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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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Sponsored by:
Community Service Administration
1200 19th Street, N.W.
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TECHNIQUE FOR TRACKING THE EFFECT OF WEATHERIZATION RETROFITS ON LOW-INCOME HOUSING

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report presents a technique for analyzing the effect of energy saving retrofits installed in low-income housing under a nationwide weatherization demonstration program. This program was undertaken by the Community Services Administration (CSA) with the technical support of the National Bureau of Standards (NBS).

A tracking technique, based on the calculated balance-point temperature of each home prior to the weatherization, was developed to estimate the would-be fuel consumption over a period of time if the house had not been weatherized. The savings in fuel consumption for a home can be determined from the difference between the actual usage after retrofit and the calculated usage if it were not retrofitted. Besides the overall reduction, the saving in energy usage during different time periods while the house is being weatherized can be visualized from the graphical representation of the tracking technique.

Fuel reduction is reported for more than 100 homes using different fuels in seven cities across the nation, selected to represent various climate zones and geographical locations. It was found that the average saving in fuel consumption for dwellings in each city is about 30 percent.

Key words: Balance point temperature; computer graphics; degree days; energy conservation; energy consumption; fuel usage records; tracking technique; weatherization retrofit.

FOREWORD

This report is one of a series documenting NBS research and analysis efforts in energy conservation to support the Optimal Weatherization Demonstration Research Project sponsored by the Community Services Administration, under Interagency Agreement No. A8B-0018.

SI CONVERSION UNITS

Physical Quality	Symbol	To Convert From	To	Multiply By
Volume	V	ft^3	m^3	2.83×10^{-3}
Temperature	T	°F	°C	T(°C) = [T(°F)-32]/1.8
Energy	F	Btu	kJ	0.9478

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1. INTRODUCTION

A nationwide weatherization demonstration program was undertaken by the Community Services Administration (CSA), with the technical advice and support of the National Bureau of Standards (NBS), to measure the reduction in energy consumption for low-income housing by applying retrofit options to those houses [1]. Test sites were selected to represent the major climate zones in the United States, as shown in figure 1.

The dwellings selected for the demonstration program were low-income type occupied continuously by the same family and having complete and accurate fuel bill records for two years prior to the program. Other factors for selection include age, size, orientation, and occupants of the house [1].

With the agreement of owners, two groups of homes were chosen for collection of fuel consumption data before and after weatherization. Homes with retrofitted improvements belong to the sample group, while those without improvements belong to the control group. Thus, the effect of seasonal changes can be identified from the fuel usage records of a control home.

Of over 200 homes selected in the demonstration program, approximately one third are in the control group. Tables 1 and 2 indicate the architectural and mechanical retrofit options given consideration for implementation in each dwelling of the sample group. The cost estimates for the weatherization retrofits were analyzed and the list of retrofitted options were prescribed in each city so that all sample homes would be brought up to a certain standard in a given city [2]. Architectural options were selected assuming a 20-year physical life for building material [3]. In general, similar sample group homes in each city have identical options after retrofit. However, mechanical options were dependent on the evaluation of the overall efficiency of the mechanical system in energy savings. Therefore, they were chosen on a house-by-house basis, and were installed separately from the architectural options.

The principal purpose of the demonstration program was to determine the effectiveness of house retrofit options in energy conservation. Several techniques have been developed for assessing energy savings potential of dwellings from weatherization [4]. Air infiltration measurement using the air bag method can determine air leakage [5, 6]. Thermography can be used to identify areas of missing insulation or improper insulation [7]. The balance point calculation technique was adapted to established the heating balance point and the rate of energy usage in Btu/degree day for each house. In this report, a tracking technique based on the calculated balance-point temperature of each home prior to the weatherization was developed to estimate ("predict") the would-be fuel consumption over a period of time if the house had not been retrofitted.*

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* Another applied research for residential energy conservation program was conducted at the same time as this demonstration program (from 1975 to 1980) to investigate the effectiveness of attic insulation using actual fuel usage records and weather data [8]. The results of this investigation were in the form of reduction in fuel consumption rate after the attics were insulated.

Besides the overall reduction, the saving in energy usage during different time periods while the house is being weatherized can be visualized from the graphical representation of the tracking technique. The following sections will discuss procedures for data interpretation and will present a generalized result of fuel reduction in seven cities. The cities and their code name are given in alphabetical order as:

ABE	Allentown, PA
CHA	Charles, GA
CSP	Colorado Springs, CO
FAR	Fargo, ND
POR	Portland, ME
STL	St. Louis, MO
TAC	Tacoma, WA

Tables 3 to 9 indicate which architectural and mechanical options were installed on each house of these cities (the 'X's in the tables). Among these dwellings, options not selected imply they were already in place (the 'E's), or they were not applicable (the 'N's). For example, wall insulation was not recommended for dwellings in Charleston, SC due to the warm climate in the south. Other options that were treated as nonapplicable were those where the home owners objected to certain options to be installed or work could not be completed due to a strike by employees of contractors.

2. DATA COLLECTION

Houses selected for the weatherization program were required to have complete and accurate records of fuel usage for the past two years. For periods prior to the beginning of the weatherization program, the bill records for fuel consumption were those submitted by the occupants. Basically, monthly or bimonthly utility meter readings were used for gas and electric heated homes, while meter readings of delivery trucks were used for bottled gas and oil heated homes. Detailed description of data collecting, editing, handling, recording, and storing from fuel usage records can be found in other reports [2, 9]. Fuel consumption data before weatherization were stored in disk files under the name: [CTC].D[#H], where [CTC] and [#H] represent the city code and house number, respectively [9]. For example, CSP.D12 is the fuel consumption of house #12 in Colorado Springs, Colorado.

During the period of weatherization, as retrofit options were being applied to the sample houses, meters and other measuring devices were installed in sample and control homes. The type of meters installed depended on the fuel type. In order to determine the total amount of time a furnace or space heater was on and the number of its on-off cycles, a run-time meter and a cycle counter were installed. In houses with natural gas and electricity, a utility (gas or electric) meter was installed to read the overall fuel usage for the whole house, including space heating and hot water heating as well as appliances if they are of the same fuel type. In houses with propane or bottled gas, gas consumption for space heating was metered independently.

For houses with oil or kerosene heating systems, fuel consumption was calculated using burner nozzle rate and readings of the run-time meter. Thus, the established result was somewhat inaccurate due to the lack of accuracy of those meter constants.

Data from house meters were collected every week during and after weatherization. After data were interpreted as fuel consumption of dwellings in the same format as [CTC].D[#H], they were stored in disc files under the name [CTC].W[#H]. Therefore, fuel consumption before and after weatherization is available for purposes of comparison and evaluation.

Besides the fuel consumption records of each dwelling, the weather data from each city were also required for the balance point calculation. Weather tapes obtained from the National Climate Center were used to represent the weather of each city to calculate the outdoor temperature for the same period of time as in fuel records.

3. BALANCE POINT CALCULATION

The fuel consumption F of a dwelling during a billing period can be linearly related to the degree days by the equation

$$F = b_o + b_1 \cdot DD_{T_\alpha} \tag{1}$$

where F is the fuel consumption;

b_o refers to the base load at base temperature T_α;

b_1 is the rate of fuel usage per degree day;

DD_{T_α} is the degree days at base temperature T_α.

The base (or balance point) temperature of a dwelling is an outdoor temperature at which the solar and internal gains will offset the heat loss of the house; and thus the average degree days at this temperature can be determined. In general, 65°F is employed as the base temperature for normal engineering practice to perform calculations of energy requirement for residences [10]. However, the balance point temperature for each individual dwelling is unique and it can be determined from the fuel records and weather data.

In order to estimate the fuel consumption of a dwelling for the period after weatherization as if no retrofits were installed to the house, it is required to establish the balance point temperature of the dwelling prior to weatherization. This balance point temperature (of a dwelling) can be determined from the fuel records before weatherization such that the fuel consumption is linearly related to the weather of the site. Since all participating residences had monthly or bimonthly fuel records from 1975 to 1977, statistical analysis through regression technique was employed to determine the balance point temperature of each home. Detailed description of the balance point temperature calculation is included in appendix A.

For a base temperature T_α, the one-parameter model of the least square regression to fit a straight line to the average daily fuel consumption with daily degree days established from the weather data of each building period is given as

$$F_D^{(k)} = b_o^{(\alpha)} + b_1^{(\alpha)} \cdot \overline{DD}_{T_\alpha}^{(k)} \qquad k = 1, 2, \ldots N \tag{2}$$

where $F_D^{(k)}$ is the average daily fuel consumption in the k^{th} billing period;

$\overline{DD}_{T_\alpha}^{(k)}$ is the average daily degree days for a base temperature T_α in the k^{th} billing period.

By fitting a series of straight lines at base temperature between 45°F and 75°F, in the increment of 0.5°F, the case of 'best fit' is obtained by the occurrence of maximum correlation coefficient r^2 (the majority of r^2 obtained has a value greater than 0.95). The base temperature corresponding to the 'best fit' is defined as the balance point temperature T_o and the parameters corresponding to the 'best fit' are defined as the house parameters $b_o^{(o)}$ and $b_1^{(o)}$ at the balance point temperature T_o.

Once the balance point temperature, T_o of a dwelling is determined a good measure of fuel consumption for the house can be predicted by the linear equation (3):

$$F_D = b_o^{(o)} + b_1^{(o)} \cdot \overline{DD}_{T_o} \tag{3}$$

where F_D is the average daily fuel consumption;

$b_o^{(o)}$ is the base load at T_o;

$b_1^{(o)}$ is the rate of fuel usage per average daily degree days;

$\overline{DD}_{T_o}$ is the average daily degree days at T_o.

For comparison, prediction of fuel consumption were also performed to cases of 1) T_α = 65°F and 2) b_o = 0. The latter corresponds to zero base load, an ideal case.

4. DESCRIPTION OF TRACKING TECHNIQUE

Based on the balance point calculation from each home's fuel bill records before weatherization, sets of house parameters (b_o, b_1 and T_α) corresponding to the 'best fit', as well as at T_α = 65°F, and at b_o = 0 were obtained. As architectural and mechanical options (see Tables 1 and 2) were being installed in the sample homes, savings in fuel consumption could be calculated by comparing fuel billing records after weatherization with "predicted" fuel usage. A computer program was developed on the Interdata 7/32 minicomputer to track the reduction of fuel usage by producing tables and graphs for both sample homes and control homes.

Ordinarily, the percentage saving of fuel consumption would be calculated from the date of installation through the end of the period of calculation. On the other hand, the percentage saving in fuel usage between certain periods of time, such as between different weatherization options, can also be established by entering to the computer program the beginning and ending dates of such periods.

There are two major branches in the tracking program; 1) to calculate the predicted fuel consumption from weather data and sets of house parameters (b_o, b_1, and T_o); and 2) to interpret the fuel bill records of meter readings. Hence, the comparison of actual and predicted fuel usage can be produced by the tracking program in the forms of tables and graphs. As a result, from the balance point calculation, three sets of house parameters were selected: 1) "best fit" corresponds to the set of maximum correlation coefficient (r^2 is a maximum); 2) "T_α = 65°F" corresponds to the set that the base temperature is equal to 65°F; and 3) "b_o = 0" corresponds to the case where the base load residues are zero. For each set of house parameters, the predicted fuel consumption was given by equation (3) with the average degree days ($DD_T^{(K)}$) calculated from weather data. The output table from the tracking program contains the city code, house number, beginning and ending dates of calculation, actual fuel consumption, predicted fuel consumption and average degree days for all three sets of house parameters, period length, dates of installation, and percentage savings after the date of installation (see table 10 as an example). The unit of actual and predicted fuel usage from the best fit are given in kBtu as well as in its own fuel unit. The graph presents information similar to that contained in the table, with the additional advantage of visualizing the variation of fuel usage (see figures 2 to 18).

In general, results of predicted fuel consumption from all three cases are close unless their correlation coefficient, r^2's, are very low. As an example, table 10, produced by the tracking program, gives a comparison of actual (F) and predicted (F_1, F_2, and F_3 for all three sets of parameters) fuel consumptions from 5/28/75 to 4/16/80 of house #41 in Colorado Springs, CO. This house uses gas for both space heating and hot water heating; and its fuel units is in 100 cu. ft. Values of F and F_1 are given both in kBtu and 100 cu. ft. As indicated in table 10, predicted fuel consumption from all three cases are fairly close to each other and to the actual fuel usage, F, before the installation date, 10/4/79. After that, readings of F have a significant drop from those predicted usages (F_1, F_2, F_3), and the percentage savings of fuel consumption was about 35 percent.

Figure 2 compares predicted fuel usage from the "best fit" parameters (with connecting curve) and actual readings (with symbol *). Prior to January 1979, this house was not weatherized (see table 3); the predicted fuel consumption curve seemed to be tracking with the actual readings quite well, which supports and validates the use of the "best fit" parameters from the balance point calculation as a predictor for post-weatherization calculations. As various retrofit options began to be installed in this particular house (the dates are shown in table 3), substantial savings of gas consumption began to show on figure 2. Note that there is a minimum gase usage equivalent to about 100 kBtu per day in the non-heating season, representing the minimum load including hot water usage in summer months. Since the fuel usage for heating hot water will not be the same in the summer months and in the winter months, the base load of fuel consumption is only an indication of minimum load in the summer months [11]. All dwellings selected in Colorado Springs use natural gas for space heating and hot water heating, and will have the same characteristics.

Figure 3 is a similar plot for a control home (#6) in Colorado Springs. As expected, both predicted and actual fuel usage of this house are tracking with each other all the way. The fuel reduction of this house, as shown in table 11 was found to be only 0.4 percent since 10/1/79. In order to compare the percentage saving in fuel consumption between sample homes and control homes, an arbitrary date (10/1/79 for Colorado Springs) was chosen for control homes in each city, equivalent to the installation date of the sample homes, for calculation.

Tables 3 to 9 give listings of sample and control homes selected in each city along with their retrofit options, installation dates, and percentage savings in fuel consumption. Information on retrofit options selected for each residence and their cost of the entire demonstration program can be found in other reports [1, 2, and 3].

5. INTERPRETATION OF RESULTS FROM TRACKING PROGRAM

Among the dwellings chosen for the weatherization program, some use different fuel types for space heating and hot water heating. As an example, house #17 in Fargo, ND has a gas space heater and electric hot water heater. Since the fuel records included only gas bills, without considering the electricity for hot water heating, fuel usage in the non-heating season was very low, or even vanished. Figure 4 demonstrates this phenomenon as both the actual and predicted fuel consumption are approaching zero in those summer months. Table 4 indicates that the installation of house retrofit options were begun in 11/78, and the fuel reduction since this date can be observed from figure 4. The percentage savings of gas consumption since 7/79 (completion of architectural options) was calculated to be about 44 percent (see table 4). In fact, the real saving due to weatherization would be even higher if savings occurred during installation periods were included.

Figure 5 is the graph of fuel consumption of another sample home in Fargo, where natural gas is used for both space heating and hot water heating. The minimum load of about 50 kBtu per day exists, including the hot water usage. Figure 6 illustrates the fuel consumption of a control home in Fargo with similar types of fuel supply (also with minimum load).

House #4 in Tacoma, WA is a total electric home, with electric space heater and electric hot water heater. Figure 7 shows the actual and predicted electric consumption of this home, including the minimum load of 200 kBtu per day from the usage of hot water, appliances, and lights in the summer months. Figure 8 and 9 show the results of two homes (a sample home and a control home, respectively) in Tacoma that use natural gas for space heating and electricity for hot water heating. As expected, the gas usage in summer months was extremely low. Information on fuel saving and retrofit options of dwellings in Tacoma can be found in table 5.

The majority of the sample homes in Portland, ME use oil for space heating. Some have electric hot water heaters and some have the hot water attached to the furnace; houses #7 and #25 are examples of these two types of homes, respectively. There were no control homes available in Portland. Figures 10 and 11 give the predicted and actual oil consumption of these two houses and they both seem to attain higher percentages of savings in the second winter (1979-80). This may be due to the fact that the modification of mechanical systems and replacement of hot water heaters were completed (7/79) more than a year after the architectural options (5/78), as given in table 6.

In St. Louis, MO all dwellings selected used natural gas for space heating and hot water heating. According to table 7, the majority of the house retrofit options in St. Louis were started after 1/79 and were completed around 1/80. Hence, most of the calculated fuel savings do not include a whole heating season. House #70 is one of the few houses in St. Louis on which retrofit options were installed between 7/79 and 10/79. The percentage fuel saving after 10/79 was found to be 21 percent; and figure 12 illustrates both predicted and actual fuel consumption for this house with no significant fuel reduction shown until 10/79. On the other hand, house #42 is a sample home in which retrofit options were installed between 1/79 and 1/80. Figure 13 illustrates that fuel reduction does exist after weatherization is partially done. The percentage savings of gas consumption after 1/80 was reported about 38 percent. Figure 14 shows that the predicted and actual fuel consumption of a control home (#10) in St. Louis are in agreement, with the predicted values slightly below the actual values. Thus the percentage savings after 1/80 was calculated to be negative 12 percent, as given in table 7. Other information about saving and options are also included in table 7. The mechanical and water heater options were never installed in dwellings of St. Louis due to a worker strike.

Allentown, PA is another city in the demonstration program having different fuel for their homes. Figures 15 and 16 show the fuel consumptions (actual and predicted) of gas homes #23 and #27 in Allentown, in which less than one year of fuel bill records were available after weatherization, and though some of the retrofit options were completed at a later date (see table 8). Even so, the calculated percentage saving of fuel consumption was to be 18 percent and 42 percent, respectively. The reason of much lower fuel saving in house #23 than that in house #27, may be that the mechanical system options were never installed to house #23, as the pre-weatherization fuel usage of these two houses were fairly similar.

In Charleston, SC most sample and control homes use bottled propane for space heating. For the hot water heaters, they use gas, electric, or propane, and some homes do not have hot water heaters at all. Furthermore, none of them have mechanical system options installed. Due to uncertainties in the weekly readings of fuel consumption after weatherization, fuel delivery bills were used even though there were only monthly delivery records. Figure 17 shows the predicted and actual fuel consumptions of house #25 in Charleston. As fuel consumption was based on delivery records, their magnitudes only represented the total consumption between deliveries. Therefore, both the magnitude and the frequency of fuel delivery should be observed in order to identify the variation of actual fuel consumption. Figure 18 is a similar graph of house #19 in Charleston, a control home. The percentage savings of fuel consumption for house #25 and #19 were calculated to be 30 percent and 4 percent respectively (see table 9). Note that, by using delivery records, there were data gaps for actual fuel usage and a complete picture of continuous fuel consumption can be seen.

6. SUMMARY AND DISCUSSION

According to the availability of fuel bill records, meter readings, and weather data, more than 120 dwellings were chosen from the weatherization program for tracking the effectiveness of house retrofit options with the end of conduction work as installation date for calculation. Those houses are in seven cities that represent different climate zones of the United States (see figure 1). Figure 19 shows the distribution of dwellings in sample and control groups in each city with regard to percentage saving in fuel consumption. From figure 19, it appears that, in each city, the distributions of homes between those including water heater usage and those excluding water heater usage are similar. The average and median values of percentage saving in fuel consumption are for all homes given in table 12.

In general, the average saving in fuel consumption for dwellings in each city was above 30 percent, except in Charleston, St. Louis and Allentown. Due to the fact that no mechanical system modifications were applied to houses in Charleston and St. Louis (no hot water heater modification was applied to St. Louis), lower reduction in saving was expected. As for Allentown, infiltration work for all houses was finished after the calculation of fuel savings began; therefore, saving was smaller than in those cities in which infiltration work was finished earlier. Furthermore, fuel data after weatherization for Allentown were not available until 8/79 so that saving in some homes due to earlier retrofit was not included. On the other hand, high saving in fuel consumption was obtained from dwellings with longer periods of fuel records after weatherization. For homes in Portland, retrofit options were installed in 1978 and in early 1979 (see table 6). Two years of fuel data were available after those houses were weatherized. The percentage saving for fuel consumption was found to be over 40 percent. In figures 20 and 21, histograms show the number of dwellings that achieved various levels of saving in fuel consumption including water heater usage and excluding water heater usage, respectively, for both sample and control groups in all seven cities. Of those homes in the sample group, about 50 percent show a saving between 20 and 40 percent, and over 80 percent show a saving between 10 and 50 percent, as illustrated in figures 20 and 21.

Since there were no retrofits installed to the dwellings in the control group the fuel savings was based on chosing an arbitrary day as the beginning date for calculation. Figures 20 and 21 indicate that the change in fuel usage in the control homes is between -30 to +30 percents. The intention to select control homes as well as sample homes was to identify the effect of seasonal change from the fuel records of the control group. However, the graphical representation by the tracking technique for fuel usage in control homes (see figures 3, 6, 9, and 14) provides support to this method, as both predicted and actual fuel consumption are tracking each other before and after weatherization.

7. CONCLUSIONS

A method is presented to determine the saving in fuel consumption realized from implementation of the CSA Weatherization Program. Based on the balance point calculation and interpretation of fuel bill records, changes in fuel consumption over time can be calculated. The computer program includes numerical calculations of percentage savings for house fuel usage from a certain date, and tablet and graphical outputs of predicted and actual average daily fuel usage before and after weatherization. Percentage saving over the same periods of time is established as various retrofit options begin to be installed to dwellings.

Over 120 homes (about 100 in the sample group and 25 in the control group) were selected to demonstrate this technique for tracking the effects of retrofit options installed in homes. It was found that about 50 percent of the sample homes had a saving between 20 and 40 percent after weatherization. On the other hand, 50 percent of the control homes show a saving between 0 and 20 percent. Note that numerical results of the control group are based on an arbitrary date as the beginning date for percentage calculation for each house. Furthermore, graphical interpretation of fuel usage provides a visualized understanding to the house performance before, during, and after weatherization, and also validates the house parameters established from the balance point calculation prior to weatherization.

8. REFERENCES

1. Crenshaw, R., Clark, R., Chapman, R., Grot, R., and Godette, M., "CSA Weatherization Demonstration Project Plan," NBSIR 79-1706, March 1979.

2. Crenshaw, R., and Clark, R., "Optimal Weatherization of Low-Income Housing in the U.S.: A Research Demonstration Project," NBS Building Science Series 144, September, 1982.

3. Chapman, R.E., Crenshaw, R.W., Bames, K.A., and Chen, P.T., "Optimizing Weatherization Investments in Low-Income Housing: Economic Guidelines and Forecasts," NBSIR 79-1948, February 1980.

4. Grot, R.A., "Field Techniques for Measuring the Savings of Energy Improving Retrofits in Single Family Dwellings," Proceedings of the International Colloquium, Comparative Experimentation of Low-Energy Houses, p. X, Liege, Belgium, May 1981.

5. Grot, R.A., "A Low-Cost Method for Measuring Air Infiltration Rates in a Large Sample of Dwellings," NBSIR 79-1728, April 1979.

6. Grot, R.A. and Clark, R.A., "Air Leakage Characteristics and Weatherization Techniques for Low-Income Housing," Thermal Performance of Exterior Envelopes of Buildings, DOE/ASHRAE Conference, Orlando, Florida, December 1979.

7. Grot, R.A., "An Assessment of the Application of Thermography for the Quality Control of Weatherization Retrofits," Proceedings of Thermosense II, Second National Conference on Thermal Infrared Sensing Technology for Energy Conservation Programs, American Society of Photogrammetry, pp. 193-208, Falls Church, VA, 1980.

8. Scanlan, T.F., Bayne, C.K., and Johnson, D.R., "Investigation of Attic Insulation Effectiveness Using Actual Energy Consumption Data," ORNL-5825, September 1982.

9. Clark, R., "The CSA Weatherization Demonstration Data Base: Contents and Descriptions," NBS Technical Note 1156, February 1982.

10. American Society of Heating, Refrigeration, and Air Conditioning Engineers, 1980, System Volume, New York, N.Y.

11. Dutt, G., Lavine, M., Levi, B., and Socolow, R., "The Modular Retrofit Experiment: Exploring the House Doctor Concept," PU/CEES Report No. 130, Princeton University, Princeton, NJ, June, 1982.

Table 1. Architectural Options Considered in Optimum Weatherization Demonstrations

INFILTRATION

1. Replace broken glass
2. Reset glazing
3. Replace threshold
4. Seal structural cracks
5. Weatherstrip windows
6. Caulk doors
7. Weatherstrip doors
8. Weatherstrip attic hatch

WINDOW

10. Install storm windows
11. Install insulation drapes (R = 1.14)
12. Install insulating shutters (R = 7.8)
13. Install low emissivity films
14. Install triple glazing

DOORS

15. Install storm door
16. Install second wood door (R = 2.18)
17. Replace exterior door with insulating door (R = 6)

INSULATION

18. Install attic insulation (R = 11, 19, 30 38)
19. Install wall insulation (R = 11+ vapor barrier where possible)
20. Install first floor insulation (R = 19, 30)
21. Install basement wall insulation (R = 7)
22. Install perimeter slab insulation

Table 2. Mechanical Options Considered in Optimum Weatherization Demonstration

FURNACE

1. Install flue or vent damper
2. Install flue or vent restrictor
3. Install electronic ignition
4. Install two-stage gas valve
5. Derate furnace - downsize orifice or nozzle size and install diverter
6. Replace burner
7. Replace furnace (change distribution system when required)

DISTRIBUTION & CONTROL SYSTEM

8. Insulate ducts and pipes
9. Install reflectors behind radiators
10. Install night setback thermostat
11. Relocate thermostat

HOT WATER HEATER

12. Install hot water heater
13. Replace hot water heater
14. Reduce temperature setting on hot water heater
15. Install flow restrictor on shower
16. Install timer on electric water heaters
17. Install flue damper in gas water heaters

Table 3. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Colorado Springs, CO

SAMPLE GROUP

OPTIONS INSTALLED \ HOUSE NUMBERS		7	11	13	14	17	20	23	24	26	28	31	34	37	41	43	44	47	49
ARCHITECTURAL	Begin	1/79	1/79	1/79	1/79	2/79	1/79	1/79	2/79	1/79	1/79	1/79	2/79	1/79	1/79	1/79	1/79	1/79	1/79
	End	8/79	11/79	9/79	10/79	9/79	8/79	10/79	3/79	9/79	4/79	10/79	9/79	11/79	10/79	10/79	10/79	9/79	10/79
Replace Broken Glass		X	X	X	X	X	X	X	X	X	X	X	X	X	N	X	N	X	N
Reset Glazing		X	N	X	X	X	N	N	N	X	X	N	X	N	N	N	N	X	N
Replace Threshold		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	N
Seal Cracks & Holes		X	X	X	N	X	X	N	N	X	X	N	X	X	X	X	X	X	N
Weatherstrip Windows		X	E	X	E	X	E	E	X	X	E	E	X	E	E	E	E	X	E
Caulk Windows		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Attic Hatch		E	E	X	X	E	E	X	E	X	X	X	X	E	E	X	X	E	E
Fireplace Damper		N	N	N	N	N	N	N	N	N	N	N	X	N	N	N	N	N	N
Insulate Attic R-30		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Install Storm Windows		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Insulate Basement Wall, Slabs or Crawl Spaces		X	X	X	X	X	E	X	E	X	X	X	X	X	X	X	X	X	X
Insulate Walls		X	X	X	X	X	X	X	E	X	E	X	X	X	X	X	X	X	X
HEATING SYSTEM	Begin	2/79	4/79		10/79	1/80	1/80	10/79	3/79	12/79		12/79	12/79	12/79	12/79	12/79	12/79	1/80	4/79
	End	1/80	12/79		12/79	1/80	1/80	12/79	11/79	1/80		1/80	1/80	1/80	12/79	12/79	1/80	1/80	1/80
Flue or Vent Damper		X	N	N	X	N	N	X	X	X	N	X	X	X	N	N	X	X	X
Electronic Ignition		N	N	N	N	X	X	X	X	X	N	X	X	X	X	X	X	N	X
Two Stage Gas Valve		N	N	N	N	N	N	N	X	N	N	N	N	N	N	N	N	X	N
Derate Furnace		N	N	N	N	N	N	N	X	N	N	N	N	N	N	N	N	X	N
Replace Furnace		N	N	N	N	N	N	N	N	N	N	N	X	N	N	N	N	N	N
Insulate Ducts & Pipes		X	X	N	N	N	N	N	N	X	N	N	X	X	X	N	N	N	X
Night Setback Thermostat		X	X	N	X	N	N	X	X	X	N	X	X	X	N	N	X	N	X
WATER HEATER	End	12/79	12/79	12/79				11/79	11/79	11/79			12/79		2/80	1/80	12/79	10/79	12/79
Insulate Water Heater		X	X	X	N	N	N	X	X	X	N	N	X	N	X	X	X	X	X
Reduce Temp Water Heater		N	X	X	N	N	N	X	X	X	N	N	X	N	X	X	X	X	X
Shower Flow Restrictor		N	N	N	N	N	N	X	X	N	N	N	N	N	X	N	X	N	X
Flue Damper Water Heater		X	N	N	N	N	N	X	X	X	N	N	X	N	N	N	X	X	X
Timer on Water Heater		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
APPLIANCES																			
Dryer Vent Diverter		N	N	N	X	N	N	X	N	N	N	X	N	N	N	N	X	N	X
PERCENT SAVING IN FUEL CONSUMPTION		24	46	1	30	29	13	30	30	18	9	47	40	36	35	38	47	40	57
INSTALLATION DATE USED (all in 1979)		8/31	11/12	9/24	10/25	9/14	8/31	10/22	3/10	9/28	3/28	10/22	9/17	11/16	10/4	10/1	10/26	9/26	10/5

CONTROL GROUP (Installation Date Used: 10/1/79)

HOUSE NUMBERS	01	05	06	08	10
PERCENT SAVING IN FUEL CONSUMPTION	2	-19	0	11	11

X: Options installed
E: Existing options
N: Options not judged to be applicable

Table 4. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Fargo, SC

SAMPLE GROUP

OPTIONS INSTALLED \ HOUSE NUMBERS		2	5	6	10	11	15	17	25	27	30	32	35	36
ARCHITECTURAL	Begin	11/78	10/78	11/78	11/78	11/78	11/78	11/78	11/78	11/78	1/79	10/78	10/78	11/78
	End	7/79	6/79	11/79	9/79	7/79	2/79	11/79	10/79	11/79	11/79	2/79	11/79	10/79
Seal Cracks & Holes		N	N	N	N	X	X	N	N	N	N	N	N	N
Weatherstrip Windows		X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Windows		E	X	X	X	X	X	X	X	X	E	E	X	X
Weatherstrip Doors		X	X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors		E	X	X	X	X	X	X	X	X	E	E	X	X
Weatherstrip Attic Hatch		X	X	X	X	X	X	X	X	X	X	X	X	X
Install Triple Glazing		X	X	X	X	X	X	X	X	X	X	X	X	X
Insulate Attic R-38		X	X	X	X	X	X	X	X	X	X	X	X	X
Install Wall Insulation		X	X	X	X	X	X	X	X	X	X	E	X	X
Insulate Basement Walls, Slabs or Crawl Spaces		X	X	X	X	X	X	X	X	X	X	X	E	X
Install Insulating Shade		E	X	E	E	E	E	X	X	X	X	E	E	E
HEATING SYSTEM	Begin	2/79	2/79	7/79	2/79	1/79	9/79	12/78	2/79		2/79	2/79	9/79	9/79
	End	9/79	9/79	7/79	5/79	1/79	9/79	9/79	2/79		9/79	9/79	9/79	9/79
Flue or Vent Damper		X	X	X	X	N	N	X	N	N	X	X	N	N
Electronic Ignition		N	N	N	N	N	N	X	N	N	X	X	N	N
Derate Furnace		X	X	N	N	N	N	X	X	X	X	X	X	X
Replace Furnace		N	N	X	X	N	X	N	N	N	N	N	N	N
Two Stage Gas Valve		N	N	N	N	N	N	N	N	N	N	X	N	N
Night Setback Thermostat		X	X	X	X	X	X	X	X	N	X	X	N	N
WATER HEATER	End	9/79	11/79	3/79	2/79	9/79	9/79	3/79	9/79	3/79	11/79	9/79	9/79	9/79
Insulate Water Heater		X	X	X	X	X	X	X	X	X	X	X	N	N
Replace Water Heater		N	N	N	N	N	N	N	N	N	N	X	N	N
Timer on Water Heater		N	N	X	X	N	N	X	N	X	N	N	N	N
Flue Damper		N	N	N	N	X	X	N	N	N	N	N	N	X
Shower Flow Restrictor		X	X	N	N	X	X	N	X	N	X	X	X	X
PERCENT SAVING IN FUEL CONSUMPTION		36	56	35	15	21	43	44	16	36	39	12	20	22

CONTROL GROUP (Installation Date Used: 7/1/79)

HOUSE NUMBER	13	22	23	26	34
PERCENT SAVING IN FUEL CONSUMPTION	2	2	16	7	-1

X: Options installed
E: Existing options
N: Options not judged to be applicable

Table 5. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Tacoma, WA

SAMPLE GROUP

OPTIONS INSTALLED \ HOUSE NUMBERS		4	21	39	45	49	55	57	81	83	87
ARCHITECTURAL	Begin	2/79	11/79	1/79	10/79	10/79	9/79	2/79	2/79	2/79	10/79
	End	11/79	1/80	10/79	1/80	11/79	1/80	7/79	11/79	12/79	12/79
Replace Broken Glass		N	X	N	N	N	X	X	N	N	N
Reset Glazing		N	X	N	N	N	X	N	N	N	N
Replace Threshold		N	N	N	X	N	N	N	N	N	N
Seal Cracks & Holes		N	N	N	X	N	N	N	N	N	N
Weatherstrip Windows		X	X	X	X	E	X	X	X	X	X
Caulk Windows		X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors		X	X	X	X	X	X	X	X	X	X
Caulk Doors		X	X	X	X	X	X	X	X	X	X
Gaskets on Electric Plugs & Switches		E	E	E	E	E	E	E	E	E	E
Weatherstrip Attic Hatch		X	X	X	E	E	X	E	X	E	E
Fireplace Doors		N	N	N	N	N	N	N	N	N	N
Install Storm Windows		X	X	X	X	E	X	X	X	X	X
Insulate Attic R-30		X	X	X	X	X	X	X	X	X	X
Insulate Walls		E	X	X	X	X	X	X	X	X	X
Insulate Basement Walls, Slabs or Crawl Spaces		X	X	X	X	X	X	X	X	X	X
HEATING SYSTEM	Begin	9/79	1/80				10/79	8/79	8/79	9/79	12/79
	End	9/79	1/80				10/79	9/79	8/79	9/79	12/79
Insulate Ducts & Pipes		X	X	N	N	N	X	X	X	X	X
Night Setback Thermostat		N	N	N	N	N	N	X	N	X	N
WATER HEATER	End	9/79	1/80	8/79		12/79	12/79	8/79	8/79	9/79	12/79
Insulate Water Heater		X	X	X	N	N	X	X	X	X	X
Reduce Temp Water Heater		X	X	X	N	X	X	X	X	X	X
Shower Flow Restrictor		X	X	X	N	N	N	N	X	X	N
Timer on Water Heater		X	X	N	N	N	X	X	X	X	N
PERCENT SAVING IN FUEL CONSUMPTION		18	23	40	40	34	49	57	22	41	27
INSTALLATION DATE USED (all in '79 except as indicated		7/31	1/16/ 80	7/24	1/17/ 80	11/21	12/3	7/25	7/16	8/2	12/18

CONTROL GROUP (Installation Date Used: 7/31/79)

HOUSE NUMBER	37	58	76	98
PERCENT SAVING IN FUEL CONSUMPTION	-4	1	11	29

X: Options installed

E: Existing options

N: Options not judged to be applicable

Table 6. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Portland, ME

SAMPLE GROUP

OPTIONS INSTALLED / HOUSE NUMBERS		4	7	10	11	12	18	19	20	21	23	25	26
ARCHITECTURAL	Begin	3/78	10/78	2/78	3/78	3/78	10/78	9/78	2/78	2/78	3/78	3/78	2/78
	End	10/78	5/79	6/78	2/79	10/78	12/78	12/78	10/78	3/78	10/78	5/78	2/79
Replace Broken Glass		X	N	N	X	X	N	N	X	X	X	N	X
Reset Glazing		X	N	X	X	X	N	N	X	X	X	N	X
Replace Threshold		N	N	N	N	N	N	N	N	X	N	N	N
Seal Cracks & Holes		N	N	X	N	N	N	N	N	X	X	N	N
Caulk Windows		X	X	X	X	X	E	E	X	X	X	X	X
Weatherstrip Doors		X	X	X	X	X	X	X	X	X	X	X	X
Caulk Doors		X	X	E	X	E	E	E	X	X	X	E	E
Weatherstrip Attic Hatch		X	X	E	E	X	E	E	X	E	X	X	E
Triple Glazing		N	N	N	N	X	N	N	N	N	N	N	X
Install R-30 Attic Insulation		X	X	X	X	X	X	E	X	X	X	X	X
Insulate Walls R-11		X	X	X	X	X	X	X	X	X	X	X	X
Insulate Basement Wall, Slabs or Crawl Spaces		X	X	X	X	X	E	E	X	X	X	E	X
Storm Doors		X	E	X	E	X	E	E	E	X	E	X	X
Storm Windows		E	X	X	X	X	E	E	E	X	X	X	X
HEATING SYSTEM	End (all 7/79)												
Flue or Vent Damper		X	N	N	N	N	X	X	X	X	X	N	X
Derate Furnace		N	N	N	N	N	N	N	N	N	X	X	N
Replace Burner		N	N	N	N	N	N	N	X	N	N	N	X
Replace Furnace		X	X	N	X	X	X	N	N	X	N	N	N
Insulate Ducts & Pipes		N	N	N	N	N	N	N	X	N	N	X	X
Night Setback Thermostat		X	X	N	X	X	X	X	N	X	X	X	X
WATER HEATER	End (all 7/79)												
Insulate Water Heater		N	N	N	N	N	N	N	N	N	X	N	N
Replace Water Heater		X	N	N	N	X	N	N	X	N	N	X	X
PERCENT SAVING IN FUEL CONSUMPTION		38	43	30	53	25	71	37	51	35	30	59	47
INSTALLATION DATE USED (all in 1978 except as indicated)		10/24	11/30	11/30	2/1/79	10/19	12/31	12/31	10/16	2/28 79	10/20	5/31	2/28/79

*CONTROL GROUP IS NOT AVAILABLE

X: Options installed
E: Existing options
N: Options not judged to be applicable

Table 7. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in St. Louis, MO

SAMPLE GROUP

OPTIONS INSTALLED \ HOUSE NUMBERS	6	7	17	34	38	41	42	49	55	56	70	77	92	93
ARCHITECTURAL Begin	2/79	1/79	2/79	1/79	2/79	6/79	1/79	2/79	2/79	6/79	7/79	2/79	7/79	2/79
End	6/79	1/80	2/79	1/80	1/80	1/80	1/80	1/80	1/80	1/80	10/79	1/80	1/80	1/80
Replace Broken Glass	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Reset Glazing	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Replace Threshold	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Seal Cracks & Holes	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Caulk Windows	X	X	E	X	X	X	X	E	X	X	X	X	X	X
Weatherstrip Windows	X	X	E	X	X	X	X	E	X	X	X	X	X	X
Caulk Doors	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Weatherstrip Doors	X	X	E	X	X	X	X	X	X	X	X	X	X	X
Install Storm Windows	X	X	E	X	X	X	E	X	X	X	X	X	X	X
Insulate Attic R-30	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Insulate Walls	E	X	E	X	X	E	X	X	X	E	E	X	E	X
Insulate Basement Walls, Slabs or Crawl Spaces	E	X	E	X	X	E	X	X	X	X	E	X	E	X
PERCENT SAVING IN FUEL CONSUMPTION	-13	35	0	0	16	20	38	26	25	13	22	40	19	45
INSTALLATION DATE USED (all in 1980 except as indicated)	6/28/79	1/31	2/28/79	1/31	1/31	1/10	1/31	1/8	1/31	1/10	1/31/79	1/31	1/4	1/10

CONTROL GROUP (Installation Date Used: 1/31/80)

HOUSE NUMBER	04	10	23
PERCENT SAVING IN FUEL CONSUMPTION	26	-12	-32

X: Options installed
E: Existing options
N: Options not judged to be applicable

Table 8. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Allentown, PA

SAMPLE GROUP

OPTIONS INSTALLED \ HOUSE NUMBERS		3	4	12	20	22	23	25	27	28	31	33	39	42
ARCHITECTURAL	Begin	4/79	2/79	1/79	4/79	4/79	3/79	2/79	1/79	2/79	2/79	2/79	9/79	9/79
	End	10/79	11/79	10/79	9/79	9/79	11/79	11/79	11/79	11/79	11/79	11/79	10/79	9/79
Replace Broken Glass		X	X	X	N	X	X	X	X	X	X	N	X	X
Reset Glazing		X	X	X	N	N	X	X	X	N	X	X	X	N
Seal Large Cracks & Holes		X	N	N	N	N	N	X	N	N	N	N	N	N
Weatherstrip Windows		X	X	X	E	E	X	E	E	X	E	X	X	E
Caulk Windows		X	X	E	E	E	E	E	E	E	E	X	X	E
Weatherstrip Doors		E	X	E	X	E	E	E	X	E	X	X	X	X
Caulk Doors		X	X	E	E	E	E	E	E	E	E	E	E	E
Weatherstrip Attic Hatch		E	X	E	X	E	E	E	X	E	X	E	E	E
Install Triple Glazing		X	X	X	X	E	X	X	E	X	X	E	E	E
Insulate Attic R-30		X	X	X	E	X	X	X	X	X	X	X	E	E
Insulate Walls		X	E	X	X	X	X	E	X	X	X	X	E	E
HEATING SYSTEM	Begin		6/79	5/79		1/80		5/79	7/79	9/79	9/78	7/79	5/79	
	End		6/79	5/79		1/80		12/79	7/79	1/80	1/80	1/80	1/80	
Flue or Vent Damper		N	N	N	N	X	N	X	N	N	X	X	X	N
Derate Furnace		N	N	N	N	X	N	X	N	X	X	X	X	N
Replace Furnace		N	N	N	N	N	N	N	N	X	N	N	N	N
Night Setback Thermostat		N	X	X	N	N	N	X	X	X	X	X	X	N
WATER HEATER	End		6/79	5/79	1/79	5/79	7/79	5/79	7/79	9/79	9/79	7/79	1/80	
Replace Water Heater		N	N	N	N	N	N	N	N	N	N	N	N	N
Insulate Water Heater		N	N	N	X	N	N	N	N	N	N	X	X	X
Reduce Temp Water Heater		N	X	X	X	X	X	X	X	X	X	N	N	X
PERCENT SAVING IN FUEL CONSUMPTION		53	0	23	8	12	18	18	42	19	7	14	18	10
INSTALLATION DATE USED (all in 1979)		9/12	9/24	9/12	9/24	9/18	3/30	9/12	2/28	2/22	9/13	2/18	11/1	11/1

CONTROL GROUP (Installation Date Used: 11/1/79)

HOUSE NUMBER	38
PERCENT SAVING IN FUEL CONSUMPTION	12

X: Options installed

E: Existing options

N: Options not judged to be applicable

Table 9. Summary of Installation Options and Percentage of Fuel Reduction of Dwellings in Charleston, SC

SAMPLE GROUP

OPTIONS INSTALLED / HOUSE NUMBERS		1	2	3	8	9	16	18	20	22	23	25	27	39	44	47	49
ARCHITECTURAL	Begin	3/79	2/79	2/79	2/79	2/79	2/79	2/79	2/79	2/79	6/79	3/79	2/79	2/79	2/79	2/79	3/79
	End	3/79	3/79	3/79	3/79	3/79	2/79	2/79	3/79	2/79	6/79	3/79	2/79	3/79	2/79	2/79	3/79
Replace Broken Glass		X	X	X	X	N	X	X	X	X	X	X	X	X	X	N	N
Reset Glazing		X	N	N	N	X	N	X	X	X	X	X	N	N	X	N	N
Replace Threshold		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Seal Cracks & Holes		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Windows		E	X	X	X	E	X	X	X	X	X	X	X	E	X	X	E
Caulk Windows		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Doors		E	X	X	X	E	X	X	X	X-	X	X	X	X	X	X	E
Caulk Doors		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Weatherstrip Attic Hatch		E	X	X	X	X	X	X	E	E	X	X	X	X	X	X	X
Insulate Attic R-11		X	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Insulate Attic R-19		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Insulate Basement Walls, Slabs or Crawl Spaces		X	X	X	X	E	X	X	X	X	X	X	X	X	X	X	X
Install Storm Windows		E	E	E	E	E	E	E	E	E	E	E	E	E	E	X	E
WATER HEATER	End	8/79	8/79	8/79	8/79	8/79	8/9		9/79		8/79		8/79		8/79	8/79	8/79
Insulate Water Heater		N	X	N	N	N	X	N	X	N	X	N	X	N	X	X	N
Replace Water Heater		N	N	N	N	N	N	N	N	N	N	N	N	N	N	X	N
Timer on Water Heater		X	N	X	X	X	X	N	X	N	N	N	X	N	X	X	X
PERCENT SAVING IN FUEL CONSUMPTION		30	21	16	34	33	38	19	23	31	18	30	13	64	34	14	35
INSTALLATION DATE USED (all in 1979)		3/7	3/3	3/3	3/2	2/13	2/12	2/28	3/5	2/28	6/15	3/13	2/8	2/13	2/21	2/16	3/9

CONTROL GROUP (Installation Date Used: 3/1/79)

HOUSE NUMBER	5	19	21	24	28
PERCENT SAVING IN FUEL CONSUMPTION	18	4	18	23	-7

X: Options installed
E: Existing options
N: Options not judged to be applicable

Table 10. Comparison of Average Daily Fuel Consumption in Colorado Springs House No 41

FUEL:GAS

CT H#	DATE BEGIN M/ D/ Y	DATE END M/ D/ Y	FUEL CONSUMPTION/DAY ACTUAL F	PREDICTED (WITH DEGREE DAYS) BEST FIT T0=60.5 F1	DD1	T0=65 F2	DD2	B0=0 F3	DD3	(100 CUFT) F	F1	PERCENTAGE SAVINGS
CSP 41	5 28 75	6 28 75	193.5	186.4	5.2	188.6	7.8	191.8	16.1	1.9	1.8	-3.8
CSP 41	6 28 75	7 28 75	120.0	116.9	0.5	105.4	1.7	85.9	7.2	1.2	1.1	-2.7
CSP 41	7 28 75	8 26 75	117.2	117.8	0.6	104.9	1.7	86.0	7.2	1.1	1.1	0.4
CSP 41	8 26 75	9 25 75	163.3	163.2	3.6	161.9	5.9	159.1	13.4	1.6	1.6	-0.1
CSP 41	9 25 75	10 28 75	242.4	252.3	9.6	255.7	12.8	261.3	22.0	2.4	2.4	3.9
CSP 41	10 28 75	11 26 75	455.2	418.6	20.8	418.4	24.7	419.0	35.2	4.4	4.1	-8.7
CSP 41	11 26 75	12 29 75	533.3	479.4	24.9	478.5	29.2	473.8	39.8	5.2	4.7	-11.3
CSP 41	12 29 75	1 28 76	610.0	566.4	30.7	558.7	35.1	543.6	45.7	5.9	5.5	-7.7
CSP 41	1 28 76	2 27 76	500.0	433.1	21.8	436.5	26.1	436.7	36.7	4.9	4.2	-15.4
CSP 41	2 27 76	3 29 76	483.9	453.8	23.1	453.7	27.3	451.4	37.9	4.7	4.4	-6.6
CSP 41	3 29 76	4 27 76	348.3	308.9	13.4	317.9	17.3	331.6	27.9	3.4	3.0	-12.8
CSP 41	4 27 76	5 26 76	286.2	253.8	9.7	264.7	13.4	278.9	23.4	2.8	2.5	-12.6
CSP 41	5 26 76	6 25 76	166.7	161.5	3.5	162.3	5.9	166.9	14.0	1.6	1.6	-3.2
CSP 41	6 25 76	7 27 76	143.8	117.1	0.5	105.0	1.7	84.8	7.1	1.4	1.1	-22.6
CSP 41	7 27 76	8 25 76	141.4	119.1	0.7	110.4	2.1	95.8	8.1	1.4	1.2	-18.7
CSP 41	8 25 76	9 24 76	153.3	154.5	3.1	155.5	5.4	160.1	13.5	1.5	1.5	0.7
CSP 41	9 24 76	10 26 76	306.3	308.7	13.4	315.3	17.2	323.9	27.2	3.0	3.0	0.6
CSP 41	10 26 76	11 26 76	406.5	408.9	20.1	413.4	24.4	416.5	35.8	3.9	4.0	0.6
CSP 41	11 26 76	12 28 76	531.3	533.6	28.5	528.9	32.9	517.8	43.5	5.2	5.2	0.4
CSP 41	12 28 76	1 27 77	603.3	605.4	33.3	594.3	37.7	574.8	48.3	5.9	5.9	0.3
CSP 41	1 27 77	2 28 77	471.9	494.2	25.9	492.8	30.2	486.2	40.9	4.6	4.8	4.5
CSP 41	2 28 77	3 26 77	496.2	447.9	22.7	449.2	27.0	447.2	37.6	4.8	4.3	-10.6
CSP 41	3 26 77	4 27 77	331.3	345.1	15.8	352.7	19.9	361.1	30.3	3.2	3.4	4.0
CSP 41	4 27 77	5 26 77	179.3	188.6	5.3	193.1	8.2	205.7	17.3	1.7	1.8	4.9
CSP 41	5 26 77	6 27 77	121.9	136.1	1.8	132.2	3.7	128.2	10.8	1.2	1.3	10.4
CSP 41	6 27 77	7 27 77	126.7	116.7	0.5	103.8	1.6	86.1	7.2	1.2	1.1	-8.5
CSP 41	7 27 77	8 25 77	124.1	116.4	0.5	106.7	1.8	98.8	8.3	1.2	1.1	-6.6
CSP 41	8 25 77	9 26 77	121.9	150.2	2.8	148.4	4.9	147.8	12.4	1.2	1.5	18.9
CSP 41	9 26 77	10 25 77	234.5	247.6	9.3	253.8	12.6	263.3	22.1	2.3	2.4	5.3
CSP 41	10 25 77	11 25 77	396.8	384.5	18.5	389.0	22.6	393.5	33.1	3.9	3.7	-3.2
CSP 41	11 25 77	12 27 77	518.8	466.5	24.0	467.3	28.3	463.9	39.0	5.0	4.5	-11.2
CSP 41	12 27 77	1 26 78	620.0	606.4	33.4	595.2	37.7	575.6	48.4	6.0	5.9	-2.2
CSP 41	1 26 78	2 27 78	584.4	597.4	32.8	587.1	37.1	568.8	47.8	5.7	5.8	2.2
CSP 41	2 27 78	3 28 78	441.4	432.5	21.7	434.8	25.9	434.8	36.5	4.3	4.2	-2.1
CSP 41	3 28 78	4 26 78	296.6	292.3	12.3	302.1	16.2	315.3	26.5	2.9	2.8	-1.5
CSP 41	4 26 78	5 25 78	255.2	290.2	12.2	293.5	15.5	298.9	25.1	2.5	2.8	12.1
CSP 41	5 25 78	6 26 78	143.8	177.0	4.6	175.2	6.9	170.4	14.3	1.4	1.7	18.6
CSP 41	6 26 78	7 26 78	113.3	125.1	1.1	111.8	2.2	90.0	7.6	1.1	1.2	9.4
CSP 41	1 3 79	1 31 79	706.3	710.1	40.3	689.6	44.7	657.9	55.3	6.9	6.9	0.5
CSP 41	1 31 79	3 7 79	430.4	614.0	33.9	616.2	39.3	626.2	52.6	4.2	6.0	29.9
CSP 41	3 7 79	4 4 79	367.9	437.9	22.1	440.9	26.4	440.3	37.0	3.6	4.3	16.0
CSP 41	4 4 79	5 16 79	356.8	365.7	17.2	390.0	22.6	447.0	37.6	3.5	3.6	2.4
CSP 41	5 16 79	6 13 79	154.5	197.7	6.0	204.5	9.0	215.1	18.1	1.5	1.9	21.9
CSP 41	6 13 79	7 11 79	139.8	124.6	1.0	116.8	2.6	102.8	8.6	1.4	1.2	-12.2
CSP 41	7 11 79	8 8 79	110.4	117.9	0.6	106.6	1.8	86.7	7.3	1.1	1.1	6.4
CSP 41	8 8 79	9 5 79	110.4	135.1	1.8	132.5	3.7	132.2	11.1	1.1	1.3	18.3
CSP 41	9 5 79	10 3 79	114.0	159.8	3.4	159.3	5.7	160.1	13.5	1.1	1.6	28.6
CSP 41	10 3 79	10 31 79	169.2	265.2	10.5	269.6	13.9	276.3	23.2	1.6	2.6	36.2
CSP 41	10 31 79	11 28 79	320.0	504.0	26.5	501.2	30.8	493.0	41.4	3.1	4.9	36.5
CSP 41	11 28 79	12 31 79	337.3	511.8	27.0	509.0	31.4	500.5	42.1	3.3	5.0	34.1
CSP 41	12 31 79	1 23 80	340.3	534.0	28.5	528.4	32.9	515.8	43.3	3.3	5.2	36.3
CSP 41	1 23 80	2 20 80	371.5	599.9	32.9	589.1	37.3	569.9	47.9	3.6	5.8	38.1
CSP 41	2 20 80	3 19 80	301.4	448.5	22.8	452.2	27.2	454.8	38.2	2.9	4.4	32.8
CSP 41	3 19 80	4 16 80	305.3	463.6	23.8	464.5	28.1	460.9	38.7	3.0	4.5	34.1

NO. OF PT. FOR WEEKLY READINGS = 54

NO. OF PT. FOR PREDICTED VALUES = 54

PERCENTAGE SAVINGS 35.5 35.1 34.0

DATE BEGIN = 1 1 75 DATE END = 6 1 80

PERIOD DAYS = 23
INSTALLATION DATE = 10 4 79

Table 11. Comparison of Average Daily Fuel Consumption in Colorado Springs House No. 6

FUEL:GAS

CT H#	DATE BEGIN M/ D/ Y	DATE END M/ D/ Y	FUEL CONSUMPTION/DAY ACTUAL F	PREDICTED (WITH DEGREE DAYS) BEST FIT T0=56.5 F1	DD1	(KBTU) T0=65 F2	DD2	BD=0 F3	DD3	(100 CUFT) F	F1	PERCENTAGE SAVINGS
CSP 06	6 18 75	7 16 75	66.7	56.0	0.6	47.2	2.5	45.5	3.5	0.6	0.5	-19.1
CSP 06	7 18 75	8 18 75	67.7	52.2	0.3	38.8	1.8	36.0	2.8	0.7	0.5	-29.6
CSP 06	8 18 75	9 17 75	80.0	68.6	1.4	62.1	3.6	61.1	4.7	0.8	0.7	-16.7
CSP 06	9 17 75	10 17 75	156.7	145.4	6.3	159.0	10.7	163.9	12.7	1.5	1.4	-7.7
CSP 06	10 17 75	11 18 75	315.6	257.0	13.5	265.5	18.6	268.5	20.9	3.1	2.5	-22.6
CSP 06	11 16 75	12 18 75	516.7	443.7	25.4	440.2	31.6	438.4	34.0	5.0	4.3	-16.4
CSP 06	12 18 75	1 19 76	543.8	477.5	27.6	471.5	33.9	468.4	36.3	5.3	4.6	-13.9
CSP 06	1 19 76	2 19 76	477.4	390.5	22.0	395.0	28.2	395.3	30.6	4.6	3.8	-22.2
CSP 06	2 19 76	3 19 76	437.9	398.1	22.5	400.8	28.7	400.8	31.1	4.3	3.9	-10.0
CSP 06	3 19 76	5 16 76	263.3	236.6	12.2	254.1	17.8	259.7	20.1	2.6	2.3	-11.3
CSP 06	5 18 76	6 17 76	90.0	95.0	3.1	104.8	6.7	108.7	8.4	0.9	0.9	5.2
CSP 06	6 17 76	7 19 76	68.8	63.2	1.0	53.4	2.9	51.4	4.0	0.7	0.6	-8.7
CSP 06	7 19 76	8 17 76	56.6	51.3	0.3	42.1	2.1	40.7	3.2	0.6	0.5	-14.2
CSP 06	8 17 76	9 16 76	70.0	70.5	1.5	68.9	4.1	69.3	5.4	0.7	0.7	0.6
CSP 06	9 16 76	10 18 76	200.0	172.5	8.0	187.9	12.9	192.7	14.9	1.9	1.7	-15.9
CSP 06	10 18 76	11 17 76	373.3	330.7	18.2	341.7	24.3	344.2	26.7	3.6	3.2	-12.9
CSP 06	11 17 76	12 17 76	486.7	444.6	25.5	442.0	31.7	440.1	34.1	4.7	4.3	-9.5
CSP 06	12 17 76	1 19 77	539.4	526.6	30.8	514.3	37.1	509.4	39.5	5.2	5.1	-2.4
CSP 06	1 19 77	2 17 77	434.5	432.2	24.7	432.0	31.0	430.6	33.4	4.2	4.2	-0.5
CSP 06	2 17 77	3 21 77	375.0	408.0	23.1	410.1	29.3	409.8	31.8	3.6	4.0	8.1
CSP 06	3 21 77	4 20 77	253.3	277.1	14.7	291.6	20.6	295.3	22.9	2.5	2.7	8.6
CSP 06	4 20 77	5 19 77	75.9	119.6	4.7	131.8	8.7	136.8	10.6	0.7	1.2	36.5
CSP 06	5 19 77	6 20 77	65.6	81.0	2.2	82.6	5.1	84.0	6.5	0.6	0.8	19.0
CSP 06	6 20 77	7 20 77	56.7	54.6	0.5	41.2	2.0	38.1	3.0	0.6	0.5	-3.7
CSP 06	7 20 77	8 18 77	58.6	50.9	0.2	33.3	1.8	37.7	2.9	0.6	0.5	-15.2
CSP 06	8 18 77	9 19 77	59.4	67.3	1.3	64.7	3.8	65.6	5.1	0.6	0.7	11.7
CSP 06	9 19 77	10 18 77	141.4	152.4	6.8	163.1	11.0	166.5	12.9	1.4	1.5	7.3
CSP 06	10 18 77	11 17 77	256.7	237.3	12.2	251.9	17.6	256.3	19.9	2.5	2.3	-8.2
CSP 06	11 17 77	12 19 77	403.1	380.1	21.3	386.1	27.6	386.8	30.0	3.9	3.7	-6.1
CSP 06	12 19 77	1 19 78	487.1	505.9	29.4	495.1	35.7	491.9	38.1	4.7	4.9	3.7
CSP 06	1 19 78	2 17 78	496.6	559.4	32.9	542.1	39.1	535.8	41.5	4.8	5.4	11.2
CSP 06	2 17 78	3 21 78	384.4	403.3	22.8	405.6	29.0	405.2	31.4	3.7	3.9	4.7
CSP 06	3 21 78	5 16 78	201.7	237.6	12.2	252.4	17.7	256.9	19.9	2.0	2.3	15.1
CSP 06	5 18 78	6 19 78	96.6	114.3	4.3	121.8	8.0	124.6	9.7	0.9	1.1	20.7
CSP 06	6 19 78	7 19 78	63.3	60.4	0.9	42.9	2.1	36.7	3.0	0.6	0.5	-4.6
CSP 06	1 2 79	1 30 79	588.6	637.3	37.8	609.4	44.1	600.1	46.5	5.7	6.2	7.6
CSP 06	1 30 79	2 27 79	467.2	456.7	26.3	451.5	32.4	449.0	34.8	4.5	4.4	-2.3
CSP 06	2 27 79	3 27 79	371.5	381.9	21.5	388.4	27.7	388.8	30.1	3.6	3.7	2.7
CSP 06	3 27 79	4 24 79	250.1	242.0	12.5	252.8	17.7	255.6	19.8	2.4	2.3	-3.4
CSP 06	4 24 79	5 22 79	180.2	193.3	9.4	207.8	14.5	214.8	16.7	1.8	1.9	6.6
CSP 06	5 22 79	6 19 79	106.7	108.3	3.9	117.0	7.6	120.2	9.3	1.0	1.1	1.5
CSP 06	6 19 79	7 17 79	73.6	53.1	0.4	41.4	2.0	39.0	3.0	0.7	0.5	-38.7
CSP 06	7 17 79	8 14 79	69.9	52.6	0.4	40.5	2.0	37.9	2.9	0.7	0.5	-32.9
CSP 06	8 14 79	9 11 79	73.6	61.7	0.9	57.1	3.2	57.0	4.4	0.7	0.6	-19.2
CSP 06	9 11 79	10 9 79	99.3	102.6	3.6	110.1	7.1	113.1	8.8	1.0	1.0	3.2
CSP 06	10 9 79	11 6 79	257.5	243.5	12.6	254.4	17.8	257.6	20.0	2.5	2.4	-5.6
CSP 06	11 6 79	12 4 79	448.8	471.5	27.2	465.3	33.4	462.3	35.8	4.4	4.6	4.8
CSP 06	12 4 79	12 31 79	454.0	425.0	24.2	425.2	30.5	424.0	32.9	4.4	4.1	-6.8
CSP 06	12 31 79	1 29 80	486.6	507.0	29.5	496.7	35.8	492.4	38.2	4.7	4.9	4.0
CSP 06	1 29 80	2 26 80	470.9	450.6	25.9	447.9	32.1	445.7	34.6	4.6	4.4	-4.4
CSP 06	2 26 80	3 25 80	377.7	380.6	21.4	388.5	27.7	390.1	30.2	3.7	3.7	0.6
CSP 06	3 25 80	4 22 80	309.0	336.2	16.5	342.1	24.3	343.1	26.6	3.0	3.3	8.1

NO. OF PT. FOR WEEKLY READINGS = 52

NO.OF PT. FOR PREDICTED VALUES = 52

PERCENTAGE SAVINGS 0.4 0.6 0.4

DATE BEGIN = 1 1 75 DATE END = 6 1 80

PERIOD DAYS = 23
INSTALLATION DATE = 10 1 79

Table 12. Percentage Saving in Fuel Consumption of all Dwellings in Each City

City Code	Average		Median	
	Sample	Control	Sample	Control
ABE	18.5	12.0	17.5	12.0
CHA	28.3	11.0	26.4	17.5
CSP	31.5	1.2	32.9	0.4
FAR	31.0	4.9	34.6	2.1
POR	43.2		40.6	
STL	23.4	- 5.9	21.1	-12
TAC	35.0	11.3	36.8	6.0

Figure 1. Sites selected for the demonstration program

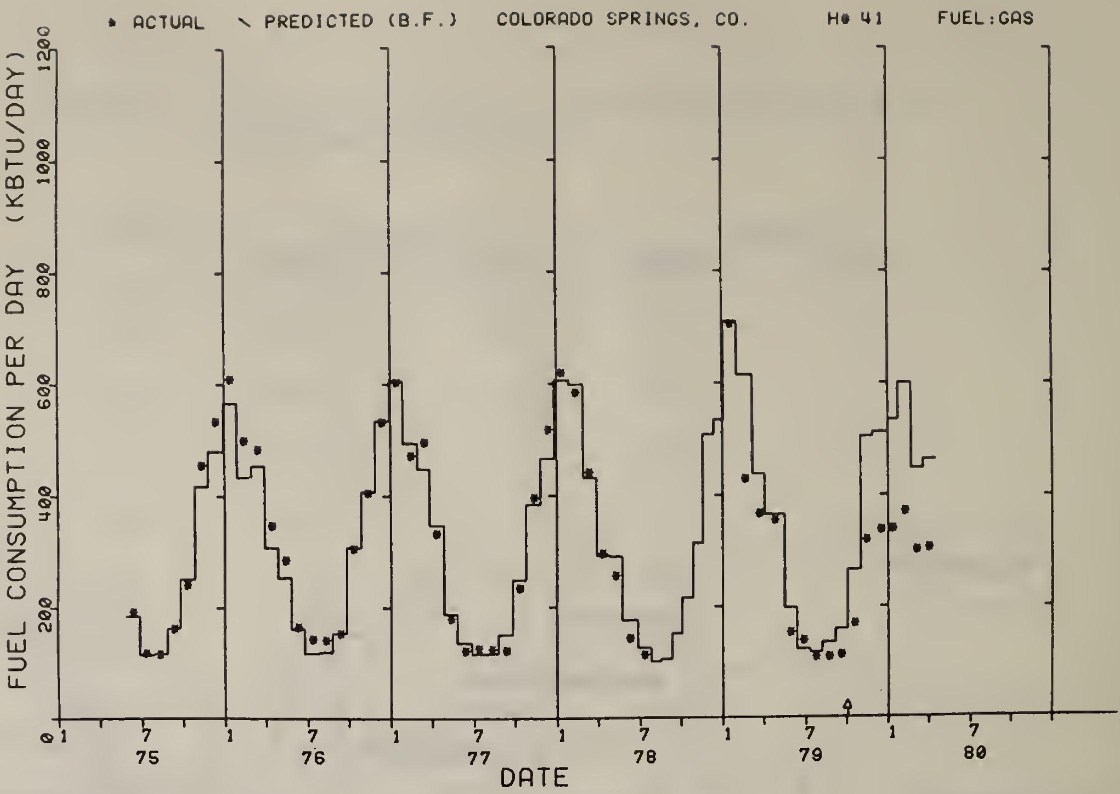

Figure 2. Graphical comparison of average daily fuel consumption of Colorado Springs house no. 41

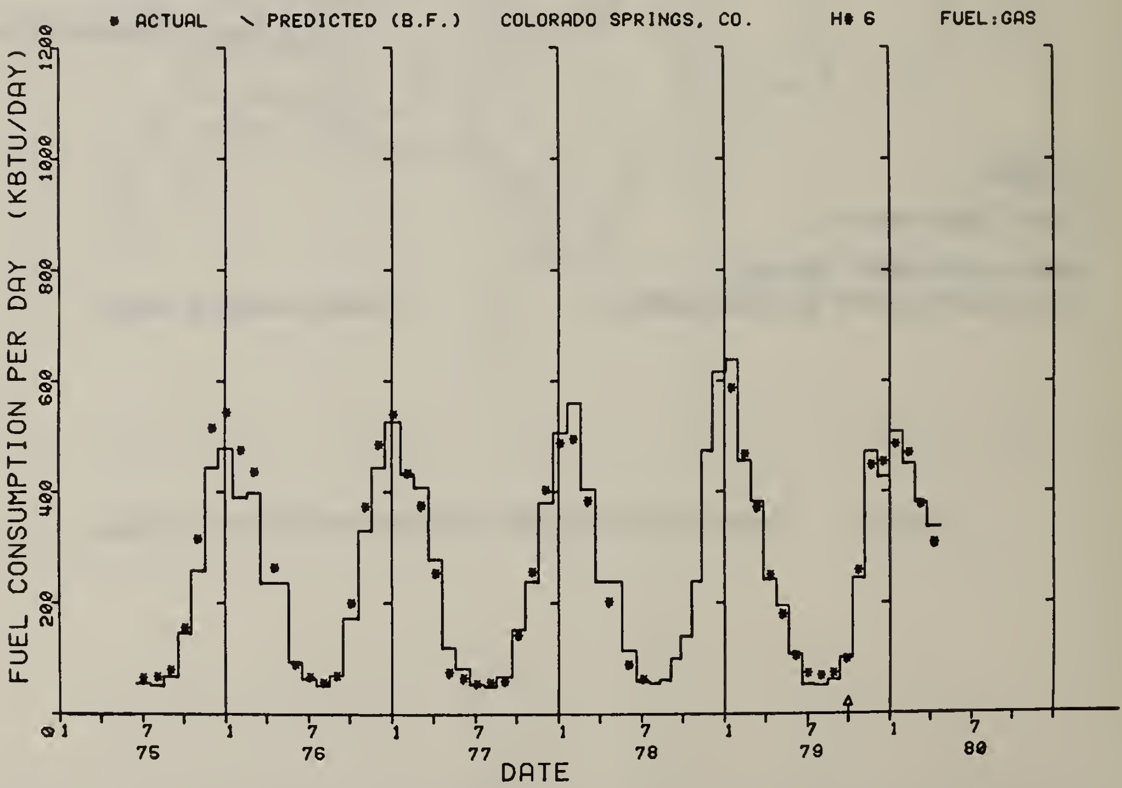

Figure 3. Graphical comparison of average daily fuel consumption of Colorado Springs house no. 6

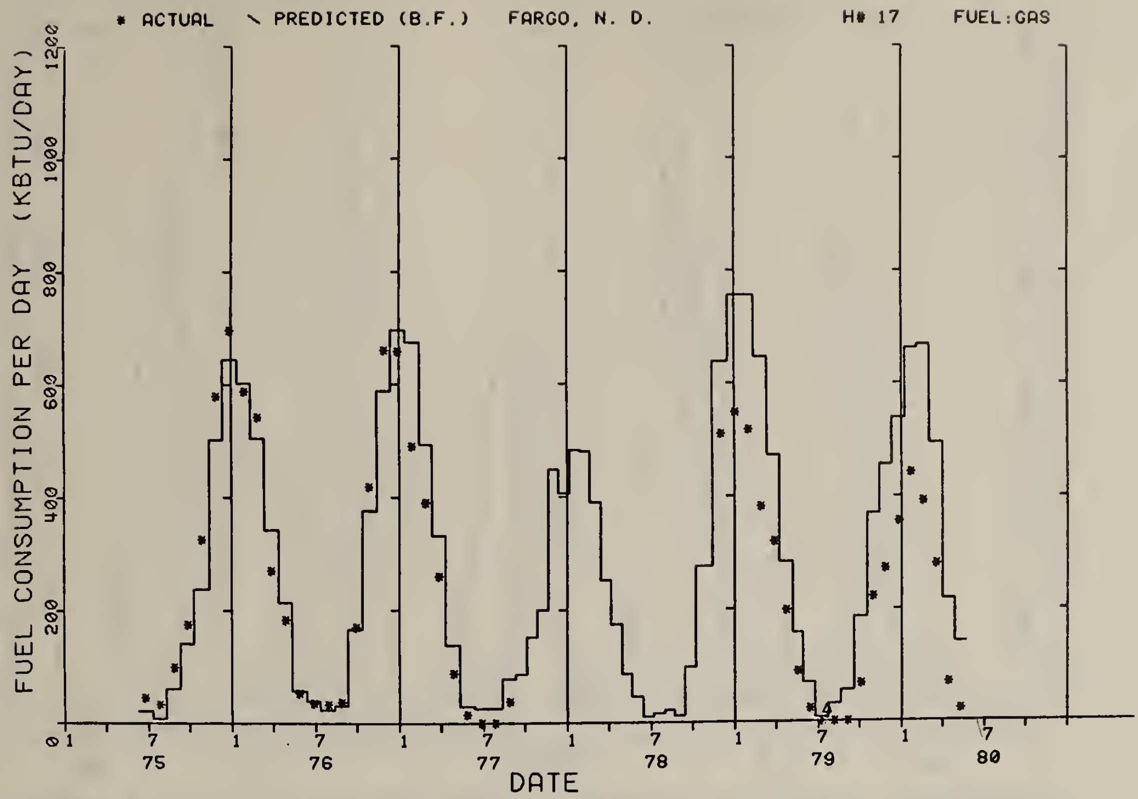

Figure 4. Graphical comparison of average daily fuel consumption of Fargo House no. 17

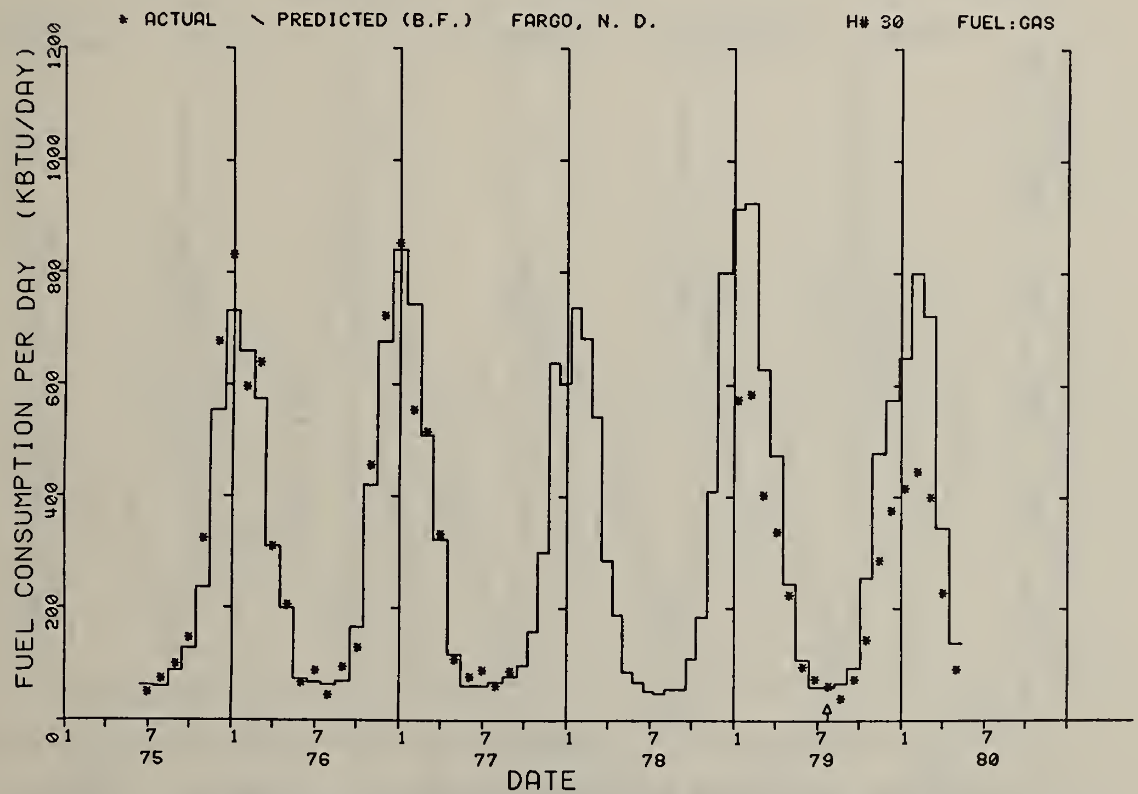

Figure 5. Graphical comparison of average daily fuel consumption of Fargo House no. 30

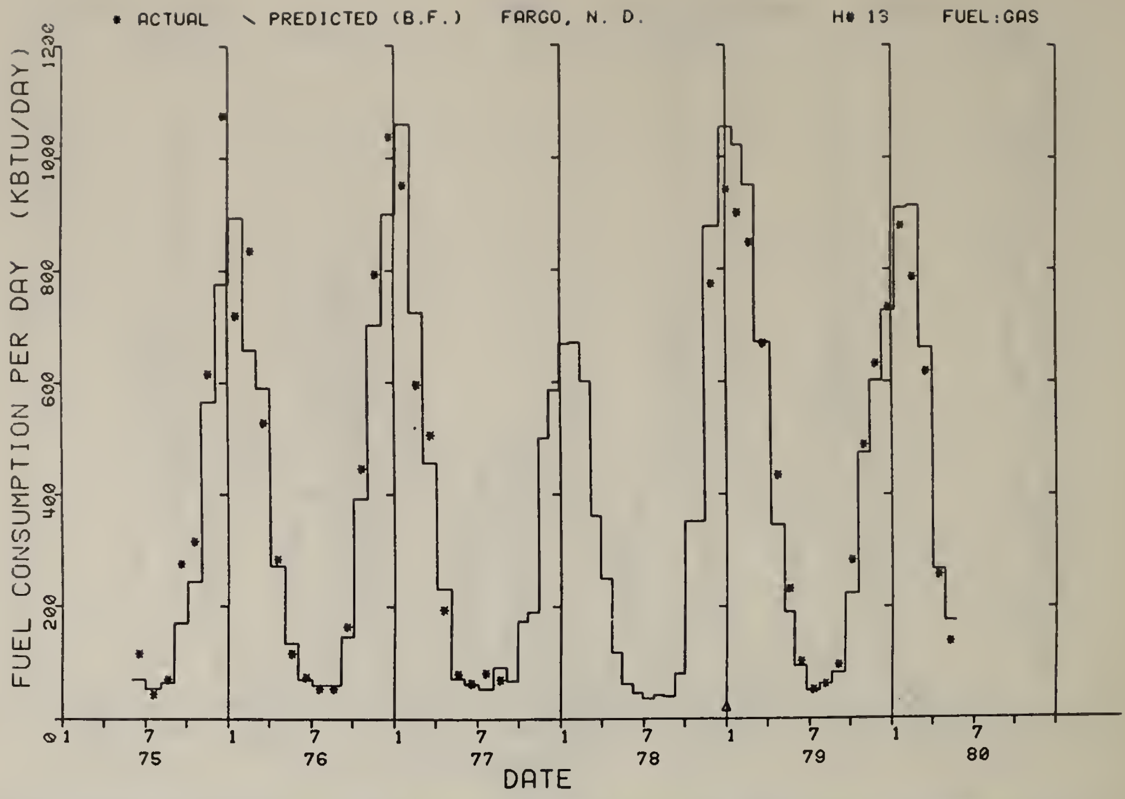

Figure 6. Graphical comparison of average daily fuel consumption of Fargo House no. 13

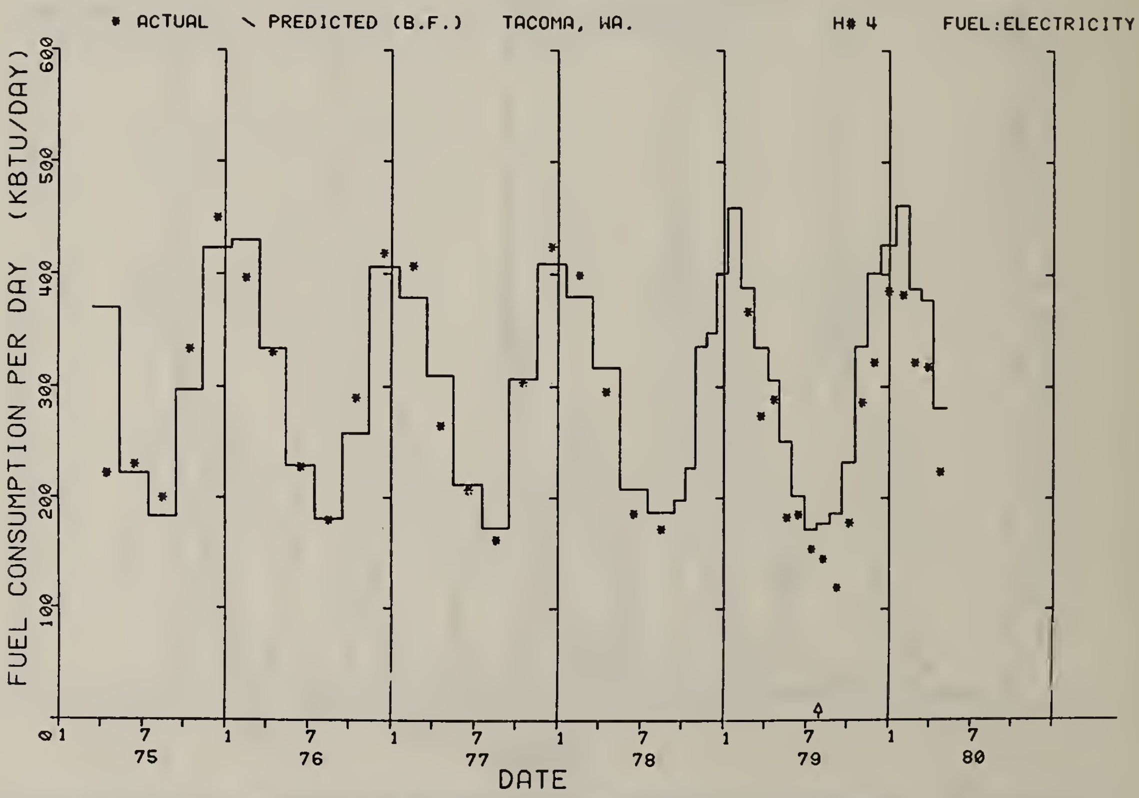

Figure 7. Graphical comparison of average daily fuel consumption of Tacoma House no. 4

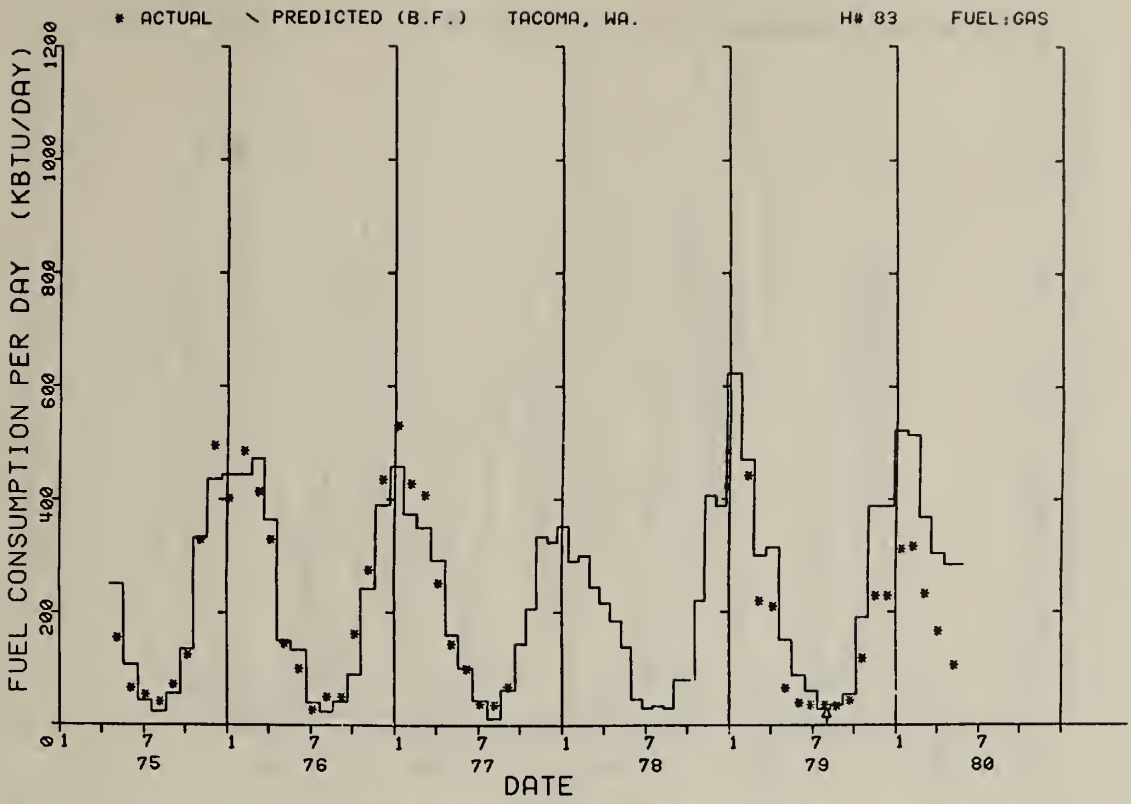

Figure 8. Graphical comparison of average daily fuel consumption of Tacoma House no. 83

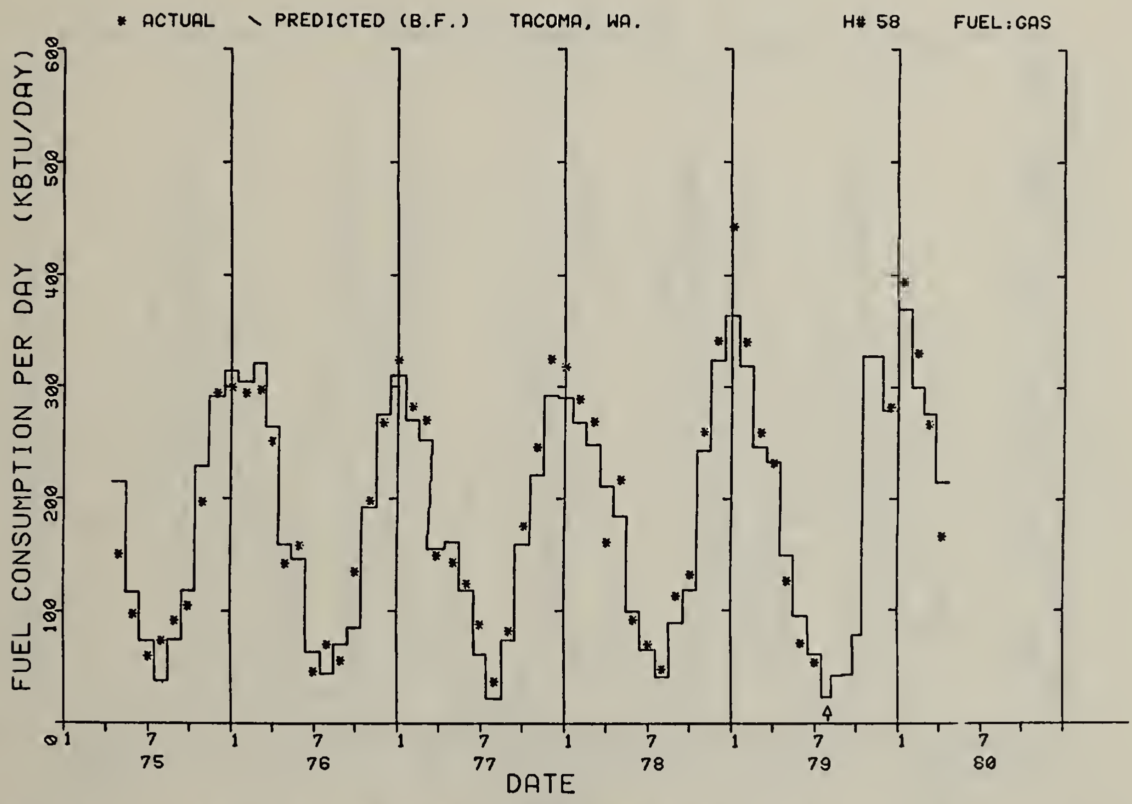

Figure 9. Graphical comparison of average daily fuel consumption of Tacoma House no. 58

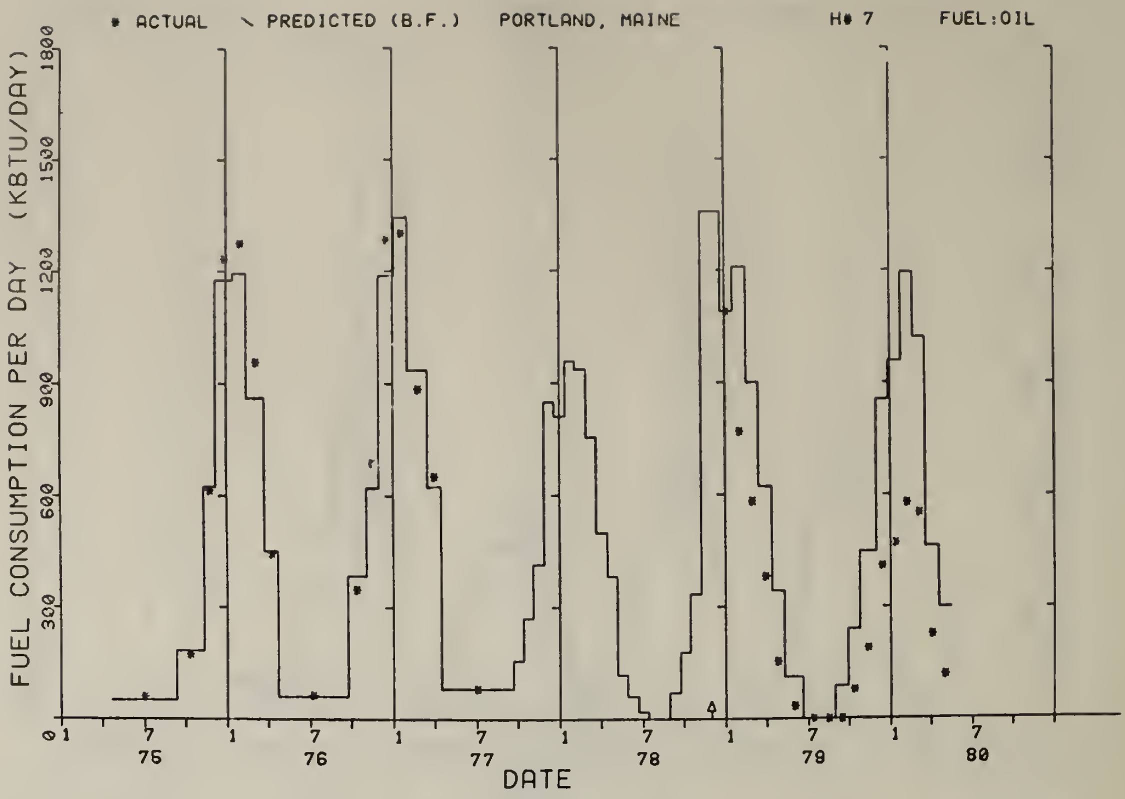

Figure 10. Graphical comparison of average daily fuel consumption of Portland House no. 7

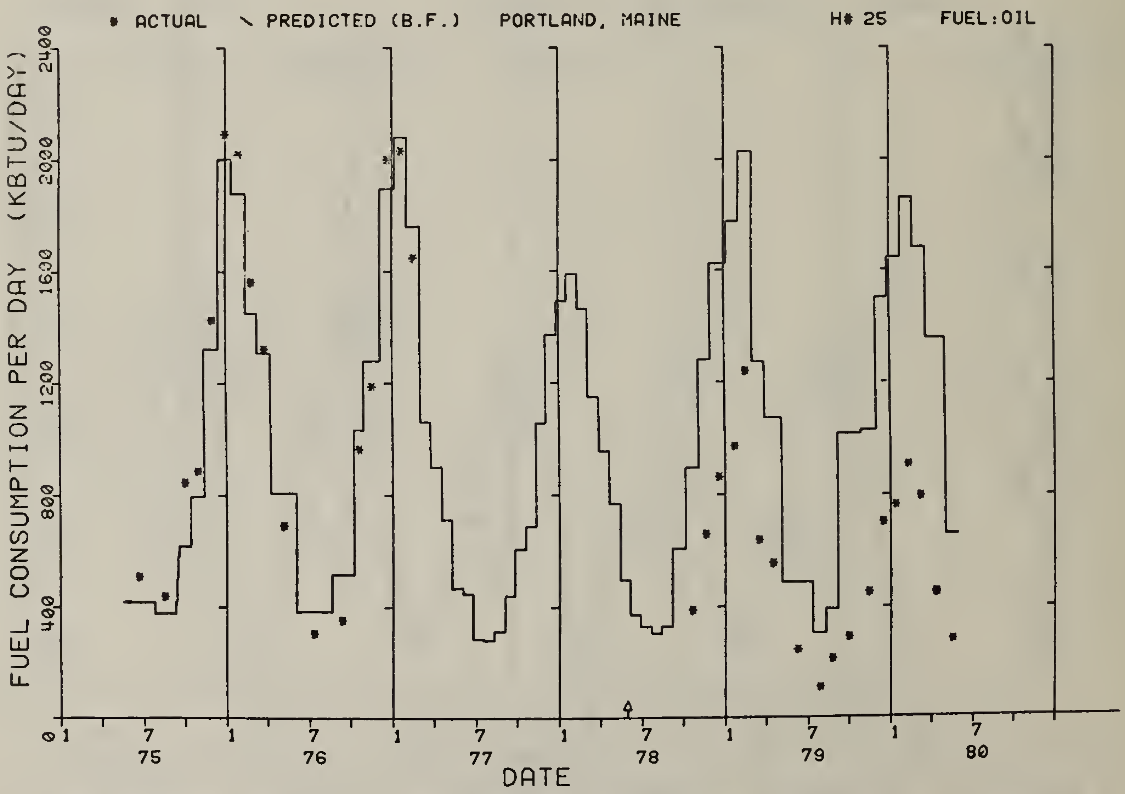

Figure 11. Graphical comparison of average daily fuel consumption of Portland House no. 25

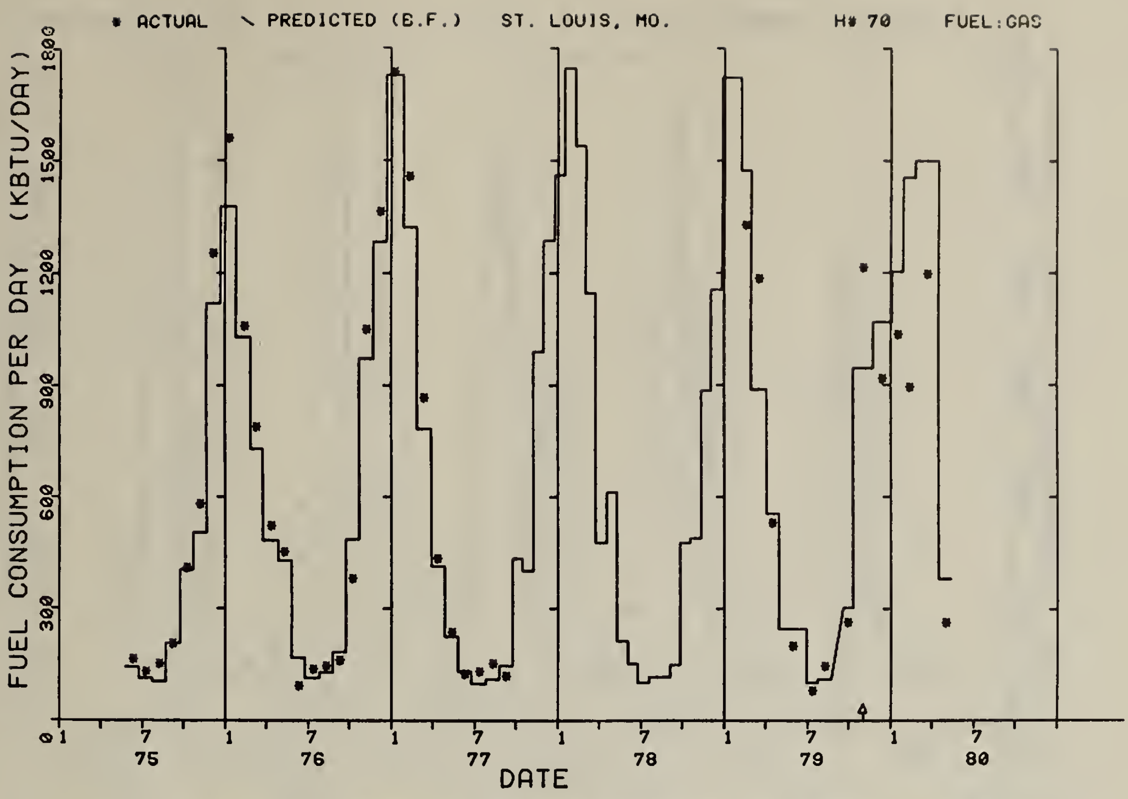

Figure 12. Graphical comparison of average daily fuel consumption of St. Louis House no. 70

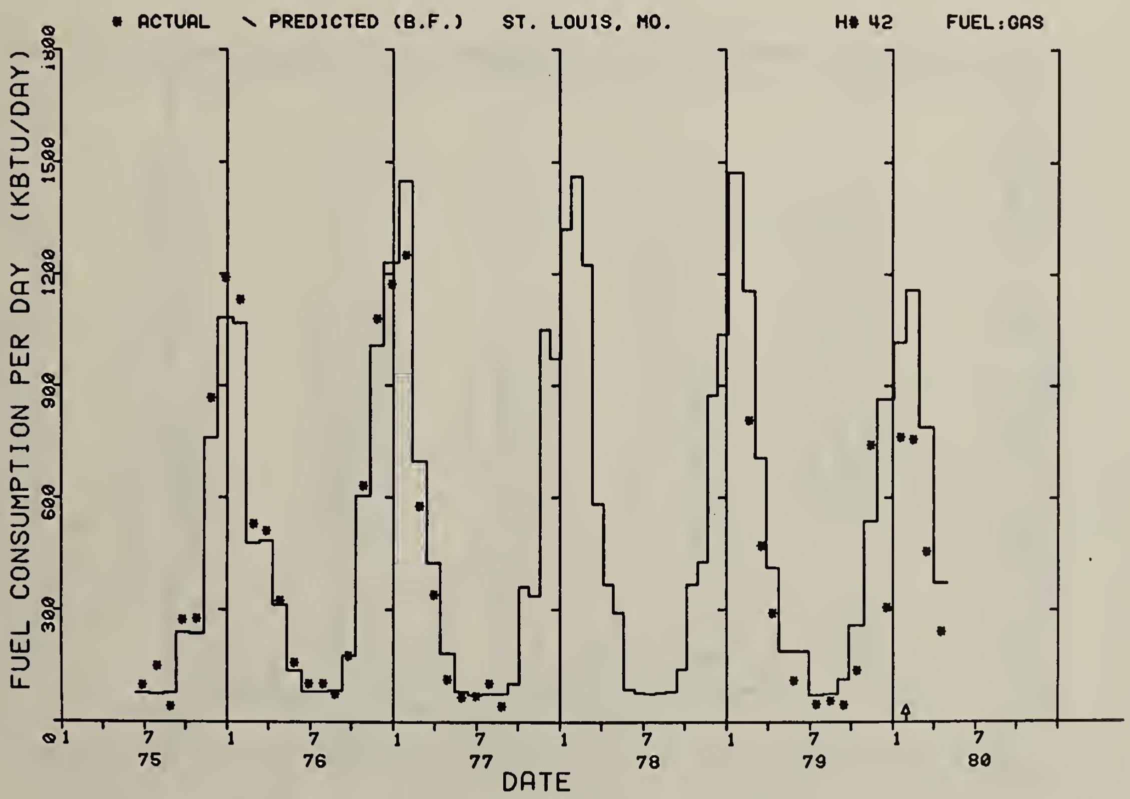

Figure 13. Graphical comparison of average daily fuel consumption of St. Louis House no. 42

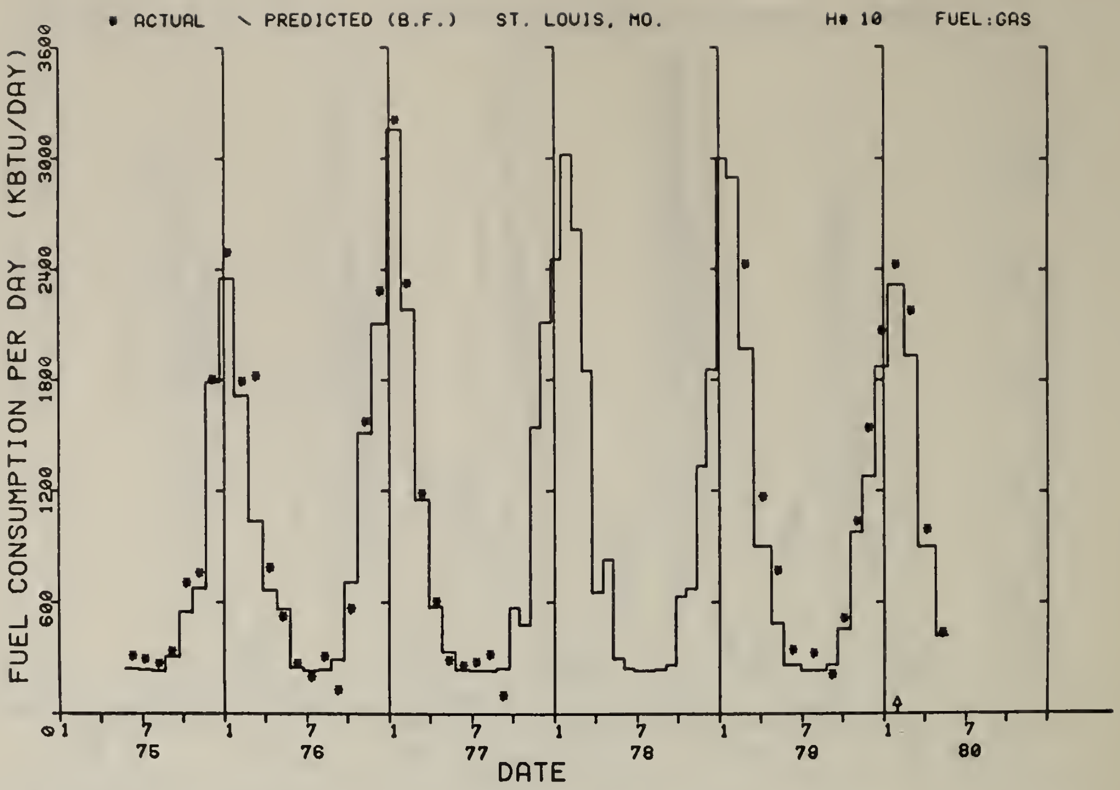

Figure 14. Graphical comparison of average daily fuel consumption of St. Louis House no. 10

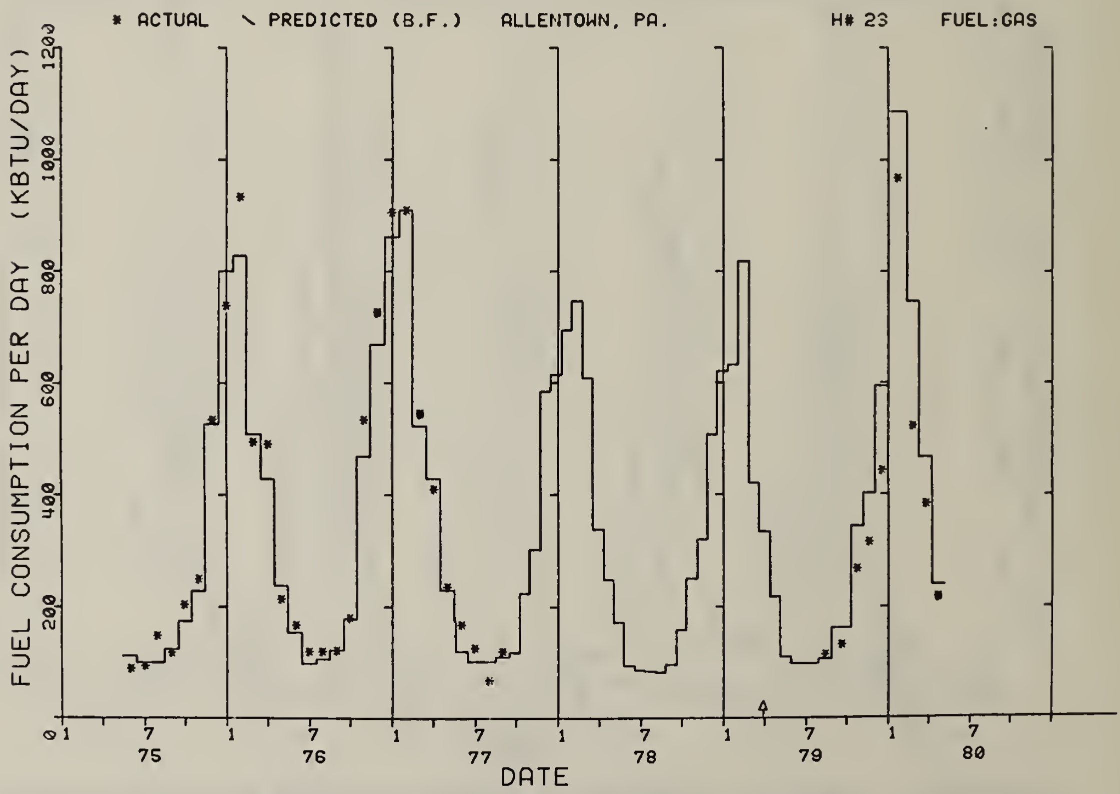

Figure 15. Graphical comparison of average daily fuel consumption of Allentown House no. 23

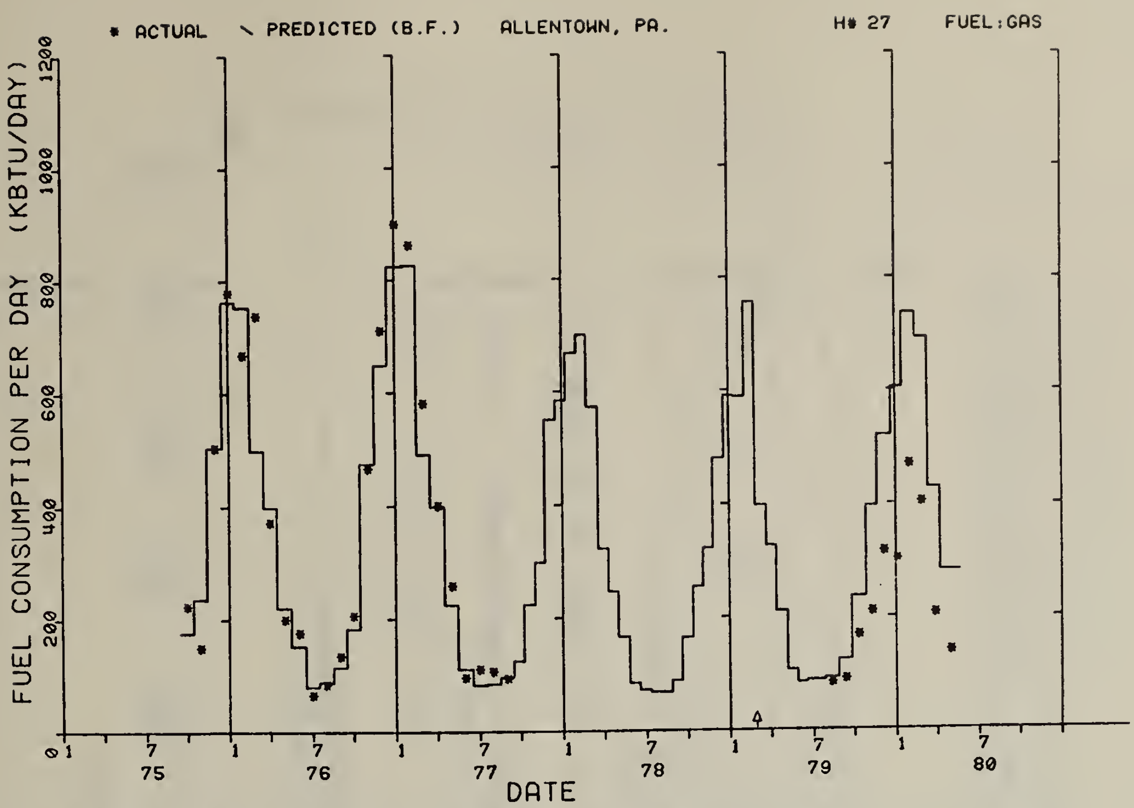

Figure 16. Graphical comparison of average daily fuel consumption of Allentown House no. 27

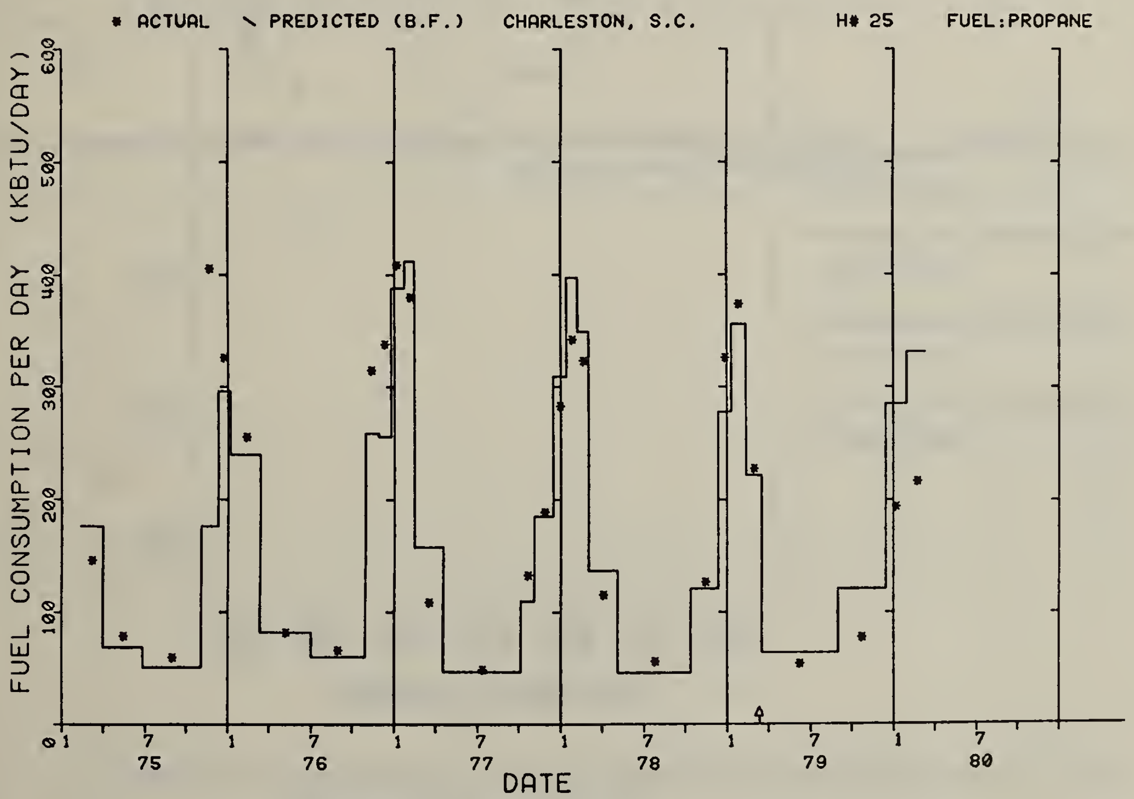

Figure 17. Graphical comparison of average daily fuel consumption of Charleston House no. 25

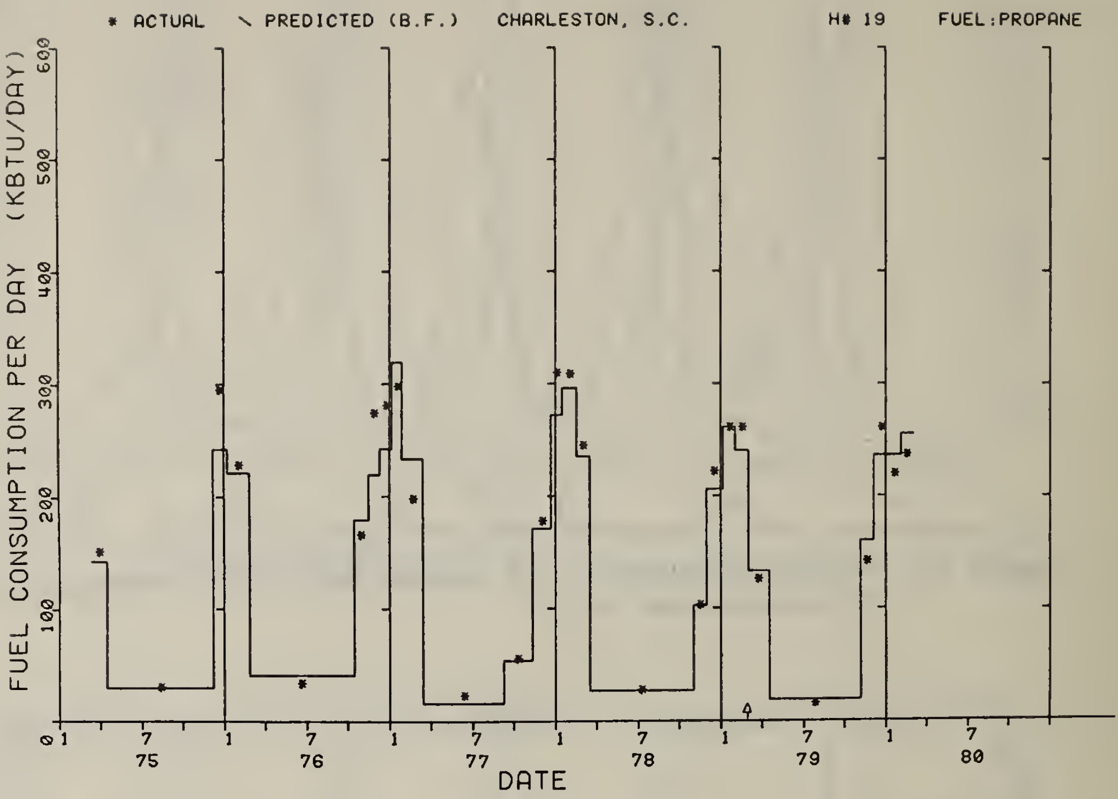

Figure 18. Graphical comparison of average daily fuel consumption of Charleston House no. 19

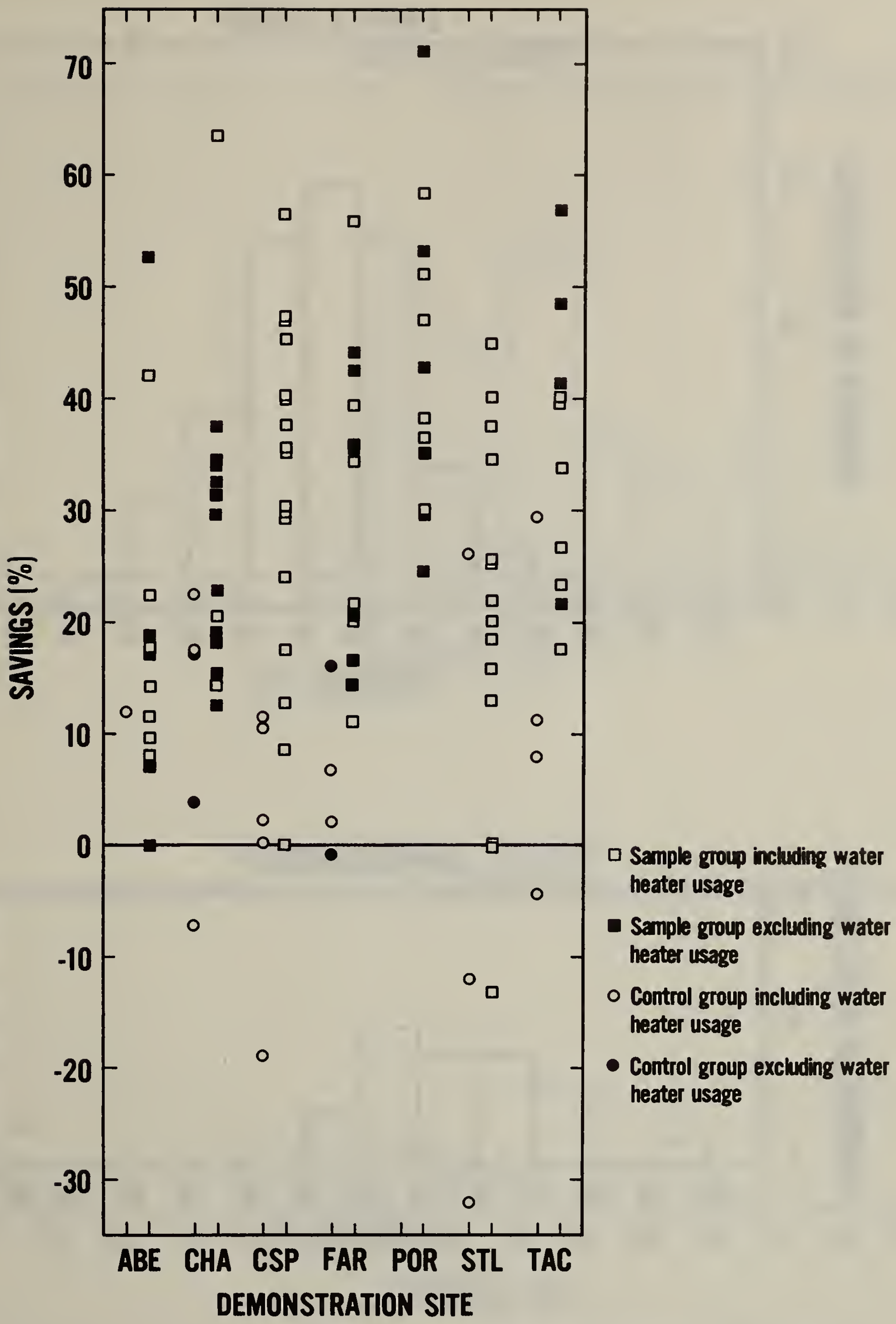

Figure 19. Percentage savings achieved for each dwelling in the demonstration program

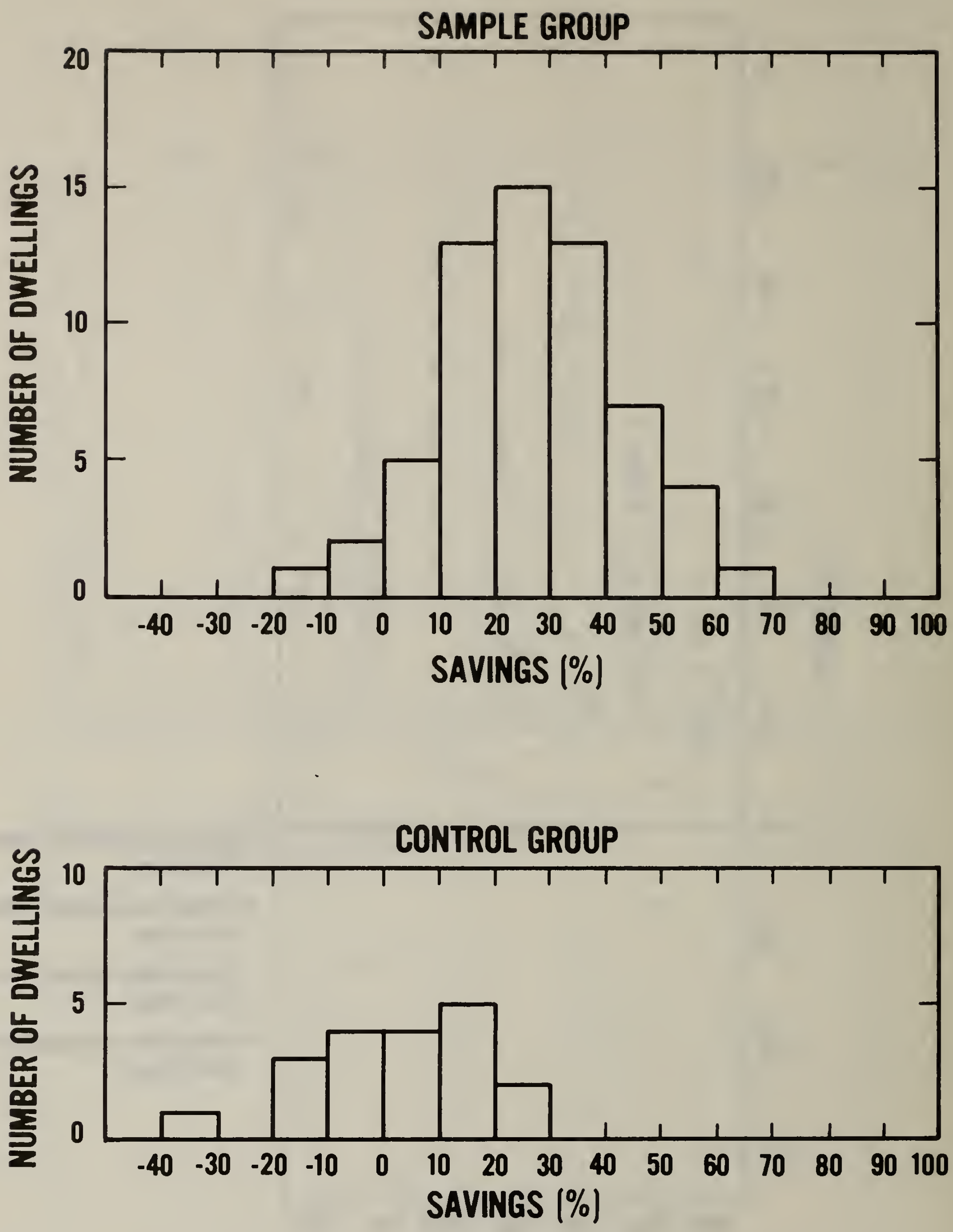

Figure 20. Histograms of fuel reductions of dwellings including water heater usage

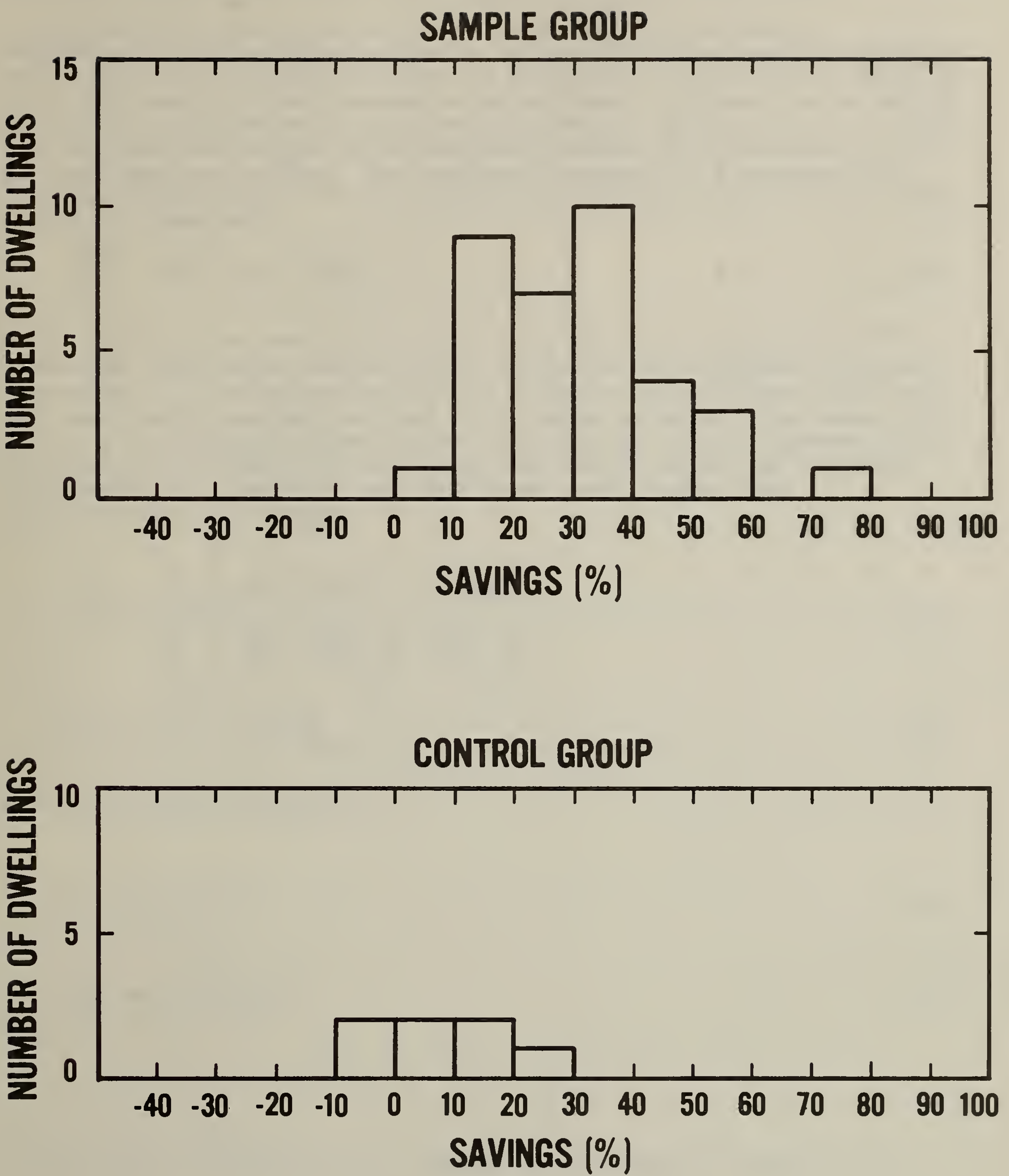

Figure 21. Histograms of fuel reductions of dwellings excluding water heater usage

APPENDIX A. THE BALANCE POINT CALCULATION BY USE OF FUEL BILL RECORDS

A condition that a home be selected as a participant in the optimal weatherization demonstration was that an adequate history of fuel consumption be available for a period of at least two years prior to the start of demonstration. This record of fuel consumption was utilized to determine the parameters b_o, b_1 and T_α of equation (2) before weatherization. Equation (2) will then be used as a predictor of how the dwelling would perform if no weatherization optimum would have been applied. The theoretical procedure used for determining these parameters consists of fitting a series of straight lines* to the billing history of a dwelling:

$$F_D^{(k)} = b_o^{(\alpha)} + b_1^{(\alpha)} \overline{DD}_{T_\alpha}^{(k)} \qquad k = 1, \ldots, N \quad (A.1)$$

where $F_D^{(k)}$ is the average daily fuel in the k^{th} billing period, $\overline{DD}_{T_\alpha}^{(k)}$ is the average daily degree days in the k^{th} billing period calculated for a base temperature T_α. The average daily fuel consumption and the average daily degree days were used in equation (A.1) due to the normal variation in the number of days in a billing period, specially for fuels such as oil and propane which are developed either on demand or at more or less constant degree day intervals. The parameter $b_o^{(\alpha)}$ and $b_1^{(\alpha)}$ were determined using standard least square regression techniques:

$$b_1^{(\alpha)} = \frac{\left(\frac{1}{N} \sum_{k=1}^{N} \overline{DD}_{T_\alpha}^{(k)} F_D^{(k)} - \overline{F}_D \, \overline{DD}_{T_\alpha}\right)}{\left(\frac{1}{N} \sum_{k=1}^{N} \overline{DD}_{T_\alpha}^{(k)} \overline{DD}_{T_\alpha}^{(k)} - \overline{DD}_{T_\alpha}^{2}\right)} \quad (A.2)$$

$$b_o^{(\alpha)} = \overline{F}_D - b_1^{(\alpha)} \overline{DD}_{T_\alpha} \quad (A.3)$$

where $\overline{F}_D$ and $\overline{DD}_{T_\alpha}$ are given by

$$\overline{F}_D = \frac{1}{N} \sum_{k=1}^{N} F_D^{(k)} \quad (A.4)$$

$$\overline{DD}_{T_\alpha} = \frac{1}{N} \sum_{k=1}^{N} \overline{DD}_{T_\alpha}^{(k)} \quad (A.5)$$

---

* The procedure outlined here is a variant of that given in reference [A.1].

The balance point T_o is then chosen to be the base temperature which gives the smallest residues (or maximum correlation) of the family of straight lines determined by equations (A.1) to (A.3).

This balance point T_o is defined as the temperature which produced the smallest $s_{(\alpha)}^2$,

where

$$s_{(\alpha)}^2 = \frac{1}{(N-1)} \sum_{k=1}^{N} (F_D^{(k)} - b_o^{(\alpha)} - b_1^{(\alpha)} \overline{DD}_{T_\alpha}^{(k)})^2 \tag{A.6}$$

or equivalently the maximum correlation coefficients r^2, where

$$r^2 = 1 - \frac{s^2(\alpha)}{S_F^2} \tag{A.7}$$

where S_F^2 is the estimate of the variation of daily fuel consumption, where

$$S_F^2 = \frac{1}{N-1} \sum_{k=1}^{N} (F_D^{(k)} - \overline{F}_D)^2 \tag{A.8}$$

The average daily degree days (based on $T\alpha$) for each billing period was calculated using weather tapes for each city obtained from the National Climatic Center.

The weather tapes were decoded to produce an hourly or three hourly weather file, depending on the particular weather station. A daily weather file was then processed by entering only the maximum and minimum temperature for each day. The degree days were calculated using a daily temperature profile T(t) by assuming a sinusoidal function with a period of 24 hours and a peak at 3 o'clock in the afternoon:

$$T(t) = (\frac{T_{max} + T_{min}}{2}) + \frac{1}{2} (T_{max} - T_{min}) \cos [\frac{2\pi(t-3)}{24}] \tag{A.9}$$

The degree days at the base temperature T_α for a given day, DD_{T_α} was determined by:

$$DD_{T_\alpha} = \frac{1}{I} \sum_{t=1}^{24} [T_\alpha - T(t)] \text{ only for } [T_2 - T(t)] > 0, \tag{A.10}$$

where I is the number of t's such that $[T_\alpha - T(t)] > 0$.

The average daily degree days in the k^{th} billing period, $\overline{DD}_{T_\alpha}^{(k)}$ was then calculated by:

$$\overline{DD}_{T_\alpha}^{(k)} = \frac{1}{M} \sum_{m=1}^{M} DD_{T_\alpha}^{(m)} \qquad (A.11)$$

where M is the number of days in the k^{th} billing period,

$DD_{T_\alpha}^{(m)}$ is the degree days for m^{th} day in the k^{th} billing period.

REFERENCE

[A.1] Woteki, T.H. and Mayer, L.S., "Fuel Consumption as a Function of Coldness of a Month," Energy and Building, Vol. 1, 1978.

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

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

This report presents a technique for analyzing the effect of energy saving retrofits installed in low-income housing under a nationwide weatherization demonstration program. This program was undertaken by the Community Services Administration (CSA) with the technical support of the National Bureau of Standards (NBS).

A tracking technique, based on the calculated balance-point temperature of each home prior to the weatherization, was developed to estimate the would-be fuel consumption over a period of time if the house had not been weatherized. The savings in fuel consumption for a home can be determined from the difference between the actual usage after retrofit and the calculated usage if it were not retrofitted. Besides the overall reduction, the saving in energy usage during different time periods while the house is being weatherized can be visualized from the graphical representation of the tracking technique.

Fuel reduction is reported for more than 100 homes using different fuels in seven cities across the nation, selected to represent various climate zones and geographical locations. It was found that the average saving in fuel consumption for dwellings in each city is about 30 percent.

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

Balance point temperature; computer graphics; degree days; energy conservation; energy consumption; fuel usage records; tracking technique; weatherization retrofit.

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