. The vent damper is then unattractive as a refit option in oil-fired hydronic systems where a retention-head burner can be installed, unless the vent damper is appreciably cheaper than the burner.

Vent damper performance on furnaces with retention-head burners is also shown in Table 2. No additional savings were observed compared to the retention-head burner alone. The somewhat poorer performance of the vent damper retention-head burner combination as compared to the retention-head burner alone is not statistically significant. The retention-head burner is clearly the preferred option of the two in furnaces compatible with its use.

o Flue Heat Exchanger. Flue heat exchangers were tested only in boilers fitted with conventional burners, yielding typical savings of 10%. The savings are thus about half those obtained from the less expensive retention-head burner. The heavy accumulation of soot observed at the end of the one-year test indicates that frequent cleaning may yield higher fuel savings but at considerably increased maintenance costs. Retention-head burners should produce less sooting. The conventional burners used in the test were tuned to Bacharach Smoke Numbers no greater than 1 at the time of installing the flue heat exchanger.

Since the boiler heat exchanger and the flue heat exchanger perform the same function, the performance of the flue heat exchanger is inversely related to the efficiency of the boiler itself. Any test results then are highly sensitive to the specific boiler used, and extrapolation to other models is not justified. Nevertheless, it appears that the gas-to-liquid stack heat exchanger with its high price and high maintenance cost is of limited utility in fuel oil conservation. The possibility of corrosion of exchanger and of chimney caused by the flue heat exchanger is an added deterrent.

o Double Setback Thermostat. The double setback thermostat was tested only with conventional burners in houses unoccupied by day. The typical savings of 11% shown compare to savings quoted by Batey (11) of 12% for a single eight hour 10^{o} setback and 23% for two such setbacks daily. The savings are, of course, entirely dependent on occupant behavior, and in this test many

TABLE 3. TIME TO PAYBACK RANKING OF DEVICES

Group Number	Description	Typical Fuel Savings %	Purchase Price $	Payback Time in Months: Small House	Payback Time in Months: Large House
BOILERS					
7	Double Setback Thermostat*	11	80	9	9
8	Double Setback Thermostat Plus Boiler Temperature Programmer*	19	395	19	11.5
2	Retention-Head Burner, Optimum Installation	18	410	21	10
1	Retention-Head Burner, Routine Installation	12	325	25	13
3	Retention-Head Burner Plus Boiler Temperature Programmer	21	678	30	15
5	Vent Damper	9	295	30	15
4	Retention-Head Burner Plus Vent Damper	20	703	32	16
6	Flue Heat Exchanger	10	520	48	24
FURNACES					
9	Retention-Head Burner, Optimum Installation	11	410	34	17
10	Retention-Head Burner, Optimum Installation, With Vent Dampers	11	703	59	29

The small house is assumed to have a single heating zone and to consume 1000 gallons per year of oil. The large house is assumed to have two heating zones and to consume 2000 gallons per year of oil.

The price of oil is assumed to be $1.30 per gallon.

* Installed in houses unoccupied during the day.

occupants had previously lowered settings and manually obtained day and night setback, thereby reducing the savings opportunity of the new thermostat.

The double setback thermostat used with a boiler temperature programmer comprised an effective controls package with typical savings of 19%. The two devices appear to work synergistically, with the thermostat reducing the heating load and the boiler temperature programmer modulating boiler response to that reduced load. These two controls plus a retention-head burner offer a package of high potential in the marketing of energy conservative equipment.

5.2 Installation and Maintenance Problems

No verifiable problems were encountered with retention-head burners, vent dampers, or double setback thermostats. The manufacturer of the boiler temperature programmer inspected several installations and reported an improper sensor location. The flue gas heat exchangers were badly clogged with soot after one year of service, leading to reduced efficiency and higher maintenance costs.

5.3 Economics of Savings

The simple payback times of the various groups of equipment tested are given in Table 3. The calculations are based upon the 1981 retail prices of the equipment as shown and a retail fuel oil price of $1.30 per gallon. These calculations do not account for maintenance costs, which if considered would extend the payback of the flue heat exchanger substantially and the vent damper to some extent. Illustrative payback times are given for a smaller single-zone house using 1,000 gallons of oil per year and a larger two-zone house using 2,000 gallons per year. Actual payback in any house will depend on the house, on the climate, and on the behavior of the occupant.

The rankings are based entirely on time to payback; consideration of both time to payback and fuel savings would rank the retention-head burner (optimized installation) as the option of first choice. The long payback time of the retention-head burner furnace refit suggests that the proper focus for oil burner conservation programs is on boilers rather than furnaces. The high ranking of Groups 2 and 8 and the complementary rather than duplicative nature of the fuel-saving mechanisms of the retention-head burner, boiler temperature programmer, and double setback thermostat suggest that such a combination can be successfully marketed, perhaps with installation of baffles. Such a combination should show savings above 30% at a 1981 cost of about $800.

5.4 Consumer Behavior with Rising Prices

The effect of oil price increases on fuel use was examined in 30 houses (see Appendix, Table A-2) in a single tract, all of the same model and occupied by two persons. The mean fuel savings of 126 gallons per year or 12% in 1978-79 (as compared to 1977-78) and of 40 gallons per year saved or 3% in 1979-80 (as compared to 1978-79) are shown in Figure 2 and Table 4. The savings are normalized to an average weather year. Fuel oil prices in the three heating seasons increased from $.50 to $.52 per gallon, $.53 to $.64, and $.82 to $1.00 respectively. Thus, voluntary fuel conservation decreased even as the fuel price rise accelerated. The expected negative correlation of 1979-80 savings to 1978-79 savings within each house was not found.

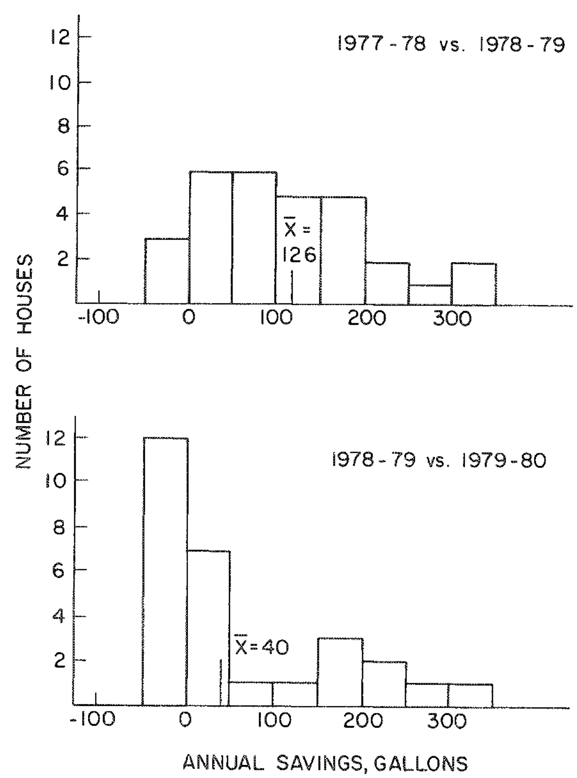

Figure 2. Distribution of Fuel Savings in 30 Identical Houses Over 2 Consecutive Heating Seasons.

The distribution of annual fuel use corrected for weather variables (heating degree days) are given in Figure 3 for three successive heating seasons.

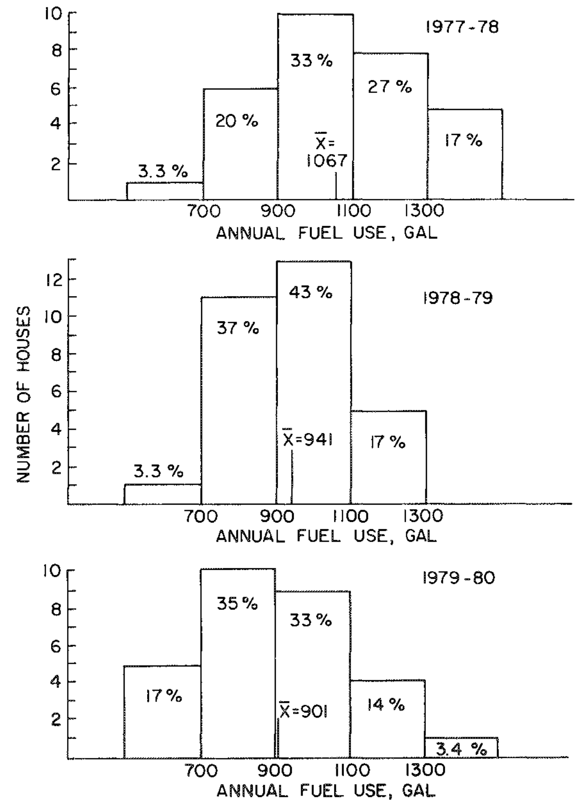

Figure 3. Distribution of Fuel Use in 30 Identical Houses Over 3 Heating Seasons.

TABLE 4. CONSUMER REACTION TO RISING PRICES

Year	Average Fuel Use, Gal.	Average Fuel Saved Gal.	%	Price Trend, $/Gal Start	End
1977-78	1,067	---	---	.50	.52
1978-79	941	126	12	.53	.64
1979-80	901	40	3	.82	1.00

It appears that the savings in fuel use decreased sharply in the third year even though the price increase in that year was greater. Such a trend may be caused by limits set by no-cost energy conservation measures implemented by homeowners such as turning down thermostats. Many persons will lower a thermostat setting from 72 to 66°F; very few will tolerate an additional reduction to 60°F.

The distribution of savings over the 30 homes is not at all uniform. The average savings and their standard deviations are:

Time Periods Compared	Savings, Gal. Mean	Standard Deviation
1978-79 vs. 1977-78	126	121
1979-80 vs. 1978-79	40	266

Thus the scatter is relatively high.

The distribution of savings versus fuel consumption is similarly very broad, as shown in Figure 3. The large number of houses showing losses in the third year, compared to the second, is indicative of the predominance of random factors. Only 3 out of 30 showed such losses in the second year, while 12 out of 29 did so in the third. There is little correlation between savings in the second versus those in the third year; i.e., homeowners apparently are not reducing oil consumption consistently, even though the opportunity for them to do so is not exhausted.

The savings in the second year is significant by the signs test at the 95% confidence level; the third year savings are not significant at that level.

Pipeline gas is not available in the tract in question, so conversion to gas is not a factor in reducing fuel oil consumption. Electric rates were high and rapidly rising during the period in question. Conversion to electric heat is not a factor. Unvented kerosene heaters are extensively marketed. They and coal stoves are expected to displace fuel oil to some extent in the 1980's. Wood heat is a minor factor in the area. Solar space heating is not used; solar water heating systems are scarce in spite of tax rebates.

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7. APPENDIX

7.1 Sample Calculation of Savings

The sample calculation shown below is made from the data in Table A-1 typifying the performance of one house over a 12-month period.

The value sought is for fuel savings in the 1978-79 heating season as compared to 1977-78. The periods are determined to be from 8/1/77 to 7/31/78 and from 9/1/78 to 8/31/79, thus bracketing the retention-head burner installation in August of 1978. The performance of the house prior to installation is characterized by the slope of the regression line:

$$y = mx + b$$
$$y = 0.186x - 225$$

where y = fuel used, gallons
x = cumulative combined heating degree days

i.e., the house uses 0.186 gallons of oil per heating degree day adjusted for domestic hot water use. The constant b depends on the arbitrary choice of a starting date for the cumulative heating degree days and is not of interest. The computer program used searches out the delivery dates prior to the beginning and end of the time period selected, i.e., it starts with 5/1/77 and ends with 5/6/78. The initial 150 gallon delivery is omitted since it was not consumed in the specified period. The use of the slope of the regression line rather than simply the ratio of total fuel deliveries to lapsed combined heating degree days minimizes the error due to changes in the oil inventory held in the tank over the time period examined. It is noted that this slope corresponds to the reciprocal of the "k" value used by oil dealers in scheduling deliveries, but is averaged over several deliveries.

A value of m_2 of 0.155 is similarly found for the 1978-79 period (not shown in Table A-1). The savings are then reported as

$$\text{savings} = \frac{m_1 - m_2}{m_1} = \frac{0.186 - 0.155}{0.186} = 16.7\%$$

The rather abstract m is converted into gallons of fuel used in a standard year at the test site by multiplying by 7,243 combined heating degree days per standard year.

In the furnace tests, heating degree days (base 65°F) rather than combined heating degree days are used since fuel oil is not used for domestic water heating.

TABLE A-1. FUEL DELIVERY AND COMBINED HEATING DEGREE DAYS

Oil Deliveries: Date	Oil Deliveries: Amount	y Cumulative Deliveries	x Cumulative Combined Heating Degree Days
5/1/77	150 gal		1,260
9/14/77	200	200 gal	2,260
11/1/77	150	350	3,030
12/5/77	220	570	4,090
1/13/78	250	820	5,380
2/20/78	240	1,060	6,530
3/25/78	120	1,180	7,520
5/6/78	160	1,340	8,280
9/4/78	190	1,530	9,410

TABLE A-2. FUEL CONSERVATION OVER PERIODS OF OIL PRICE INCREASES

Case No.	(1) Adjusted Annual Fuel Use, Gallons	(2)	(3)	(1)-(2) Savings, Gal.	(2)-(3)	$\frac{(1)-(2)}{(1)}$ Savings, %	$\frac{(2)-(3)}{(2)}$
	77-78	78-79	79-80	78-79	79-80	78-79	79-80
28	1,041	1,074	1,094	-33	-20	-3.2	-1.9
31	855	855	895	0	-40	0.0	-4.7
34	815	769	597	46	172	5.7	2.2
37	862	775	742	86	33	10.0	4.3
60	1,147	974	988	172	-13	15.0	-1.4
61	1,319	762	1,723	557	-961	42.2	-126.1
62	1,054	875	709	179	166	17.0	18.9
63	1,094	981	954	113	27	10.3	2.7
64	1,107	928	935	179	-7	16.2	-.7
65	1,127	1,001	1,007	126	-7	11.2	-.7
67	935	809	802	126	7	13.5	.8
68	875	795	809	80	-13	9.1	-1.6
70	948	709	861	239	-152	25.2	-21.4
71	1,193	915	935	278	-20	23.3	-2.2
72	1,080	1,087	---	-7	---	-1.0	---
74	1,100	1,054	1,014	46	40	4.2	3.8
75	1,485	1,147	252	338	895	22.8	78.0
76	928	921	762	6	159	.7	17.3
77	855	835	888	19	-53	2.3	-6.3
78	1,405	1,246	1,253	159	-7	11.3	-.5
79	1,007	815	583	192	232	19.1	28.5
80	1,312	1,246	1,246	66	0	5.1	0.0
89	1,067	1,087	1,041	-20	46	-1.9	4.3
95	842	762	510	80	252	9.4	33.0
97	1,399	1,186	1,167	212	20	15.2	1.7
102	1,114	1,027	1,094	86	-66	7.7	-6.4
270	948	908	769	40	139	4.1	15.3
276	1,226	1,087	882	139	205	11.4	18.9
277	630	504	484	126	20	20.0	3.9
280	1,259	1,167	1,101	93	66	7.4	5.7
$\bar{x}$[1]	1,067	941	901	126	40	11.5	2.3
s[2]	199	172	285	121	266	9.6	3.03
Range							
Max	1,485	1,246	1,723				
Min	630	504	252				

[1]mean
[2]standard deviation

"Adjusted" fuel use is corrected for differences in weather over the several years shown.