Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

OIL CONSERVATION IN HOME HEATING

A. C. S. Hayden, R. Braaten and T. D. Brown

Canadian Combustion Research Laboratory

June 1976

For Presentation at the American Society of Mechanical Engineers Winter Annual Conference, December 1976

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
ERP/ERL 76-55 (OP) (J)

OIL CONSERVATION IN HOME HEATING

by

A. C. S. Hayden*, R. W. Braaten** and T. D. Brown*

ABSTRACT

Field studies of the oil consumption characteristics of oil-fired residential heating systems have been carried out in several homes in a severe winter climate. Daily recording of the fuel consumption, cycling frequency and cycle length allowed the data to be used in conjunction with hourly meteorological records to establish baseline consumption patterns for comparison with consumption levels measured during the use of selected residential oil conservation techniques.

Improved burner performance and overnight thermostat cut-back are each shown to offer greater fuel savings than the use of a positive chimney damper designed to minimize "off" cycle losses.

*Research Scientists, **Engineer, Canadian Combustion Research Laboratory, Energy Research Laboratories, CANMET, Department of Energy, Mines and Resources, Ottawa, Canada.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

The use of energy in the forms of electricity and heating fuel in Canadian homes represents about one-fifth of the total national consumption. Fuel conservation in oil- or gas-fired residential heating equipment is, therefore, one area where absolute savings of a significant magnitude can be made and where direct effects are immediately perceived by the homeowner as dollar savings. Perhaps more important is the knowledge of a personal contribution to a national energy conservation policy.

A major difficulty in establishing possible fuel savings with residential heating equipment is the lack of reliable experimental data that can be used to substantiate the claims made for many fuel conservation techniques. Furthermore, if accurate predictions are to be made, the data should be capable of extrapolation to the wide ranges of climatic conditions, living habits and construction practices that are encountered across a sub-continent. This paper describes a series of field experiments which have been carried out in selected homes to evaluate several well-publicized fuel conservation strategies and to establish the relative merits of these strategies. The investigation was carried out in support of the National Fuel Conservation Policy.

The test homes, located in the Ottawa area, all used oil-fired heating equipment which occupies a dominant position in the Canadian home-heating market. The typical winter which these homes experience amounts to over 4000 Celsius degree days (below 18°C) with a minimum temperature of - 30°C, a winter average temperature of -2°C and a typical total snowfall of 250 cm.

THE EXPERIMENTAL PROGRAM

Records of the daily fuel consumption in five homes, selected for these systems analyses, have been accumulated over two consecutive winters (1974/75 and 1975/76). A brief description of the homes is given in Table 1.

The fuel consumption and cyclic operation of the heating system in each home was monitored with three digital-display meters as follows:

1) a volumetric fuel-oil meter (± 0.01 Imperial gallons), which was installed in the oil supply line to the burner,

2) a total elapsed-time indicator (± 0.1 hr), which was connected across the power supply to the burner and which displayed total burner operating time, and

3) an event counter, which was connected across the power supply to the burner and displayed the number of burner operating cycles.

The home owners were provided with data sheets on which the displays from the three meters were recorded twice daily (generally at 07.00 and 19.00 hrs) together with any additional commentary on disturbances to the normal domestic routine. The use of open fires or a week-end absence with its attendant thermostat cut-back were typical disturbances that might have had short-term effects on fuel consumption.

Throughout the course of the experiment, periods of time were designated as representing "normal" operation for each home; during these periods each control thermostat remained at a constant set-point of the home-owner's choice. The time periods were chosen to give fuel consumption data across the complete range of external (outdoor) temperatures which might be encountered in an Ottawa winter.

Weather data provided by the Atmospheric Environment Service at Ottawa International Airport included hourly temperature readings which allowed the accurate calculation of a mean temperature for any selected time period. The degree-day record for a number of years showed that for the period from October to April the average-degree day accumulation (relative to 18°C) was 4260 Celsius degree days and the mean temperature throughout the same period was -2°C. Although some heating is required outside this time period, it contributes little to the total fuel consumption and unduly biases the average winter temperature to a higher level. The studies were, therefore, restricted to the period between October 1st and April 30th.

THE EXPERIMENTAL DATA

The steady-state heat loss from a home can be regarded as a linear function of the temperature difference between the internal and external air temperatures; it is recognized that the external air temperature can be modified to take account of solar radiation by using the sol-air temperature. This technique has not been applied to the data presented in this paper.

The data from the monthly log sheets was matched with the hourly temperature readings to give an average external air temperature for the time period between recorded data points. This average temperature was then converted to degree days below 18^{0}C and used as the abscissa in graphical presentations with ordinates such as fuel consumption (Imperial gallons/hr), burner "on" time (hr/hr) and cycles/hr. The regularity of readings provided by the home owners was good and allowed data to be obtained throughout both winters with the understandable exception of a few days between December 29th - January 4th.

The results presented in this paper are based on readings taken at 24 hr intervals and do not, therefore, illustrate effects due to daily temperature variations. A representative plot of data points is shown in Figure 1; the scatter reflects the situation in the real world where several factors are beyond experimental control or numerical correction. These factors include domestic traffic patterns, the use of drapes on an irregular basis and changes in occupancy rate. Other factors such as solar heat gain and wind chill are amenable to numerical correction and preliminary studies of these corrections are now being undertaken.

Linear equations were fitted to all the experimental data obtained during discrete parts of the experimental program and the 95% confidence limits obtained by standard statistical techniques. With a single exception, it was found that polynomials of higher order did not substantially improve the correlation coefficient above that of the linear equation. The exception occurred in part of the data from Home B when the heating system was unable to maintain the thermostat set-temperature during very cold weather. The furnace was operating continuously and further drops in external temperature could not increase the fuel consumption, the burner operating time or the cycling frequency. Consequently, the linear correlations used were considered to be fully justified.

Using this simple data recording and reduction technique, the following variations in furnace operation and burner hardware were studied during the course of the two test winters: -

Thermostat Operation	:	Moderate overnight cut-back
		Severe overnight cut-back
Reduced "off" cycle losses	:	Positive chimney damper
		Reduced firing rate.
Burner Performance	:	Retention-head burner
		Prototype blue-flame burner

THE EFFECT OF INSULATION

The reduction of heating load and fuel consumption by improvement in insulation standard is an acknowledged conservation technique. This effect and a secondary effect of improved insulation are shown in Figure 2 where the hourly fuel consumption, as a function of external temperature, is compared for two homes of equal floor area having closely similar orientation and exposure. Home A was insulated to a standard better than that required for electrically heated homes, whereas Home B incorporated only conventional insulation.

In both cases the hourly fuel consumption followed the external temperature variation without any significant thermal storage effect.

Home A showed an average fuel consumption of 0.2 I gph, whereas the poorer insulation of Home B increased this figure to 0.3 I gph during the test period illustrated. It is also noticeable that the amplitude of the swings in the hourly fuel consumption is much smaller in the well-insulated home. As a result, burner cycling frequency remained constant over a much wider range of external temperature and this was reflected in smaller swings in internal temperature and closer control of the internal comfort condition.

THE EFFECT OF OVERNIGHT THERMOSTAT CUT-BACK

During the program, the homeowners were requested to vary their usual pattern of thermostat operation to give information on the effects of overnight thermostat cut-back on fuel consumption. To minimise interference with normal domestic routines, the overnight period was defined as being between "going to bed" and "getting up".

Typical results from two homes are illustrated in Figures 3 and 4. Home D was one in which the savings due to overnight thermostat cut-back were small and, although a fuel saving was indicated, it fell within the confidence limits of the normal (no cut-back) data. Figure 3 shows data from Home E in which two levels of cut-back from a base of 22.2°C (72°F) were practised. An overnight cut-back of 2°C (4°F) produced no appreciable differences in fuel consumption, whereas a 4°C (7°F) cut-back to 18.2°C produced reductions in fuel consumption at all external temperatures above -22°C. No data were recorded at temperatures below this level where the early morning heat requirement had increased presumably to the point of negating any fuel savings that had accrued during the overnight cut-back.

Figure 4 shows the effect of a cut-back in Home B where the daytime thermostat setting was 21.1°C (70°F) and the cut-back was to 16.1°C (61°F). In this case, the reductions in fuel consumption were to levels outside the confidence limits of the normal (no cut-back) data and the two consumption lines were marginally divergent indicating that a fuel saving would accrue from overnight cut-back at all external temperatures.

REDUCTION OF OFF-CYCLE LOSSES

Heat losses during the "off" cycle can severely reduce the overall home heating efficiency. These losses occur by two mechanisms:

1) heat stored in the furnace structure can be lost, by natural convection, up the chimney, and
2) basement air at indoor temperatures allows the chimney to provide a ventilation loss with a driving force determined by the temperature difference between the indoor and outdoor temperatures.

In this program two methods of reducing this "off" cycle loss were investigated. The first was to reduce the burner firing rate and thus increase burner operating time for a specific heat demand; the second was to restrict flow through the chimney by use of a positive chimney damper, safety-interlocked with the burner operation.

The Effect of Reduced Firing Rate

The effect of reduced firing rate in one home is clearly illustrated in Figure 5. In this case the reduction of firing rate from 1.00 US gph to 0.85 US gph was accompanied by a decrease in furnace efficiency from 79.1% to 78.3%. Despite this, the lower firing rate gave higher cyclic efficiencies which more than offset the reduced steady-running efficiency.

Limitations to this technique are imposed by the maximum heat requirement of the home since reductions in firing rate must reduce the output capacity of the furnace. Furnace sizing during installation is usually generous, as the operating times shown in Figure 6 illustrate.

The furnace in Home B operates continuously at external temperatures below -24°C and reductions in nozzle size could lead to uncomfortably low internal temperatures. The furnaces in Homes C, D and E have all passed their 50% operating time at external temperatures of -40°C and could accommodate marginally lower firing rates. The furnace in Home A had not reached its 50% operating time at an external temperature of -50°C and this was the home used for the data presented in Figure 5.

The Effect of a Positive Chimney Damper

To establish the effect of a positive chimney damper on fuel consumption, prototype dampers were constructed to laboratory specifications and installed after the barometric damper in the flue pipes of selected homes. The clearance on these dampers was small (1.6 mm). A safety interlock was added to the burner power circuit to ensure that the burner could not ignite whilst the damper was in a closed or partially-closed position. The spring-loaded damper returned to its fully-closed position 30 seconds after the end of the burner operating cycle.

These dampers have operated over two winter test periods and have not experienced any mechanical failures when installed in rigid flue pipes; deformation of the flue pipes can lead to the damper locking in a partially-closed position. When these dampers are in use it has been found essential to maintain a high standard of burner shut-down performance by the use of a solenoid valve to avoid odours from the combustion of oil-dribble from the atomising nozzle.

Where chimney dampers were installed, fuel savings of between 5 and 10 per cent were achieved. The extent of these savings is a function of external temperature and may also be related to the type of heating system since the highest savings were recorded in a home heated by hot water where a continuous chimney loss by convection from relatively high-temperature surfaces (60°C, 140°F) existed.

THE EFFECT OF IMPROVED BURNER PERFORMANCE

The effect of upgrading the burner performance was investigated using different burners in two homes. The first burner, installed in Home E, was a prototype blue-flame burner developed at the Canadian Combustion Research Laboratory[1] and capable of smoke-free operation at an excess-air level of 25% when used as a retrofit burner in an existing furnace. The second burner, installed in Home C, was a commercial, flame retention-head burner known to be capable of performance comparable to that of the blue-flame prototype.

The results from these two homes are shown in Figures 7 and 8. In both homes a reduction in fuel consumption was recorded which was of constant magnitude; when expressed as a percentage of fuel used this saving decreased with decreasing external temperature. Although the saving from the prototype blue-flame burner was smaller than that from the commercial retention-head burner, the result was considered satisfactory to the blue-flame development program since it was intended that this burner should be used with an optimized combustion chamber whilst preserving a physical retrofit capability.

COMPARISON OF FUEL CONSERVATION TECHNIQUES

In order to provide a simple comparison of the merits of the various fuel conservation techniques investigated in the course of the experimental program, the linear equations relating fuel consumption in Imperial gallons/hr to degree days below $18^{o}C$ have been integrated over a simulated winter of 4260 Celsius degree days with a mean winter temperature of $-2^{o}C$. The results are presented in Table 2.

The absolute magnitude of the saving from any fuel conservation technique must depend on the normal fuel consumption. When the percentage saving figures listed in Table 2 are compared, the order of effectiveness in Table 3 emerges.

Plainly, the most cost-effective technique is severe thermostat cut-back. In view of the magnitude of the normal fuel consumptions recorded in these experiments and current trends in the price of home heating oil, all of these techniques can be regarded as offering significant dollar advantages to the home owner within three years.

CONCLUSIONS

A simple evaluation procedure has been developed which enables a precise field assessment of fuel conservation techniques to be made.

Several fuel conservation techniques have been assessed using this procedure and placed in the following order of effectiveness:

1) Improved burner performance

2) Severe overnight thermostat cut-back

3) Reduced firing rate
   Moderate thermostat cut-back

4) Positive chimney damper

5) Slight thermostat cut-back.

ACKNOWLEDGEMENTS

In a field study of residential heating the willing co-operation of the homeowners is invaluable. The authors wish to acknowledge the patient daily recording of data made by Mr. and Mrs. E. R. Mitchell, Mr. and Mrs. B. C. Post, Mr. and Mrs. G. K. Lee, Mr. and Mrs. F. D. Friedrich and Mrs. T. D. Brown. In addition, the continuing discussion of the test data with colleagues at the Canadian Combustion Research Laboratory has contributed greatly to the content of this paper.

REFERENCES

(1) Canadian Patent Application 230, 344
"Oil Burner Assembly". E. R. Mitchell, T. D. Brown and B.C. Post.

TABLE 1

THE EXPERIMENTAL HOMES

Description	Type	Floor Area of Heated Space	Type of Heating	Standard of Insulation
Home A	Two storey	230 m^2	Warm-air	High
Home B	Two storey	230 m^2	Warm-air	Poor
Home C	Two storey	160 m^2	Warm-air	Average
Home D	Bungalow	110 m^2	Hot-water	Average
Home E	Bungalow	170 m^2	Warm-air	Average

TABLE 2

A COMPARISON OF THE FUEL CONSERVATION TECHNIQUES
OVER A TYPICAL WINTER (4260 Degree Days below 18°C)

Conservation Technique	Fuel Consumption : Imperial Gallons				
	HOME A	HOME B	HOME C	HOME D	HOME E
None	789.0	1381.5	716.4	881.6	953.2
Thermostat Cut-Back					
Slight .			717.6		932.3
Moderate .					887.0
Severe .		1171.7			
Improved Burner Performance			578.2		818.8
Positive Chimney Damper			658.8	798.7	
Reduced Firing Rate	715.5				

TABLE 3

THE RELATIVE EFFECTIVENESS OF VARIOUS FUEL CONSERVATION TECHNIQUES

Conservation Technique	% Fuel Saving	Approximate Cost
High Efficiency Burner	14 - 20	$100
Severe Thermostat Cut-back	15.2	$ 0
Reduced Nozzle Size Moderate Thermostat Cut-back	7 - 10	$ 10 $ 0
Positive Chimney Damper	0 - 10	$ 60 (est.)
Slight Thermostat Cut-back	0 - 2	$ 0

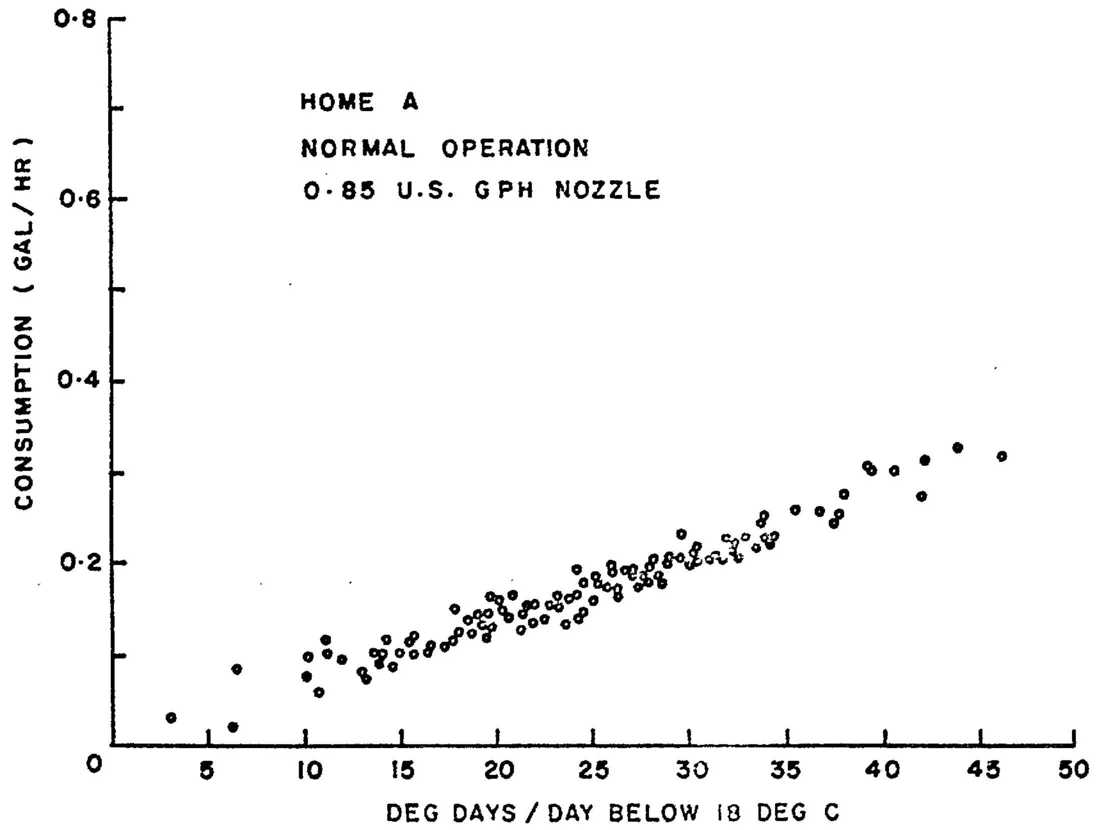

FIGURE 1 TYPICAL DATA PLOT

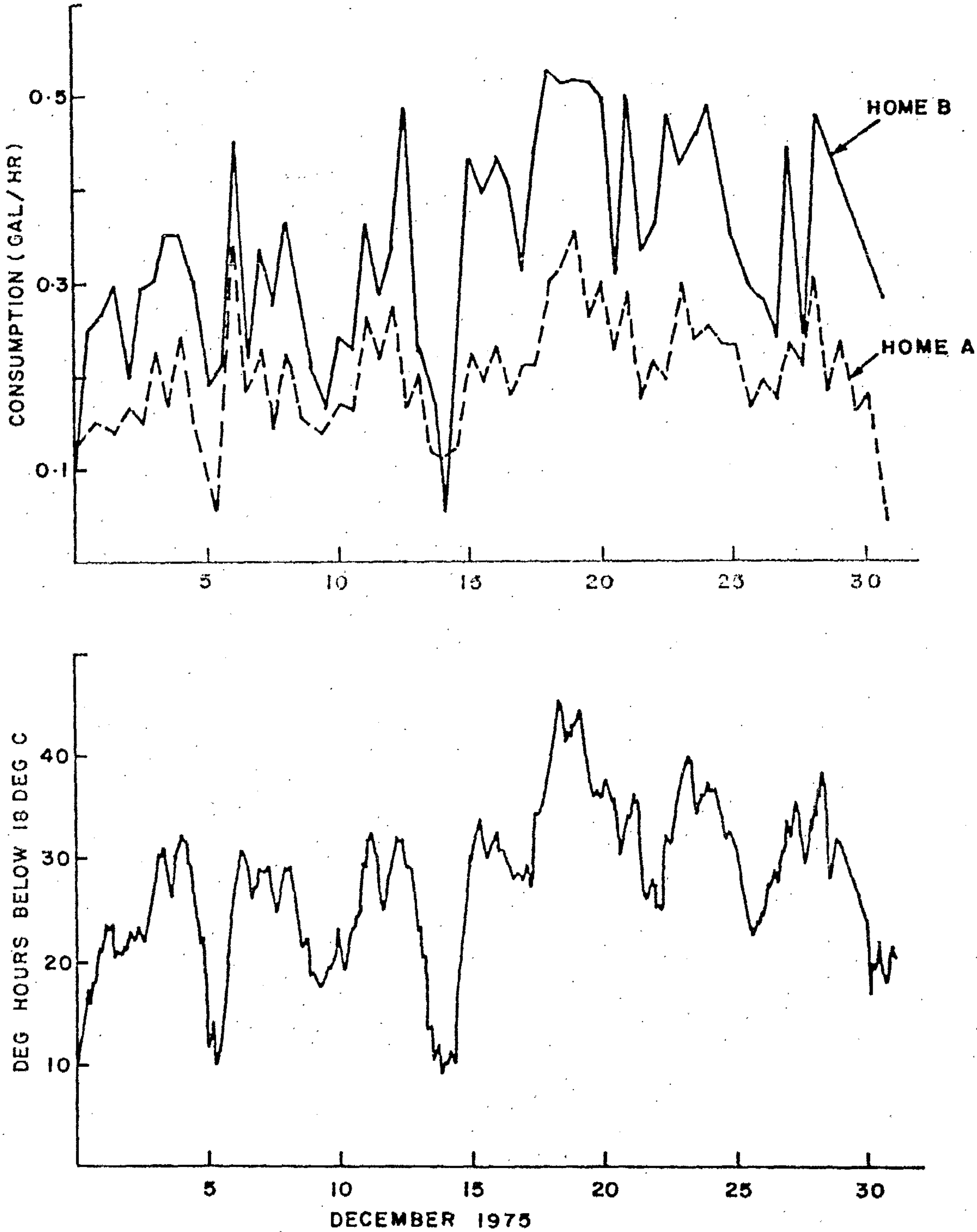

FIGURE 2 THE EFFECT OF EXTERNAL TEMPERATURE
ON FUEL CONSUMPTION
HOMES A AND B

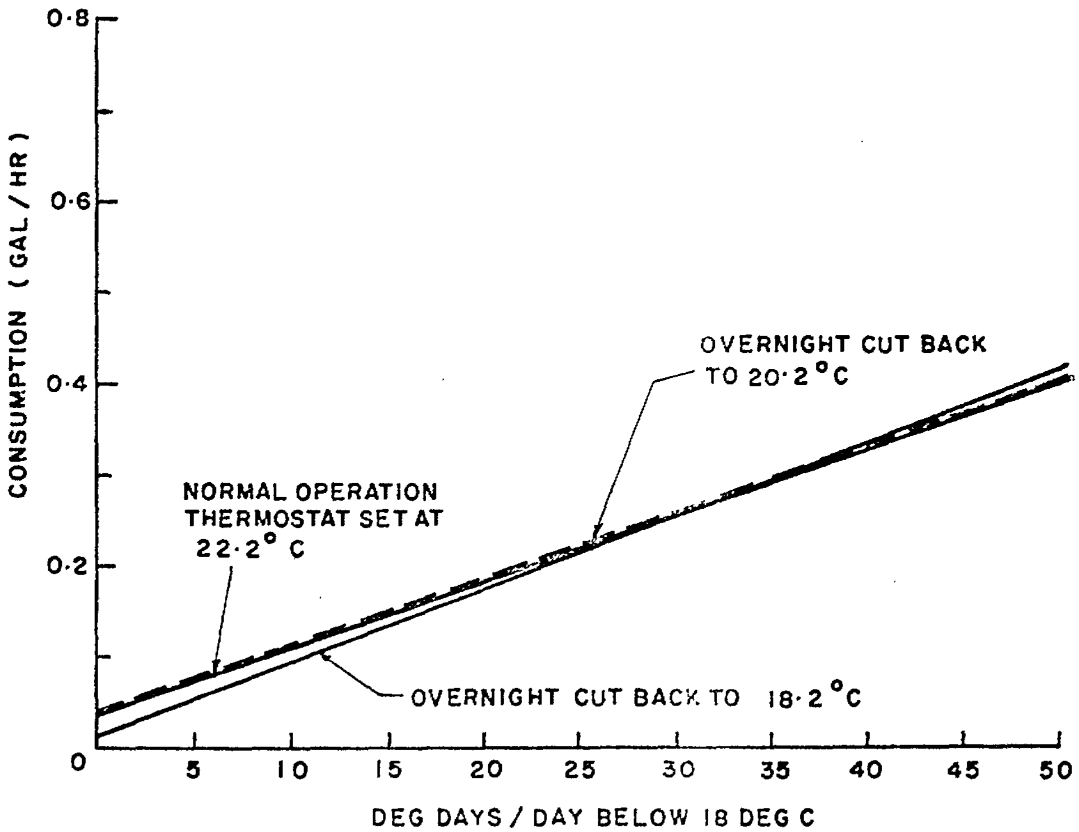

FIGURE 3 THE EFFECT OF TWO LEVELS OF OVERNIGHT CUT-BACK ON FUEL CONSUMPTION. HOME E

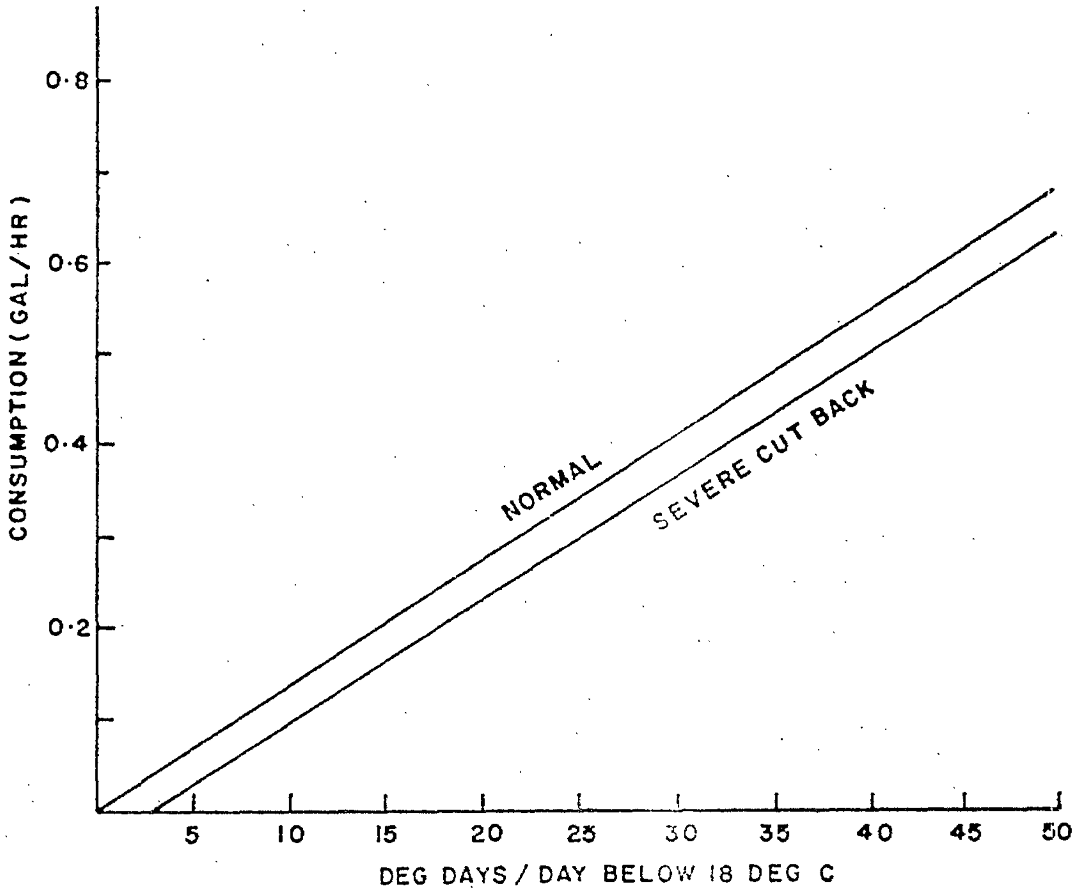

FIGURE 4 THE EFFECT OF SEVERE OVERNIGHT THERMOSTAT CUT-BACK ON FUEL CONSUMPTION. HOME B

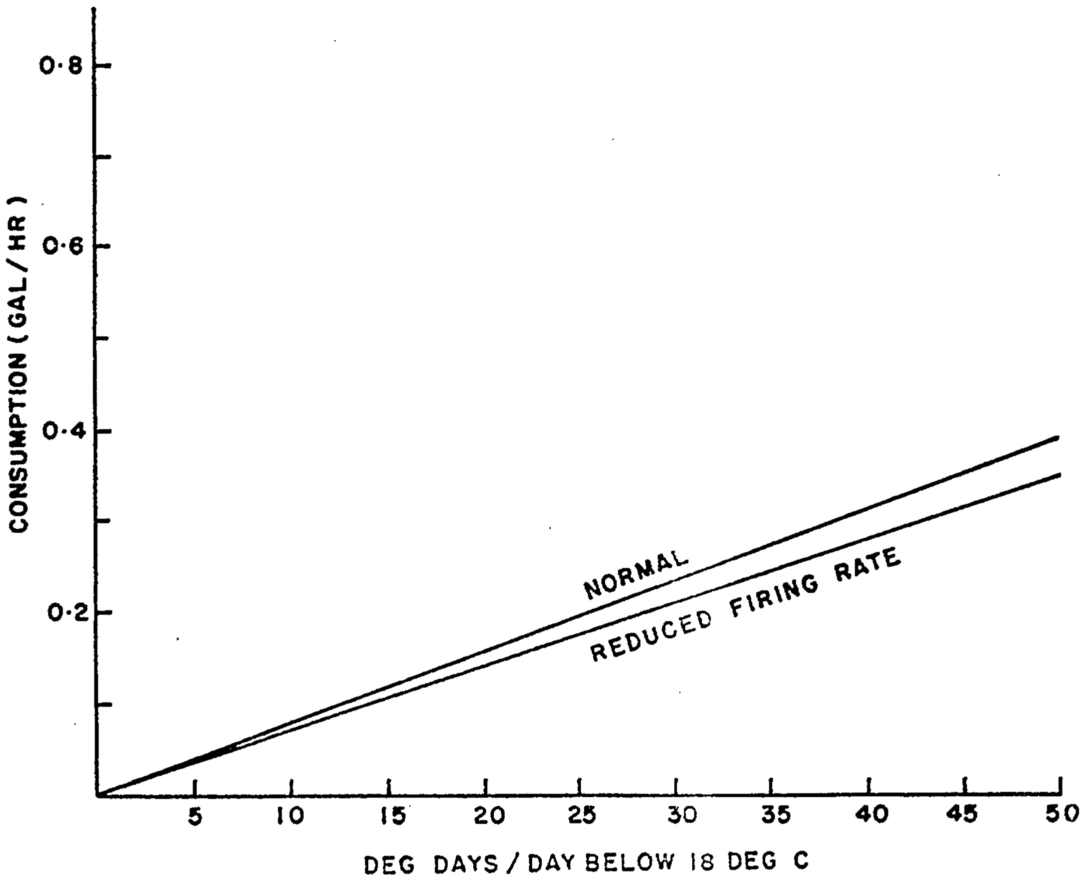

FIGURE 5 THE EFFECT OF REDUCED FIRING RATE ON FUEL CONSUMPTION. HOME A

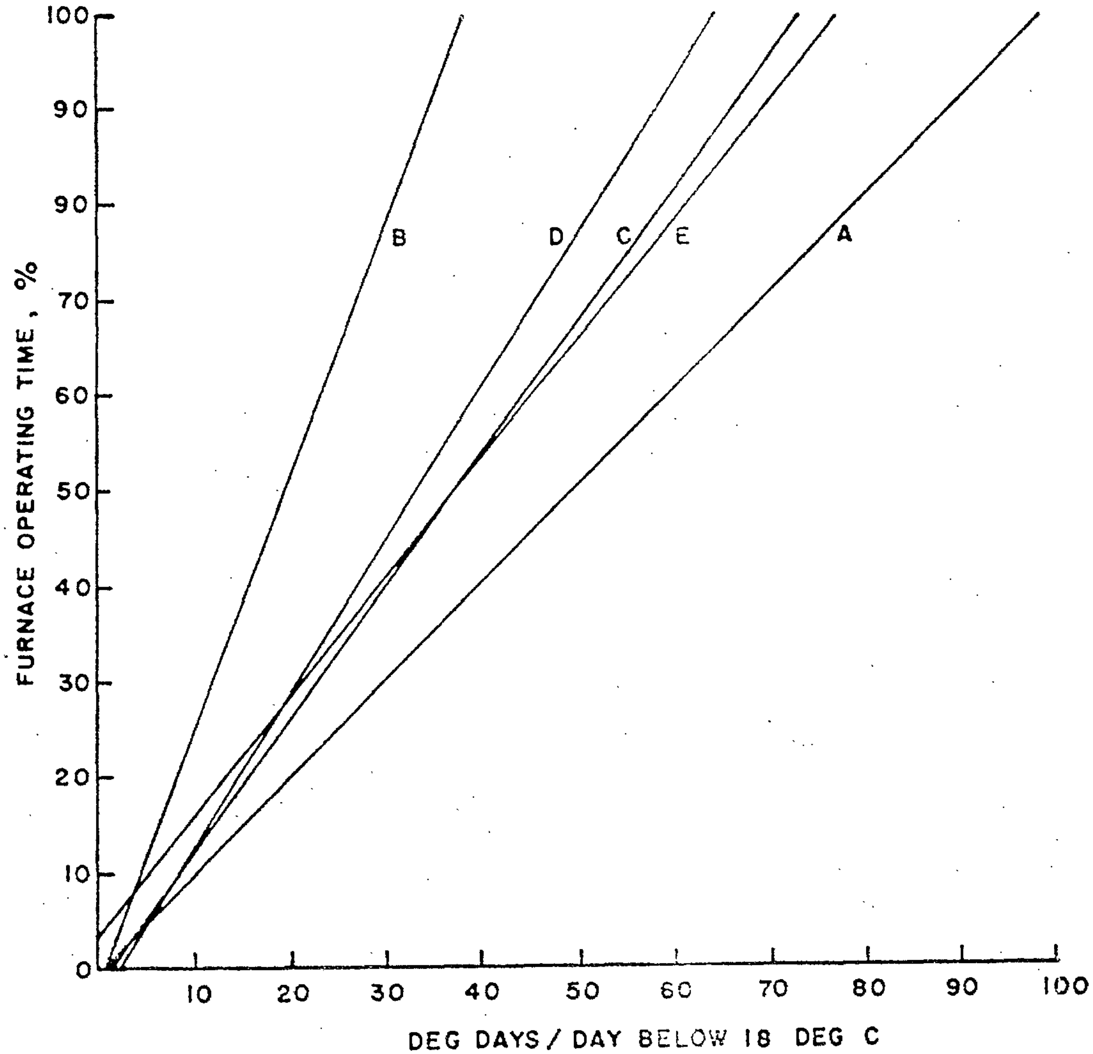

FIGURE 6 THE EFFECT OF EXTERNAL TEMPERATURE ON FURNACE CYCLING FREQUENCY

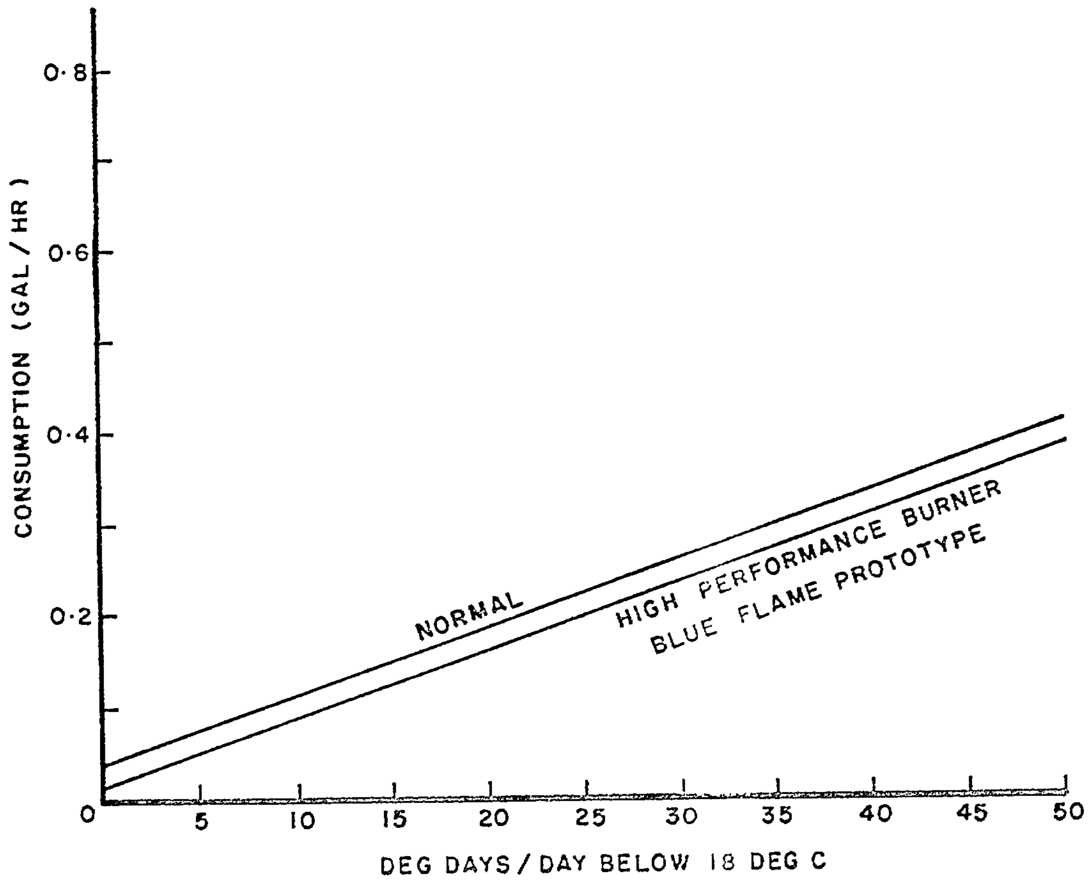

FIGURE 7 THE EFFECT OF IMPROVED BURNER PERFORMANCE. PROTOTYPE BLUE FLAME BURNER HOME E