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Investigation of the Performance of Automatic Storage-type Gas and Electric Domestic Water Heaters

by

Eugene F. Hebrank

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A REPORT OF AN INVESTIGATION

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Investigation of the Performance of Automatic Storage-type Gas and Electric Domestic Water Heaters

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PROFESSOR OF MECHANICAL ENGINEERING

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ABSTRACT

In the fall of 1951, the Committee on Comparison of Competitive Services of the American Gas Association entered into an agreement for cooperative research with the Engineering Experiment Station at the University of Illinois to investigate the performance characteristics of automatic storage-type gas and electric domestic water heaters.

The performance tests included in this program were conducted on commercial models of commonly used comparable and representative water heaters. Six gas heaters representing both external and internal flue types and having nominal tank capacities ranging from 20 gal to 50 gal were studied. The gross heat input rates ranged from 20,000 to 42,900 Btu per hr. The seven electric heaters ranged in size from 30 gal to 80 gal nominal tank capacity, their input rates ranged from 1600 watts to 5000 watts; both immersion-type and attached-type heating elements were represented. In general, the test installations were established in accordance with American Standards Association standards for gas and electric water heaters. Usable hot water was defined as water at temperature of 120 F or higher.

From the results of this investigation the following general conclusions may be drawn:

The one-hour delivery studies showed an average recovery efficiency, i.e. ratio of heat utilized in heating water to heat input, for the gas water heaters to be 76 percent compared with 93 percent for the electric water heaters. The one-hour delivery for a 90 F temperature rise varied widely due to the wide variation in tank capacities and gross heat input rates. However, on a comparable figure, namely gallons delivered per gallon of actual tank capacity, the gas heaters showed a value of 1.88 as compared to 0.94 for the electric, or twice as great an output for the gas heaters. The required heat input per gallon of hot water delivered was found to be 1000 Btu for the gas and 800 Btu for the electric.

The two-hour delivery studies showed the same recovery efficiencies at the one-hour studies, whereas the delivery per hour per gallon of actual tank capacity was found to show 1.50 to 0.62, or about $2\frac{1}{2}$ times as much output from the gas as from the electric water heaters. The required heat input was the same as that found in the one-hour tests.

With regard to the daily usage tests the results are best shown by the accompanying figures:

Table A shows the daily withdrawal schedule that was used. This schedule is taken from the A.S.A. Standards Bulletin C72.1-1949 "Household Automatic Electric Storage-Type Water Heaters" and is presumed to be representative of the daily hot water draw-offs of an average family from 6:30 a.m. until 10:30 p.m. It shows the time and quantity of each withdrawal, with the quantity expressed as a percentage of the total withdrawal.

Table A. Daily Withdrawal Schedule

Rate: 5 gpm

Time of Day	Withdrawal % of total
6:30 a.m.	11
7:30	5
8:00	17
9:00	14
10:00	13
11:00	4
12:00 noon	4
1:00 p.m.	7
5:00	3
6:00	4
7:30	5
10:30	13
	100%

These percentages were applied to the basic daily hot water usage rates to simulate the daily usage habits of the average householder.

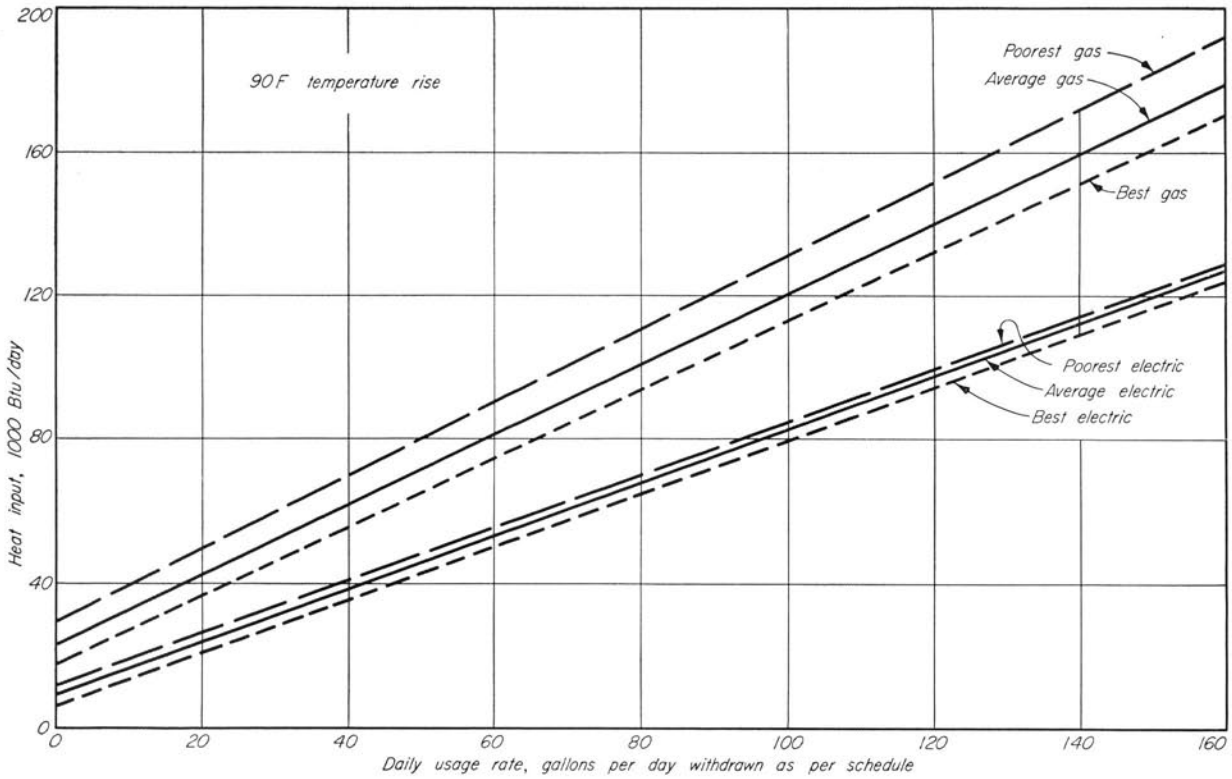

Fig. A. Required Heat Input During 24-Hour Period for Water Heating at Various Daily Usage Rates

Figure A shows the required heat input during a 24-hr period for variable daily usages of water heated through a 90 F temperature rise and withdrawn in a 24-hr day as specified in the predetermined draw-off schedule. The figure shows average values for the gas and electric water heaters over a range of 50 to 150 gal used daily. This range is shown because most of the heaters performed satisfactorily over this range. The figure also shows curves of heat input for the most efficient and least efficient heaters of each type.

Figure B shows the same series of curves for

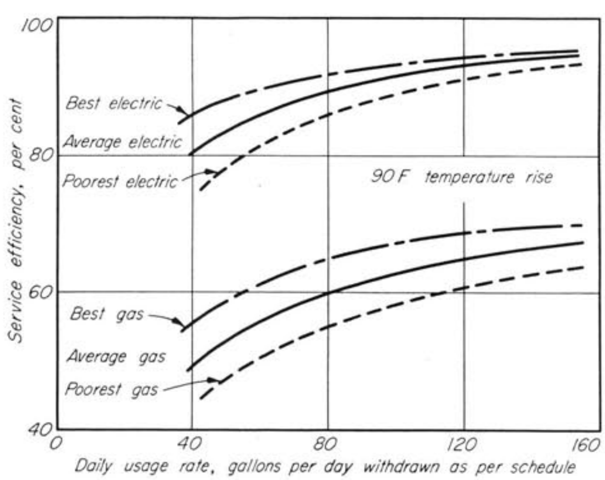

Fig. B. Service Efficiencies

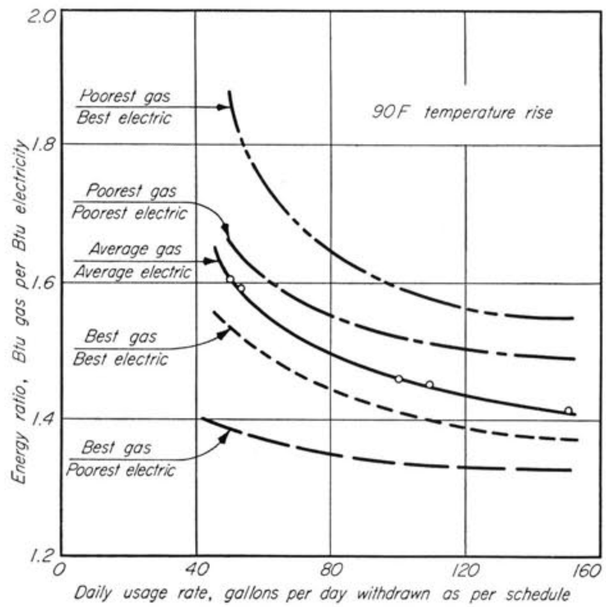

Fig. C. Gas vs. Electric Energy Ratios

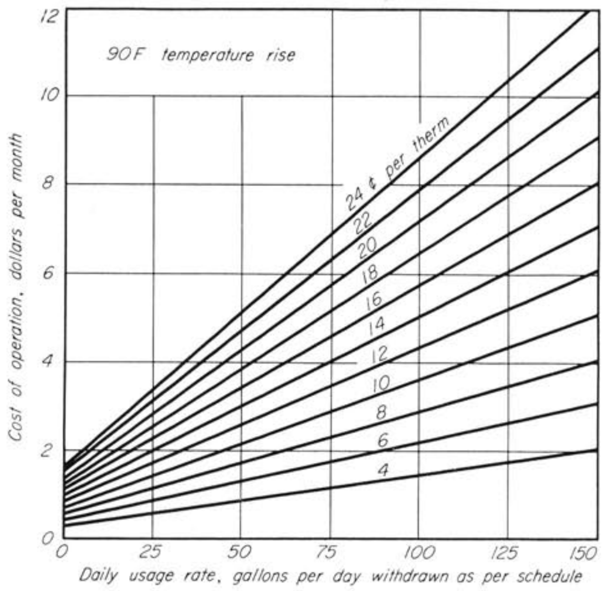

Fig. D. Monthly Cost of Operation of Gas Water Heaters

service efficiency against daily usage rates. The service efficiency may be defined as the ratio of the heat utilized in the hot water delivered compared to the heat input per day to heat this delivered water, as well as the heat required to maintain the tank full of hot water.

In Figure C the energy ratio, i.e. the ratio of required Btu per 24-hr day heat input of the gas water heaters to the required Btu per 24-hr day heat input of the electric water heaters, is plotted against daily usage rates. The center curve is the average of all the gas water heaters compared with the average of all electric water heaters. The upper curve is a comparison of the poorest gas heater to the best electric; the lower curve shows the best gas heater compared with the poorest electric.

Also shown are curves representing the energy ratio for the comparison of poorest gas to poorest electric and best gas to best electric water heaters. It can be seen that the average ranges from about 1.60:1 at 50 gal per day to about 1.41:1 at 150 gal per day.

Figures D and E show average monthly operating costs for gas fired and electric water heaters respectively. These figures are shown with different gas rates from 4¢ to 24¢ per therm and electric rates of ¾¢ to 2.5¢ per kilowatt-hour, and both are shown for daily usages up to 150 gal per day. It can be seen that a gas rate of 20¢ per therm is approximately equivalent to an electric rate of

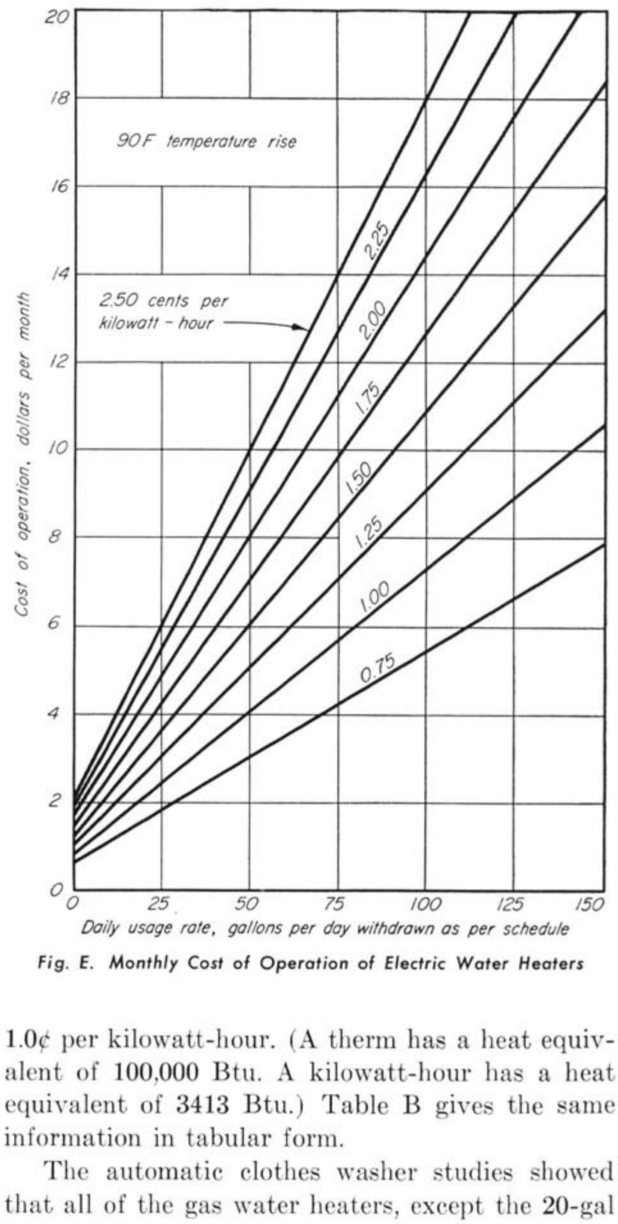

Fig. E. Monthly Cost of Operation of Electric Water Heaters

1.0¢ per kilowatt-hour. (A therm has a heat equivalent of 100,000 Btu. A kilowatt-hour has a heat equivalent of 3413 Btu.) Table B gives the same information in tabular form.

The automatic clothes washer studies showed that all of the gas water heaters, except the 20-gal heater, satisfactorily supplied hot water for four consecutive washer cycles; whereas only the 80-gal electric heater satisfactorily supplied hot water. Electric heater L having a 66-gal capacity and 4.5 kilowatt input fulfilled the requirements, but the water temperature in the fourth cycle averaged 125.3 F. The required input per cycle for the gas water heaters was approximately 22,500 Btu as compared with a requirement of approximately 15,900 Btu for the electric water heaters, or an energy ratio of about 1.41:1.

The stand-by studies showed that the daily required input for the gas water heaters was, on the average, approximately 23,000 Btu per day. This ranged from a low of 17,900 to a high of 27,600 Btu per day. The average for all of the electric heaters was approximately 9100 Btu per day with a range from 6690 to 12,600 Btu per day. From the average it can be seen that approximately 2½ times more heat is required by the gas water heaters than the electric heaters to maintain a tank full of hot water.

Table B. Cost of Operation

Gas Water Heaters
(Dollars per Month)

Gas Rate per Therm	4	6	8	10	12	14	16	18	20	22	24
0 Gal Hot Water/Day 6.90 Therms/Month	0.27	0.41	0.55	0.69	0.83	0.97	1.10	1.24	1.38	1.52	1.66
50 Gal Hot Water/Day 21.45 Therms/Month	0.86	1.29	1.72	2.15	2.57	3.00	3.43	3.86	4.29	4.72	5.15
100 Gal Hot Water/Day 36.24 Therms/Month	1.45	2.17	2.90	3.62	4.35	5.07	5.80	6.52	7.25	7.97	8.70
150 Gal Hot Water/Day 50.55 Therms/Month	2.02	3.03	4.04	5.06	6.07	7.08	8.09	9.10	10.11	11.12	12.13

Note: Monthly costs are based on average performance of all heaters tested.

Electric Water Heaters
(Dollars per Month)

Electric Rate per Kilowatt-Hour	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50
0 Gal Hot Water/Day 80.3 kwh/Month	0.60	0.80	1.00	1.21	1.41	1.61	1.81	2.01
50 Gal Hot Water/Day 393 kwh/Month	2.95	3.93	4.91	5.90	6.88	7.86	8.84	9.83
100 Gal Hot Water/Day 728 kwh/Month	5.46	7.28	9.10	10.92	12.74	14.56	16.38	18.20
150 Gal Hot Water/Day 1050 kwh/Month	7.88	10.50	13.13	15.75	18.38	21.01	23.63	26.26

Note: Monthly costs are based on average performance of all heaters tested.

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I. INTRODUCTION

1. Preliminary Statement

In recent years large new demands have been imposed on domestic (residential) water heaters due to the greatly increased usage of household appliances which use considerable quantities of hot water, i.e. automatic clothes washers and dishwashers, to mention but two. In many instances the water must be at a higher temperature than was formerly considered satisfactory. These demands have introduced many problems involving quantities, temperatures, recovery rates, corrosion, and scaling, to mention a few.

The average householder has little knowledge of the actual requirements he will impose on his hot water heater. Even members of the water heater industry, manufacturers, dealers, and some government agencies need adequate and reliable performance information and acceptable procedures for selecting the proper sizes and capacities of domestic water heaters. All are cognizant of the fact that nominal storage tank size alone is not an adequate specification for capacity.

2. Objective and Scope of Investigation

The objective of the investigation was to obtain engineering performance data on commonly used, comparable and representative, automatic, storage-type, gas and electric domestic water heaters.

The scope of the investigation was to determine this performance under, as nearly as possible, actual operating conditions for both normal usage of the heaters and for predetermined specific uses.

3. Acknowledgments

This bulletin is a report of an investigation conducted in the Mechanical Engineering Laboratory under the terms of a cooperative research agreement between the American Gas Association and the University of Illinois. The Committee on Comparison of Competitive Services which represented the American Gas Association during the period of this investigation included the following men:

J. R. Gardner, Central Hudson Gas and Electric Corp., Poughkeepsie, N. Y. (Chairman)

G. C. Beck, The Brooklyn Union Gas Company, Brooklyn 2, N. Y.

J. W. Carpenter, Long Island Lighting Company, Mineola, N. Y.

H. H. Christ, Union Gas and Electric Company, Bloomington, Ill.

Guy Corfield, Southern California Gas Company, Los Angeles, Calif.

J. R. Delaney, The Cincinnati Gas and Electric Co., Cincinnati, Ohio

H. W. Gee, Volunteer Natural Gas Company, Johnson City, Tenn.

R. E. Ginna, Rochester Gas and Electric Corporation, Rochester, N. Y.

C. C. Hanthorn, The Philadelphia Gas Works Division of United Gas Improvement, Philadelphia 5, Pa.

L. M. Holmes, The Dayton Power and Light Company, Dayton, Ohio

W. B. Kirk, American Gas Association Laboratories, Cleveland 3, Ohio

L. R. Leslie, Delaware Power and Light Company, Wilmington, Delaware

W. H. Loving, Washington Gas Light Company, Washington, D. C.

E. J. Nelson, Rochester Gas and Electric Corporation, Rochester, N. Y.

I. J. Rapson, Michigan Consolidated Gas Company, Detroit, Mich.

Henry Rohrs, Elizabethtown Consolidated Gas Company, Elizabeth, N. J.

W. D. Williams, New Jersey Natural Gas Company, Asbury Park, N. J.

C. G. Segeler, American Gas Association, New York, N. Y. (Secretary)

The investigation, a part of the work of the Engineering Experiment Station and a project of the Department of Mechanical Engineering, was conducted under the general administrative direction of W. L. Everitt, Dean of the College of Engineering and Director of the Engineering Experiment Station, and of Professor N. A. Parker, Head of the Department of Mechanical Engineering.

Acknowledgment is made to Professors M. K. Fahnestock and E. L. Broghamer for assistance in planning the project and analyzing the results, and to Mr. E. O. Schneider for setting up the test laboratory and collecting much of the data.

II. LABORATORY AND EQUIPMENT

4. Laboratory

The heaters were located in a 9′9″ x 12′7″ x 7′6″ high room, as shown in Fig. 1, during all studies. This room was equipped with individual Type B vents 4 in. in diameter and 15 ft in vertical height for use in operating each gas water heater. The horizontal distance from the center of each heater to the center of the vertical vent was maintained at 4½ ft maximum. The slope of the horizontal run of each vent connection was maintained at 1 in. per ft. Adequate openings were supplied in the north wall of the room for the admission of combustion air and to insure free venting.

The ambient air temperature in the room was maintained automatically at 75 F ± 2 F by means of an air conditioner located outside of the room. The conditioned air was introduced and removed in such a manner that the air movement was minimal. A record of the air temperature in the center of the room 30 in. above the floor, as well as the inside surface temperature of the four walls, was made during all tests. Humidity observations were also recorded.

5. Water Control

The inlet water to the heaters was maintained at 58 F ± 2 F and the flow was measured with a calibrated water meter located in the ¾-in. inlet water line to each heater. A pressure regulator located in the inlet line maintained a pressure of 45 psig.

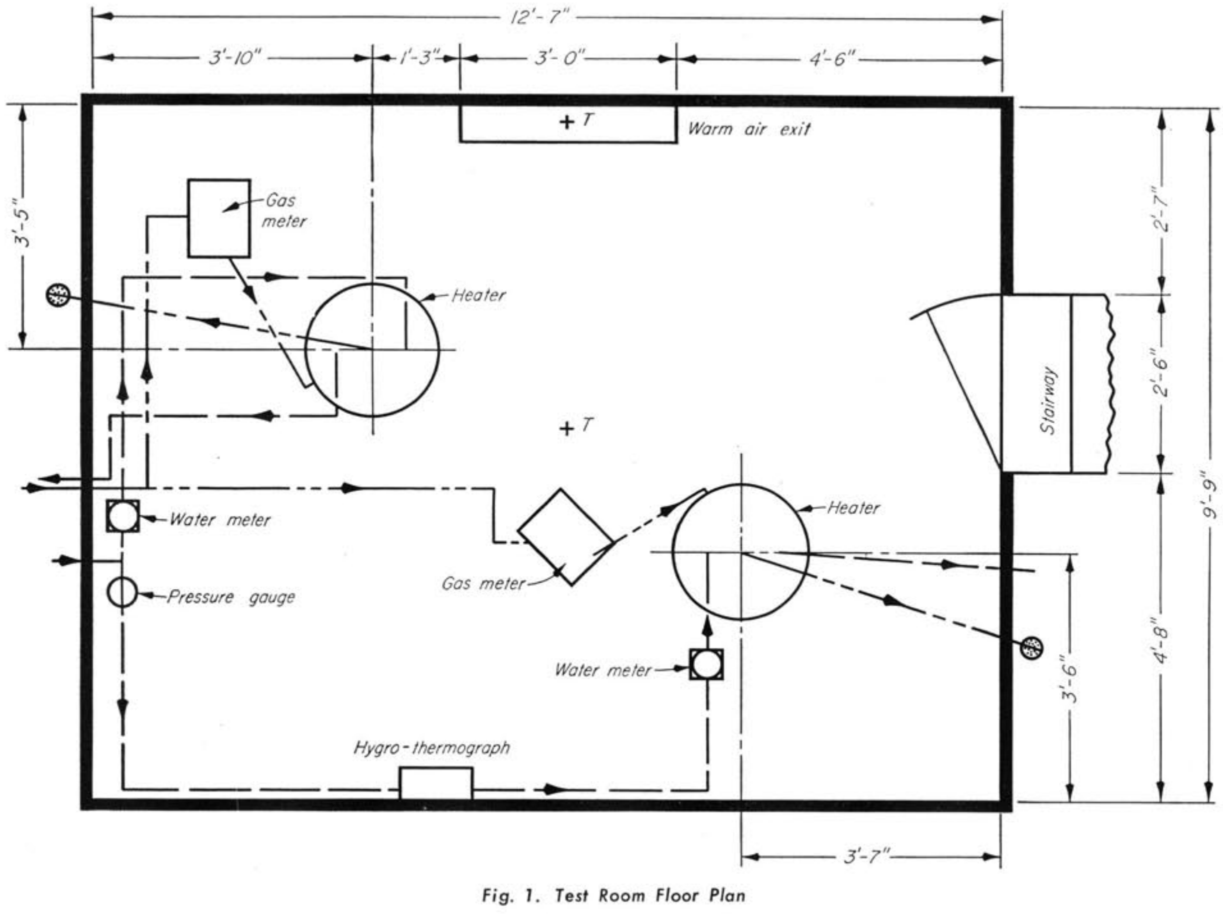

Fig. 1. Test Room Floor Plan

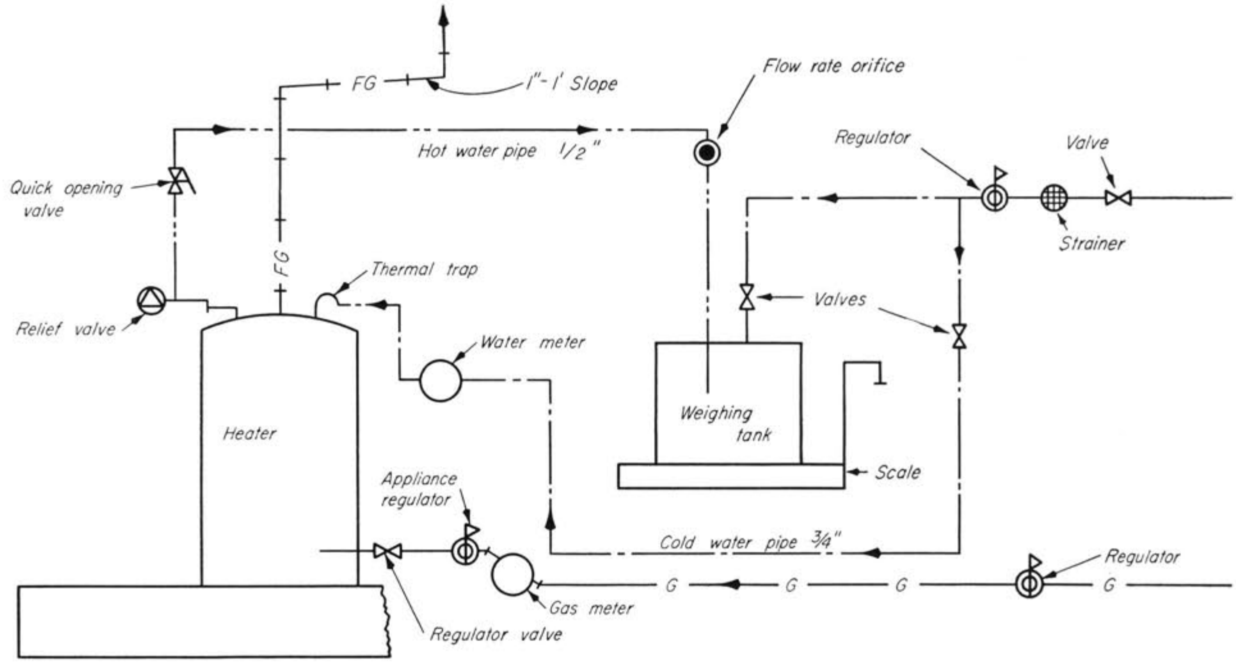

Fig. 2. Gas Water Heater Test Equipment Diagram

All draw-offs of hot water were made at a rate of 5 gal per min through a ½-in. line, 15 ft long. This rate was fixed and maintained by a calibrated orifice located in the hot water line near the weighing tank. The draw-offs were made through a quick opening valve. Figures 2 and 3 show the arrangement of the piping and equipment for the gas and electric water heaters, respectively.

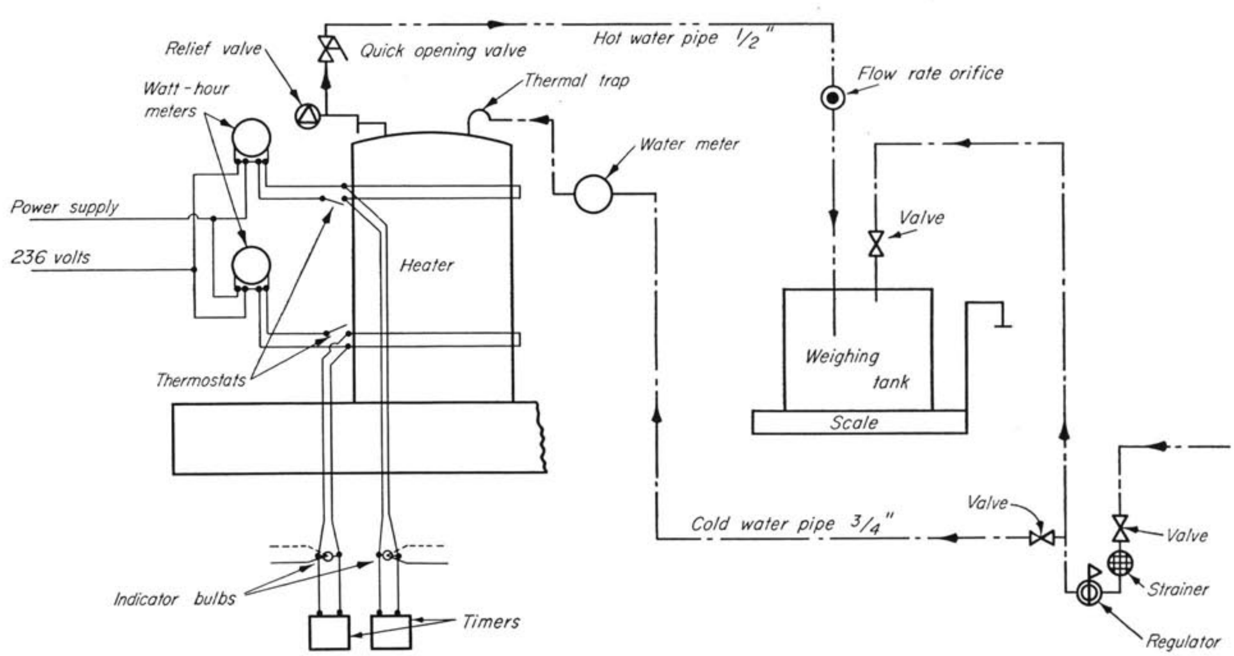

Fig. 3. Electric Water Heater Test Equipment Diagram

6. Gas and Electric Control

The natural gas was supplied through a typical household gas pressure regulator set to deliver gas at a pressure of 7 in. of water. The water heaters which were equipped by the manufacturer with an appliance pressure regulator, namely heaters B and F, were tested with gas supplied at 3½ in. water pressure at the appliance regulator outlet. The gas pressure in the line to the burners was read and recorded during the testing. A calibrated, wet-type gas flow meter was used to determine the gas consumption. It was installed between the line pressure regulator and the heater, or the appliance regulator, if one was used. The gas consumed and its heating value, as supplied by the distributor of the natural gas, were used to determine the heat input to the heater. The heating value of the natural gas ranged from 982 to 1011 Btu per cu ft. The orifice to the burner of each heater was initially adjusted so that the rated heat input, as specified on the heater data plate, was obtained. Figure 2 shows the diagrammatic arrangement of the gas piping and metering.

The electric energy input to each electric heater was measured with a calibrated watt-hour meter. The voltage of the electric supply was maintained with an automatic voltage regulator at 236 volts ± 2 volts, and this voltage was recorded by a recording voltmeter. Both heating elements in each heater were available for use during all tests as required and they were controlled by their individual thermostats. Each heating element was checked for rated input. Figure 3 shows the electrical wiring and metering.

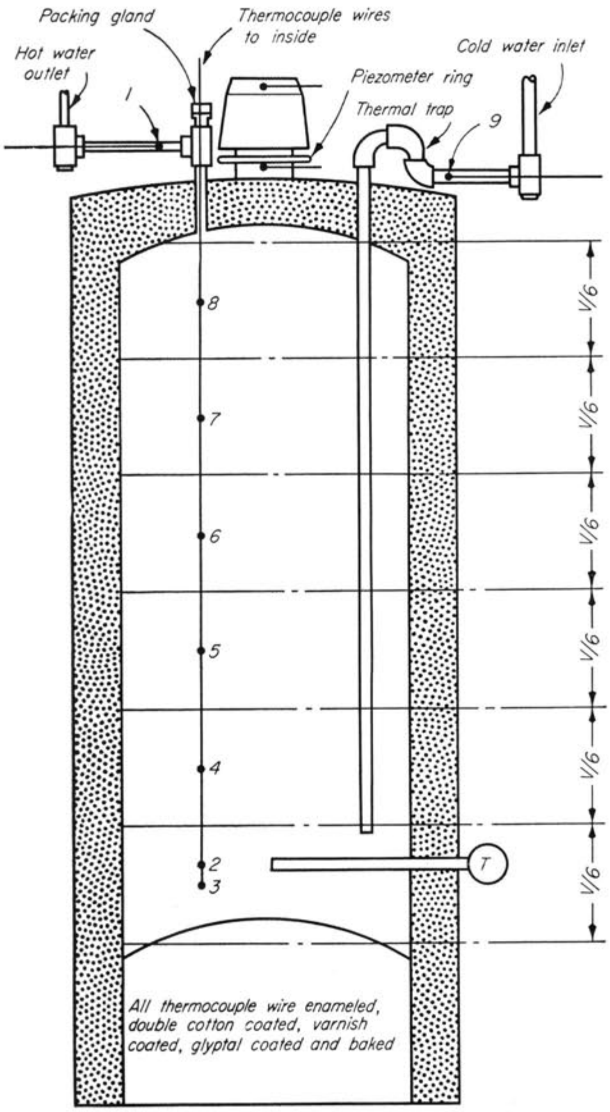

Fig. 4. Water Heater Section Showing Thermocouple Location

7. Thermostat Settings

All thermostats were set to cut-off when the temperature of the water at the given thermostat level was 150 F ± 3 F. These settings were made with the water slowly heating to this temperature.

The electric water heaters were so connected to the power supply that each of the two heating elements was separately activated by its own thermostat. In a few cases, due to unusual conditions existing during certain draw-offs, the temperature of the water at the level of the upper thermostat exceeded the set temperature of 150 F.

8. Heater Instrumentation

Each heater was equipped with 6 exposed thermocouples located inside of the water tank at the mid-point of each six sections of equal volume from the top to the bottom of the water tank as shown in Fig. 4. In addition, thermocouples were located within the tank at the horizontal level of each thermostat. Thermocouples were also located in the hot water outlet pipe within 6 in. of the heater, and in the cold water inlet pipe, upstream from a thermal trap but still within 6 in. of the heater. All of the readings of these thermocouples were recorded throughout the test period by automatic recorders, as shown in Fig. 5, and these recorded data were utilized in the performance calculations. The recorders were checked hourly by means of a manually operated potentiometer.

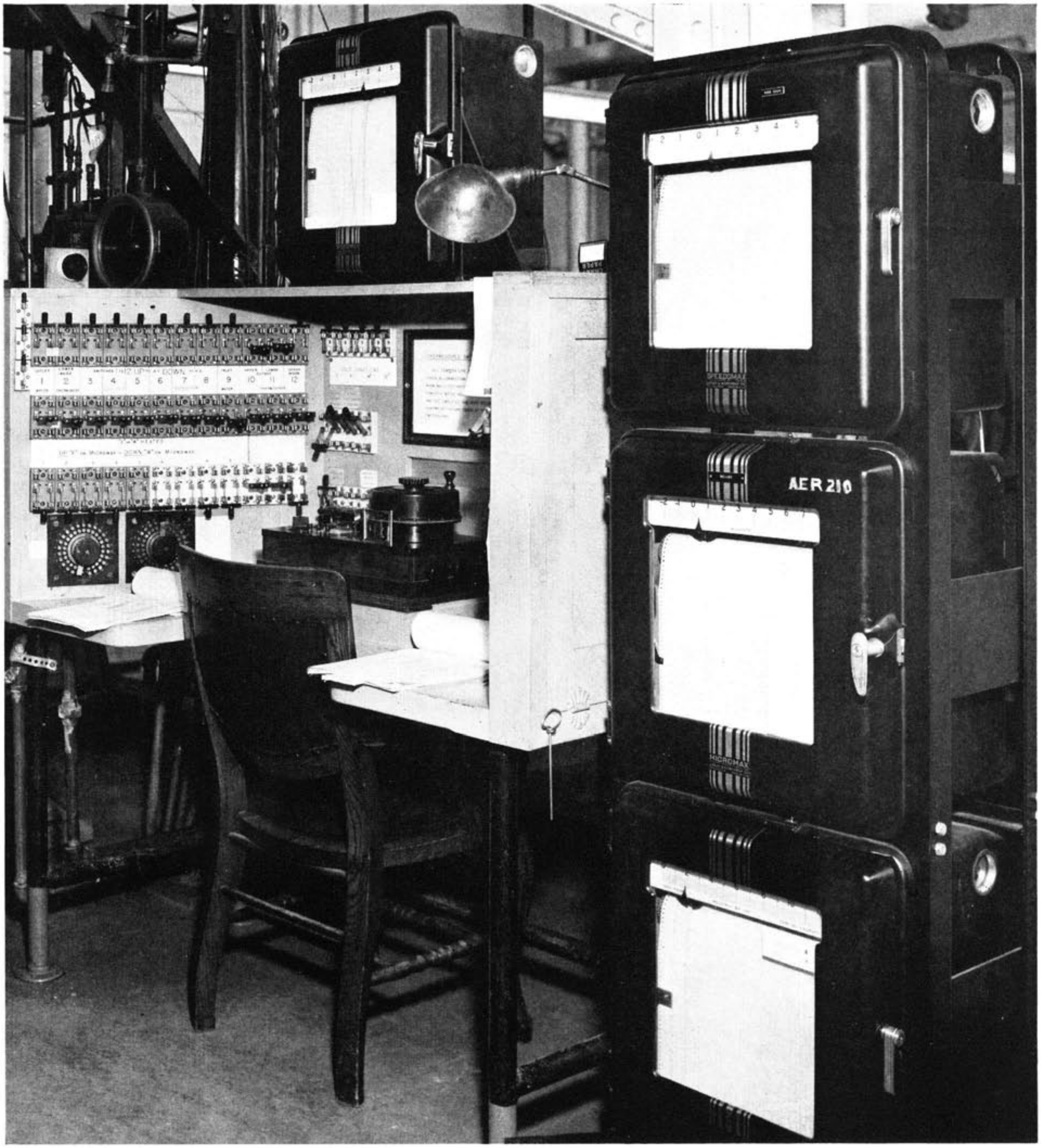

Fig. 5. The Data Recording Station which was situated directly below the enclosed, temperature-controlled room contained weighing and temperature measuring equipment. Equipment at the station included water piping with valves and orifices for regulating water flow rates and a quick emptying tank on a precision scale for accurately measuring water flow rates. The thermocouple switchboard had selector switches, type K-2 potentiometer for manual reading of the thermocouple millivoltages, and four 16-point indicating-recording potentiometers for making continuous records of water, heater, flue gas, and ambient air temperatures. The gage for indicating the water pressure, as well as the gas flow meters and the watt-hour meters for measuring the energy input to the water heaters, was located in the room with the water heaters as shown in Figs. 6 and 7.

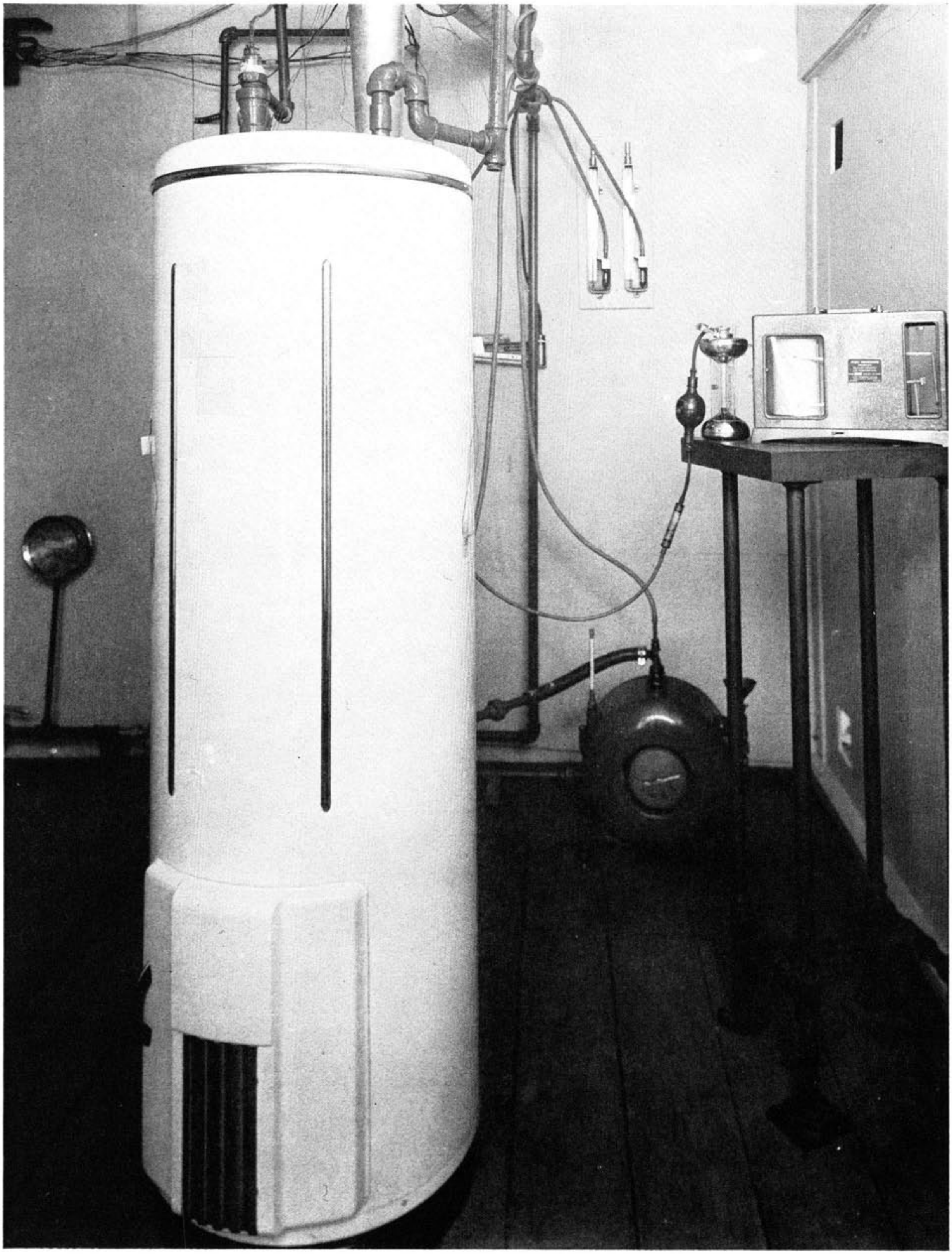

Fig. 6. Typical Gas Water Heater Installation

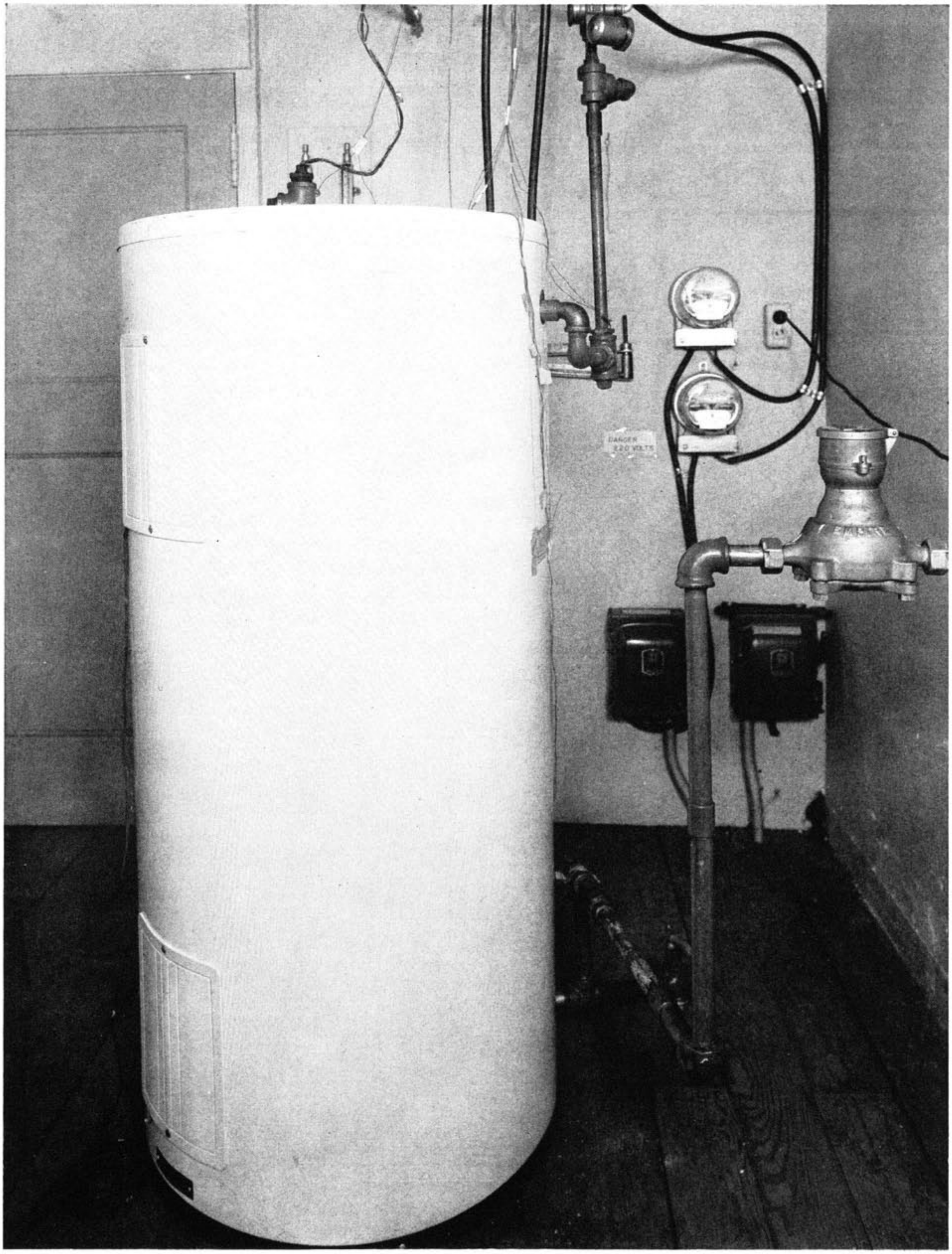

Fig. 7. Typical Electric Water Heater Installation

9. Water Heaters Studied

The six representative gas and seven electric water heaters studied are listed in Table 1. A typical gas water heater hookup is shown in Fig. 6, and an electric water heater installation in Fig. 7. The gas heaters were assigned the letters A, B, C, D, E, and F and the electric heaters the letters G, H, J, K, L, M, and N. Each heater was also assigned a built-up designation number composed of letters and numbers. The explanation of the significance of each letter and each number in these designation numbers is given in Table 1. Hereafter each heater is referred to by letter, such as heater A, B, C, etc.

The nominal tank capacities of the gas water heaters ranged from 20 to 50 gal, with a range of heat inputs from 20,000 to 42,900 Btu per hr. Two different types were studied, one with an internal flue in which the flame and products of combustion passed up through a circular flue or opening extending up through the center of the water tank, and another with an external or annular flue in which the flame and products of combustion passed up around the water tank.

The nominal tank capacities of the electric water heaters ranged from 30 to 80 gal, with a range of heat inputs from 1600 to 5000 watts (5461 to 17,045 Btu per hr). Two different types were studied, one with an immersion-type heating element in which the heating element is inserted into the water through a fitting in the water tank; another with an external-type heating element in which the heating element is wrapped around the outside surface of the water tank. In both types there were two heating elements, one placed in the lower third of the water heater and the other in the upper third.

Table 1

Water Heaters Studied

Gas	
Heater A	GI -1-20-20.0
Heater B	GI -2-30-32.0
Heater C	GI -3-50-38.0
Heater D	GE-1-30-30.0
Heater E	GE-2-30-32.5
Heater F	GE-3-25-42.9

The heater designation signifies: G—Gas; I or E—Internal or External flue; single number—heater number; double number—heater's nominal capacity; double number plus decimal—heater input in thousands of Btu/hr. (Example: Heater E—Gas, External flue, heater number 2, 30-gal rated capacity, 32,500 Btu/hr input.)

Electric	
Heater G	EI -1-30-1.0/0.6
Heater H	EI -2-52-1.5/1.0
Heater J	EA-3-52-1.5/1.0
Heater K	EA-4-66-2.0/1.25
Heater L	EA-5-66-2.5/2.0
Heater M	EI -6-80-2.5/1.5
Heater N	EI -7-80-3.0/2.0

The heater designation signifies: E—Electric; I or A—Immersion or externally attached heating elements; single number—heater number; double number—heater's nominal capacity; mixed numbers with inclined break between them represent the heat input in kilowatts with the upper heating element represented first and followed by the heat input of the lower heating element. (Example: Heater K—Electric, attached heating element, heater number 4, 66-gal rated capacity, 2.0 kilowatt input in upper element and 1.25 kilowatt input in lower element. These heaters comply with NEMA recommended ratings with the exception of heaters L and N.

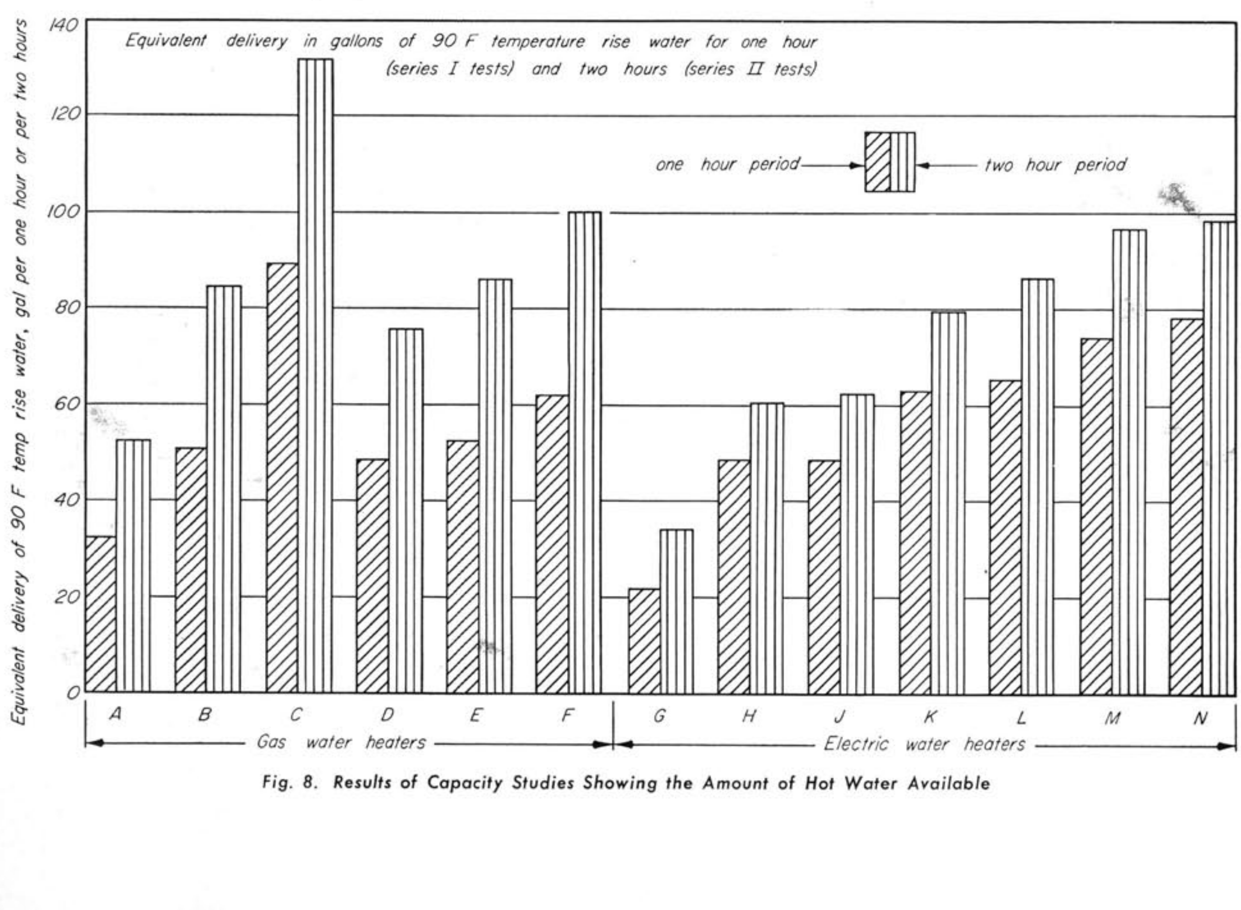

Fig. 8. Results of Capacity Studies Showing the Amount of Hot Water Available

III. CAPACITY STUDIES FOR ONE-HOUR AND TWO-HOUR PERIODS

Two series of tests were made to determine the maximum amount of usable hot water which could be drawn off at the rate of 5 gal per min in a 1-hr and a 2-hr period. Usable hot water was defined as water at a temperature of 120 F or higher. These tests were started at the completion of a thermostat cycle, that is, with the tank full of water at 150 F, the thermostat satisfied and equilibrium conditions in the heater. Water was withdrawn at the prescribed rate until the temperature of the outlet water dropped to 120 F. The withdrawal was then stopped. The test was continued with no further withdrawal until 30 min after the start of the test. If any water above 120 F was available at the heater outlet, a withdrawal of water was then repeated as before. If the temperature of the water at the heater outlet was still below 120 F, the test was continued without drawing water for another 30-min interval. At that time, water was withdrawn as at the start of the test. The sum of these withdrawals was construed to be the total hot water capacity of the heater for a 1-hr period, Series I Tests. A similar procedure was followed for a 2-hr period, Series II Tests, except that there were four 30-min periods instead of two.

However, if observation showed that the thermostat was satisfied before the expiration of any of the 30-min periods between draw-offs, the test procedure was modified to provide for shorter periods; namely, with the withdrawals starting at the time of recovery. Recovery is defined as the point at which the thermostat was satisfied. This occurred when the temperature of the water at the thermostat level was within the range of 150 F ± 3.0 F. If observations indicated that the heater would not fully recover during the following 30-min interval, the available hot water was not withdrawn at the end of the present period unless said period was the last period of the test.

In determining the fuel or energy consumption for these tests, the heaters were maintained in operation after the completion of the last withdrawal

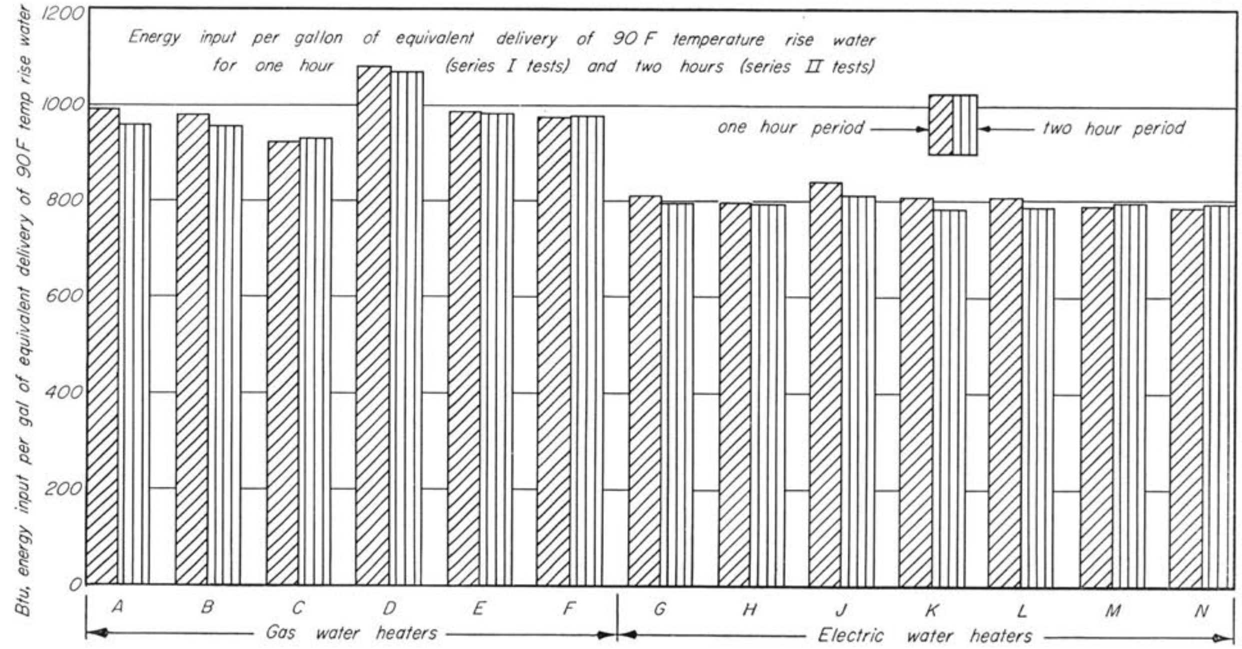

Fig. 9. Results of Capacity Studies Showing Required Heat Input per Gallon of Hot Water Delivered

until the thermostat was again satisfied and the heater had returned to the equilibrium state that existed at the start of the test. If the final equilibrium state differed from the initial equilibrium state, the difference in energy content of the tank full of water at the beginning and the end of the test was computed and applied to the total measured heat input for the test period. The fuel, or energy consumption, for the given test was then taken as that consumed between the time of the start of the original withdrawal and the end of the final withdrawal corrected for difference in stored energy at the beginning and end of the test period.

The results of these two series of tests are shown in Tables 2 and 3. The "Recovery Efficiency" as shown in these tables is the ratio of the energy utilized in heating the water contrasted with the energy consumption of the heater during the complete test period.

Figure 8 shows the equivalent delivery of 90 F temperature rise water in gallons for both the 1-hr and 2-hr periods.

Figure 9 shows the energy input per gal of equivalent delivery of 90 F rise water for both the 1-hr and 2-hr series of tests for each water heater. The graph shows that approximately 1000 Btu input is required to supply a gallon of 90 F temperature rise water by the gas water heaters and approximately 800 Btu per gallon by the electric water heaters.

Table 2
Hot Water Delivery: Capacity of Heaters in One-Hour Period
Series I Tests

	Gas Water Heaters						Electric Water Heaters						
	A	B	C	D	E	F	G	H	J	K	L	M	N
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Initial Draw-Water above 120 F (gal)	17.1	26.7	52.3	25.7	28.3	23.0	23.3	48.4	49.2	63.1	63.3	75.9	75.8
3. Total Water above 120 F Delivered (gal/test)	34.1	53.3	10.1	51.4	55.9	67.8	23.3	48.4	49.2	63.1	63.3	75.9	75.8
4. Usable Hot Water (deg-gal)	786	1220	1630	1160	1210	1280	521	1380	1300	1730	1920	1940	2270
5. Recovery Efficiency (%)	75.5	76.5	81.5	69.5	76.1	77.0	93.0	94.1	89.3	93.0	92.9	94.5	95.3
6. Equivalent Delivery for 90 F Temperature Rise (gal/test)	32.3	50.9	89.0	48.5	52.4	62.1	21.9	48.6	48.7	62.7	65.4	74.0	78.0
7. Heat Input/Gal Delivered for 90 F Temp Rise (Btu)	993	981	921	1080	986	975	806	797	840	807	807	793	787

Table 3
Hot Water Delivery: Capacity of Heaters in Two-Hour Period
Series II Tests

	Gas Water Heaters						Electric Water Heaters						
	A	B	C	D	E	F	G	H	J	K	L	M	N
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Initial Draw-Water above 120 F (gal)	17.0	26.7	52.2	25.8	28.1	22.6	23.4	49.0	49.3	63.2	63.7	75.7	76.7
3. Total Water above 120 F Delivered (gal/test)	60.7	96.3	150	88.6	98.1	110	39.0	61.6	65.1	85.9	88.5	100	98.1
4. Usable Hot Water (deg-gal)	968	1490	2310	1330	1520	2030	681	1580	1610	1830	2250	2450	2730
5. Recovery Efficiency (%)	78.1	78.2	80.7	70.2	76.3	76.7	94.2	94.4	92.6	95.7	94.9	94.4	94.5
6. Equivalent Delivery for 90 F Temperature Rise (gal/test)	52.5	84.5	131	75.6	85.9	100	33.9	60.2	62.6	79.6	86.2	96.6	97.9
7. Heat Input/Gal Delivered for 90 F Temp Rise (Btu)	961	959	929	1070	984	978	796	795	810	784	790	795	794

IV. DAILY USAGE STUDIES WITH CONVENTIONAL AND AUTOMATIC WASHING MACHINES

Tests simulating the daily hot water requirements of an average family were conducted with each water heater to determine the maximum quantity of water available at temperatures above 120 F when the water was withdrawn in accordance with the preselected daily draw-off schedule shown in Table 4. This schedule, taken from A.S.A. Standards Bulletin C72.1-1949*, is presumed to be representative of the daily hot water draw-offs of an average family from 6:30 a.m. until 10:30 p.m. It gives the time and quantity of each withdrawal, with the quantity expressed as a percent of the total withdrawal for the simulated day of 16 hr.

The hot water requirements of a conventional clothes washing machine were taken into consideration in the development of Table 4. In order to adjust the schedule to make it more representative of the usage of a family using an automatic clothes washing machine, 3 gal were added to the 9 a.m. withdrawal, for daily usages of less than 100 gal. If the total daily withdrawal was 100 gal or more, it was decided that an average family would require in addition 6 gal of hot water to provide for three consecutive cycles of an automatic clothes washer. To meet this estimated requirement, 3 gal were added to the 8 a.m., 9 a.m., and 10 a.m. withdrawals.

An initial test based on a total withdrawal of 50 gal for the day or 16-hr period was conducted on each water heater. Additional tests with withdrawals based on increased per day rate of usage in increments of 50 gal per day were made until the outlet water temperature during any individual withdrawal dropped below 120 F. For each water heater the maximum daily usage was determined to the nearest 10 gal. A service efficiency was determined for each test. The results of these tests are presented in two forms. Table 5 gives the results of

* Household Automatic Electric Storage-Type Water Heaters — A.S.A. Bulletin C72.1-1949, Paragraph 5.6,4.6, Page 15.

Table 4

Daily Withdrawal Schedule for an Average Family

Schedule A includes conventional clothes washing machine requirements. Schedule B includes automatic clothes washing machine requirements; 3 gallons added to 9 a.m. withdrawals for daily usages of less than 100 gal per day or 3 gal added to each of the 8 a.m., 9 a.m., and 10 a.m. withdrawals for daily usage of 100 gal or more per day.

Time of Day	Elapsed Time, Hours	Withdrawal, Percent of Total	
		Schedule A	*Schedule B*
6:30 a.m.	0.5	11	11
7:30	1.5	5	5
8:00	2.0	17	17 + 3 gal
9:00	3.0	14	14 + 3 gal
10:00	4.0	13	13 + 3 gal
11:00	5.0	4	4
12:00	6.0	4	4
1:00 p.m.	7.0	7	7
5:00	11.0	3	3
6:00	12.0	4	4
7:30	13.5	5	5
10:30	16.5	13	13
		100%	100% + 9 ga

All withdrawals were at the rate of 5 gal per min. The percentages shown were applied to the basic daily hot water usage rates to simulate the daily usage habits of the average householder.

tests conducted on each heater with different daily usage rates. Withdrawal schedule A is for an average family with a conventional clothes washing machine and withdrawal schedule B for an average family with an automatic clothes washing machine. In Table 5 the highest actual delivery is the maximum daily usage rate for the heater.

The service efficiencies and the heat inputs for different daily usage rates withdrawn as per Schedule A and as per Schedule B, and corrected to a common 90 F rise in water temperature, are given for each of the water heaters in Figures 10, 11 and 12. In Figure 10 are shown the performance characteristics for all of the gas water heaters investigated. It should be noted that the curve for heater C, the middle graph on the left, is to a different scale than the other graphs. This was necessitated by the large capacity of this heater in comparison to the other heaters. The data for electric water heater G is shown in Figure 12, separately from that of the other electric heaters, since it has a much smaller capacity. It is a special purpose appliance which does not have the application of the other heaters investigated.

All tabulated results and plotted data are an average of at least two test runs that agree within

Service efficiency and heat input required for varied daily consumption of hot water

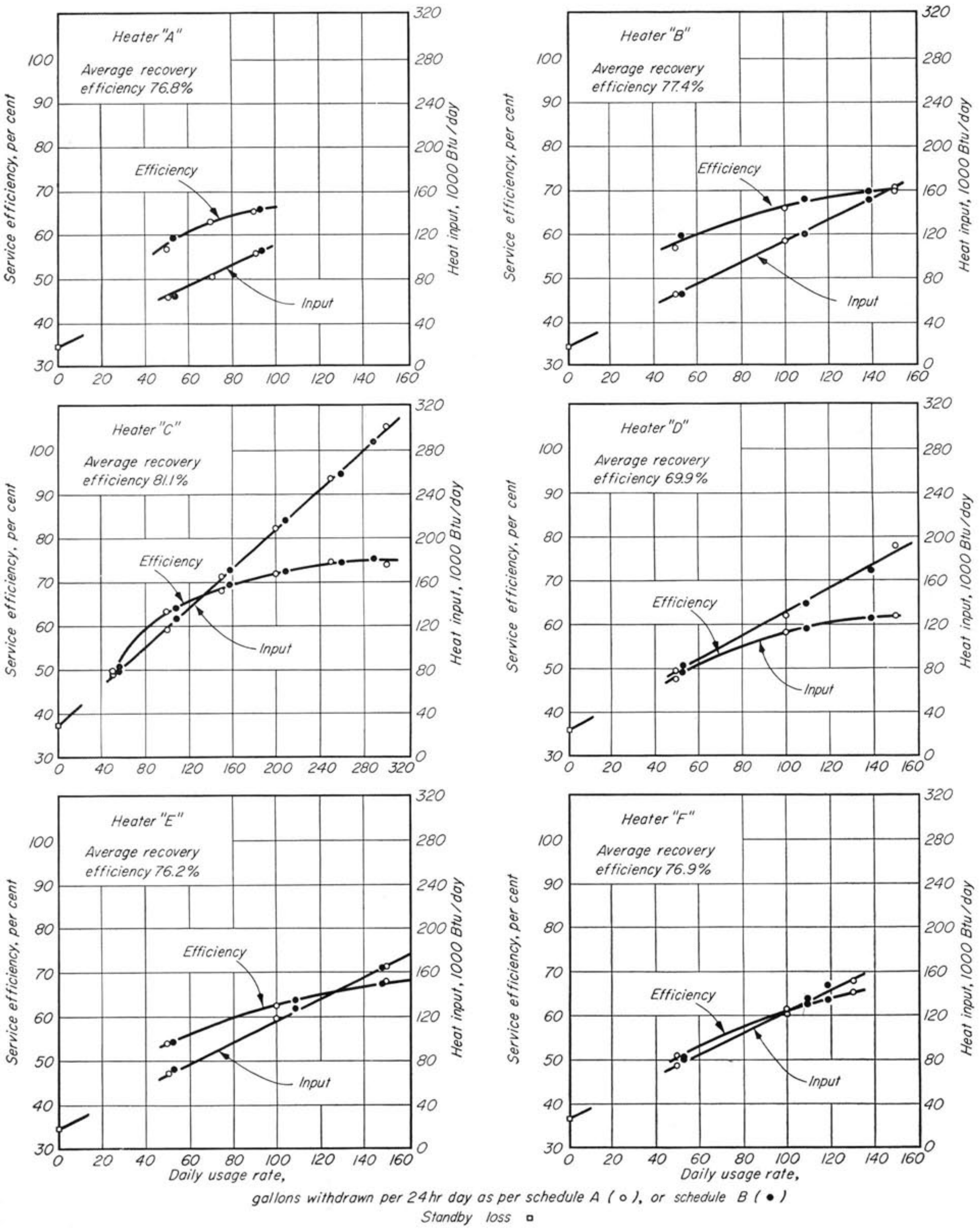

Fig. 10. Performance Curves for Gas Water Heaters A-F During Daily Usage Studies

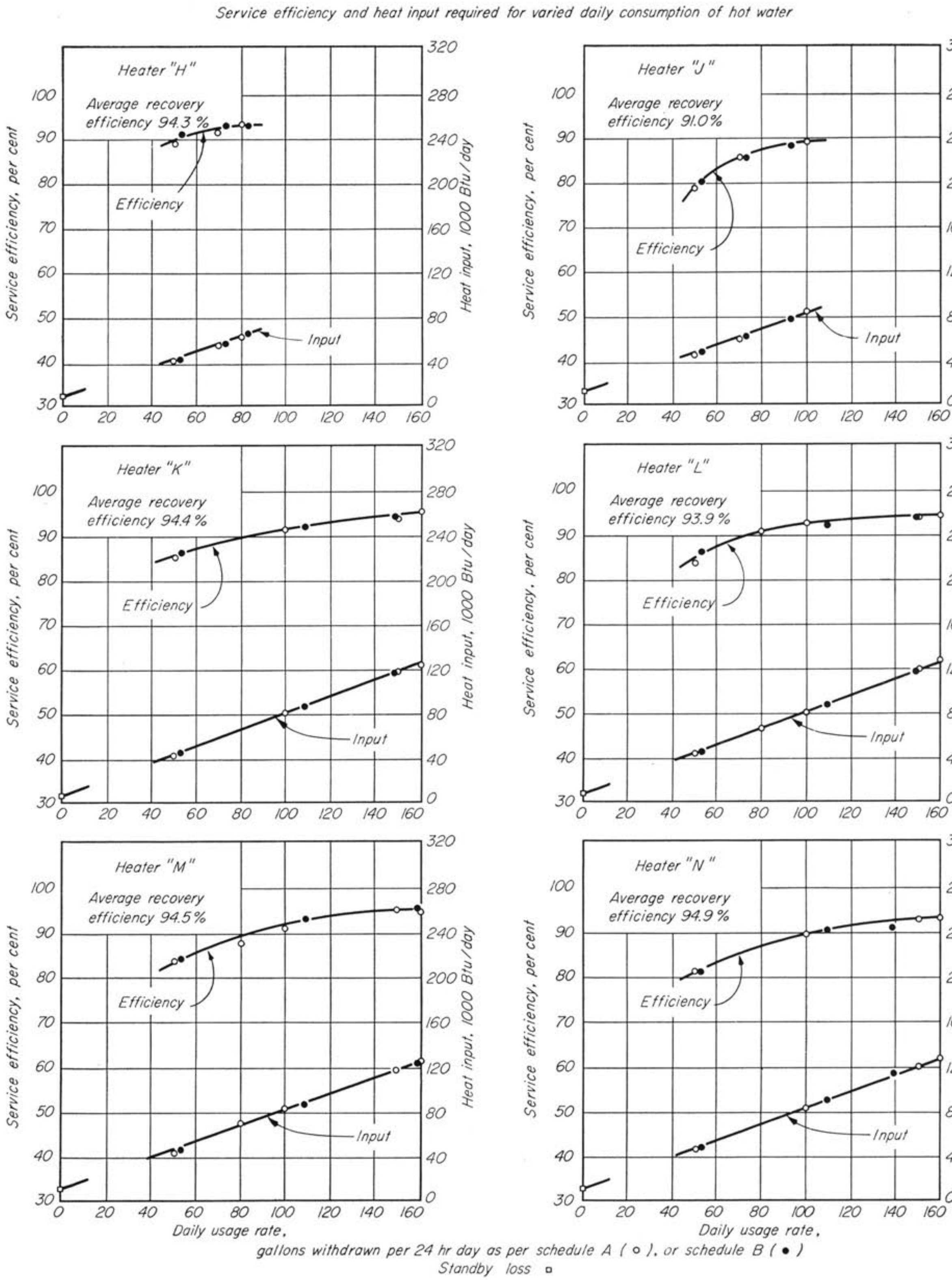

Fig. 11. Performance Curves for Electric Water Heaters H-N During Daily Usage Studies

Table 5
Results of Daily Usage Studies for Each Heater

Schedule A represents an average family with conventional clothes washing machine;
Schedule B represents an average family with automatic clothes washing machine.
All results corrected for a 90 F temperature rise.

Water Heater		*Withdrawal Schedule A*						*Withdrawal Schedule B*					
A	1. Daily Usage Rate, gal/day	50	70	90				50+3	90+3				
	2. Actual Delivery (gal/test)	50	70	90				53	93				
	3. Heat Input (Btu/day)	66200	83400	103400				66600	105800				
	4. Service Efficiency by Test (%)	56.6	62.9	65.3				59.7	65.9				
	5. Deg-Gal Actually Delivered	4500	6300	8100				4770	8370				
	6. Btu Input/Deg-Gal Delivered	14.7	13.2	17.8				14.0	12.6				
B	1. Daily Usage Rate, gal/day	50	100	150				50+3	100+9	130+9			
	2. Actual Delivery (gal/test)	50	100	150				53	109	139			
	3. Heat Input (Btu/day)	65800	114400	161200				66400	120300	149900			
	4. Service Efficiency by Test (%)	57.0	65.6	69.8				59.9	68.0	69.6			
	5. Deg-Gal Actually Delivered	4500	9000	13500				4770	9810	12510			
	6. Btu Input/Deg-Gal Delivered	14.6	12.7	11.9				13.9	12.3	12.0			
C	1. Daily Usage Rate, gal/day	50	100	150	200	250	300	50+3	100+9	150+9	200+9	250+9	280+9
	2. Actual Delivery (gal/test)	50	100	150	200	250	300	53	109	159	209	259	289
	3. Heat Input (Btu/day)	75300	118900	165800	208300	252100	305000	78400	127500	171300	216800	258900	288600
	4. Service Efficiency by Test (%)	49.8	63.1	67.9	72.0	74.4	73.8	50.7	64.1	69.6	72.3	75.0	75.1
	5. Deg-Gal Actually Delivered	4500	9000	13500	18000	22500	27000	4770	9810	14310	18810	23310	26010
	6. Btu Input/Deg-Gal Delivered	16.7	13.2	12.3	11.6	11.2	11.3	16.4	13.0	12.0	11.5	11.1	11.1
D	1. Daily Usage Rate, gal/day	50	100	150				50+3	100+9	130+9			
	2. Actual Delivery (gal/test)	50	100	150				53	109	139			
	3. Heat Input (Btu/day)	78600	128700	182300				81300	137400	169400			
	4. Service Efficiency by Test (%)	47.7	58.3	61.7				48.9	59.5	61.5			
	5. Deg-Gal Actually Delivered	4500	9000	13500				4770	9810	12510			
	6. Btu Input/Deg-Gal Delivered	17.5	14.3	13.5				17.0	14.0	13.5			
E	1. Daily Usage Rate, gal/day	50	100	150	160			50+3	100+9	140+9			
	2. Actual Delivery (gal/test)	50	100	150	160			53	109	149			
	3. Heat Input (Btu/day)	69200	119500	164800	178200			72600	127700	164500			
	4. Service Efficiency by Test (%)	54.2	62.8	68.2	67.3			54.6	64.0	67.9			
	5. Deg-Gal Actually Delivered	4500	9000	13500	14400			4770	9810	13410			
	6. Btu Input/Deg-Gal Delivered	15.4	13.3	12.2	12.4			15.2	13.0	12.3			
F	1. Daily Usage Rate, gal/day	50	100	130				50+3	100+9	110+9			
	2. Actual Delivery (gal/test)	50	100	130				53	109	119			
	3. Heat Input (Btu/day)	74000	122500	150000				78400	130500	140700			
	4. Service Efficiency by Test (%)	50.7	61.2	65.0				50.7	62.7	63.4			
	5. Deg-Gal Actually Delivered	4500	9000	11700				4770	9810	10710			
	6. Btu Input/Deg-Gal Delivered	16.4	13.6	12.8				16.4	13.3	13.1			
G	1. Daily Usage Rate, gal/day	30	50	70				30+3	50+3	60+3			
	2. Actual Delivery (gal/test)	30	50	70				33	53	63			
	3. Heat Input (Btu/day)	29200	43500	57400				31600	44500	53500			
	4. Service Efficiency by Test (%)	77.0	86.2	91.5				78.3	89.3	88.3			
	5. Deg-Gal Actually Delivered	2700	4500	6300				2970	4770	5670			
	6. Btu Input/Deg-Gal Delivered	10.8	9.67	9.11				10.7	9.33	9.44			
H	1. Daily Usage Rate, gal/day	50	70	80				50+3	70+3	80+3			
	2. Actual Delivery (gal/test)	50	70	80				53	73	83			
	3. Heat Input (Btu/day)	42300	57500	64400				43700	58900	66800			
	4. Service Efficiency by Test (%)	88.6	91.2	93.2				91.0	92.9	93.1			
	5. Deg-Gal Actually Delivered	4500	6300	7200				4770	6570	7470			
	6. Btu Input/Deg-Gal Delivered	9.41	9.13	8.94				9.16	8.97	8.95			
J	1. Daily Usage Rate, gal/day	50	70	100				50+3	70+3	90+3			
	2. Actual Delivery (gal/test)	50	70	100				53	73	93			
	3. Heat Input (Btu/day)	47600	61300	84900				49600	63900	78300			
	4. Service Efficiency by Test (%)	78.9	85.7	88.4				80.2	85.7	89.1			
	5. Deg-Gal Actually Delivered	4500	6300	9000				4770	6570	8370			
	6. Btu Input/Deg-Gal Delivered	10.6	9.73	9.43				10.4	9.72	9.35			
K	1. Daily Usage Rate, gal/day	50	100	150	160			50+3	100+9	140+9			
	2. Actual Delivery (gal/test)	50	100	150	160			53	109	149			
	3. Heat Input (Btu/day)	44000	82100	119700	125800			46000	88700	118400			
	4. Service Efficiency by Test (%)	85.3	91.3	94.0	95.4			86.4	92.2	94.4			
	5. Deg-Gal Actually Delivered	4500	9000	13500	14400			4770	9810	13410			
	6. Btu Input/Deg-Gal Delivered	9.77	9.13	8.86	8.73			9.64	9.04	8.83			
L	1. Daily Usage Rate, gal/day	50	80	100	150	160		50+3	100+9	140+9			
	2. Actual Delivery (gal/test)	50	80	100	150	160		53	109	149			
	3. Heat Input (Btu/day)	44800	66100	80900	119700	127500		46000	88100	118700			
	4. Service Efficiency by Test (%)	83.7	90.8	92.7	94.0	94.1		86.4	92.7	94.1			
	5. Deg-Gal Actually Delivered	4500	7200	9000	13500	14400		4770	9810	13410			
	6. Btu Input/Deg-Gal Delivered	9.96	9.17	8.99	8.87	8.85		9.65	8.99	8.85			
M	1. Daily Usage Rate, gal/day	50	80	100	150	160		50+3	100+9	150+9			
	2. Actual Delivery (gal/test)	50	80	100	150	160		53	109	159			
	3. Heat Input (Btu/day)	44700	68200	82400	117800	126600		47200	87600	125400			
	4. Service Efficiency by Test (%)	83.8	88.0	91.1	95.5	94.8		84.3	93.3	95.1			
	5. Deg-Gal Actually Delivered	4500	7200	9000	13500	14400		4770	9810	14310			
	6. Btu Input/Deg-Gal Delivered	9.94	9.47	9.15	8.72	8.79		9.89	8.93	8.76			
N	1. Daily Usage Rate, gal/day	50	100	150	160			50+3	100+9	130+9			
	2. Actual Delivery (gal/test)	50	100	150	160			53	109	139			
	3. Heat Input (Btu/day)	46100	83700	120900	128700			48800	90300	114100			
	4. Service Efficiency by Test (%)	81.4	89.6	93.1	93.3			81.4	90.5	91.4			
	5. Deg-Gal Actually Delivered	4500	9000	13500	14400			4770	9810	12510			
	6. Btu Input/Deg-Gal Delivered	10.2	9.31	8.95	8.93			10.2	9.20	9.12			

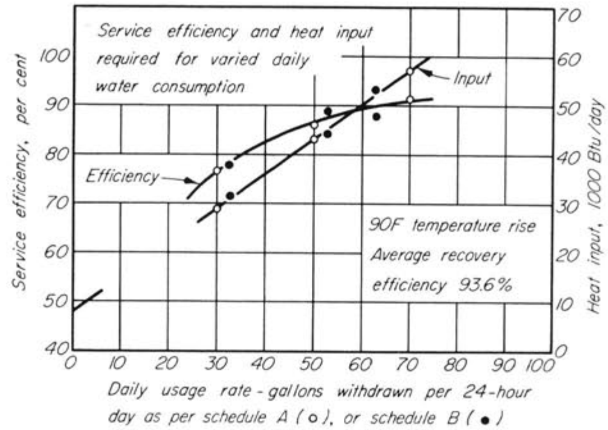

Fig. 12. Performance Curves for Electric Water Heater G During Daily Usage Studies

2%. For all tests the actual results were reduced to a common 90 F water temperature rise in accordance with the procedures agreed to by the sponsor's committee and the research staff. The heat input curves in Figures 10, 11 and 12 have been extended to the left to show the heat input for zero withdrawal, which is the standby loss for each of the heaters as explained in Part VI.

In Table 6 the performance data of each of the water heaters are arranged in accordance with the different daily usage rates and withdrawal schedules. This arrangement expedites the comparison of one water heater with another for a given daily usage rate and withdrawal schedule. Again, all of the data are corrected to a common 90 F rise in water temperature.

Figure 13 is a compilation of the service efficiencies of all tests at different daily usage rates as per Schedule A and as per Schedule B, corrected to a common 90 F rise in water temperature. In general, the service efficiencies of the gas water heaters were 48 to 70% over the range of daily usage rates of from 50 to 160 gallons per day, whereas the efficiencies of the electric water heaters were 77 to 96%. Most of the heaters in this investigation operated satisfactorily throughout the above mentioned daily usage rate.

It should be noted that with each water heater the service efficiency increases quite rapidly with increased daily water usage rate and approaches the recovery efficiency of the heater. This is true because as the usage rate increases, the standby loss has less influence on the efficiency.

Table 6
Results of Daily Usage Studies for Variable Deliveries

Schedule A represents an average family with conventional clothes washing machine; Schedule B represents an average family with automatic clothes washing machine.

	Gas Water Heaters						Electric Water Heaters						
	A	B	C	D	E	F	G	H	J	K	L	M	N
WITHDRAWAL SCHEDULE A													
50 Gallons													
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Average Output (Btu/day)	37500	37500	37500	37500	37500	37500	37500	37500	37500	37500	37500	37500	37500
3. Heat Input (Btu/day)	66200	65800	75300	78600	69200	74000	43500	42300	47600	44000	44800	44700	46100
4. Service Efficiency by Test (%)	56.6	57.0	49.8	47.7	54.2	50.7	86.2	88.6	78.9	85.3	83.7	83.8	81.4
5. Deg Gal Actually Delivered	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
6. Btu Input/Deg Gal Delivered	14.7	14.6	16.7	17.5	15.4	16.4	9.67	9.41	10.6	9.77	9.96	9.94	10.2
100 Gallons/Day													
1. Actual Tank Capacity (gal)	Out	28.5	52.9	28.3	30.9	23.3	Out	Out	50.3	64.2	64.2	80.2	80.2
2. Average Output (Btu/day)	"	75000	75000	75000	75000	75000	"	"	75000	75000	75000	75000	75000
3. Average Input (Btu/day)	"	114400	118900	128700	119500	122500	"	"	84900	82100	80900	82400	83700
4. Service Efficiency by Test (%)	"	65.5	63.1	58.3	62.8	61.2	"	"	88.4	91.3	92.7	91.1	89.6
5. Deg Gal Actually Delivered	"	9000	9000	9000	9000	9000	"	"	9000	9000	9000	9000	9000
6. Btu Input/Deg Gal Delivered	"	12.7	13.2	14.3	13.3	13.6	"	"	9.45	9.13	8.99	9.15	9.31
150 Gallons/Day													
1. Actual Tank Capacity (gal)	Out	28.5	52.8	28.3	30.9	Out	Out	Out	Out	64.2	64.2	80.2	80.2
2. Average Output (Btu/day)	"	112500	112500	112500	112500	"	"	"	"	112500	112500	112500	112500
3. Average Input (Btu/day)	"	161200	165800	182300	164800	"	"	"	"	119700	119700	117800	120900
4. Service Efficiency by Test (%)	"	69.8	67.7	61.7	68.2	"	"	"	"	94.0	94.0	95.5	93.1
5. Deg Gal Actually Delivered	"	13500	13500	13500	13500	"	"	"	"	13500	13500	13500	13500
6. Btu Input/Deg Gal Delivered	"	11.9	12.3	13.5	12.2	"	"	"	"	8.87	8.87	8.72	8.95
WITHDRAWAL SCHEDULE B													
50 Gallons/Day+3 Gallons													
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Average Output (Btu/day)	39700	39700	39700	39700	39700	39700	39700	39700	39700	39700	39700	39700	39700
3. Average Input (Btu/day)	66600	66400	78400	81300	72600	78400	44500	43700	49600	46000	46000	47200	48800
4. Service Efficiency by Test (%)	59.7	59.9	50.7	48.9	54.8	50.7	89.3	91.0	80.2	86.4	86.4	84.3	81.4
5. Deg Gal Actually Delivered	4770	4770	4770	4770	4770	4770	4770	4770	4770	4770	4770	4770	4770
6. Btu Input/Deg Gal Delivered	14.0	13.9	16.4	17.0	15.2	16.4	9.33	9.16	10.4	9.65	9.65	9.89	10.2
100 Gallons/Day+9 Gallons													
1. Actual Tank Capacity (gal)	Out	28.5	52.9	28.3	30.9	23.3	Out	Out	Out	64.2	64.2	80.2	80.2
2. Average Output (Btu/day)	"	81700	81700	81700	81700	81700	"	"	"	81700	81700	81700	81700
3. Average Input (Btu/day)	"	120300	127500	137400	127700	130500	"	"	"	88700	88100	87600	90300
4. Service Efficiency by Test (%)	"	68.0	64.1	59.5	64.0	62.7	"	"	"	92.2	92.7	93.3	90.5
5. Deg Gal Actually Delivered	"	9810	9810	9810	9810	9810	"	"	"	9810	9810	9810	9810
6. Btu Input/Deg Gal Delivered	"	12.3	13.0	14.0	13.0	13.3	"	"	"	9.04	8.99	8.93	9.20

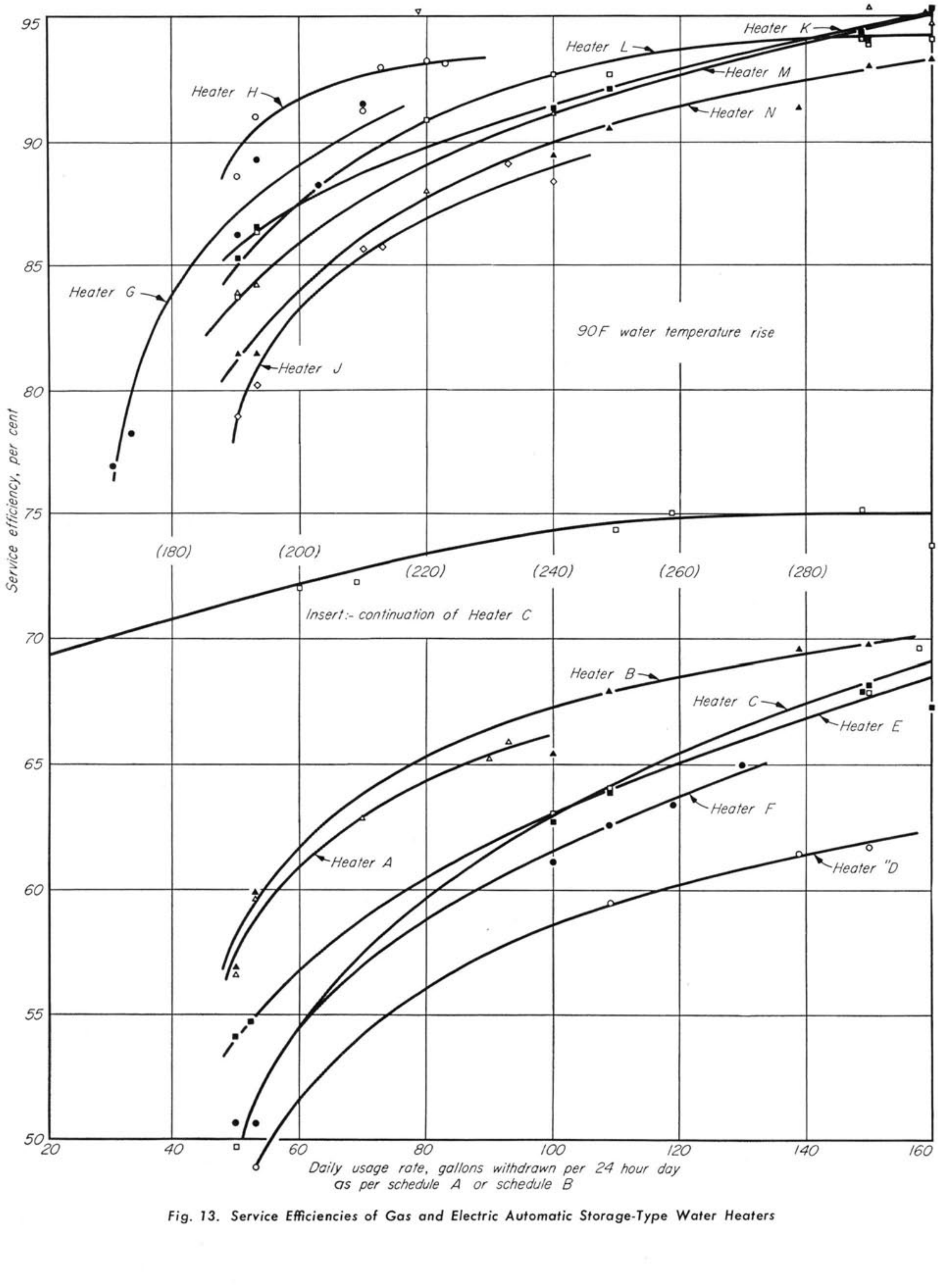

Fig. 13. Service Efficiencies of Gas and Electric Automatic Storage-Type Water Heaters

V. HOT WATER REQUIREMENTS FOR AUTOMATIC CLOTHES WASHING MACHINE

The hot water requirements for automatic clothes washing machines were regarded as very important in determining the performance of water heaters for householders. A typical operating cycle and the hot water requirements for a representative 8-gal per tub automatic clothes washing machine was set up. It is shown in Table 7. This operating cycle shows load, soak, wash, spray-rinse, first-rinse, second-rinse and dry periods, with the quantity of 150 F and 60 F water and the temperature of the water required for each period. The soak period requirements were included in addition to that of the wash period in order to study the performance of the water heaters under maximum demand.

Continuous performance tests were conducted with repeated operation of this cycle until the outlet water temperature dropped to 120 F, or until the 4 complete washing cycles were completed. The results of this series of tests conducted on each water heater are given in Table 8. They include the heat input per operating cycle and the outlet water temperature for each cycle.

The word "out" is used in Table 8 to indicate the particular cycle in which the outlet water temperature dropped below 120 F. This occurred during the second operating cycle in the case of gas water heater A and electric water heater G. With electric water heaters H and J the outlet water temperature dropped below 120 F during the third operating cycle. In the case of electric water heater K the requirements for three cycles were available, but there was no water above 120 F available to start the fourth cycle. With all of the other water heaters the outlet water temperature remained above 120 F at all times during the continuous test composed of four repeated operating cycles. However, the average temperature of rinse water for electric water heater L was at 120 F and, as shown in Table 8, the average wash water temperature was 125.3 F. This heater barely fulfilled the agreed requirements.

Table 7
Typical Operating Cycle and Water Requirements for Automatic Washing Machine

Time, min	Operation	Water Used, gal* *150 F Water*	Water Used, gal* *60 F Water*	Water Temperature for Operation, deg F
0- 5	Load	...	...	
5-15	Soak	3.5	4.5	90-110
15-27	Wash	8.0	...	150
27-28	Spray Rinse	2.2	2.8	90-110
28-35	1st Rinse	3.5	4.5	90-110
35-41	2nd Rinse	3.5	4.5	90-110
41-45	Dry	0	0	
		20.7	16.3	

* Based on 8 gal per tub.

Table 8
Results of Automatic Washing Machine Studies

	Gas Water Heaters						Electric Water Heaters							
	A	B	C	D	E	F	G	H	J	K	L	M	N
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Inlet Water Temp (deg F)	57.7	56.3	56.6	57.4	56.8	57.1	57.5	58.5	57.0	59.4	56.7	58.0	57.6
3. Wash Water Temp (deg F)*													
Cycle 1	152.4	151.3	154.4	154.4	154.4	153.2	149.2	155.0	151.1	151.3	148.4	149.6	152.9
Cycle 2	126.7	150.8	165.3	149.5	149.5	156.7	Out	154.2	150.3	151.2	148.0	149.1	152.7
Cycle 3	Out	151.8	171.8	148.0	149.0	156.6	Out	114.3	122.3	150.1	146.4	148.4	152.1
Cycle 4	Out	152.3	173.9	147.5	148.5	156.8	Out	Out	Out	Out	125.3	137.6	140.6
4. Input/Test (Btu)	34800	85800	97800	92300	84500	92100	18500	41100	42100	48400	60400	61700	65400
5. Input/Cycle (Btu)	17400	21500	24500	23100	21100	23000	15800	16100	16500	16100	15100	15400	16400

* Average outlet water temperature of 8.0 gal withdrawal for wash operation.

VI. STAND-BY STUDIES

The fuel or energy consumption required to maintain a water heater filled with water at a given temperature during a day in which no water was withdrawn was determined. The test was started at the completion of a thermostat cycle; namely, when the water in the tank had been heated to 150 F ± 3.0 F. At this time the initial readings were recorded. After an interval of at least 48 hr a final reading was recorded, again at the completion of a thermostat cycle. From these data the test results, shown in Table 9, were determined.*

From the tabulated results it can be seen that, on the average, the stand-by loss in Btu per 24-hr day for the gas water heaters is about two and one-half times that for the electric heaters.

* The stand-by loss (%/Hour) was calculated by means of the following expression:

$$S = \frac{H}{8.333 \times \Delta t \times V \times L} \times 100$$

where

S = stand-by loss, % per hour
H = total gas consumption, Btu/test
Δt = temperature difference between room and hot water stored
V = capacity of storage vessel, gal
L = duration of stand-by period, hr

Fundamentals of Domestic Gas Water Heating. Bulletin No. 9, American Gas Association Testing Laboratories, January 1940, Chapter VI, page 147.

Table 9
Results of Stand-by Studies

Heat input required to maintain tank filled with hot water with no withdrawals for a 24-hr period

	Gas Water Heaters						Electric Water Heaters						
	A	B	C	D	E	F	G	H	J	K	L	M	N
1. Actual Tank Capacity (gal)	18.5	28.5	52.9	28.3	30.9	23.3	28.5	50.2	50.3	64.2	64.2	80.2	80.2
2. Stand-by loss (Btu/24-hr Day)	19100	17900	27600	25900	22400	25100	7830	7950	12600	6690	7080	10500	11300
3. Stand-by Loss (%/hr)	7.63	4.84	3.77	6.35	5.44	7.76	1.97	1.17	1.82	0.74	0.81	0.94	0.99

VII. GENERAL CONCLUSIONS

The following general conclusions may be drawn from the results of this investigation:

1) For both the 1-hr and 2-hr capacity tests, Series I Tests and Series II Tests, the average energy input per gallon of equivalent delivery of 90 F temperature rise water was about 1000 Btu and 800 Btu, respectively, for the gas and electric water heaters. The average recovery efficiencies for 1-hr and 2-hr tests ranged from 69.9 to 81.1% for the gas water heaters and from 91.0 to 94.9 percent for the electric water heaters.

2) Over the range of daily usage rates of from 50 to 160 gal per day, the service efficiencies of the gas water heaters were 48 to 70% and those of the electric water heaters were 77 to 96%.

3) The energy ratio, or the ratio of the average of the energy inputs of all of the gas water heaters compared with the average of the energy inputs of all of the electric water heaters, varied with the daily usage rate. For daily usage rates of 50, 100 and 150 gal, energy ratios were 1.60, 1.46 and 1.41.

4) The energy input required to heat 1 gal of water from 60 F to 150 F varied with each water heater, but in all cases it decreased with increased daily usage rates. For daily usage rates of 50, 100 and 150 gal, the average of these energy inputs for the gas water heaters were 1400, 1200 and 1100 Btu, and for the electric water heaters 880, 830 and 800 Btu. These values may be compared with the actual quantity of energy, 750 Btu required to heat 1 gal of water from 60 to 150 F. For these same daily usage rates, the average energy inputs per degree gallon for the gas water heaters were 15.5, 13.4 and 12.5 Btu and for the electric water heaters 9.75, 9.20 and 8.85 Btu. These may be compared with an actual energy requirement of 8.33 Btu per degree-gallon.

5) The maximum daily usage rates were determined and are shown in Table 5 for each heater as the highest actual delivery under each withdrawal schedule.

6) All of the gas water heaters, except Heater A, supplied sufficient hot water (above 120 F) withdrawn in accordance with the requirements of four consecutive complete operating cycles of a representative automatic clothes washing machine. Electric water heaters L, M and N also met these hot water requirements, but electric water heaters G, H, J and K did not. However, heater L met the requirements by the narrowest of margins as the last rinse water average temperature was 120 F and the wash water average temperature was 125.3 F. It would therefore be questionable whether heater L would prove satisfactory in household usage.

7) The stand-by losses, expressed as heat input in Btu per 24-hr day with no water drawn, ranged from 17,900 to 27,600 Btu for the gas water heaters and from 6690 to 12,600 Btu for the electric water heaters.

The results, as given in the tables, are in all cases the average of a minimum of two test runs that agree within ± 2 percent. For this reason the sample calculations, as shown in Appendices A through F, will not show the actual values as found in the tabulated results. In Appendix G will be found an aid for the home owner in determining the required size heater and the approximate cost of operation for this heater.

APPENDIX A: SAMPLE DATA SHEET AND CALCULATIONS FOR CAPACITY STUDIES FOR ONE-HOUR PERIOD (Table 2)

GAS WATER HEATER "C"

Rate 5 gpm
Date: December 17, 1952

	Start	*½ Hour*	*1 Hour*	*Recovery*
1. Inlet Water	56.7 F			
2. Inlet Air	64.9 F			
3. Outlet Air	72.3 F			
4. Room	74.0 F			
5. Top of Tank No. 8	148.8 F			
6. Water Meter	16421.4	16473.7	16522.0	
7. Gas Meter	421.65			507.87
8. Gas Line Pressure	7.0			
9. Gas Heater Pressure	7.0			

Item 1. Actual tank capacity: Measured in laboratory—52.9 gal

Item 2. Initial draw-water above 120 F (gal): Difference between second and first water meter reading, $16473.7-16421.4=52.3$ gal

Item 3. Total water above 120 F delivered (gal): Difference between final and initial water meter reading, $16522.0-16421.4=100.6$ gal

Item 4. Usable hot water (deg-gal): Sum of gallons delivered per withdrawal times average temperature of delivered water minus 120 F

First withdrawal:
- Delivery—52.3 gal
- Average temperature of delivered water — 142.7 F
- Degree-gallons — $52.3\times(142.7-120)=1187$

Second withdrawal:
- Delivery — 48.3 gal
- Average temperature of delivered water — 129.2 F
- Degree-gallons — $48.3\times(129.2-120)=444$

Usable hot water $=1187+444=1631$ deg-gal above 120 F

Item 5. Recovery efficiency: Ratio of heat utilized to heat input

Heat utilized $=8.333\times$sum of (gallons delivered per withdrawal times average temperature of delivered water minus inlet water temperature)

First withdrawal: $52.3\times(142.7-56.7)=4497.8$

Second withdrawal: $48.3\times(129.2-56.7)=3501.8$

Total: $7999\times8.333=66660$ Btu/test

Heat input: Higher heating value$\times$gas consumption$\times$correction factors — $971.9\times86.22\times0.958=80{,}280$ Btu/test

Correction for stored heat in water in tank due to difference in initial tank temperature and tank temperature after recovery = 0 Btu due to zero temperature difference between tank temperature at start of test and tank temperatures at recovery

$$\text{Recovery efficiency}=\frac{66660}{80280}=83.0\%$$

Item 6. Equivalent delivery for 90 F temperature rise (gal/hr):

$$\text{Test delivery} \times \frac{\text{average temp rise}}{90}$$

$$100.6 \times \frac{79.5}{90} = 88.9 \text{ gal}$$

Item 7. Heat input per gallon of equivalent delivery (Btu/gal):
Corrected heat input: 80,280 Btu/test
Equivalent delivery: 88.9 gal

$$\text{Heat input per gallon of equivalent delivery} = \frac{80,280}{88.9} = 903 \text{ Btu/gal}$$

ELECTRIC WATER HEATER "L"

Rate 5 gpm
Date: March 27, 1953

	Start	½ Hour	1 Hour	Recovery
1. Thermostat — Inside				
Top off	152.3 F			
Bottom off	150.0 F			
2. Inlet Water	58.3 F			
3. Inlet Air	74.4 F			
4. Outlet Air	73.5 F			
5. Room	75.5 F			
6. Top of Tank No. 8	152.3 F			
7. Water Meter	26188.7	26251.9		
8. Electric Meter				
Top	651.70			656.11
Bottom	482.26			493.29
9. Clock Time				
Top	1 hr 40 min			
Bottom	5 hr 24 min			

Item 1. Actual tank capacity: Measured in laboratory — 64.2 gal

Item 2. Initial draw-water above 120 F (gal): Difference between second and first water meter reading, $26251.9 - 26188.7 = 63.2$ gal

Item 3. Total water above 120 F delivered (gal): Difference between final and initial water meter reading, $26251.9 - 26188.7 = 63.2$ gal

Item 4. Usable hot water (deg-gal): Average temperature of delivered water minus 120 F $= 149.4 - 120 = 29.4$ F
Usable hot water $= 29.4 \times 63.2 = 1860$ deg gal above 120 F

Item 5. Recovery efficiency: Ratio of heat utilized to heat input
Heat utilized $= 8.333 \times 63.2 \times (149.4 - 58.3) = 48,000$ Btu
Heat input = Corrected power consumption $\times 3413$
$(15.44 - 0.17) \times 3413 = 15.27 \times 3413 = 52,100$
Correction for stored heat in tank = -447 Btu due to 0.8 F temperature increase between tank temperature at start of test and tank temperature at recovery

$$\text{Recovery efficiency} = \frac{48,000}{52,100 - 447} = 92.8\%$$

Item 6. Equivalent delivery for 90 F temperature rise (gal/hr): $63.2 \times \frac{91.1}{90} = 64.0$ gal

Item 7. Heat input per gallon of equivalent delivery: $\frac{51,650}{64.0} = 808$ Btu/gal

APPENDIX B: SAMPLE DATA SHEET AND CALCULATIONS FOR CAPACITY STUDIES FOR TWO-HOUR PERIOD (Table 3)

GAS HEATER "C"

Rate 5 gpm

Date: December 29, 1952

	Start	*½ Hour*	*1 Hour*	*1½ Hour*	*2 Hour*	*Recovery*
1. Inlet Water	56.1 F		56.5 F		56.3	
2. Inlet Air	74.4 F		74.2 F			
3. Outlet Air	71.5 F		72.6 F			
4. Room	74.3 F		75.1 F			
5. Top of Tank No. 8	149.7 F					
6. Water Meter	17367.0	17419.2	17467.5		17517.0	
7. Gas Meter	1746.35					1877.38
8. Gas Line Pressure	7.0					
9. Gas Heater Pressure	7.0					

Item 1. Actual tank capacity: Measured in laboratory — 52.9 gal

Item 2. Initial draw-water above 120 F (gal): Difference between second and first water meter reading, 17419.2 − 17367.0 = 52.2 gal

Item 3. Total water above 120 F delivered: Difference between final and initial water meter reading, 17517.0 − 17367.0 = 150.0 gal

Item 4. Usable hot water (deg-gal):

First withdrawal
- Delivery — 52.2 gal
- Average temp of delivered water — 146.2 F
- Degree-gallons — 52.2 (146.2 − 120) = 1370

Second withdrawal
- Delivery — 48.3 gal
- Average temp of delivered water — 127.6 F
- Degree-gallons — 48.3 (127.6 − 120) = 370

Third withdrawal
- Delivery — 49.5 gal
- Average temp of delivered water — 130.3 F
- Degree-gallons — 49.5 (130.3 − 120) = 510

Usable hot water = 1370 + 370 + 510 = 2250 deg-gal above 120 F

Item 5. Recovery efficiency:

Heat utilized:

First withdrawal: 52.2 (146.2 − 56.1) = 4700

Second withdrawal: 48.3 (127.6 − 56.5) = 3430

Third withdrawal: 49.5 (130.3 − 56.3) = 3670

11,800 × 8.333 = 98.300 Btu

Heat input: 131.03 × 974.8 × 0.958 = 122,400 Btu

Correction for stored heat in water in tank = +1100 due to 2.1 F temperature decrease between tank temperature at start of test and tank temperature at recovery

$$\text{Recovery efficiency} = \frac{98{,}300}{122{,}400 + 1100} = 79.6\%$$

Item 6. Equivalent delivery for 90 F temperature rise (gal/test): $150.0\times\frac{78.7}{90}=131$ gal per test

Item 7. Heat input per gallon of equivalent delivery (Btu/gal): $\frac{122{,}400+1100}{131}=942$ Btu/gal

ELECTRIC WATER HEATER "L"

Rate 5 gpm

Date: August 5, 1953

	Start	½ Hour	1 Hour	1½ Hour	2 Hour	Recovery
1. Thermostat — Inside						
Top off	150.3 F					
Bottom off	150.0 F					
2. Inlet Water	58.3 F				57.1	
3. Inlet Air	66.1 F					
4. Outlet Air	75.7 F					
5. Room	75.2 F					
6. Top of Tank No. 8	150.0 F					
7. Water Meter	29502.8		29566.4		29591.2	
8. Electric Meter						
Top	235.59					243.35
Bottom	896.11					908.40
9. Clock Time						
Top	2 hr 57 min					
Bottom	5 hr 56 min					

Item 1. Actual tank capacity: Measured in laboratory — 64.2 gal

Item 2. Initial draw-water above 120 F (gal): Difference between second and first water meter reading, $29566.4-29502.8=63.6$ gal

Item 3. Total water above 120 F delivered (gal): Difference between final and initial water meter reading, $29591.2-29502.8=88.4$ gal

Item 4. Usable hot water (deg-gal):

First withdrawal:
- Delivery — 63.6 gal
- Average temperature of delivered water — 147.6
- Degree-gallons — $63.6\ (147.6-120)=1760$

Second withdrawal:
- Delivery — 24.8 gal
- Average temperature of delivered water — 139.0
- Degree-gallons — $24.8\ (139.0-120)=470$

Usable hot water $=1760+470=2230$ deg-gal above 120 F

Item 5. Recovery efficiency:

Heat utilized:

First withdrawal: $63.6\times(147.6-58.3)=5680$

Second withdrawal: $24.8\times(139.0-57.1)=\underline{2030}$

$$7710\times8.333=64{,}200$$

Heat input: $(20.05-0.21)\times3413=67{,}700$

Correction for stored heat in tank $=+670$ due to 1.2 F decrease between tank temperature at start of test and tank temperature at recovery

$$\text{Recovery efficiency}=\frac{64{,}200}{67{,}700+670}=94.0\%$$

Item 6. Equivalent delivery: $88.4\times\frac{87.2}{90.0}=85.7$ gal

Item 7. Heat input per gallon of equivalent delivery: $\frac{67{,}700+670}{85.7}=798$ Btu/gal

APPENDIX C: SAMPLE DATA SHEETS AND CALCULATIONS FOR DAILY USAGE STUDIES (Table 5)

GAS WATER HEATER "C"

Schedule "B"

Rate 5 gpm

Date: January 21, 1953

Total Daily: 100+9

Time of Day	*Withdrawal "B"* %	*Withdrawal* *gal*
6:30 a.m.	11	11.0
7:30	5	5.0
8:00	17+3 gal	20.0
9:00	14+3 gal	17.0
10:00	13+3 gal	16.0
11:00	4	4.0
12:00 noon	4	4.0
1:00 p.m.	7	7.0
5:00	3	3.0
6:00	4	4.0
7:30	5	5.0
10:30	13	13.0
	100%+9 gal	Total 109.0

1. Thermostat
   On 126.4 F   Off 150.9 F
2. Inlet Water   58.4 F
3. Room   75.9 F
4. Top of Tank No. 8   151.5 F
5. Inlet Air   75.9 F
6. Outlet Air   74.0 F
7. Water Meter Reading   20579.4–20688.4
8. Gas Meter Reading   5883.89–6036.68
9. Gas Line Pressure   7.0
10. Gas Heater Pressure   7.0

Item 1. Daily usage rate (gal/day): 100 gal per day plus 3 additions of 3 gal each

Item 2. Actual delivery (gal/day): 109 gal per day

Item 3. Heat input (Btu/day):

Heat input from start of test until recovery after final drawoff:

$=$ Gas consumption $\times$ correction factor $\times$ higher heating value

$=(6036.68-5883.89)\times 0.955\times 981.7=143{,}150$ Btu

Correction for stored heat in tank = -2670 Btu due to 4.9 F temperature increase between tank temperature at start of test and tank temperature at recovery

Item 3 (Cont.)

Heat input while tank is on stand-by: (7.5 hr from recorder)
$= 7.5 \text{ hours} \times 1150 \text{ Btu/hr} = +8630 \text{ Btu}$

Total heat input $= 143{,}150 - 2670 + 8630 = 149{,}100$

Corrected for 90 F temperature rise $= 149{,}100 \times \frac{90}{105} = 127{,}900$ Btu/day (105 F is average temperature rise between inlet and withdrawal water temperature)

Item 4. Service efficiency by test: Ratio of heat to water for daily consumption compared to heat input in 24-hr day

Heat to water $= 8.333 \times 109 \times 90 = 81{,}700$ Btu/day

Heat input – from Item 3 $= 127{,}900$ Btu/day

Service efficiency $= \frac{81{,}700}{127{,}900} \times 100 = 63.9\%$

Item 5. Degree-gallons delivered: $90 \times 109 = 9810$ deg-gal

Item 6. Btu input per degree-gallon delivered: $\frac{\text{Item 3}}{\text{Item 5}} = \frac{127{,}900}{9810} = 13.0$ Btu per deg-gal

Electric Water Heater "L"

Schedule "A"

Rate 5 gpm

Date: April 2, 1953

Total Daily: 160

Time of Day	*Withdrawal "A"* %	*Withdrawal* *gal*
6:30 a.m.	11	17.6
7:30	5	8.0
8:00	17	27.2
9:00	14	22.4
10:00	13	20.8
11:00	4	6.4
12:00 noon	4	6.4
1:00 p.m.	7	11.2
5:00	3	4.8
6:00	4	6.4
7:30	5	8.0
10:30	13	20.8
	100%	Total 160.0

1. Thermostat	
Top off	150.3 F
Bottom off	150.9 F
2. Inlet Water	58.7 F
3. Room	76.1 F
4. Top of Tank	150.9 F
5. Inlet Air	76.1 F
6. Outlet Air	76.1 F
7. Water Meter Reading	26795.9–26955.9
8. Electric Meter Reading	
Top	679.90–688.98
Bottom	600.12–629.46
9. Clock Time	
Top	3 hr 26 min
Bottom	17 hr 48 min

Item 1. Daily usage rate (gal/day): 160 gal per day

Item 2. Actual delivery (gal/day): 160 gal per day

Item 3. Heat input (Btu/day):

Heat input from start of test until recovery after final draw-off:

$= \text{corrected meter reading} \times 3413 = (38.42 - 0.42) \times 3413 = 129{,}680$ Btu/day

Correction for stored heat in tank $= -670$ Btu/day due to 1.2 F temperature increase between tank temperature at start of test and tank temperature at recovery

Heat input while tank is on stand-by $= 5.33 \text{ hr} \times 29.5 \text{ Btu/hr} = 1570$ Btu/day

Total heat input $= 129{,}680 - 670 + 1570 = 130{,}580$ Btu/day

Corrected for 90 F temperature rise $= 130{,}580 \times \frac{90}{92.3} = 127{,}300$ Btu/day (92.3 F is average temperature rise between inlet and withdrawal water temperature)

Item 4. Service efficiency by test: as above

Heat to water $= 8.333 \times 160 \times 90 = 120{,}000$ Btu/day

Heat input — from Item 3 $= 127{,}300$ Btu/day

Service efficiency $= \frac{120{,}000}{127{,}300} = 94.2\%$

Item 5. Degree-gallons delivered: $90 \times 160 = 14{,}400$ deg-gal

Item 6. Btu input per degree-gallon: $\frac{\text{Item 3}}{\text{Item 5}} = \frac{127{,}300}{14{,}400} = 8.85$ Btu per deg-gal

APPENDIX D: SAMPLE DATA SHEETS AND CALCULATIONS FOR DAILY USAGE STUDIES (Table 6)

See data sheet for the gas water heater given in Appendix C.

GAS WATER HEATER "C"

Schedule "B"

109 gal per day

Item 1. Actual capacity (gal): Measured in laboratory — 52.9 gal

Item 2. Average output (Btu/day): $8.333 \times 90 \times 109 = 81{,}700$ Btu/day

Item 3. Heat input (Btu/day): Same as Item 3, Appendix C $= 127{,}900$ Btu/day

Item 4. Service efficiency by test: Same as Item 4, Appendix C $= 63.9\%$

Item 5. Degree-gallons delivered: Same as Item 5, Appendix C $= 9810$ deg-gal

Item 6. Btu input per degree-gallon delivered: Same as Item 6, Appendix C $= 13.0$ Btu per deg-gal

Sample calculations for the electric water heater are similar to those in Appendix C, Table 5

APPENDIX E: SAMPLE DATA SHEET AND CALCULATIONS FOR AUTOMATIC CLOTHES WASHING MACHINE STUDIES (Table 8)

GAS WATER HEATER "C"

Rate 5 gpm

Date: December 24, 1952

Cycle 1			*Cycle 2*			*Cycle 3*			*Cycle 4*		
Time		Draw-Off	Time		Draw-Off	Time		Draw-Off	Time		Draw-Off
0 – 5	8:10	0	0 – 5	8:55	0	0 – 5	9:40	0	0 – 5	10:25	0
5 –15	8:15	4.00	5 –15	9:00	4.00	5 –15	9:45	4.00	5 –15	10:30	4.00
15–27	8:25	8.00	15–27	9:10	8.00	15–27	9:55	8.00	15–27	10:40	8.00
27–28	8:37	2.50	27–28	9:22	2.50	27–28	10:07	2.50	27–28	10:52	2.50
28–35	8:38	4.00	28–35	9:23	4.00	28–35	10:08	4.00	25–35	10:53	4.00
35–41	8:45	4.00	35–41	9:30	4.00	35–41	10:15	4.00	35–41	11:00	4.00
41–45	8:51	0	41–45	9:36	0	41–45	10:21	0	41–45	11:06	0

1. Thermostat	
On	126.7 F
Off	148.6 F
2. Inlet Water	56.9 F
3. Room	74.8 F
4. Top of Tank No. 8	150.0 F
5. Inlet Air	73.2 F
6. Outlet Air	74.8 F
7. Water Meter Reading	17082.5–17165.3
8. Gas Meter Reading	1292.75–1403.37
9. Gas Line Pressure	7.0
10. Gas Heater Pressure	7.0

Item 1. Actual tank capacity (gal): Measured in laboratory — 52.9 gal

Item 2. Inlet water temperature (deg F): As recorded on temperature recorder — 56.9 F

Item 3. Wash water temperature (deg F): As recorded on temperature recorder:
Cycle 1 = 154.6 F; Cycle 2 = 165.3 F; Cycle 3 = 171.9 F; Cycle 4 = 174.3 F

Item 4. Input per test (Btu): Differential gas meter reading × correction factor × higher heating
Value stored heat corrections = $(1403.37 - 1292.75) \times 0.963 \times 974.8 = 103{,}800$ Btu/test
Correction for stored heat in tank = −3300 Btu/test due to 6.1 F temperature increase between tank temperature at start of test and tank temperature at recovery
Heat input = 100,500 Btu/test

Item 5. Input per cycle (Btu): $\frac{\text{Item 4}}{\text{Number of Complete Cycles}} = \frac{100{,}500}{4} = 25{,}100$ Btu per cycle

ELECTRIC WATER HEATER "L"

Rate 5 gpm

Date: March 30, 1953

Cycle 1			*Cycle 2*			*Cycle 3*			*Cycle 4*		
Time		Draw-Off	Time		Draw-Off	Time		Draw-Off	Time		Draw-Off
0 – 5	11:50	0	0 – 5	12:35	0	0 – 5	1:20	0	0 – 5	2:05	0
5 –15	11:55	4.00	5 –15	12:40	4.00	5 –15	1:25	4.00	5 –15	2:10	4.00
15–27	12:05	8.00	15–27	12:50	8.00	15–27	1:35	8.00	15–27	2:20	8.00
27–28	12:17	2.50	27–28	1:02	2.50	27–28	1:47	2.50	27–28	2:32	2.50
28–35	12:18	4.00	28–35	1:03	4.00	28–35	1:48	4.00	28–35	2:33	4.00
35–41	12:25	4.00	35–41	1:10	4.00	35–41	1:55	4.00	35–41	2:40	4.00
41–45	12:31	0	41–45	1:16	0	41–45	2:01	0	41–45	2:46	0

1. Inlet Water	56.7 F
2. Room	74.3 F
3. Top of Tank No. 8	149.1 F
4. Inlet Air	65.5 F
5. Outlet Air	74.3 F
6. Water Meter Reading	26377.2–26460.0
7. Electric Meter Reading	
Top	659.45–664.23
Bottom	524.23–537.75
8. Clock Time	
Top	1 hr 48 min
Bottom	6 hr 37 min

Item 1. Actual tank capacity (gal): Measured in laboratory — 64.2 gal

Item 2. Inlet water temperature (deg F): As recorded on temperature recorder — 56.7 F

Item 3. Wash water temperature (deg F): As recorded on temperature recorder:
Cycle 1 = 148.4 F; Cycle 2 = 148.0 F; Cycle 3 = 146.4 F; Cycle 4 = 125.3 F

Item 4. Input per test (Btu): Corrected power consumption × 3413 − stored heat correction
= (18.30 − 0.20) 3413 = 61,800 Btu per test

Correction for stored heat in tank = −1400 Btu/test due to 2.5 F temperature increase between tank temperature at start of test and tank temperature at recovery

Heat input = 60,400 Btu/test

Item 5. Input per cycle (Btu): $\frac{\text{Item 4}}{\text{Number of Complete Cycles}} = \frac{60{,}400}{4} = 15{,}100$ Btu per cycle

APPENDIX F: SAMPLE DATA SHEETS AND CALCULATIONS FOR STAND-BY STUDIES (Table 9)

GAS WATER HEATER "C"

Date: January 3-4-5, 1953	*Start* *8:00 a.m.*	*24 Hour* *8:00 a.m.*	*48 Hour* *8:00 a.m.*	*Recovery* *55 Hour* *3:00 p.m.*
1. Gas Meter Reading	2651.08	2675.80	2708.40	2718.62
2. Gas Meter Temp	75 F	74.8 F	75 F	74.6 F
3. Gas Line Pressure	7.0	7.0	7.0	7.0
4. Gas Heater Pressure	7.0	7.0	7.0	7.0
5. Water Meter Reading	18103.0	18103.0	18103.0	18103.0
6. Readings on K_2 Potentiometer				
1. Thermostat	149.2 F	138.2 F	148.2 F	149.0 F
2. Top of Tank No. 8	151.1 F	142.8 F	148.7 F	
3. Room	74.8 F	76.8 F	73.8 F	74.0 F

Item 1. Actual tank capacity: Measured in laboratory — 52.9 gal

Item 2. Stand-by loss (Btu/24-hr day)

Gas consumption: 67.54 ft³

Elapsed time: 55.0 hr

Gas consumption: $\frac{67.54}{55.0} \times 24.0 = 29.47$ ft³/day

Gas consumption: $29.47 \times C_f = 28.06$ Std ft³/day

H.H.V. fuel (saturated): 984.7 Btu/ft³

Heat input: $28.06 \times 984.7 = 27{,}600$ Btu/day

Item 3. Stand-by loss (%/hr)

$$S = \frac{H}{8.333 \times \Delta t \times V \times L} \times 100$$

H = heat input, Btu/day: 27,600 (Item 2)

Δt = temperature difference between room and hot water stored

Average tank water temperature read from recorder: 144.3 F

Average room temperature read from recorder: 75.0 F

$\Delta t = 69.3$ F

V = capacity of storage vessel: 52.9 gal (Item 1)

L = duration of stand-by period: 24 hr

$$S = \frac{27{,}600}{8.333 \times 69.3 \times 52.9 \times 24} \times 100 = 3.77\%$$

ELECTRIC WATER HEATER "L"

Date: April 11-13, 1953	*Start* *7:50 a.m.*	*24 Hour* *7:50 a.m.*	*48 Hour* *7:50 a.m.*	*Recovery* *57.6 Hour* *5:26 p.m.*
1. Electric Meter Reading				
Top	724.38	724.38	724.38	724.38
Bottom	802.48	804.23	806.52	807.60
2. Clock Time				
Top	0:0	0:0	0:0	0:0
Bottom	0:0	0:51	1:59	2:30
3. Water Meter Reading	27810.0	27810.0	27810.0	27810.0
4. Readings on K_2				
1. Thermostat — Inside				
Top	149.2 F	146.7 F	147.2 F	148.4 F
Bottom	148.7 F	146.3 F	146.4 F	147.8 F
2. Top of Tank No. 8	149.2 F	146.5 F	146.9 F	148.4 F
3. Room	76.4 F	76.6 F	75.2 F	76.2 F

Item 1. Actual tank capacity: Measured in laboratory — 64.2 gal

Item 2. Stand-by loss (Btu/24 hr day)
Corrected power consumption: 5.06 Kw Hr
Elapsed time: 57.6 hr

Heat input: $\frac{5.06}{57.6} \times 24 \times 3413 = 7200$ Btu/day

Item 3. Stand-by loss (%/hr)

$$S = \frac{H}{8.333 \times \Delta t \times V \times L} \times 100$$

H = heat input, Btu/day: 7200 (Item 2)
Δt = temperature difference between room and hot water stored as determined for gas water heaters: $\Delta t = 68.4$ F
V = capacity of stored vessel: 64.2 gal (Item 1)
L = duration of stand-by period: 24 hr

$$S = \frac{7200}{8.333 \times 68.4 \times 64.2 \times 24} \times 100 = 0.82\%$$

APPENDIX G: SELECTION OF HOT WATER HEATERS

In selecting a water heater for a given home and family, a number of factors should be taken into consideration. For the purpose of this study it is assumed that both sources of energy (gas and electricity) are readily available, that material used in the tank meets water conditions in the locale, that adequate space and ventilating facilities are available and that the initial costs of the heaters, including installation, are competitive.

There then remains the amount of hot water required and the cost to heat the water to the required temperature.

One must know the following in order to determine the total water required:

1. Number of consecutive automatic clothes washer cycles expected.

2. Maximum daily consumption expected on most critical day (wash day) based on following quantities of hot water reportedly required:

Tub bath	15 gal
Shower	3 gal/min
Dishwasher (automatic)	7 gal/load
Dishwashing (hand)	3 gal/meal
Personal toilet	2 gal/person/day
Washing machines, conventional type	17.5 gal/load
Washing machines, automatic cycle type	20.7 gal/load

Assuming the maximum clothes washing required would be three consecutive loads, the Heaters A and G would automatically be out. Heaters H and J would do, but would not be too satisfactory (see Table 8). Then determine required additional hot water based on above table. Let us assume:

2 Tub baths	30 gal
1 Shower, 5 minutes	15 gal
2 Automatic dishwasher loads	14 gal
Personal toilet	8 gal
3 Automatic clothes washer loads	62.1 gal
TOTAL	129.1 gal/day

From this total requirement one could eliminate Heaters A, G, H, and J. Any of the other heaters should be satisfactory and supply enough hot water to satisfy the above demands (Tables 5 and 6).

In order to estimate the monthly operating cost using gas or electricity, it is necessary to estimate in a similar manner the *average daily* hot water requirement. Such an average could probably best be obtained by prorating over a 7-day period the number of gallons of water used for clothes washing on the laundry day or days and adding this figure to the normal daily hot water requirements for personal and household uses. Using this resultant average gallons per day figure and knowing the gas rate in cents per therm (100,000 Btu) and the electric rate in cents per kilowatt hour (3413 Btu) Figures E and F of the abstract can be used to obtain the monthly gas and electric costs.

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