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An Investigation as to the Comparative Cost of Fuels for Heating Homes in the City of Brookings, South Dakota

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AN INVESTIGATION AS TO THE COMPARATIVE COST OF FUELS FOR HEATING HOMES IN THE CITY OF BROOKINGS, SOUTH DAKOTA

By

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser

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INTRODUCTION

The object or intent of this investigation was to make a study of comparative costs of heating homes in the city of Brookings. Six different fuels or methods of firing of these fuels were compared in the two main categories of home heating; hot water radiators and warm air furnaces.

The investigation was not intended to increase the efficiency of any specific installation. However, the efficiencies of several of the atomizing oil burners were increased considerably by changes in the air settings which should have been made by the installer when the furnace was originally installed.

The homes ranged in age from several built between 1910 and 1920 to those which had only been completed during the past summer. Some of the older homes were well insulated and consequently had a very low overall heat loss coefficient. All of the newer homes were well insulated and this was evidenced by the results of the investigation. All of the older homes were either heated by hand-fired coal systems or stoker-fired coal systems using high-volatile bituminous coal. Nearly all of the homes in Brookings which have been constructed since World War II have had oil heat, but perhaps 10 percent have been heated by liquified petroleum gas (propane). Natural gas service was started in Brookings after the investigations were begun.

The tests were not conclusive as to which fuel is the most economical to use as there are too many extenuating factors which enter in the results and may only be estimated for a study such as this one.

The fuels and methods of firing of these fuels, which were originally intended for use in these tests included the following: hand-fired bituminous coal, stoker-fired bituminous coal, pressure or atomizating type oil burning (the most common in Brookings), pot or vaporizing type oil burners, and liquified petroleum gas (propane). During the second month of the test, natural gas (which consists principally of methane) was run into one of the houses under investigation and this fuel too was then entered in the results.

The results show that the most economical house, on an adjusted volume basis, to heat to be an older one story home with an originally hand-fired hot air furnace which had been converted to a stoker-fired installation using Olga stoker coal.

The poorest example as far as cost was concerned was an older two story home with a hand-fired system burning petroleum briquetts. It cost nearly 2½ times more to heat the same volume as did the most economical house. This home, needless to say, was uninsulated, had extremely poor fitting windows, and the furnace was a definite hazard to the occupants.

COMPARATIVE COST OF FUELS

The easiest and most generally accepted method of analyzing comparative fuel costs is by comparing the unit cost of each fuel against its heat content. Table 1 illustrates this comparison for fuels used in this test.

Table 1. Comparative Fuel Costs

FUEL	COST PER UNIT	NO. BTU PER UNIT	COST PER 100,000 BTU
#1 fuel oil	15.5¢ per gal.	140,000 per gal.	11.1¢
#2 fuel oil	14.2¢ per gal.	140,000 per gal.	10.1¢
Olga stoker coal	$21.90 per ton	14,755 btu/lb.	7.45¢
Odin stoker coal	$21.20 per ton	14,477/lb.	7.35¢
Pocohontas lump	$23.60 per ton	14,597/lb.	8.1¢
Blue Flame lump	$23.70 per ton	14,771/lb.	8.0¢
Petroleum briq.	$24.80 per ton	14,939/lb.	8.3¢
Propane	13.0¢ per gal.	91,500/gal.	14.2¢
Natural gas	Sliding scale	100,000/therm	11.4¢ (Avg. consump)

The cost per 100,000 btu's is not, however, the true criteria for determining the most economical fuel to burn. The Small Homes Council of the University of Illinois bases their fuel cost comparisons also on the approximate efficiencies shown in Table 2.

Table 2. Approximate efficiencies to be employed in comparing fuel costs.

FUEL	TYPE OF UNIT	EFFICIENCY PER CENT
Fuel oil	Boiler or furnace burner	75
Gas	Boiler or furnace burner	75
Fuel oil	Conversion burner	65
Coal, bituminous	Hand-fired	50
Coal, bituminous	Stoker-fired	60

As mentioned in the preceding paragraph, fuel costs comparisons based on heat units alone are false and misleading. Numerous other conditions must be understood. Both the operating efficiency of the heating plant and the thermal efficiency of the building have a direct bearing on fuel consumption.

Thus, even where gas unit-costs may be more than double those of fuel oil, it would be possible to almost equalize the costs between two houses of similar size if the gas heated house is a "thermos bottle" and the oil heated home a "sieve". Such factors are not relevant when considering the application of various fuels to a specific building, but are important when one neighbor may be matching fuel bills with another and erroneously assuming that only the fuels are responsible for the difference.

Heating plant losses have much bearing on comparative fuel costs. Many factors enter into consideration and they will be taken up in detail in the next chapter.

As a rule, a boiler or furnace that has been designed for a specific fuel will provide higher efficiency than one designed to permit firing of various fuels or one which has been converted from one fuel to another. The restricted passages of a unit designed for oil or gas usually make it impractical for coal firing, and a heating plant designed primarily for coal may have excessive combustion and gas passages for use with other fuels. We may then say that it is usually unsound to compare the fuel costs of a modern oil or gas boiler-burner unit with those of an oil or gas conversion burner installed in a coal burner.

The accuracy of an estimate of the comparative consumption of two fuels in a given installation will be in direct proportion to the accuracy of the information available. If we were to convert the Gilbert stoker-fired bituminous hot air furnace to a conversion burner using number 2 fuel oil with a heating value of 140,000 btu per gallon, and assuming an efficiency of 65 per cent from Table 2, the following equation may be used:

$$X_o = \frac{P \times C \times H_c \times E_c}{H_o \times E_o}$$

Where X_o = number of gallons of oil required

C = number of tons of coal used

H_c = btu's per pound of coal

H_o = btu's per gallon of fuel oil

E_c = efficiency of coal burning plant

E_o = efficiency of oil burning plant

P = pounds of coal per ton

Substituting in this equation the values which we have known and those which we have assumed from the tables, the equation then becomes

$$X_o = \frac{2000 \times 6.5 \times 14,755 \times .60}{140,000 \times .65} = 1266 \text{ gallons}$$

With the Olga stoker coal at $22.00 per ton delivered in Brookings and number 2 fuel oil at 14.2¢ per gallon, the comparative fuel costs may be calculated as follows:

6.5 tons x $22.00	=	$143.00
1266 gallons x 14.2¢	=	179.77

The difference between these two figures, $36.77, is the increased cost resulting from the conversion to oil. The conversion could hardly be justified in this case due to the 25 per cent increase in cost per year unless you would justify some of the expense due to the increase in usable space in the fuel storage area, the absence of coal dust and dirt, and the elimination of the hauling out of the ashes.

To calculate the number of therms of natural gas necessary to supply an amount of heat equivalent to that supplied by the fuel oil, the following equation may be used:

$$X_g = \frac{O \times H_o \times E_o}{H_g \times E_g}$$

Where X_g = number of therms of gas required

O = number of gallons of oil used

E_g = efficiency at which gas is utilized

E_o = efficiency at which the oil is utilized

H_g = heat content of gas (100,000 btu per therm)

H_o = heat content of oil (140,000 btu per gallon)

For example, the Skubic residence utilized a total of 1020 gallons of fuel oil during the heating season with an assumed efficiency of 75%. To find the equivalent amount of natural gas which would be required at 100,000 btu per therm and 75 per cent efficiency, substitute in the above formula.

$$X_g = \frac{1020 \times 140{,}000 \times .75}{100{,}000 \times .75} = 1430 \text{ therms}$$

The gas rate for this quantity of gas would average out to about 12.2¢ per therm over the period of one year. The number 2 fuel oil cost is at a flat rate of 14.2¢ per gallon. The comparative fuel cost may be calculated as follows:

1430 therms x 12.2¢ per therm = $174.46

1020 gals. x 14.2¢ per gal. = 144.84

This results in an additional cost of $31.72 per year by using natural gas. This additional cost for using natural gas may be overcome in several ways. If the individual is heating water with electricity, which most homes in Brookings are doing, and the average amount of electricity used per month for heating hot water is 400 Kilowatt-hours, the cost of the electricity then being $5.00 per month. Heating an equivalent amount of water with natural gas would only cost $1.95 per month. Taking the difference between these two figures ($5.00 - 1.95) = $3.05 times twelve months, we find a net saving of $36.60 per year in the heating of water. This more than makes up the additional cost of heating the house with natural gas. An additional saving could be made if the cooking was also converted from electricity to natural gas, although this would not be nearly as great. Table 3 is a cost comparison for the heating of water by natural gas, electricity and liquified petroleum gas (propane). The net saving or increased cost of any amount of water heating may be readily calculated from this table.

Once the advantages of automatic heat are experienced in the home, the operating cost becomes of secondary consideration. This is clearly indicated in a nationwide survey made

Table 3. Water Heating Cost Comparison - Natural Gas-Electricity-Propane

No. KWH Electricity Used	No. Therms Natural Gas 70% Eff.	No. Gals. Propane 70% Eff.	Electricity Cost $1\frac{1}{4}$¢ KWH.	Natural Gas Cost Winter	Natural Gas Cost Summer	Propane Cost 13¢ Gal.
100	4.87	5.32	$ 1.25	$ .487	$1.221	$ .69
120	5.85	6.39	1.50	.585	1.46	.83
140	6.83	7.46	1.75	.683	1.71	.97
160	7.81	8.53	2.00	.781	1.95	1.11
180	8.78	9.59	2.25	.878	2.20	1.25
200	9.75	10.65	2.50	.975	2.44	1.39
220	10.73	11.72	2.75	1.073	2.65	1.53
240	11.70	12.78	3.00	1.17	2.84	1.67
260	12.68	13.85	3.25	1.268	2.94	1.81
280	13.65	14.92	3.50	1.365	3.23	1.95
300	14.62	15.98	3.75	1.462	3.42	2.08
320	15.59	17.05	4.00	1.559	3.62	2.22
340	16.57	18.11	4.25	1.657	3.82	2.36
360	17.54	19.18	4.50	1.754	4.01	2.50
380	18.52	20.24	4.75	1.85	4.21	2.64
400	19.49	21.31	5.00	1.95	4.40	2.77
420	20.47	22.38	5.25	2.05	4.59	2.91
440	21.45	23.44	5.50	2.15	4.79	3.05
460	22.42	24.51	5.75	2.24	4.98	3.19
480	23.39	25.58	6.00	2.34	5.18	3.33
500	24.36	26.64	6.25	2.44	5.37	3.46
520	25.34	27.71	6.50	2.53	5.57	3.60
540	26.31	28.77	6.75	2.63	5.76	3.74
560	27.29	29.83	7.00	2.73	5.96	3.88
580	28.27	30.91	7.25	2.83	6.15	4.02
600	29.25	31.97	7.50	2.93	6.35	4.16

by FUEL OIL & OIL HEAT magazine, in which families were asked why they preferred oil heating. Among dozens of reasons given, these four led:

Convenience	32%
Economy	17%
Cleanliness	16%
Comfort	9%

While these are the results of a survey about oil heating, it is most likely that a very similar survey by the natural gas industry would give results of the same order and magnitude.

The subject of comparative fuel costs is an interesting one. The principal advantage of a thorough understanding of this subject is the ability to disprove exaggerated statements made by those selling competing fuels.

COMBUSTION HEAT LOSSES

Combustion is defined as the chemical union of oxygen with combustible materials, accompanied by the evolution of light and the rapid production of heat. A furnace is a fairly gas-tight and well-insulated space in which coal, oil or gas and the combustible gases from solid-fuel beds may be burned with a minimum amount of excess air and with reasonably complete combustion. Near the exit from the furnace, at which place most of the fuel has been burned, the furnace gases will consist of inert gases such as CO_2, N_2, and H_2O vapor, together with some O_2 and some combustible gases such as CO, H_2, hydrocarbons, and particles of free carbon, (soot). If combustion is to be complete, the combustible gases must be brought into intimate contact with the residual oxygen in a furnace atmosphere composed principally of inert gases. Also, the oxygen must be kept to a minimum if the loss due to heating excess air from room temperature to chimney gas temperature is to be low. Consequently, THE MAJOR FUNCTION OF THE FURNACE IS TO PROVIDE SPACE IN WHICH THE FUEL MAY BE BURNED WITH A MINIMUM AMOUNT OF EXCESS AIR AND WITH A MINIMUM LOSS DUE TO THE ESCAPE OF UNBURNED FUEL.

The design of a satisfactory furnace is based upon the "three T's" of combustion; TEMPERATURE, TURBULENCE, and TIME.

For each particular fuel, there is a minimum TEMPERATURE, known as the ignition temperature, below which the combustion of that fuel in the correct amount of air will not take place. The ignition temperature of a fuel in air for some of the common gases is shown in Table 4.

Table 4. Ignition Temperatures for some Common Gases

Hydrogen (H_2)	1075 - 1095 ° F.
Carbon monoxide (CO)	1190 - 1215 ° F.
Methane (CH_4)	1200 - 1380 ° F.
Ethane (C_2H_6)	970 - 1165 ° F.

If the combustion gases are cooled below the ignition temperature, they will not burn, regardless of the amount of oxygen present.

TURBULENCE is essential if combustion is to be complete in a furnace of economical size. Violent mixing of oxygen with the combustible gases in the furnace increases the rate of combustion, shortens the flame, reduces the required volume, and decreases the chance that the combustible gases will escape from the furnace without coming into contact with the oxygen necessary for their combustion.

Since combustion is not an instantaneous process, TIME must be provided for the oxygen to find and react with the combustible gases in the furnace. In burning fuels such as gas or oil, the incoming fuel-air mixture must be heated above the ignition temperature by radiation from the flame or hot walls of the furnace.

If the combustible gases, which contain hydrocarbons, are allowed to cool below the ignition temperature of the gases before becoming completely burned, they form what we know as soot. Once we have soot formed it is almost impossible to heat it sufficiently to burn and it clogs up our heat transfer surface.

A complete analysis of the combustion efficiency necessitates accounting for all of the various heat losses. These various losses may be summarized as follows:

L_s Heat carried off by the dry flue gas

L_h Heat lost due to superheating the moisture formed by combustion of the hydrogen

L_{co} Heat lost due to incomplete combustion of carbon

L_{ma} Heat lost due to heating moisture in air

L_{mf} Heat lost due to vaporizing and superheating moisture in the fuel

L_r Heat lost through radiation

L_c Unaccounted for heat losses

The first five of these losses constitute the sources of loss due to the flue. Heat lost due to radiation, and those losses which are usually listed as being unaccounted for, represent heat losses from the furnace or boiler to its immediate surroundings. As such, these radiation and unaccounted for losses are commonly considered not to be heat losses in a practical sense, since they serve to provide heat supply to building space which otherwise must be supplied from the heat circulating system.

The largest loss (8 to 10 percent) which occurs in most fuel burning installations is the loss due to the sensible heat in the dry gaseous products of combustion. This results from the discharge to waste of the products of combustion at a temperature above that at which the air for combustion is supplied. Any excess air supplied for combustion only tends to increase this loss. This loss may be calculated as follows:

$$L_s = G_f \times c_p \times (t_g - t_a) = .24 G_f (t_g - t_a)$$

where G_f = dry gaseous products of combustion, lb/lb fuel

c_p = .24 = mean specific heat of the dry gaseous products of combustion, btu/lb - ° F.

t_g = temperature at which the dry gaseous products of combustion are discharge to waste, ° F.

t_a = temperature of inlet air, ° F.

A typical coal will have about 12 pounds of dry gaseous products of combustion per pound of fuel. The flue gas temperature will be about 500 ° F. and the inlet air temperature will be approximately 70 ° F.

$$L_s = .24 \times 12 \times (500 - 70) = 1240 \text{ btu/ pound of coal}$$

This loss, which we said was the largest single loss, may be reduced by lowering the exit gas temperature or by reducing the amount of the dry gaseous products of combustion. The minimum value of t_g is generally fixed by the amount of heat transfer surface which the equipment contains. In home furnace or boiler design, the ultimate price of the equipment plays a large part, and consequently the size of the surface is held to a minimum. The quantity of the dry gaseous products of combustion is dependent upon the excess air which cannot be reduced too much without seriously increasing the losses due to incomplete combustion. If we encounter incomplete combustion our heat transfer surfaces usually become covered with soot which decreases the rate of heat transfer, increasing the stack or flue temperature and generally, decreasing the efficiency of the furnace or boiler unit.

The heat lost due to superheating the moisture formed from the combustion of hydrogen is about the next greatest loss and the equation is as follows:

$$L_h = 9H \left[(212 - t_a) + 970.4 + 0.48(t_g - 212)\right]$$

where H = per cent hydrogen in the fuel by weight

t_a = fuel temperature as it enters combustion chamber

t_g = temperature of the flue gases

970.4 = latent heat of vaporization of water

212 = temperature of steam at atmospheric pressure °F.

0.48 = specific heat of steam (approximately)

With an average value of $5\frac{1}{2}$ per cent of hydrogen from the ultimate analysis of coal and flue gas temperatures as obtained from the first example, the equation takes on the form:

$$L_h = 9 \times .055 \left[(212-70) + 970.4 + 0.48(500 - 212)\right]$$
$$= 619 \text{ btu per pound of fuel burned}$$

The heat lost due to incomplete combustion of the carbon would depend primarily upon the amount of carbon in the ashpit and the amount of carbon monoxide (CO) which is going out the flue. In any case it is one of the smaller losses and would amount to perhaps a total of 200 btu per pound of fuel with good firing techniques.

The loss due to heating moisture in the air is another small loss and would account for perhaps a maximum of 15 btu per pound of fuel burned. This may be computed on the basis that the amount of air necessary to burn one pound of a typical coal would be approximately 12 pounds. If the relative humidity of this air was 30 per cent, the air would then contain 0.30 x 0.015 x 12 = 0.054 pounds of water vapor. The heat lost to the flue, L_{ma}, by the heating of this water then may be calculated from

$$L_{ma} = W_w \times 0.48(t_g - t_a)$$
$$= 0.054 \times 0.48 (500 - 70) = 11 \text{ btu per pound fuel}$$

Because the one pound of coal contained about 5 per cent moisture in the form of water, the heat lost due to moisture in the fuel, L_{mf}, may be calculated from

$$L_{mf} = W_f \left[(212 - t_a) + 970.4 + 0.48 (t_g - 212)\right]$$

where W_f is the percent of moisture in the fuel and the other symbols are as previously defined.

$$L_{mf} = 0.05 \left[(212 - 70) + 970.4 + 0.48(500 - 70)\right]$$
$$= 62.5 \text{ btu per pound of fuel burned}$$

These calculated heat losses are tabulated in Table 5, which shows the percentage of total heat lost to the flue, accounted for by each source:

Table 5. Total Heat Lost to the Flue

Source of Heat Loss	Heat Lost Btu per pound Fuel	Total Heat Lost Percent
Dry flue gases, L_s	1240 btu	43.2%
Moisture formed by combustion of hydrogen in fuel, L_h	619 btu	21.6%
Incomplete combustion, L_{co}	200 btu	7.0%
Moisture in air supplied, L_{ma}	11 btu	0.4%
Moisture in fuel, L_{mf}	63 btu	2.2%
Unaccounted for heat losses, L_c[1]	740 btu	25.6%
	2873 btu	100.0%

The total combustion efficiency is calculated on the basis of a percent heat lost of the total heating value of

1 The unaccounted for heat losses are estimated to be 5 per cent of the total heating value of the coal, 14,755 btu per pound.

the fuel. For this particular example the calculations would be as follows:

$$\frac{2873}{14,755} \times 100 = 18.8\%$$

The combustion efficiency is then 100 - 18.8% = 81.2 per cent.

The above illustration of the complete energy balance for one fuel could be duplicated for any of the other fuels which were under the test. However, as we have shown, the largest losses are due to the dry flue gas and to the amount of excess air. These two factors are those which relate directly to field servicing. They are usually determined by (1) measurement of the stack temperature, and (2) measurement of the percentage of carbon dioxide (CO_2).

We may show that with clean combustion, the percentage of carbon dioxide (CO_2) is a direct proportional measurement of the amount of excess air. While it is theoretically possible to obtain 15.6 per cent CO_2 in the combustion gases with an average fuel oil, most authorities regard adjustment of excess air to produce from 10 to 12 per cent CO_2 as sound practice. Adjustments within these limits will insure against changes in fuel or in combustion conditions acting to cause a smoky flame with attendant incomplete combustion. Figure 1 illustrates the effect of the percentage of excess, not only on the cleanliness of the flame but on stack temperature and CO_2 content of the stack gases. Variations in fuel and burn-

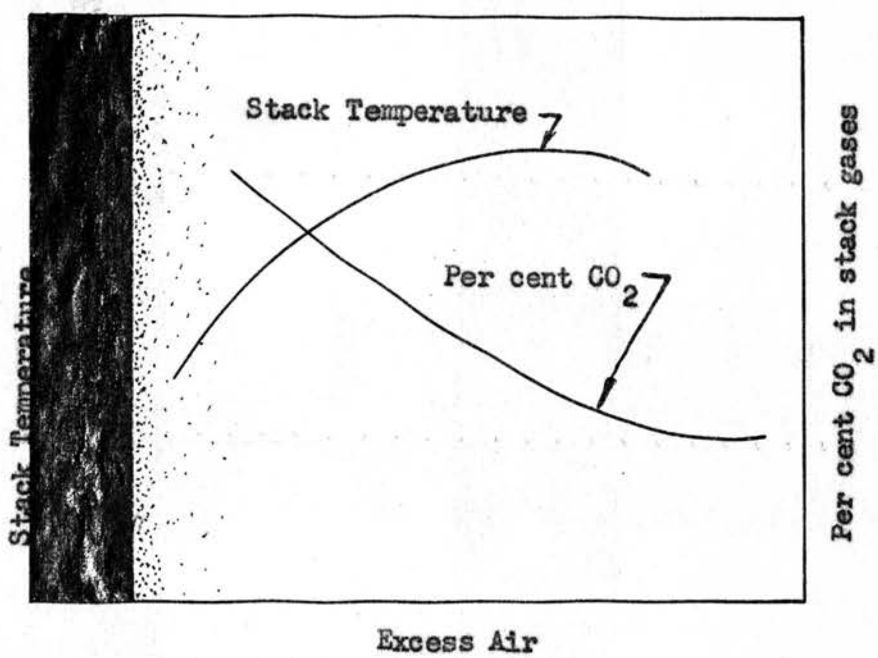

Figure 1 Effect of Excess Air on Smoke, CO_2 and Stack Temperature

ing equipment make it impractical to put units on this figure. However, it is apparent that as excess air is increased, the stack temperature first increases, reaches a maximum, and then decreases. Although an increase in excess air reduces flame temperature and size, an initial increase in stack temperature occurs because less heat is radiated to the surroundings, leaving more heat to be transferred by convection. The diluting effect of increased excess air becomes so great that a decrease in stack temperature evidently occurs as excess air increases. Regulation of excess air as gauged by CO_2 analysis can result in increased CO_2 in the stack gases and in reduction of stack temperatures without producing a

Table 6. Causes of Low Carbon Dioxide Content in Flue Gases

1	Too much air from blower
2	Air leaks in furnace chamber need sealing
3	Draft set too high
4	Poor design of heat exchanger surfaces
5	Wrong flame shape (Associated with oil and gas)
6	Unit fired too lightly (Associated with coal)
7	Nozzle or orifice plugged or worn (Oil and gas)
8	Air handling parts need servicing and cleaning
9	Coarse atomization (Oil only)
10	Obsolete and inefficient equipment

Table 7. Causes of High Stack Temperatures

1	Fire oversize for load
2	Heat exchanger surfaces are dirty
3	Additional baffles or heat exchanger surface needed in furnace or boiler
4	Undersize unit
5	Improper fuel for unit
6	Poor combustion chamber
7	Burner needs expert servicing
8	Dirty and plugged air filters
9	Obsolete and inefficient equipment

smoky flame. Some of the associated reasons for low carbon dioxide (CO_2) content and high stack temperatures are shown in Tables 6 and 7.

Tests were run on some of the units measuring the stack temperature, carbon dioxide (CO_2) content, and smoke tests with a Dwyer Portable Combustion test set. This set consists of a simplified Orsat type apparatus which used the absorbing fluid also as the indicating fluid so that one vessel takes the place of both measuring burette and absorption pipette. The flue gas sample is drawn into the Orsat apparatus by twenty strokes of the aspirator bulb. The instrument is then inverted, righted to permit fluid drainage, and the per cent of sample absorbed is read from the scale on the right hand side of the instrument. Absorption of the fluid in the left leg causes a decrease in pressure in that leg which results in lowering of the liquid level in the right hand leg by an equalization in pressures. Also in the test set is a bimetal, dial face, thermometer for direct insertion into the stack for flue gas temperatures. For the smoke test there is an aspirator bulb and hose with a special holder for a small sample of filter paper. The flue gas sample is drawn through the filter paper by twenty strokes of the aspirator bulb and the resulting change in color of the filter paper compared with a color chart. The draft setting is checked by a small inclinded tube manometer which has magnetic blocks attached for direct mounting on the furnace units.

DESCRIPTION OF HOMES UNDER TEST

Using number 2 fuel oil

1 Louis J. Skubic residence at 1428 First Street. This home is a story and one-half house with an attached, unheated, garage. The house was built in 1955 and is completely insulated. Constructed with a full basement, this house contains 15,820 cubic feet. During the test period, November 1, 1956 to April 1, 1957, this home required 820 gallons of fuel oil at a total cost of $116.44.

2 R. P. Puncochar residence at 1211 First Street. This home is also a story and one-half house but without the attached garage. The house was built in 1950 and is completely insulated with balsam wool blankets. It has a full basement and contains 17,105 cubic feet. During the test period, July 1, 1956 to April 1, 1957, this home used 948 gallons of fuel oil at a cost of $133.40.

3 Robert Stewart residence at 413 Medary Avenue. This home is single story and with a full heated basement. The house was constructed in 1956 and contains one inch of rock wool in the sidewalls and four inches of loose fill rock wool in the ceiling. It contains 18,820 cubic feet of space. During the test period, November 1, 1956 to April 1, 1957, this home required 1005 gallons of fuel oil at a total cost of $150.70.

4 J. P. Dodds residence at 1319 Second Street. This home is a single-story house with a partially heated basement. The house was built new in 1956 and contains one inch of rock wool in the sidewalls and four inches of loose fill rock wool in the ceilings. It contains a total of 18,855 cubic feet. During the test period, November 1, 1956 to April 1, 1957, this home required a total of 850 gallons of fuel oil at a total expenditure of $127.50

5 W. E. Watson residence at 902 Second Street. This is an older, single-story home originally built during the '20's and completely remodeled in 1955. The amount and location of the insulation is unknown, but it is assumed to be at least well insulated in the newly remodeled area. During the test period, November 1, 1956 to April 1, 1957, this home required a total of 872 gallons of fuel oil at a cost of $123.82. The volume of the house is 14,680 cubic feet.

Using number 1 fuel oil (Vaporizing burners)

6 James Dornbush residence at 1203 First Street. This is a single-story home without a basement on a concrete slab floor. Since this was the only house under the test without a basement, the figures of fuel consumption leave nothing for comparison. This house also has a pot or vaporizing type of oil burner which must use number 1 fuel oil. The house has a volume of 5760 cubic feet. During

the test period, November 1, 1956 to April 1, 1957, this home required a total of 600 gallons of fuel oil at a total cost of $92.91.

Using liquified petroleum gas (Propane)

7 Francis Dolan residence at 103 Fourteenth Avenue South. This is a newly built split-level home. It contains a garage, located beneath the bedroom area, which is heated to about 50° F., the year around. The house is well insulated and faces west. Hot water is also heated by gas but is not separately metered. However, this was taken into account when comparisons were made. During the period, August 28, 1956 to April 1, 1957, this home required a total of 1292 gallons of propane at a total cost of $167.44.

8 John F. Younger residence at 1332 Second Street. This home was new in 1956 and is a single-story, full basemented house, facing north. A double attached garage is on the east. The basement is heated to a comfort temperature for student rooms. The house is insulated with four inches of loose-fill rock wool in the ceiling and one inch of the same material in the sidewalls. Water heating and cooking are also done with gas which is not separately metered. The volume of the house, exclusive of the garage, is 21,720 cubic feet. During the test period, July 12, 1956 to March 28, 1957, this home required, for heating only, a

total of 1292 gallons of propane at a cost of $167.96. On March 28, 1957, this residence was changed from propane to natural gas.

Using natural gas

9 Maoling Liu residence at 1326 Second Street. This is a concrete block home with furred and insulated walls built in 1955. It faces north and has an attached garage. The basement is used also as a living area so it is heated in its entirety. The garage is not counted in the total volume. Water heating and cooking also use gas which is not separately metered. The volume of the house is 17,500 cubic feet. During the test period, December 29, 1956 to April 1, 1957, this home required a total of 76,200 cubic feet of gas (762 therms) at a total cost of $80.52.

Using stoker-fired coal

10 J. E. Harvey residence at 1224 Fourth Street. This home is an older, single-story house probably built between 1910 and 1920. The furnace was originally hand-fired but has been converted to a stoker-fired unit with a hot air blower. The volume of the house is 15,440 cubic feet. During the test period, September 9, 1956 to April 1, 1957, this home required a total of 12,980 pounds of Odin stoker coal at a cost of $140.64.

11 Charles Gilbert residence at 725 Second Street. This older home faces south and has one heated room on the second floor. It utilizes a Link-Belt stoker in an originally hand-fired furnace manufactured by Round Oak. There is a thermostatically-controlled blower on the plenum of the furnace. The volume of the house is 22,290 cubic feet. During the test period, September 25, 1956 to April 1, 1957, the home required 11,000 pounds of Olga stoker coal, delivered price $22.00 per ton, for a total cost of $120.15.

12 Gabriel Lundy residence at 1203 Eighth Street. This two-story, very high house was built about 1920. It uses a stoker-fired Kohler boiler burning Olga stoker coal at a delivered price of $21.60 per ton. Only the north wall of the kitchen and the attic are insulated in this house. The volume of this house, the largest under the test, is 26,200 cubic feet. During the test period, July 1, 1956 to April 1, 1957, the fuel requirements of this house were 17,400 pounds of coal at a cost of $188.58.

13 George McKnight residence at 721 Twelfth Avenue. This is also a stoker-fired boiler installation. Both the stoker and boiler were built by the American Radiator Company. The house is single-story, probably built during the 1920's. It contains a total of 15,580 cubic feet of space. During the test period, July 1, 1956 to April 1, 1957, this home

used a total of 12,270 pounds of Olga stoker coal at a cost of $133.10.

Using hand-fired coal installations

14 Alfred Sween residence at 609 First Avenue. This is an older home which has been remodeled quite extensively several times. During the remodeling, parts of this home have been insulated. The volume of this home is 18,250 cubic feet. During the test period, September 26, 1956 to April 1, 1957, this home required a total of 11,075 pounds of Pocohontas Lump coal at a cost of $122.20.

15 Charles Raker residence at 316 Ninth Avenue. This house had one of the highest heat losses for its size in the test. The house is a story and one-half with a very inefficient central heating system. The house is not insulated. The volume of the house is 14,260 cubic feet. During the test period, October 18, 1956 to April 1, 1957, this house required a total of 11,430 pounds of Pocohontas Lump coal at a cost of $137.80. During the test period, the occupants also maintained that they had had difficulty in being comfortable in the house.

16 Harlan Olson residence at 812 Fourteenth Avenue. Possibly a combination of poor insulation and ill-fitting windows and doors are increasing the coal requirements for this small 11,910 cubic feet house. The house is single-story

with a shallow basement. A thermostatically-controlled blower is attached to the plenum of the furnace. During the test period, October 5, 1956 to April 1, 1957, the house required a total of 9,650 pounds of Blue Flame lump coal at a cost of $114.29. The delivered price of this coal was $23.70 per ton.

17 Charles A. Taylor residence at 909 Third Street. The furnace in this 1920 vintage house was in a very bad state of repair. There were a considerable number of air leaks in the furnace casing and the flue was badly rusted in a number of places. The house is two stories with no insulation and ill-fitting doors and windows. The volume of the house is 15,400 cubic feet. The owners had a very complete record of fuel costs over the past four heating seasons and they substantiated the findings which we determined during the present heating season as to the number of degree-days per ton or pound of coal. During the test period, October 19, 1956 to March 1, 1957, this house required a total of 12,820 pounds of petroleum coke. At a delivered price of $24.80 per ton, this made a total cost of $158.70.

PROCEDURES USED IN RUNNING TESTS

The Degree-Day

As early as 1925 it became evident that some unit based on outdoor temperature should be devised to permit measuring or estimating, with a reasonable degree of accuracy, yearly fuel requirements for heating plants. The American Gas Association and others, undertook to do this.

Their research disclosed that heat is not actually required in a home as long as the outdoor daily mean temperature[1] is 65 degrees Fahrenheit or above, but that when the daily mean temperature is below 65° F., heat is required in an amount proportional to the difference between 65 and the daily mean temperature. The fact that 65° F. was selected as the base temperature, in spite of the fact that this temperature is a comfortable indoor temperature to only a few people, is accounted for by a number of reasons. The indoor temperature will ordinarily be a few degrees higher than the outdoor, because retention of heat within buildings by their walls, roofs, and floors, causes a lag in the drop of indoor temperature upon a drop in outdoor temperature. The sun adds heat to the interior of buildings by radiation but does not correspondingly affect the outdoor temperature.

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1 The daily mean temperature as published in the reports of the U. S. Weather Bureau is one-half the sum of the highest and lowest temperatures occurring during the twenty-four hour period beginning and ending at midnight.

Having established 65° F. as the division point between the outside temperature at which homes require heat and those at which they do not, the researchers decided to make this temperature the base of a scale for measuring fuel requirements, and to make the units of measurement the degrees of temperature difference between the base and the daily mean temperature. Since each of these units represents the product of one DEGREE of temperature and one DAY, it was decided to give the unit the name "DEGREE-DAY".

The headquarters office of the U. S. Weather Bureau at Washington, D. C. publishes a tabulation of the average monthly and seasonal DEGREE-DAYS for over 200 cities and towns throughout the United States. Three cities in South Dakota are represented on this tabulation. They are Huron, Pierre, and Rapid City. Their average monthly and seasonal records are shown with one which has been tabulated by the author.

From the records which the volunteer weather observers in Brookings have kept over the past years, the author tabulated the average daily temperature and the number of DEGREE-DAYS for each month and for the past several seasons. These calculations are shown in tabular form in Table 8.

The fuel consumption characteristics of homes follow a fairly regular pattern that changes with little else than changes in outside temperature. With this fact in mind, we may take the fuel consumption over a fairly representative period of the year, and by combining the known fuel consumption

Table 8. Average Monthly and Seasonal Degree-Days (Base 65° F.)

City No. of Seasons	July	August	September	October	November	December	January	February	March	April	May	June	Seasonal Total
Brookings 5	9	12	177	451	954	1383	1636	1295	1139	608	231	64	7959
Brookings 1956-57	13	24	191	303	1011	1274	1775	1266	1072				
Huron 48	10	20	159	502	962	1409	1572	1353	1039	573	271	70	7940
Pierre 47	4	11	136	438	887	1317	1460	1253	971	516	238	52	7283
Rapid City 48	15	28	192	495	842	1178	1280	1140	981	598	339	109	7197

with number of DEGREE-DAYS in that period and the average number of DEGREE-DAYS remaining in that year, and estimate very closely the fuel consumption for the entire year. This function can best be explained by an example.

During the test period, November 1, 1956 to April 1, 1957, Brookings accumulated 6,398 DEGREE-DAYS. During this same period, the Skubic home used 820 gallons of fuel oil. The so-called "K" factor would be 7.8 (6,398 ÷ 820) DEGREE-DAYS per gallon of oil. Thus, this residence used one gallon of fuel oil for each 7.8 DEGREE-DAYS that accumulated during the heating season. If we then take the average number of DEGREE-DAYS' accumulation during the months not included in the test, we find that we have an additional 1552 DEGREE-DAYS. (See Table 8 for this information.) Dividing the additional 1552 DEGREE-DAYS by the "K" factor, 7.8, will give us an additional 200 gallons of fuel oil which would be used during the year, or a grand total of 820 + 200 = 1020 gallons of fuel. At an average cost of 14.2¢ per gallon, this will then give us a total yearly heating bill of $144.84.

This same type of calculation may also be applied to any of the other fuels under the test. The "K" factor for coal would be DEGREE-DAYS per pound, and for gas either DEGREE-DAYS per therm or DEGREE-DAYS per gallon.

In order that all of the houses under the test might be evaluated even closer, it was decided to adjust the volume of each house so that it was calculated on a basis of 15,000 cubic feet. This method, applied to a majority of the houses in the 12,000 to 19,000 cubic feet bracket, would not include any appreciable error. However, there is one slab house of 5,760 cubic feet and three larger ones in the 21,000 to 26,000 cubic foot range where serious errors will be incurred. It tends to raise the yearly heating bill of the smaller home way out of proportion and to decrease the seasonal heating bill of larger homes slightly. The actual values and the adjusted values are shown in Table 9.

The procedures followed varied slightly with the different fuels, but basically it was done in the following manner: On November 1, 1956 each of the residences was visited and the quantity of fuel in the tank, or volume of coal in the bin was noted. In most instances, where coal was used, the owner had filled the bin earlier in the season. The quantity in the bin and the total amount put into the bin were then noted and the test was run from the date of the bin filling. A sample of coal was also taken so that calorimeter tests of the heating value could also be obtained. Several of the owners had records of fuel bills for past years and the quantity of fuel required, and the dollar value noted.

During the five month period when the test was being run, efficiency tests were taken on some of the units. This was not done to see if the furnaces or boilers could be adjusted to operate more efficiently, but to correlate the information which is shown in Table 2. The number 2 fuel oil

Table 9. Annual Heating Costs of Homes

Fuel	Residence	Actual Volume Cubic Feet	Actual Yearly Cost	Adjusted Yearly Cost *
No. 1 Oil	Dornbush	5,760	$115.50	$300.00
No. 2 Oil	Skubic	15,820	144.90	137.00
	Puncochar	17,105	153.20	134.20
	Stewart	18,820	187.00	149.10
	Dodds	18,555	158.30	128.00
	Watson	14,680	153.70	157.00
Propane	Dolan	14,550	193.00	199.00
	Younger	21,720	192.70	133.00
Natural Gas	Liu	17,500	167.40	143.30
Stoker Bituminous Coal	Gilbert	22,290	142.00	95.60
	Harvey	15,440	163.00	158.30
	Lundy	26,200	216.20	123.90
	McKnight	15,580	153.00	147.30
Hand-Fired Bituminous Coal	Sween	18,250	144.30	118.80
	Raker	14,260	181.00	190.20
	Olson	11,910	136.30	171.50
	Taylor	15,400	230.00	224.00

* The adjusted yearly cost is based on a 15,000 cubic foot home over an average yearly period of 7,959 Degree-Days.

installations had efficiencies in the vicinity of 72-75 per cent as did both the liquified petroleum gas and natural gas installations. The efficiencies of both hand and stoker-fired units are very hard to determine accurately with portable equipment because of the wide variance in CO_2 content and stack temperature. When the draft is closed the stack temperature drops as does the CO_2 content, and when the draft is opened they both rise again. The only way to obtain a true picture of these units would be with recording devices. The tests did show that hand-fired installations were operating in the 50 to 60 per cent range and that stoker-fired units were not too much higher.

The heating value of the coal samples was determined by means of the Parr Peroxide Bomb calorimeter. This was necessary because the heating value of coal varies so widely from mine to mine and seam to seam. Brand names on coals do not have much bearing on the heating value of a particular fuel. The results are shown in Table 1 with a sample calculation sheet for the Olga stoker coal being shown in Table 10.

The heating value of number 2 fuel oil is commonly accepted to be 140,000 btu per gallon and that of number 1 fuel oil to be only slightly lower. The main difference between number 1 and number 2 fuel oil is that number 1 has a pour point of 0° F., while that of number 2 is about 20° F. Number 1 fuel is also slightly more volatile.

Table 10. Heating Value of Coal by the Peroxide Bomb Calorimeter

Test of Gilbert Coal
Sample No. Olga Stoker
Analysis of Sample:
Ash. 5%
Sulfur . . . .
Moisture, air dry
Moisture as rec'd. 3%

Bomb Weight. . .

Sample Weight. . .5000 gr.

Accel. Wgt.. . .1.0000 gr.
2000 ml. water

Calorimeter Readings:

Min:	Sec:	Temp:
0	0	72.91 fired
0	30	74.90
1	0	76.25
1	30	77.00
2	0	77.35
2	30	77.62
3	0	77.75
3	30	77.85
4	0	77.92
4	30	77.94
5	0	77.96
6	0	77.97 peak
8	0	77.97
10	0	77.97
13	0	77.96

Heat of Combustion:

"Air-Dry" Basis
4.772 x 3092 = 14755 btu/#

"As-Rec'd" Basis
14,755(1- .03) = 14,312 btu/#

Test No. 3
Date 2-1-57
Observer . . . . . . Puncochar
Calorimeter No . . 4192
Bomb No. 960
Thermometer No . . 140978
Water Equivalent . 3092
Av.Room Temp . . 76.1° F.

Final Temperature. 77.970°F.

Scale Correction . -.020

True Final Temp. . 77.950

Heat Loss Rate after Final Temp

$$\frac{.01 \times 5}{7} = -.007$$

Radiation Correction

Final Temp. Corr. for Radiation . 77.957

Combustion Corr.:

Fuse Wire .005°F

Ash(.005)x(5).025

S.(.01)x(1) .010

Accelerator .200

Hydration .070 -.310

Corrected Final Temperature . . 77.647

Initial Temp 72.910

Scale Corr. -.035

True Initial Temperature72.875

Net Corrected Temperature Rise 4.772

Liquified petroleum gas, commercial propane (C_3H_8), has a heating value of 91,500 btu per gallon which weighs 4.24 pounds. This then is also a heating value of 21,560 btu per pound. The quantity is determined by the percentage of gas remaining within the storage tank.

Natural gas is measured by the cubic foot but is sold by the therm which is 100,000 btu. The assumption made by the gas company is that the gas contains 1000 btu per cubic foot. In effect you are actually buying the gas in 100 cubic foot quantities. Its actual heating value will vary from a low of perhaps 964 btu per cubic foot to a high of 1272 btu per cubic foot.

Natural gas is perhaps the closest approach to an ideal fuel because it is practically free from non-combustible gas or solid residue. It is found compressed in porous rock or shale formations, or cavities, which are sealed between strata of close textured rocks under the earth's surface. Natural gas consists mainly of methane (CH_4), with smaller amounts of other hydrocarbons, particularly ethane (C_2H_6), although carbon dioxide (CO_2) and nitrogen (N_2) are usually present in small amounts, and sometimes there are also appreciable amounts of hydrogen sulphide (H_2S).

On April 1, 1957 the amounts of fuel remaining in the tanks were determined and the amount of coal remaining in the bins in the case of hand-fired and stoker-fired coal installations. Also, the owners were quiered as to whether or not any additional fuel had been purchased during the test period, and if so, this was then added to the total amount.

During the five month test period, November 1, 1956 to April 1, 1957, a total of 6,398 DEGREE-DAYS were accumulated. This represents over 80 per cent of the average yearly accumulation of 7,950 DEGREE-DAYS. This, I then feel, is a very representative sample of the heating season.

DISCUSSION AND CONCLUSIONS

For an investigation of this type, there cannot be too definite a conclusion drawn. Each residence and fuel presents a problem all its own. Whether or not one fuel or another is better for heating the home is determined by a long list of circumstances and conditions.

From our investigation we can show that one of the most economical fuels to use is coal, but yet equipment to burn this type of fuel is not being installed in the homes being built at the present time. Why is this so? Some of the many reasons which home owners will advance are the following:

1 The fuel is dirty and burns dirty.

2 There is the chore of hauling ashes and clinkers.

3 Holding the fire in mild weather is difficult.

4 The initial expense of the equipment is high.

5 The fuel is bulky and requires a large storage space.

It does not take too much of a salesman to convert a prospective coal-burning home owner to oil or gas. The home owner is quick to realize that perhaps it will cost him a few dollars more per year, but he is also rid of a great deal of inconvenience.

In Brookings last fall and at the present time, the question of whether or not to convert from oil to natural gas was the question of the day. Table 11 shows the cost comparison between number 2 fuel oil, natural gas, and liquified

Table No. 11. Heating Cost Comparison - No. 2 Fuel Oil, Natural Gas, Propane

Gallons No. 2 Fuel Oil	Cost of Oil @ .142/Gal.	Oil No. BTU's x 10^5 75% Eff.	No. Therms Natural Gas 75% Eff.	Cost Natural Gas Brookings	Cost Natural Gas Minneapolis	Cost Propane @ .13/Gal.
10	$ 1.42	10.5	14	$ 3.30	$ 2.57	$ 1.99
20	2.84	21.0	28	6.10	3.80	3.98
30	4.26	31.5	42	7.70	5.03	5.97
40	5.68	42.0	56	9.10	6.26	7.96
50	7.10	52.5	70	10.50	7.49	9.95
60	8.52	63.0	84	11.90	8.72	11.94
70	9.94	73.5	98	13.30	9.96	13.93
80	11.36	84.0	112	14.70	11.19	15.92
90	12.78	94.5	126	16.10	12.42	17.90
100	14.20	105.0	140	17.50	13.65	19.88
110	15.62	115.5	154	18.90	14.88	21.87
120	17.04	126.0	168	20.30	16.12	23.86
130	18.46	136.5	182	21.70	17.35	25.85
140	19.88	147.0	196	23.10	18.58	27.84
150	21.30	157.5	210	24.50	19.81	29.83
160	22.72	168.0	224	25.90	21.04	31.81
170	24.14	178.5	238	27.30	22.27	33.80
180	25.56	189.0	252	28.70	23.51	35.79
190	26.98	199.5	266	30.10	24.74	37.78
200	28.40	210.0	280	31.50	25.97	39.77
210	29.82	220.5	294	32.90	27.20	41.76
220	31.24	231.0	308	34.30	28.43	43.75
230	32.66	241.5	322	35.70	29.66	45.74
240	34.08	252.0	336	37.10	30.90	47.72
250	35.50	262.5	350	38.50	32.13	49.71
260	36.92	273.0	364	39.90	33.36	51.70
270	38.34	283.5	378	41.30	34.59	53.69
280	39.76	294.0	392	42.70	35.83	55.68
290	41.18	304.5	406	44.10	37.06	57.67
300	42.60	315.0	420	45.50	38.30	59.66

petroleum gas (propane). This table uses efficiencies which are given in Table 2. The Minneapolis gas rate was also shown on this Table because so often one hears the story, "My brother heats his home, cooks with gas, and heats water, all for $15 per month in the coldest weather in Minneapolis." There are other factors which enter in in other localities, such as the number of Degree-Days, but this shows some comparison with local rates.

The Table very definitely shows that as far as economics are concerned, it would be unwise to switch from oil to gas if only heating of the home is desired. In most cases water heating will also be required, and in some cases, cooking. I have shown, on page 8, that with heating the home and water only, one may justify the changeover to natural gas. The cost of installation of a natural gas furnace and water heater in a new home will be about $150 less than the same size atomizing oil burner. For this reason I can easily recommend the natural gas installation in new homes. In older homes a little more thought must be given to some of the factors mentioned above. Another advantage in favor of natural gas is that it requires no storage space within the home. In these times when home construction costs are in the vicinity of $13 per square foot, this means an appreciable additional saving.

As far as the relative safety of the fuel is concerned, it is a matter of so-called "owner-error". In the airlines industry this would be called "pilot-error". All of the equipment which is being installed today should, and usually does, bear the Underwriters Seal of Approval. The oil burning installations are equipped with automatic devices which shut the pump off in case of a flame failure or failure to ignite within 90 seconds. This prevents an accumulation of oil in the pot which could explode, if on the next cycle, it ignited. They are also equipped with plenum switches which will shut off the burner in case of over-heating of the plenum.

The liquified petroleum gas installations are equipped with 100 per cent shut off of the gas in case of a pilot light failure. This is necessary because propane is heavier than air and would gather in the basement rather than dissipating in the atmosphere. They also contain the plenum overheating switch like the oil burners.

Most natural gas installations are equipped like the propane. However, the possibility of explosion is somewhat reduced with natural gas because it is lighter than air and would be drawn up the flue by natural convection currents.

The question of fuel choice is one that must be answered ultimately by the individual home owner. We can only make recommendations as to the most economical fuel and show some of the other factors which should help in the decision.

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