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Performance of Three Types of Indirect Water Heaters

by

Warren S. Harris

Lyman L. Hill
A REPORT OF AN INVESTIGATION

Conducted by
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

In Cooperation with
THE INSTITUTE OF BOILER AND RADIATOR MANUFACTURERS

Price: Seventy-five Cents
Performance of Three Types of Indirect Water Heaters

by

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ENGINEERING EXPERIMENT STATION BULLETIN NO. 432
ABSTRACT

In homes using steam or hot water as the heating medium it is common practice to supply hot water for domestic use by means of an indirect water heater attached to the house heating boiler. Since performance data on indirect water heaters were very meager, an extensive research program on this type of equipment was initiated in 1942. The first tests were made during the summers of 1942 and 1943 and the winter of 1943-44. These tests were run using an internal storage-type heater located in the house heating boiler and connected by suitable piping to a horizontal, insulated, 30-gal hot water storage tank. The boiler was oil fired. Operating characteristics for this system, the value of insulating the piping between the heater and the storage tank, and the fuel consumption for both summer and winter operation are discussed in University of Illinois Engineering Experiment Station Bulletin No. 366.

Bulletin No. 432 deals with domestic hot water heater tests which have been run since the publication of Bulletin No. 366. The program included tests on an external tankless heater and on both external and internal storage type heaters. All of the heaters were used in conjunction with the gas-fired house heating boiler in the I=B=R Research Home. The two storage-type heaters were tested with both 30- and 66-gal horizontal hot water storage tanks. In addition, the internal storage-type heater was connected by various piping arrangements to the 30-gal storage tank mounted in the vertical position.

The basic objectives of the test program were to determine the availability of hot water and the cost of heating water for each of three types of indirect water heaters under both summer and winter conditions of operation.

Concerning the availability of hot water, tests were designed to determine:
(a) The maximum quantity of hot water that could be continuously drawn off at any one time
(b) The rate of recovery
(c) The ability of the heater to meet severe short-period demands for hot water such as occasioned by the use of an automatic washing machine
(d) The operating characteristics of each heater under service conditions similar to family usage.

In analyzing the cost of heating water, it was desirable to break the fuel consumption down into its component parts and to determine the daily fuel consumption chargeable to:
(a) Heat loss from the boiler
(b) Heat loss from the heater, storage tank, and piping
(c) Actual heating of various quantities of hot water.

The bulletin contains a discussion of factors related to each of these items as well as a discussion of the relationships between tankless heater size, water content of the boiler, and the required minimum heat input to the boiler to supply given quantities of hot water at one time. A few of the more important conclusions expressed in the bulletin are:
(1) The rate of heating water by indirect storage heaters was dependent upon the size of the heater and the difference between the boiler water temperature and the temperature of the water entering the heater, but was independent of the control setting. As would be expected, the water in the 30-gal tank increased in temperature at a more rapid rate than did the water in the 66-gal tank. However, the output of the heater in Btuh was essentially unaffected by the tank size.
(2) The recovery rate of the indirect storage-type heater was greatly reduced if rust or sediment was permitted to accumulate in the heater or piping. After four weeks operation without flushing, the recovery rate of the heater was reduced by 27 percent and after eight weeks by 40 percent. Flushing the heater and piping restored normal output. Possibly the observed reduction in recovery rate with continued operation without flushing would
not have occurred had the water supply been soft; however, the tests indicate that at least under certain conditions, the recovery rate of an indirect storage-type heater may be greatly reduced unless the piping and heater are flushed at regular intervals to remove any accumulation of foreign material.

(3) A tabular summary of the effect of the control setting, the storage tank size, and the inlet water temperature on the maximum number of tubs of clothes which could be washed in succession in an automatic washing machine is shown below.

<table>
<thead>
<tr>
<th>Number of Automatic Washer Cycles Before Temperature of Water Drawn Dropped (Below Indicated Minimum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Setting Cold Water (Boiler Water Supply Temp.)</td>
</tr>
<tr>
<td>Temp. (F)</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>185</td>
</tr>
<tr>
<td>165</td>
</tr>
<tr>
<td>140</td>
</tr>
</tbody>
</table>

The automatic washing machine represents one of the largest demands for hot water normally encountered in the home. Since there is some difference in opinion as to the minimum usable water temperature for washing clothes, tests were run to determine the number of wash cycles that could be completed before the temperature of the water drawn dropped below both 125°F and 140°F.

(4) During the winter the main load on the boiler was the house heating load, and a large portion of the heat escaping from the surfaces of the boiler, the chimney, the water heater, the storage tank and the piping (which was lost heat as far as summer operation was concerned) was utilized in supplying heat to the house. Accordingly, it was necessary to determine the portion of the winter fuel consumption actually chargeable to heating water under various conditions of operation. In summer the only function of the boiler was to supply heat for domestic water heating, and therefore, all summer fuel consumption was chargeable to the cost of providing hot water. A summary of the fuel consumptions chargeable to heating domestic hot water is given in the table below.

<table>
<thead>
<tr>
<th>DISTRIBUTION OF AVERAGE OUTDOOR TEMPERATURES AND CORRESPONDING FUEL CONSUMPTION CHARGEABLE TO HEATING WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>Cold Water = 140 F;</td>
</tr>
<tr>
<td>-10 to -30</td>
</tr>
<tr>
<td>30 to 35</td>
</tr>
<tr>
<td>35 to 40</td>
</tr>
<tr>
<td>40 to 45</td>
</tr>
<tr>
<td>45 to 50</td>
</tr>
<tr>
<td>50 to 55</td>
</tr>
<tr>
<td>55 to 60</td>
</tr>
<tr>
<td>60 to 65</td>
</tr>
<tr>
<td>65 to 70</td>
</tr>
<tr>
<td>Winter Total</td>
</tr>
<tr>
<td>Summer Total</td>
</tr>
<tr>
<td>Yearly Total</td>
</tr>
</tbody>
</table>

The table is based on a daily hot water usage of 50 gal. It was found that a 10 gal per day increase in hot water usage resulted in a 9 percent increase in fuel consumption.

(5) At a cost of 6 cents per therm (1 therm = 100,000 Btu, or 100 cu ft of the gas used in the tests) the estimated annual fuel consumption chargeable to the storage heater (Col. 5, table above) represented a total cost of $18.94 per year, or an average of $1.58 per month. At a cost of 6 cents per therm for the gas the average monthly cost of operation would be $2.63. At a cost of 6 cents per therm, the yearly cost for the estimated fuel consumption chargeable to the tankless heater (Col. 7, table above) would be $15.25, or an average of $1.27 per month. At 10 cents per therm the average monthly cost would be $2.12.
CONTENTS

I. INTRODUCTION 9
   1. Preliminary Statement 9
   2. Objects of Investigation 10

II. DESCRIPTION OF EQUIPMENT 11
   3. I=B=R Research Home 11
   4. Indirect Water Heating System 11
   5. Control System 12
   6. Instrumentation 13

III. TEST PROCEDURES 14
   7. Stand-by Losses, Boiler Only 14
   8. Stand-by Losses, Entire System 14
   9. Heating Up 14
   10. Continuous Draw-Off 14
   11. Service Draw-Off 15
   12. Automatic Washer Draw-Off 15

IV. WATER TEMPERATURES 16
   13. Storage Water Temperatures, Summer Stand-by Operation 16
   14. Storage Water Temperatures, Winter Stand-by Operation 18
   15. Water Temperatures, Service Conditions 19

V. RECOVERY RATE 22
   16. Recovery Rate, Storage Heaters 22
   17. Importance of Flushing the System, Storage-Type Heaters 23

VI. AVAILABILITY OF HOT WATER 24
   18. Automatic Washer Draw-Off Tests 24
   19. Effect of Tank and Pipe Arrangements 25
   20. Water Available at a Single Draw 28

VII. HEAT LOSSES FROM STORAGE TANKS, CONNECTING PIPING, AND HEATERS 30

VIII. WATER HEATING LOADS 31
   21. Water Heating Load, Storage-Type Heaters 31
   22. Water Heating Load, Tankless Heater 32

IX. FUEL CONSUMPTION 35
   23. Effect of Test Conditions on Fuel Consumption 35
   24. Fuel Consumption, Winter Operation 35
   25. Fuel Consumption, Summer Operation 37
      A. Stand-by 37
      B. Service Conditions: 30-Gal Draw-Off 38
      C. Service Conditions: 75-Gal Draw-Off 39
      D. Effect of Quantity of Water Used on Required Heat Input 39

X. WATER HEATING COSTS 41

XI. SUMMARY OF RESULTS 44
FIGURES

1. I = B = R Research Home 11
2. Schematic Diagram of Test Equipment 12
3. Heaters Used in Tests 12
4. Control System 13
5. Boiler Water Temperatures, Stand-by Operation 17
6. Temperature of Water in Storage Tank, Summer Stand-by Operation 18
7. Temperature of Water in Storage Tank, Winter Operation, Internal Storage-Type Heater 18
8. Water Temperatures in Boiler and Storage Tank, Winter Operation, External Storage-Type Heater 19
9. Graphic Log of Service Draw-Off Test 20
10. Temperature of Water Drawn During Service Draw-Off Tests 21
11. Graphic Log, Typical Recovery Test 22
12. Rate of Heating Water in Storage Tank 23
13. Effect of Sludge on Rate of Heating Water in Storage Tank 23
15. Tank and Pipe Arrangements 26
16. Graphic Log, Typical Continuous Draw-Off Test 28
17. Hot Water Available at Single Draw, Storage-Type Heaters 28
18. Hot Water Available at a Single Draw, Tankless Heater 29
19. Rate of Cooling of Water in Storage Tank 30
20. Heat Losses of Hot Water Storage Tanks and Piping 30
21. Water Heating Load During Heating Up Period 31
22. Total Water Heating Load, Storage Heaters 32
23. Relationship Between Firing Rate, Water Content of Boiler, Heater Size, and Maximum Quantity of Water Drawn at One Time 33
24. Effect of Time Delay on Minimum Firing Rate of Boiler 34
25. Variations in Fuel Consumption Due to Change in Basement Air Temperature 36
FIGURES (Continued)

27. Daily Gas Consumption, Winter Operation — Effect of Low-Limit Control Setting and Quantity of Water Heated 36
29. Daily Gas Consumption for Both Heat and Hot Water 37
30. Stand-by Heat Input Curves, Summer Operation 38
31. Daily Heat Input, Internal and External Storage Heaters 38
32. Effect of Cold Water Supply Temperature on Daily Heat Input, 30 gal/day 38
33. Daily Heat Input, Storage-Type and Tankless Heaters 39
34. Effect of Cold Water Supply Temperature on Daily Heat Input, 75 gal/day 39
35. Daily Heat Input for Summer Operation 40
36. Average Monthly Cost of Heating Water 42
37. Correction Factor to Obtain Cost of Heating Water When Usage Is Other Than 50 Gal per 24 Hr 43

TABLES

1. Service Draw-Off Schedule 15
2. Automatic Washer Draw-Off Schedule 15
3. Number of Washer Cycles Before Temperature of Water Drawn Dropped Below Indicated Minimum 25
4. Comparison of Water Temperatures in Storage Tank During Stand-by 27
5. Distribution of Average Outdoor Temperatures and Corresponding Fuel Consumption Chargeable to Heating Water 41
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I. INTRODUCTION

1. Preliminary Statement

This is the ninth bulletin to be published under a cooperative agreement between the Institute of Boiler and Radiator Manufacturers and the University of Illinois. This agreement was formally approved January 2, 1940. Under the terms of the agreement, the Institute is represented by a Research Committee consisting of engineers active in the heating industry. One of the functions of this committee is to propose such problems for investigation as are of the greatest concern to the manufacturers and installers of steam and hot-water heating equipment. Of these problems, the Engineering Experiment Station staff selects for study those which can best be investigated with the facilities and equipment available at the University. The Institute provides funds for defraying a major part of the expense of the research work.

In homes using steam or hot water as the heating medium, it is becoming common practice to supply hot water for domestic use by means of an indirect water heater attached to the house heating boiler. An indirect water heater is, basically, an exchanger for transferring heat from the boiler water or steam to the domestic water. The heat transfer surface generally consists of some arrangement of coiled or U-shaped copper tubes which are submerged in the boiler water. The domestic water circulates inside the tubes so that the two water circuits are separated and never mix.

Indirect heaters may be classified as to type (storage or tankless), and as to location with reference to the boiler (external or internal). The external heater has the heat transfer coils enclosed in a steel or cast-iron shell located outside the boiler; it thus requires the addition of suitable piping to enable boiler water to circulate over the coils. The internal heater is screwed into or bolted onto the boiler and extends directly into the boiler proper. A storage-type heater requires less coil surface than a tankless heater because a reserve supply of hot water can be stored in the tank against periods of peak demand. A tankless heater, on the other hand, has no storage tank and thus requires a large heat transfer surface in order to provide sufficient hot water to handle maximum load conditions. Tankless-type heaters are not recommended for territories with extremely hard water unless a softener is used.

Since performance data on indirect water heaters were very meager, an extensive research program on this type of equipment was initiated in 1942. The first tests were made during the summers of 1942 and 1943 and the winter of 1943-44. These tests were run using an internal storage-type heater located in the house heating boiler and connected by suitable piping to a horizontal, insulated, 30-gal hot water storage tank. The boiler was oil fired. Operating characteristics for this system, the value of insulating the piping between the heater and the storage tank, and the fuel consumption for both summer and winter operation are discussed in University of Illinois Engineering Experiment Station Bulletin No. 366.

The present bulletin deals with domestic hot water heater tests which have been run since the publication of Bulletin 366. Some tests were made during the summer of 1944, but most of the work was done during the summer of 1948, the winter of 1948-49, and the summers of 1949, 1950, 1951, and 1952. The program included tests on an external tankless heater and on both external and internal storage-type heaters. All of the heaters were used in conjunction with the gas-fired house heating boiler in the I-B-R Research Home. The two storage-type heaters were tested with both 30- and 66-gal horizontal hot water storage tanks. In addition, the internal storage-type heater was connected by various piping arrangements to the 30-gal storage tank mounted in a vertical position.

To the various manufacturers who cooperated by furnishing materials and equipment used in the investigation, acknowledgment is hereby made.
2. Objects of Investigation

The basic objectives of the test program were to determine the availability of hot water and the cost of heating water for each of three types of indirect water heaters under both summer and winter conditions of operation.

Concerning the availability of hot water, tests were designed to determine:

(a) The maximum quantity of hot water that could be continuously drawn off at any one time
(b) The rate of recovery
(c) The ability of each heater to meet severe short period demands for hot water such as occasioned by the use of automatic washing machines
(d) The operating characteristics of each heater under service conditions similar to family usage.

In analyzing the cost of heating water it was desirable to break the fuel consumption down into its component parts and to determine the daily fuel consumption chargeable to:

(a) Heat loss from the boiler
(b) Heat loss from the heater, storage tank, and piping
(c) Actual heating of various quantities of hot water.
II. DESCRIPTION OF EQUIPMENT

3. I=B=R Research Home

The Research Home, shown in Fig. 1, and described in detail in Engineering Experiment Station Bulletin 349, is a two-story building typical of the small, well-built American home of 1940. The construction is brick veneer on wood frame, and all the outside walls and the second-story ceiling are insulated with mineral wool batts 3% in. thick. The total calculated heat loss for the house (excluding basement) is 43,370 Btuh at temperatures of -10 F outdoors and 70 F indoors.

4. Indirect Water Heating System

The domestic water heating system in the Research Home consisted of a gas-fired boiler, an indirect water heater, a water tempering tank, and, in the case of storage-type heaters, a hot water storage tank. A schematic diagram of a typical test setup is shown in Fig. 2.

A dry bottom, cast-iron boiler composed of three 4-in. sections was used in all tests. This boiler was insulated on the front, back, sides and top by a mineral wool blanket 1-in. in thickness and was completely enclosed in an enameled sheet metal jacket. All cracks around the base of the boiler and between sections were sealed with asbestos cement. The boiler was equipped with a conversion-type gas burner, adjusted to a burning rate of approximately 100 cu ft per hr. The fuel was natural gas having a heating value of 1,000 Btu per cu ft.

During the 1948-49 heating season, when winter operation of indirect water heaters was studied, a one-pipe forced circulation, hot water heating system was used in the Research Home. Convectors were used in all rooms of the house.

The three heaters used in the test program are shown in Fig. 3. The internal storage-type heater was of the trombone type consisting of three 31/4-in. copper “U” tubes having a heating surface of a little less than 2 sq ft. The heater extended into the back section of the boiler a distance of 21 in. and was located 4 in. above the level of the low-limit control. Insulated 1-in. pipe connected the heater to the storage tank.

The external storage-type heater consisted of a single, helical, copper coil located within a cast-iron shell measuring 121/2 in. by 71/2 in. Although the heater was located outside the boiler, it was placed at the same level as the internal storage-type heater in order to keep the circulating head and the length of pipe connecting the heaters to the storage tank the same in both cases. Like the internal heater, the heating surface of the coil was about 2 sq ft. The external heater was covered with magnesia insulation to a depth of about 1 in. and was connected to the boiler with insulated 11/4-in. pipe and to the storage tank with 1-in. pipe.

The tankless heater was composed of copper “U”-shaped coils having a heating surface of 14 sq ft, located within a cast-iron shell whose overall dimensions were 111/2 in. by 161/2 in. by 81/2 in. Boiler water circulated to the heater through insulated 2-in. pipe, and 1/2-in. pipe was used on the domestic hot water circuit. The heater was covered with 1 in. of magnesia insulation.

Thirty-gal and 66-gal storage tanks were used in the investigation. The 30-gal tank, 12 in. in diam and 60 in. long, was insulated on the sides with 4-ply corrugated asbestos 1 in. in thickness, and on
the heads with 1 in. of magnesia insulation. The 66-gal tank, 18 in. in diam and 60 in. in length, was similarly insulated except that the depth of the insulation was 1\(\frac{1}{2}\) in. The measured water capacity was 242 lb for the 30-gal tank and 515 lb for the 66-gal tank. With the exception of one study, in which the 30-gal tank was placed in a vertical position near the boiler, the tank being used to store the hot water was suspended in a horizontal position near the basement ceiling.

5. Control System

The operation of the burner and circulator was regulated by means of a conventional set of controls consisting of a room thermostat located in the liv-
ing room, a low-limit control, a high-limit control, a magnetic gas valve, a safety pilot, a transformer, and a relay. The room thermostat was of the heat-anticipating type and was placed 30 in. above the floor. The direct-acting, low-limit control, of the immersion type, was located in the rear section of the boiler approximately 26 in. above the bottom of the water leg. This control started the burner whenever the temperature of the water in the boiler reached a prescribed minimum. The high-limit control, which served to prevent overheating of the water in the boiler, was also of the immersion type and was located in the top of the back section of the boiler. A flow control valve prevented gravity circulation of boiler water through the heating system when the thermostat did not call for heat. A schematic wiring diagram of the control system and the sequence of operations is shown in Fig. 4.

In order to regulate the temperature of the cold water supply, the tempering tank was equipped with a separate control system consisting of an immersion-type water temperature control, a transformer, a relay, and a 250-watt immersion electric heater.

### 6. Instrumentation

Copper constantan thermocouples were used to measure the temperature of the cold water supply, the temperature of the water drawn off, the temperature of the domestic water at the inlet and outlet of the heater, the temperature of the boiler water entering and leaving the heater, and the temperature of the water at different levels in the boiler and in the storage tank. These thermocouple locations are shown in Fig. 2. A central switchboard was located in the basement, and all the thermocouples were connected to selector switches on this board. The electromotive force of each thermocouple could be read quickly on a precision potentiometer in connection with a highly sensitive galvanometer. A 10-point recording potentiometer provided a continuous record of water temperatures at selected points in the system. Water was weighed on platform scales sensitive to 0.01 lb, and the gas consumption was measured by a special test meter reading directly to 0.01 cu ft.
III. TEST PROCEDURES

7. Stand-by Losses, Boiler Only

In order to determine the portion of the total fuel consumption chargeable to heat losses from the boiler and chimney, stand-by tests were made on the boiler with the water heater disconnected. The stand-by tests were approximately 48 hr in length, starting and stopping at the ends of burner on-periods. Low-limit control settings ranging from about 140 F to 200 F were used. The temperatures of the water at the top and bottom of the boiler, and at the level of the temperature control, were continuously recorded as was the temperature of the flue gas at the smoke collar. The observed data included the basement temperature, the total gas consumption for each test, and the total operating time of the burner.

8. Stand-by Losses, Entire System

These tests were made to determine the portion of the total fuel consumption chargeable to heat losses from the heater, the hot water storage tank, and the connecting piping, and were similar to the stand-by tests made on the boiler alone except that the domestic hot water system was connected to the boiler and filled with water. For any given control setting all water temperatures in the system were allowed to stabilize before a test was started, and no hot water was drawn during the test. In addition to the readings taken for the stand-by tests for the boiler only, data taken during these tests included a continuous printed record of the temperature of the boiler water entering and leaving the heater, of the domestic water at the inlet and outlet of the heater, and when using the storage-type heaters, a record of the temperatures of the water at the top and bottom of the storage tank.

9. Heating Up

These tests were made on the storage-type heaters to determine the rate at which the water in the storage tank could be heated, and the maximum load imposed on the boiler by the water heater. The tests were run at several different boiler water temperatures, and the heaters were used in conjunction with both 30- and 66-gal storage tanks. No heating up test was run on the tankless heater as its storage capacity consisted only of the heating coils themselves, and the water in the coils rapidly reached a maximum temperature when water was not being drawn off.

At the beginning of each test the storage tank was filled with water at a temperature of about 60 F. The valve in the piping between the storage tank and the heater outlet was closed to prevent circulation of water through the heater. At the end of a normal burner on-period, the test was started by opening the valve in the line between the outlet of the heater and the storage tank. The test continued until the temperature of the water in the storage tank had reached a maximum. A continuous record was made of the temperature of the water at the top, at the control level, and at the bottom of the boiler. The temperatures of the domestic water at the top and bottom of the storage tank and at the inlet and outlet of the water heater were also continuously recorded.

10. Continuous Draw-Off

For each low-limit control setting, tests were made to determine the maximum quantity of water that could be drawn off before the temperature of the hot water dropped below a specified value. When all water temperatures in the system had become stabilized, a test was started by opening the outlet valve in the hot water line. This valve had previously been adjusted so that water was discharged into the weighing tank at a specified rate — 17, 25, or 40 lb per min. — depending upon the test. By means of thermocouples, the temperature of the water being drawn off was read every 15 sec, and the temperature of the cold water supply was read every minute during the test. The draw-off was continued until the temperature of the hot water
had dropped below 125 F. At the completion of the draw, the total weight of water drawn was recorded, together with the exact time interval required.

11. Service Draw-Off

In order to obtain data necessary for the prediction of the fuel consumption under service conditions, one series of tests was made in which, at various intervals during the day, quantities of hot water were drawn approximating those used in actual service. The three draw-off schedules used are given in Table 1. It is true that the actual demands encountered in service will deviate from the test schedule used. However, other investiga-

Table 1

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Time of Day</th>
<th>Water Drawn Off, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8:00 a.m.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>9:00 a.m.</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>10:00 a.m.</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>11:00 a.m.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>12:00 noon</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>1:00 p.m.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>2:00 p.m.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>3:00 p.m.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>4:00 p.m.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>5:00 p.m.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>6:00 p.m.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>7:00 p.m.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>8:00 p.m.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>9:00 p.m.</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Operation</th>
<th>Water Temperature (F)</th>
<th>Water Used (gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>70</td>
<td>150</td>
</tr>
<tr>
<td>5-15</td>
<td>80</td>
<td>150</td>
</tr>
<tr>
<td>15-25</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>25-28</td>
<td>110</td>
<td>150</td>
</tr>
<tr>
<td>28-35</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>35-41</td>
<td>130</td>
<td>150</td>
</tr>
<tr>
<td>41-45</td>
<td>140</td>
<td>150</td>
</tr>
</tbody>
</table>

* Combined in tests to one draw of 5 gal.

12. Automatic Washer Draw-Off

Since the automatic washing machine makes one of the heaviest demands on a heater, tests were devised in which the water was drawn off at intervals simulating automatic washing machine demands for hot water, both as to quantity and frequency of draw-off. The automatic washer schedule used is given in Table 2. This schedule represents a complete wash cycle from the time the clothes are loaded into the machine until they are taken out damp dry; it was developed from hot water requirements as obtained from several automatic washing machine manufacturers. A test was started at the end of a burner on-period, after it was observed that water temperatures in the system were stabilized. The complete cycle was repeated until the temperature of the hot water was too low to be satisfactory for use, noting the number of washes thus obtained. The temperature of the hot water at the start and end of each draw-off was recorded as was the temperature of the cold water supply. The water used was weighed to the nearest 0.01 lb.

These tests were made at low-limit control settings of 140, 155 and 185 F, and with cold water supply temperatures of both 60 and 80 F. Draw-off rates were 17 and 25 lb per min on the tankless heater, and 40 lb per min on the storage-type heaters. Two storage tank sizes were used with the storage heaters.
IV. WATER TEMPERATURES

13. Storage Water Temperatures, Summer Stand-by Operation

Figure 5 shows water temperatures at three levels in the boiler: (a) with no water heater attached; (b) when using the external tankless heater; (c) when using the external storage-type heater; and (d) when using the internal storage-type heater. These water temperatures were recorded during periods when the control in the boiler was set at 188°F and no hot water was being drawn. The curves show how water temperatures in the boiler changed as the burner cycled on the low-limit control and also indicate the magnitude of the temperature gradient in the boiler water for each type of heater tested.

With the particular boiler and low-limit control used in the tests, the average burner on-period lasted about 5½ min, during which time the temperature of the water in the boiler was raised approximately 30°F. During the off-period the water gradually cooled to the setting of the low-limit control. At this point the control again started the burner, and the cycle was repeated. The frequency with which the burner operated depended upon the load imposed on the boiler by the water heater; the greater the load, the more frequent the cycles.

As can be seen by reference to Fig. 5, the temperature gradient from the top to the bottom of the boiler differed for each test setup. The maximum value was about 30°F, obtained with no water heater attached; the minimum was 2 to 3°F, obtained when the internal storage-type heater was attached. The magnitude of the temperature gradient depended on the manner in which heat was removed from the water and on the rate of water circulation. With no water heater attached, the boiler water cooled more rapidly near the bottom of the boiler. This produced a minimum of circulation, and the large temperature gradient was noted. On the other hand, when a heater was used, the boiler water cooled most rapidly around the heater. This created a circulation which tended to equalize the temperature of the water throughout the boiler.

The performance of an indirect heater is a function of the average temperature of the boiler water surrounding the heater coils; however, it is not always a simple matter to obtain this temperature during a test. It was therefore desirable to use the boiler water temperature at the low-limit control level, which not only was easily obtainable but also had the advantage of being the one point in the boiler where the temperature was fixed by the low-limit control.

The internal heater was located 5½ in. below the thermocouple which measured the temperature of the boiler water at the top of the boiler and 4¾ in. above the thermocouple which measured the temperature at the control level. Hence, an average of these two temperatures should represent the average temperature of the water around the heater. Moreover, these two temperatures were always within 2 or 3°F of each other, and, therefore, the temperature at the low-limit control level could be substituted for the average temperature of the water around the heater and not introduce serious error. Tests run on the external heaters indicated that the temperature of the water in the boiler at the control level was also a very close approximation of the average temperature of the water in the shell of the heater. Therefore, in plotting performance curves for all heaters tested, it seemed that using the temperature of the boiler water at the control level as an independent factor was justified. For the setup used during the tests on the storage-type heaters, it was found that the control setting and the average water temperature in the storage tank were the same, while the corresponding average boiler water temperature at the control level was approximately 15°F higher. For example, with a control setting of 140°F, the temperature of the water in the hot water storage tank was 142°F, and the average temperature of the boiler water at the control level was 153°F. For a control setting of
Fig. 5. Boiler Water Temperatures, Stand-by Operation
190 F these temperatures were 190 F, and 205 F, respectively.

For the summer months, Fig. 6 shows a plot of average boiler water temperatures at the control level vs. average water temperatures in both the 30-gal and 66-gal storage tanks when used with the storage-type heaters. For any given boiler water temperature and with either the external or internal storage-type heater, the average temperature of the water in the storage tank was about 2 F higher when using the 30-gal tank than when using the 66-gal tank. Other recorded data showed that the difference between the water temperatures at the top and bottom of the storage tank was of the same magnitude in both sizes of tanks, being 4 F at control settings of 140 F and increasing to about 6 F at a control setting of 190 F. It is questionable whether these small differences in temperature are of any practical importance. Thus, for any low-limit control setting, the external and internal storage-type heaters used in conjunction with either 30- or 66-gal storage tanks produced the same water temperature in the storage tanks during summer stand-by operation.

For winter operation with the internal heater there was always an increase in storage tank temperature with an increase in boiler water temperature as shown in Fig. 7. This did not hold true for tests on the external heater. Figure 8 shows average water temperatures in the system plotted against indoor-outdoor temperature difference for the external heater connected to the 66-gal tank. The low-limit control setting was 165 F. The water temperature was controlled by the low-limit control in the boiler until the indoor-outdoor temperature difference reached 45 F (approximately 25 F outdoor temperature). At this point, the length of time that the burner was on by action of the thermostat was sufficient to increase the temperature of the boiler water above that maintained by the low-limit control. However, instead of the temperature of the water in the storage tank increasing as it did with the internal heater, it dropped off slightly. The test data showed some evidence that circulator operation retarded the flow of boiler water through the external heater, and indicated that this may have...
been sufficient in cold weather, with long periods of circulator operation, to cause the slight drop in the temperature of the water in the storage tank indicated in Fig. 8.

Field observations have shown that with the piping arrangement used in these tests, the operation of the circulator can retard or even reverse the flow of water between the boiler and external heater and thus result in unsatisfactory water heater operation during cold weather. One method of correcting this condition is to provide separate circuits for the house heating and the water heating system. The two circuits may have a common supply, but each should have its own return connection to the boiler. If a common return must be used, a "Y" or a special aspirating tee should be provided at the point where the water heater and the house heating circuits join.

15. Water Temperatures, Service Conditions

The variations in the temperature of the water drawn during a 75-gal service draw-off test using a 30-gal tank are shown in Fig. 9. Also shown are the temperature of the water in the boiler and the temperature of the cold water supplied to the storage tank to replace the hot water used. The locations of the bars at the top of Fig. 9 show the time of each draw-off and the height indicates the quantity of water drawn. At the first draw-off, 1 hr after the start of the test, the initial temperature of the water drawn from the top of the tank was 186°F. The temperature dropped to 177.5°F as a result of drawing off 83 lb of water. The second draw-off of 83 lb 1 hr later reduced the temperature further to 153°F. For the third draw-off, amounting to 100 lb, the water temperatures at the start and end of the draw-off were 167.5°F and 141°F, respectively. Thus, for these relatively heavy draws, the heater did not have sufficient capacity to provide an adequate recovery rate during the hour between draws, and the storage tank volume was not large enough to make up for the heater deficiency. Through the rest of the test, the recovery and storage capacities were sufficient to maintain reasonably uniform water temperatures as shown by curve 3 of Fig. 9.

The variation in the temperature of the water drawn off when operating with a tankless heater, with a storage heater connected to a 30-gal storage tank, and with a storage heater connected to a 66-gal storage tank are shown in Fig. 10 for both 75- and 30-gal per day service draw-off tests. When 75 gal of water were used per day, the capacity of the storage heater and 30-gal tank was heavily taxed, resulting in wide variations in temperature between draws and as much as a 20°F drop in temperature during any particular draw. The temperature of the water drawn off at various times during the day varied from 186 to 147°F. The storage heater and 66-gal tank were a much more stable combination, both as to temperature variation between draws and temperature drop during a draw. The maximum temperature drop during any draw was 12°F, and the water temperature during the day remained between 165°F and 185°F.

When using the tankless heater the average temperature of the water drawn did not vary greatly between individual draws, but the temperature drop during any particular draw was large, generally running about 45°F. The drop in temperature experienced with the tankless heater would have been reduced had a fast acting water temperature control been used to start the burner as soon as possible after the start of a draw.

At the rather low usage of 30 gal of hot water per day, the storage heater and 30-gal tank were well able to meet the demands, and there was little to choose between the 30- and 66-gal tanks, although the temperature remained a little more uniform in the case of the larger tank.
Fig. 9. Graphic Log of Service Draw-Off Test

1. Cold water temp, supply to storage tank
2. Water temp at bottom of storage tank
3. Water temp at top of storage tank
4. Water temp in boiler at low limit control setting of 185°F
5. Total water heating load

Burner operating cycles

Time in hours from start of test

Water temperature, degrees F

Heating load, Btu per hour

Weight of water drawn, pounds

30 gal

- Piping insulated
- Cold water supply to storage tank
- Summer operation
- 75 gal draw-off
- Ave basement air temp, 80°F
Fig. 10. Temperature of Water Drawn During Service Draw-Off Tests

- Internal heater, 66 gal tank
- Internal heater, 30 gal tank
- Tankless heater

Hot water temp approx 185 F at start of first draw-off
V. RECOVERY RATE

16. Recovery Rate, Storage Heaters

Recovery tests were run over a wide range of control settings with the external and internal storage type heaters used in conjunction with either a 30-gal or 66-gal storage tank. A graphic log of water temperatures and burner operations for a typical recovery test is shown in Fig. 11. Curves similar to those of Fig. 11 were drawn for each test, and the rate of increase in the temperature of the water in the storage tank at any given point on those curves was then plotted against the corresponding difference between the average temperature of the water in the boiler at the control level and the temperature of the water entering the water heater. The resulting curves are presented in Fig. 12.

Figure 12 shows that the rate of heating the water in the storage tank was dependent upon the difference between the boiler water temperature and the temperature of the water entering the heater, but was independent of the control setting. As would be expected, the water in the 30-gal tank increased in temperature at a more rapid rate than did the water in the 66-gal tank. However, when the rate of increase was multiplied by the weight of water in the system, it was found that the output of the heater in Btuh was essentially unaffected by the tank size. For example, at 140°F difference in the temperature of the boiler water and the water entering the heater, an output of \((242 \times 55 = 13,300 \text{ Btuh})\) was obtained with the 30-gal tank and \((515 \times 27 = 13,900 \text{ Btuh})\) with the 66-gal
Tank. The external and internal heaters had the same recovery capacity.

17. Importance of Flushing the System, Storage-Type Heaters

The recovery rate of an indirect storage-type heater may be greatly reduced if rust or sediment is permitted to accumulate in the heater or piping. Figure 13 shows the percent reduction in the rate of heating water for the external storage heater when it was permitted to operate without flushing. After four weeks' operation, the recovery rate of the heater was reduced by 27 percent and after eight weeks by 40 percent. At the end of three months, not only was the speed of recovery greatly reduced, but the average temperature of the water in the storage tank after complete recovery was 8°F below normal. A 75-gal service draw-off test run at this time with a control setting of 185°F resulted in the temperature of the water drawn off being some 15°F cooler than for a comparable test made when the system was first put into operation. Flushing the system by opening valve C, Fig. 2, and alternately closing valves A and B caused a return to the initial recovery rate and final water temperature.

Since simply flushing the heater and piping restored normal output it was apparent that the reduction in output prior to flushing was not due to a scale deposit on the tubes of the heater, but rather to an accumulation of foreign material in the pipe which retarded the rate of flow, or to a similar accumulation in the heater which may have retarded the rate of heat transfer. The water used during these tests had a hardness of 260 parts per million expressed as calcium carbonate. With this type of water it is quite possible that part of the carbonates were precipitated as flocculant substance rather than as a hard scale. Such a deposit would reduce the rate of heat transfer and could be flushed from the system easily.

The external storage heater was examined for scale deposits after tests had been continued for one year. About 1/64 in. of hard scale had accumulated on the inside of the tubes. This scale was removed by chemical action, and tests before and after removing the scale showed that it had not made any measurable reduction in the recovery rate of the heater.

Possibly the observed reduction in recovery rate with continued operation without flushing would not have occurred had the water supply been soft; however, the tests did indicate that at least under certain conditions, the recovery rate of an indirect storage-type heater may be greatly reduced unless the piping and heater are flushed at regular intervals to remove any accumulation of foreign material.
VI. AVAILABILITY OF HOT WATER

18. Automatic Washer Draw-Off Tests

Water requirements for automatic washing machines were obtained from several automatic washing machine manufacturers as well as a local “serve yourself” laundry. This information served as a basis for the automatic washer draw-off schedule shown in Table 2. The quantities shown are based on a total water requirement of 8 gal per fill. The column headed “150 F” shows the quantity of hot water which must be supplied by the heater. To test for the availability of hot water from any heater, hot water was drawn at the times and in the quantities indicated in Table 2, and the complete cycle was repeated as often as the water was hot enough for use.

A graphic log of a set of automatic washer tests is shown in Fig. 14. Typical tests are shown for both the tankless heater and the storage-type heaters. Only cycles in which the water temperature remained above 125 F are shown.

Assuming 125 F as the lowest useful water temperature, Fig. 14 shows that when using a low-limit control setting of 185 F, a cold water supply temperature of 80 F, a 66-gal storage tank and a storage type heater, as many as seven consecutive tubs of clothes could be washed; if the cold water supply was 60 F, the limit was five tubs. Because of the large storage capacity of the 66-gal tank, there was very little change in temperature during any draw-off. Replacing the 66-gal storage tank by a 30-gal tank limited the number of consecutive washes to three if the temperature of the cold water supply was 80 F, and to two if the cold water temperature was 60 F. The mixing of the cold and hot water was quite evident in the tests in which the 30-gal tank was used. During the first cycle, the water temperature dropped from 187 F at the start to below 150 F at the conclusion of the cycle. In the second cycle, it dropped to 130 F when using 80 F inlet water and below 125 F when using 60 F water. During the wash period of the second cycle (8 gal of hot water used), the water temperature dropped nearly 15 F. Thus, the use of the 66-gal tank not only enabled more tubs of clothes to be washed, but also resulted in more uniform water temperatures throughout the time that the water was being drawn.

There was no limit on the number of wash cycles which could be made when using the tankless heater as long as the low-limit control setting was above about 150 F. However, the variation in water temperature during any draw was appreciable. When the control was set at 165 F and the draw-off rate was 3 gal/min, the water temperature dropped from 185 F to 134 F, a drop of 50 F, between the start and finish of the draw representing the wash period of the cycle. A draw-off rate of 2 gal per min reduced this temperature drop to 40 F. Using 80 F water rather than 60 F water did not appreciably affect the temperature of water drawn off when the draw-off rate was 2 gal per min, but it did reduce the water temperature variation during a draw-off by approximately 5 to 10 F as compared to a draw-off rate of 3 gal per min.

A tabular summary of the effect of the control setting, the storage tank size, and the inlet water temperature on the maximum number of tubs of clothes which could be washed in succession is shown in Table 3. Since there is some difference in opinion as to the minimum usable water temperature for washing clothes, the number of wash cycles that could be completed before the temperature of the water drawn dropped below both 125 F and 140 F are shown. For a given control setting, and when using 125 F as the minimum usable water temperature, it was possible to complete at least twice as many cycles when using the 66-gal tank as when using the 30-gal tank. However, the superiority of the 66-gal tank over the 30-gal tank was even more apparent when 140 F was taken as the minimum allowable water temperature. Here the mixing action between the hot and cold water that took place in the 30-gal tank limited the number of
cycles to one, even at a control setting of 185°F, while with a 66-gal tank as many as four cycles were completed.

19. Effect of Tank and Pipe Arrangements

The location of the storage tank and the piping connections to the tank both play an important part in the satisfactory performance of storage-type water heaters. In home installations, water circulation between the heater and the storage tank is generally limited to gravity action. The head creating this circulation depends on the difference in density of the water in the hot and cold sides of the loop connecting the tank and the heater, and on the vertical height of the circuit. For every 10°F difference in the temperature of the water in the hot and cold side of the loop, the gravity head available to cause water circulation is about 0.03 in. of water per ft of vertical height. Thus, it can be seen that the higher the tank is located above the heater, the better will be the circulation of water.

The storage tank may either be mounted vertically so that it stands on end, or it may be suspended horizontally from the ceiling. Because of the low gravity head available and the low ceiling height found in many basements, horizontal tanks are usually preferred to vertical ones. However, the mixing action of the cold inlet water with the stored hot water is a problem in horizontal tanks, particularly in the smaller tank sizes.
To determine the effect of tank position on the performance of a given storage-type water heater, an investigation was made of the operating characteristics of the internal heater when used with a 30-gal storage tank mounted in both vertical and horizontal positions. Several different piping arrangements were used when the tank was mounted vertically. The range boilers were provided with a tapping in the center of each head, one on the side of the shell half way between the two heads, and two on the other side of the shell at points near either end of the tank. This provided several possible choices as to piping connections. The various tank and pipe arrangements used in this investigation are shown in Fig. 15.

The curves in Fig. 15 represent data taken during continuous draw-off tests in which the low-limit control located in the boiler was set at 185 F. The maximum water temperature was approximately the same for all arrangements except A. Arrangement A was unsatisfactory as there was not enough vertical height between the heater and the point where the pipe from the heater entered the tank to create adequate water circulation. The maximum
water temperature was some 25 °F lower than the other arrangements and only a limited quantity of water was available even at this low temperature.

Excessive mixing of the hot and cold water was very apparent on the horizontal arrangement. A tapping on the top of the storage tank at the opposite end from the point at which hot water was being drawn was used to bring the cold water supply to the tank, and the inlet pipe was extended down into the tank within approximately 1 in. of the bottom in order to "lay" the cold water at the bottom of the tank. Even with these precautions to keep mixing at a minimum, the water drawn from the horizontal tank rapidly declined in temperature after only one-third of the tank capacity had been drawn. The draw-off rate may have had something to do with this, as 5 gal per min is a rapid enough flow to cause the incoming cold water to "splash" against the bottom of the tank. Also, the small tank size aggravated the mixing problem. As noted previously, the problem of mixing in the horizontal tank decreased in seriousness as the diameter of the tank was increased. For the horizontal arrangement and a control setting of 185 °F, 80 percent of the capacity of the 66-gal tank could be drawn before the water temperature dropped to 165 °F while about 55 percent of the 30-gal tank could be drawn under the same conditions.

Vertical arrangement B gave improved results over either the horizontal tank or arrangement A. Eighty percent of the water in the tank could be drawn with setup B-1 before there was a break in the temperature curve.

Attaching the cold water supply to the pipe between the bottom of the storage tank and the heater (arrangement C) gave the best results of all. The entire tank capacity could be drawn before the break in water temperature occurred.

The curves A, B, and C were obtained with the storage tank mounted on the conventional stand with 12-in. legs. To determine what effect elevating the tank might have on performance, a stand with 21-in. legs was used. The piping connections were the same as at B and C, respectively. Elevating the tank, Curve C-2, Fig. 15, resulted in higher water temperatures up to the break point, with the total volume of water drawn the same as with setup C-1. B-2 was omitted from Fig. 15 for sake of clarity, but showed the same characteristics as C-2, i.e., slightly higher water temperature up to the break point with the break in temperature occurring at about the same point as its counterpart, B-1.

Table 4 shows a comparison of the water temperature in the storage tank for the various setups during stand-by operation. Allowing for slight variations in the exact setting of the low-limit control, it will be noted that the water temperature at the top of the tank was approximately the same for all arrangements except A. However, the temperature at the bottom of the tank and the average tank temperature did change as the tank position was changed. The horizontal arrangement gave the highest average tank temperature with the temperature difference between the bottom and top of the tank being about 6 °F. The high vertical position (B-2 and C-2) gave a temperature difference between the bottom and top of the tank of 11 °F with the average tank temperature being about 3 °F cooler than for the horizontal tank. The low vertical position (B-1 and C-1) dropped the temperature at the bottom of the tank some 24 °F below the temperature at the top and reduced the average tank temperature about 7 °F as compared to the horizontal arrangement. As noted previously, arrangement A was very poor, the tank temperature being more than 35 °F lower than that obtained with the horizontal position. This table shows the importance of placing the storage tank as high above the heater as possible in order to obtain the hottest possible water for a given control setting.

<table>
<thead>
<tr>
<th>Tank and Piping Arrangement</th>
<th>Boiler Water Temperature at Control Level</th>
<th>Average Storage Tank Temperature During Stand-by (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>Horizontal</td>
<td>197.5</td>
<td>180.2</td>
</tr>
<tr>
<td>Vertical A</td>
<td>201.5</td>
<td>182.4</td>
</tr>
<tr>
<td>Vertical B-1</td>
<td>197.2</td>
<td>187.2</td>
</tr>
<tr>
<td>Vertical C-1</td>
<td>194.6</td>
<td>178.7</td>
</tr>
<tr>
<td>Vertical B-2</td>
<td>197.7</td>
<td>186.7</td>
</tr>
<tr>
<td>Vertical C-2</td>
<td>197.0</td>
<td>185.8</td>
</tr>
</tbody>
</table>

The rate at which a cold tank of water could be heated with the various arrangements is shown in Fig. 15. The high vertical positions (B-2 and C-2) show a recovery rate on a par with the horizontal tank. Positions B-1 and C-1 show a lower recovery rate, and arrangement A shows to the poorest advantage of all.

Thus, all things considered, arrangement C-2 was the most satisfactory for the 30-gal tank. The average water temperature in the tank was only a few degrees lower than for the horizontal arrange-
ment, the rate of heating water was as high as for any other condition, and the piping connection for the cold water supply created a minimum of mixing action; therefore a full tank of water could be drawn off before there was any decided drop in the water temperature. The advantage of the high vertical tank position over the horizontal was less pronounced for tanks as large as 66-gal capacity.

20. Water Available at a Single Draw

Continuous draw-off tests were made to determine the maximum quantity of water above a specified minimum temperature which could be drawn off at any one time. Figure 16 is a graphic log of the data taken during such a test using the internal storage type heater connected to the 66-gal tank. The low-limit control setting was 185°F. Similar tests were run at other low-limit control settings and with other heaters and storage tanks.

From the results of these tests on the storage-type heaters, the curves shown in Fig. 17 were plotted. As far as the quantity of hot water available at a single draw was concerned, no difference was observed between the external and internal heaters, but the size of the storage tank and the initial temperature of the water in the storage tank did have an appreciable effect on the quantity of water available. It is self-evident that as the tank size is increased there should be an increase in the amount of hot water available. However, Fig. 17 shows that changing from the 30-gal to the 66-gal storage tank resulted in a greater increase in the amount of hot water available than might be expected from tank volume considerations alone. The actual measured capacity of the 66-gal tank was only slightly more than twice that of the 30-gal tank. Yet for any given initial water temperature, approximately three times as much hot water could be obtained from the larger tank.

The better results obtained with the larger tank were apparently due to the fact that the cold inlet water did not mix as rapidly in the 66-gal tank as was the case in the 30-gal tank. This is seen more clearly if we look at the percentage of the total tank capacity that could be drawn from each tank before the water temperature dropped below specific minimum values. When the maximum temperature of the water in the storage tank was 160°F, about 70 percent of the total capacity of the 66-gal tank could be drawn before the temperature of the water dropped below 145°F, while for the same conditions only about 43 percent of the capacity of the 30-gal tank could be drawn. If the temperature of the water in the tank was allowed to drop to 125°F, 94 percent of the total capacity of the 66-gal tank could be drawn, while the draw on the 30-gal tank was limited to 70 percent of capacity.

Both tanks were the same length and were mounted in a horizontal position. The 30-gal tank was 12 in. in diam while the diam of the 66-gal tank was 18 in. As shown in the previous section, the mixing problem between the cold and hot water was much less serious with the larger diameter.
tank. It may thus be concluded that for two tanks of equal capacity, used in a horizontal position, a short tank of larger diameter is preferable to a long tank of smaller diameter.

The water tempering tank which was used to control the temperature of the cold water supplied to the storage tank did not have sufficient capacity to allow control of the temperature of the cold water supply during continuous draw-off tests. As a result, the effect of changes in the temperature of the cold water supply on the availability of hot water at a single draw could not be determined.

Figure 18 shows the availability of hot water in a single draw when using the tankless heater. Since no storage tank is used with these heaters, the abscissa was taken as the maximum temperature of the water drawn off. This corresponded closely to the maximum temperature of the water in the storage tank which was used as the abscissa when plotting the performance of the storage-type heaters in Fig. 17.

With the low-limit control set to produce a maximum temperature of the water drawn off equal to 210 F, and the draw-off rate set at 2 gpm, there was no limit to the quantity of water that could be drawn at a temperature of 130 F or less. With the low-limit control set to produce maximum water temperatures lower than 210 F, the quantity of hot water available dropped off rapidly. For example, when the maximum temperature of the water drawn off was 180 F, 183 lb (about 22 gal) was all that could be drawn off; and at a maximum water temperature of 150 F, the limit was 82 lb (10 gal).

Only one test was run at a draw-off rate of 3 gpm. The maximum water temperature during this test was 210 F, and even at this high temperature setting, only 135 lb (16 gal) of water could be drawn before the temperature of the water dropped to 140 F.

The results of the continuous draw-off tests on the tankless heaters are somewhat limited in value because of the type of low-limit control used. The same low-limit control was used for the tankless heater tests as was used for the tests on the storage-type heaters. This control, located in the back section of the boiler, had a bi-metal element inserted in a well. Controls of this type are inherently slow to respond to changes in water temperature. In the continuous draw-off tests, some 6 or 7 min elapsed between the start of the draw-off and the time the burner started to operate. As pointed out in Section 15, the quantity of hot water available at a single draw-off would have been increased materially had there been used a fast acting low-limit control capable of starting the burner within 1/2 or 1 min after the start of the draw.
VII. HEAT LOSSES FROM STORAGE TANKS, CONNECTING PIPING, AND HEATERS

The actual volume of water held by the two storage tanks used in these tests was 29.0 gal or 242 lb for the smaller tank, and 62.0 gal or 515 lb for the larger tank. Knowing the volume of the tank, it was possible to determine the heat loss at any given water temperature by observing the rate the water cooled when the valves in the water circulating lines were closed and no circulation of water could take place between the tank and the heater.

The mean temperature of the water in the two tanks during the first 24 hr of a cooling period is shown in Fig. 19. The mean temperature of the water at the start of a cooling period was 182°F, and at the end of 24 hr it had dropped to 123°F in the 30-gal tank and to 140°F in the 66-gal tank. For each hour of the test, the heat loss from the tank was obtained by multiplying the change in the mean temperature of the water during the hour by the weight of the water in the tank. The heat losses thus obtained were plotted against the average difference between the temperature of the water in the tank during the hour and the basement air temperature (curves 2 and 3, Fig. 20).

Because the insulation of the 66-gal tank was 1 1/2 in. in thickness while that on the 30-gal tank was only 1 in. in thickness, there was not a great difference in the heat loss of the two tanks. Even when the water in the storage tank was 110°F warmer than the basement air, the heat loss for the 66-gal tank was only 160 Btuh greater than for the 30-gal tank. This difference was too small to have any appreciable effect on fuel consumption.

The heat loss from the insulated 1-in. pipe between the storage tank and the heater (curve 1, Fig. 20) could not be determined experimentally. Therefore, this heat loss was calculated from data given in Chapter 28 of the American Society of Heating and Ventilating Engineers Guide 1953. For the purpose of the calculations, the temperature of the basement air at a height of 60 in. above the floor was used. The temperature of the water in the pipe connecting the bottom of the tank to the water heater was assumed to be the same as that of the water in the bottom of the storage tank, while the temperature of the water in the pipe connecting the heater to the top of the storage tank was assumed to be the same as that of the water at the top of the storage tank. The length of pipe connecting the heater to the storage tank was the same whether a 30-gal or a 66-gal tank was used.
VIII. WATER HEATING LOADS

21. Water Heating Load, Storage-Type Heaters

The curves shown in Figs. 11 and 12 were used in computing the load imposed on the boiler by the storage-type heaters at various temperatures when using both 30- and 66-gal storage tanks. For example, as shown in Fig. 11, the temperature of the water entering the heater at the start of a typical recovery test with a 30-gal tank was 62°F, and the average temperature of water in the boiler at the control level was 203°F. Under these conditions, the rate of heating the water in the storage tank, as shown in Fig. 12, was 55.5°F per hr; since the water capacity of the storage tank and piping was 242 lb, the water heating load was $55.5 \times 242 = 13,430$ Btuh. From similar calculations made for each succeeding hour of the test, curve 1 of Fig. 21 was plotted. This curve represents the load on the boiler due to the actual heating of water at any given time during the test. To obtain the total load, it was necessary to add to the load as shown by this curve, the load due to the heat losses from the storage tank and piping. The latter losses, computed in accordance with the methods described in Chapter VII, are shown by the shaded area between curves 1 and 2 in Fig. 21. For the conditions of operation noted, curve 2 then represents the total load on the boiler when using a 30-gal storage tank. Similar calculations were made for the 66-gal tank, resulting in curves 3 and 4 of Fig. 21. Because of its increased water volume, the 66-gal tank required twice as much time to reach steady-state conditions, starting with cold water in the tank as did the 30-gal tank; also, the maximum water heating load was of longer duration.

![Graph showing water heating load during heating up period](image_url)
The water heating load is dependent upon the size of the water heater and on the mean temperature difference between the water immediately surrounding the heater coil and the water in the coil itself. Since it was impossible actually to measure these two temperatures, the difference between the average temperature of the water in the boiler at the control level and of the domestic water entering the heater was assumed to be characteristic of the mean temperature difference of the water inside and outside the coil and hence was used as the abscissa for plotting curves representing the total load on the boiler. The results are shown in Fig. 22. It was found that the load on the boiler was not affected by either the setting of the low-limit control or the size of the storage tank, but was dependent on the difference between the temperatures of the boiler water at the control level and of the domestic water entering the heater. Knowing the difference between these temperatures, it was possible to use Fig. 22 to determine the actual water heating load for any particular service condition.

A comparison of Figs. 9 and 11 shows that under normal service conditions the maximum load imposed by the storage-type water heater was never as great as the maximum obtained during a heating-up test starting with cold water in the tank. The maximum load under the severe service conditions imposed by the 75-gal daily demand schedule was about 8,000 Btuh, and the duration of this load was for very short periods of time. Since for any given water demand schedule the temperature of the water entering the heater was only slightly affected by the size of the storage tank, the water heating load was essentially the same when either the 30-gal or the 66-gal storage tank was used.

During the summer there is no house heating load, and hence the heating capacity of the boiler is more than sufficient to handle hot water needs. It was concluded in Bulletin 366 that for slow recovery water heaters, similar to the ones used in these tests, the usual allowance made for pick-up and piping losses was more than adequate to provide for the small additional load imposed by heating domestic hot water during the winter. In other words, no water heating allowance need be added to the house heating load in selecting a boiler to be used with a storage-type water heater.

22. Water Heating Load, Tankless Heater

In the case of the tankless heater, there is no water heating load during periods in which there is no hot water demand. However, the moment hot water is needed, the load on the boiler is instantaneous and severe. Enough heat must be available to raise the cold inlet water to the desired hot water temperature during the short period required for the water to circulate through the heater coil. Since the water circulates through the coil at the rate at which it is being drawn from the hot water tap, the load during the draw-off may exceed 150,000 Btuh. Many installations may be found where the water heating load is greater than the rated output of the boiler to which the heater is attached.

For a tankless water heater to operate in a satisfactory manner, the heat removed from the boiler during any draw-off must not exceed the sum of the heat supplied to the boiler by the burner during the draw, the heat stored in the boiler water previous to the draw, and the heat stored in the metal of which the boiler is made. The latter is very small and may be neglected without serious consequence.
The heat stored in the boiler water may be expressed as:
\[ H_w = W (t_1 - t_2) \]
where
- \( H_w \) = Heat stored in boiler water in Btu
- \( W \) = Weight of water in boiler in lb
- \( t_1 \) = Temperature of water in boiler at start of draw
- \( t_2 \) = Minimum temperature of water in boiler during draw

The heat supplied by the burner would be:
\[ H_b = h_f \times E \times F \times T \]
where
- \( H_b \) = Heat supplied by the burner in Btu
- \( h_f \) = Heat content of fuel in Btu per unit used (lb, gal, or cu ft)
- \( E \) = Operating efficiency
- \( F \) = Fuel burning rate in units used per hr
- \( T \) = Time burner is in operation in hr

The time the burner is in operation during any draw is equal to the total length of the draw-off periods minus the time delay before the low-limit control starts the burner.

The curves of Fig. 23 were computed from the preceding equations and show the theoretical relationship between tankless heater size, water content of boiler, maximum quantity of water drawn at one time, and the required minimum heat input to the burner. In developing these curves the following conditions were assumed: an operating efficiency of 70 percent, good circulation of all boiler water through the heater, a maximum drop in the temperature of the boiler water of 30 F, a 45-sec time delay in starting the burner, and a 100 F rise in the temperature of the domestic water passing through the heater. If the design of the boiler is such that the circulation of boiler water through the heater is restricted, or if the average reduction in the temperature of the boiler water is less than 30 F, the actual heat input rates to the boiler must be somewhat higher than those indicated in Figs. 23 and 24.

Figure 23 shows that the required heat input to the burner is increased by any one of the following changes:
- (a) An increase in heater size
- (b) An increase in the quantity of water drawn
- (c) A decrease in the water content of the boiler

For boilers having water contents of 15 gal and 25 gal, the effect of time delay in starting the burner on the required heat input to the burner is shown in Fig. 24. The same formulas were used in developing these curves as were used for Fig. 23. These curves show the importance of starting the burner operation as soon after the start of the draw as possible when using a tankless heater. This is especially true for boilers of small water content. The right-hand end of each curve represents the maximum time delay that can be permitted regardless of the rate of heat input to the burner if the temperature drop of the water in the boiler is limited to 30 F.

Figure 24 may be used in selecting the proper combination of boiler, burner, and water heater to meet a given requirement. To illustrate: Determine the minimum firing rate for the following conditions:
- (a) Heater size — 3 gal per min
- (b) Water content of boiler — 25 gal
- (c) Burner starts 1 min after start of draw
- (d) Maximum single draw — 10 gal

Curve 4, Fig. 24, shows that the minimum heat input rate should be 77,000 Btuh for the assumed conditions.

Had the water content of the boiler been 15 gal, the minimum heat input rate would have had to be 168,000 Btuh (Curve 10). Reducing the time delay from 1 min to 1/2 min would reduce the minimum heat input rates to 63,000 and 138,000 Btuh.
Fig. 24. Effect of Time Delay on Minimum Firing Rate of Boiler

- 15 gallon boiler
  - Max drop in boiler water temp. 30°F
  - 7 - 4 gpm, 15 gal
  - 8 - 4 gpm, 10 gal
  - 9 - 3 gpm, 15 gal
  - 10 - 3 gpm, 10 gal
  - Curve 12 - draw rate 2 gpm max draw 10 gal

- 25 gallon boiler
  - Max drop in boiler water temp. 30°F
  - 1 - 4 gpm, 15 gal
  - 2 - 4 gpm, 10 gal
  - 3 - 3 gpm, 15 gal
  - 4 - 3 gpm, 10 gal
  - 5 - 2 gpm 15 gal
  - Curve 6 - draw rate 2 gpm max draw 10 gal
IX. FUEL CONSUMPTION

23. Effect of Test Conditions on Fuel Consumption

One of the objectives of the test program was to determine the fuel consumption for different combinations of heaters and storage tanks and for different conditions of operation. It was possible to obtain much closer control of test conditions during the summer months than during the winter since during the summer the only function of the boiler was to supply heat for the heating of domestic hot water. Control of boiler water temperatures in summer was obtained by means of the low-limit control located in the boiler. During the winter, the boiler supplied heat for both the house heating and the domestic water heating, with the house heating load being much the larger. Thus, except in mild weather, the temperature of the water in the boiler during winter operation was determined by action of the thermostat with a variable demand depending on outdoor temperature, sun load, occupancy of house, etc. As a result, it was possible to detect differences in fuel consumption of as little as 5 cu ft during the summer, while during the winter the possibility of any such small difference being detected was out of the question.

The heaters and tanks had to be changed a number of times during the test program, and in the process slight differences in insulation thickness invariably occurred. It was discovered when the external heater was removed after one series of tests that it had not been sufficiently insulated. Since this was giving the internal heater an unfair advantage, the heater was re-insulated to a depth of 1 in. and the stand-by series of tests were repeated. Increasing the thickness of the insulation to 1 in. resulted in a decrease in fuel consumption of about 5 cu ft of gas per day. Accordingly, all fuel consumptions for tests made during the series when the heater did not have adequate insulation were reduced by 5 cu ft.

Problems due to the accumulation of rust and sediment in the piping connecting the heater to the storage tank were also encountered. Since this accumulation was found to affect water circulation through the heater, and hence heater efficiency, the heater and piping were flushed once a week to make sure of getting uniform results.

One of the biggest uncontrolled factors which affected the consistency of results was the fact that basement air temperatures did not remain constant over the summer months. This variation in temperature was capable of producing more of a change in fuel consumption than did some of the parameters under study. The basement air temperature at the storage tank level was recorded at all times, and 80 F was selected as the average for summer conditions. The effect of basement air temperature on fuel consumption was determined by running duplicate tests at different times during the year. The fuel consumption for each of these tests was plotted against the average basement air temperature at the storage tank level. The fuel consumption as read from this curve at a basement air temperature of 80 F was selected as the standard fuel consumption. The curve of Fig. 25 was then constructed by plotting the deviation between the standard fuel consumption and the fuel consumption for each test against the average basement air temperature at the storage tank level as recorded during the test. This curve indicates that for a given condition of operation, fuel readings over the summer months varied by as much as 15 to 20 cu ft per day, depending upon the basement air temperature at the time the test was made.

Summer fuel consumptions for storage type heaters were corrected for the effect of basement air temperature by applying the correction shown in Fig. 25. This curve was determined for a 66-gal storage tank, but it was used for the 30-gal tank as well since the two tanks were so insulated that the heat losses from them were almost the same.

24. Fuel Consumption, Winter Operation

During the winter, the main load on the boiler is the house heating load, and a large portion of the
heat escaping from the surfaces of the boiler, the chimney, the storage tank and the piping, (which is lost heat as far as summer operation is concerned) is utilized in supplying heat to the house. Accordingly, several series of tests were run to determine the portion of the winter fuel consumption actually chargeable to heating water under various conditions of operation.

Figure 26 shows the total daily fuel consumption necessary to provide for both house heating and heating 50 gal of domestic hot water daily in the winter with each of the three types of heaters.

In addition, the internal storage-type heater was operated with both a 30- and a 66-gal storage tank. The test points are so grouped that except possibly for very mild weather a single curve represents all four series of tests equally well. In other words, neither the type of heater nor the capacity of the storage tank affected the daily fuel consumption during normal winter operation.

Figure 27 shows the test points for another four series of tests in which the internal storage heater was used, but both the low-limit control setting and the quantity of water used per day were changed. The same curve as shown in Fig. 26 also fits the test points plotted in Fig. 27, showing that for winter operation neither the setting of the low-limit control nor the quantity of hot water used affected the total daily fuel consumption.

Since in all the tests plotted in Figs. 26 and 27 the cold water temperature was 80°F, still another set of tests had to be made to determine the effect of using an inlet water temperature of 60°F. The points representing these tests have been plotted in Fig. 28, and again the curve of Fig. 26 fits the test points. In other words, changing the temperature of the cold water supply had no effect on the daily fuel consumption under conditions of winter operation.
It may be concluded that the total daily fuel consumption for winter operation was dependent upon the indoor-outdoor temperature difference, but, within the scope of the tests, appeared to be independent of the type of water heater used, the size of the storage tank, the setting of the low-limit control, the temperature of the cold water, and the quantity of hot water used.

The curve produced in Figs. 26, 27, and 28 gives no clue as to what portion of the daily fuel consumption is chargeable to house heating and what portion to the heating of water. In Series BA-47 no water heater was attached to the boiler, and the low-limit control and flow control valve were not used. All of the fuel consumption in Series BA-47 was chargeable to house heating as this was the only function performed by the boiler; no provision was made for water heating. Since the curve for Series BA-47 (solid line, Fig. 29) represents daily fuel consumption for house heating only, and the dotted curve, taken from Fig. 26, represents daily fuel consumption for both house heating and domestic hot water, the difference between these two curves must represent the daily fuel consumption chargeable to water heating for winter operation.

The two curves shown in Fig. 29 differ from one another during mild winter days due to the fact that the low-limit control was dominant over the room thermostat in controlling the boiler water temperature during this period. Any increase in boiler water temperature over that needed to heat the house meant increased burner operation and increased wasted heat from the boiler and chimney. Where no low-limit control was used, as Series BA-47, the water in the boiler was permitted to cool during times when there was no heat demand from the room thermostat. This resulted in a decrease in fuel consumption compared to operation where the boiler water temperature was maintained above a set minimum. As the outdoor temperature got colder, the room thermostat, rather than the low-limit control, gradually became the controlling factor in determining burner operation and the temperature of the water in the boiler. Then gas consumption was identical for all methods of operation.

25. Fuel Consumption, Summer Operation

A. Stand-by. — In the summer the only function of the boiler is to supply heat for domestic water heating, and, therefore, all summer fuel consumption is chargeable to the cost of providing hot water. Figure 30 shows the gas consumption chargeable to the three types of heaters and to the boiler alone for periods during which no hot water was drawn off. Curve 1 represents the fuel consumption chargeable to the heat loss from the boiler with no water heater attached. The difference between Curve 1 and the other curves represents the fuel consumption chargeable to the heat losses of the different heaters, connecting piping, and, when used,
the storage tank. With an average boiler water
temperature of 180°F at the control level, 15 cu ft 
of gas per day were required to offset the heat loss 
from the external tankless heater and piping; 46 cu 
ft per day for the internal heater, piping and 
storage tank; and 56 cu ft for the external heater, 
piping and storage tank. The heat losses of the 30- 
and the 66-gal tanks were so near equal that no 
significant difference in fuel consumption was noted 
between them.

For the combinations of boiler and heaters 
tested, the stand-by fuel consumption when using 
the external tankless heater was 22 to 26 percent 
less than when using either storage-type heater. 
Therefore it is apparent that, even though insulated, 
the heat loss of the storage tanks caused an appreciable increase in the stand-by fuel consumption. 
Since domestic water heating systems operate at 
stand-by a large percentage of the total time, the tankless heater is inherently the more economical 
to operate and at the same time it releases less unwanted heat into the house during the warm 
summer months.

B. Service Conditions: 30-Gal Draw-Off. —
Figure 31 shows a comparison of the daily heat 
input rates for the two storage-type heaters used 
with 30- and 66-gal tanks. The hot water was 
drawn off in accordance with Schedule A, Table 1, 
and the temperature of the cold water supplied to 
the system was 80°F. No tests were run on the 
tankless heater at this water usage schedule. The 
test points indicate a slightly higher input to the 
boiler with the 66-gal storage tank than with the 
30-gal tank, but no difference in heat input when 
comparing the two types of heaters.

Figure 32 shows that, when using 30 gal of 
180°F water daily, changing the temperature of the 
inlet water from 80°F to 60°F increased the heat 
input by only 8,000 Btu or 8 cu ft of gas per day. 
This was an increase of approximately 3 1/2 percent.
C. Service Conditions: 75-Gal Draw-Off.—
The daily fuel requirements for each of the heaters when hot water was used in accordance with Schedule C, Table 1, is shown in Fig. 33. The draw-off rate when using the storage-type heaters was 5 gpm while both 2 gpm and 3 gpm draw-off rates were used with the tankless heater.

Figure 33 shows that, as was the case for the 30-gal service draw-off tests, both the internal and external storage-type heaters required the same heat input for the same storage tank size and operating conditions. However, when using either of the storage heaters in conjunction with the 30-gal storage tank, the total heat input was about 8,000 Btu per day higher than when used in conjunction with the 66-gal tank. This was just opposite to the observations made during the 30-gal service draw-off tests. Thirty gallons storage capacity was not adequate to provide for a 75-gal service draw-off and, to compensate for the lack of storage capacity, it was necessary to increase the boiler water temperature. This increased the heat losses from the system which in turn increased the required heat input. These observations point to the desirability of providing adequate water storage capacity when storage-type heaters are used.

The required heat input when using the tankless water heater was 40,000 to 60,000 Btu per day less than that required when using the storage-type heaters under the same general operating conditions. Over the whole range of water temperatures included in the tests on the tankless heaters, reducing the draw-off rate from 3 gpm to 2 gpm effected a reduction of about 8,000 Btu per day in the heat input.

While reducing the temperature of the cold water supplied to the system from 80 F to 60 F increased the required heat input by 8,000 Btu or 31/2 percent when operating storage-type heaters and drawing 30 gal of 180 F water per day, Fig. 34 shows that when using 75 gal of hot water per day, changing the cold water supply temperature from 80 F to 60 F increased the required heat input by 20,000 Btu per day, or about 7 percent, for the storage-type heaters, and by 11,000 Btu per day, or 5.8 percent, for the tankless heater. Obviously, the effect of the inlet water temperature on the heat input increases as the quantity of water used is increased.

D. Effect of Quantity of Water Used on Required Heat Input.—The curves of Fig. 35 were derived from Figs. 30, 31, 32, 33, and 34 and show the daily heat input required for both storage and
tankless water heaters for summer operation at water temperatures of 140 F and 180 F and all daily water usages from 0 to 75 gal per day. Since for a given water temperature the difference in the required heat input for the external and internal storage heaters with either the 30- or 66-gal storage tank was very small, only one set of curves for each water temperature is given for the storage-type heaters. The values on this set of curves represent average heat inputs for the two heaters and the two sizes of storage tanks included in the tests.

Figure 35 shows that for summer operation the tankless heater was much more efficient than the storage-type heaters. In fact, the required heat input for the tankless heater was from 20 to 25 percent less than for the storage heaters over the whole range of test conditions. Figure 35 also shows that the stand-by losses (no water used) represent a large percentage of the total heat requirements for summer operation. The stand-by heat input was from 47 to 62 percent of the total heat input required when supplying 75 gal of hot water daily. Similar tests made using an oil-fired boiler indicated over 70 percent of the fuel required to supply 75 gal of hot water daily was chargeable to stand-by losses.* Since for any operating temperature the heat losses from the heater, storage tank, and piping should be the same regardless of the fuel used, it appears that either the oil-burning boiler had a greater heat loss than did the gas-fired boiler, or else the short operating cycles occurring during stand-by operation resulted in a decreased combustion efficiency when oil was used as the fuel.

X. WATER HEATING COSTS

Because of the number of variables involved, it is not easy to determine the yearly cost of heating water with an indirect water heater. Some of the more important variables are: (a) the type and size of the heater; (b) the average quantity of hot water used per day; (c) the temperature of the hot water; (d) the unit cost of the fuel; and (e) the method of control. For the types of heaters and method of control used in the I=B=R Research Home, an estimate of the yearly cost of heating water was made based on the assumptions that the average family of four uses about 50 gal of 140 F water per day, and cold water is available at a temperature of 60 F. Since it is recognized that operating conditions vary widely, correction factors have been determined for other water usage schedules and water temperatures.

The frequency of the different outdoor temperatures occurring during the nine months of the heating season in Urbana, Illinois, is shown in Table 5. The data for this table were obtained from records of the United States Weather Bureau Station at the University of Illinois for the five years from September 1936 to May 1941, inclusive.

Column 4 shows the estimated daily fuel consumption chargeable to heating 50 gal of water daily with the storage-type heater for the assumed conditions. The values shown for the winter days represent the difference between the two curves of Fig. 29, corresponding to indoor-outdoor temperature differences represented by the mean temperature of each bracket in Column 1. The fuel consumptions shown in Column 5 were then calculated by multiplying the daily fuel consumptions (Col. 4) by the average number of days per year having an average temperature falling within the limits of each bracket (Col. 3). The winter total of Column 5 represents an estimated gas consumption of 16,380 cu ft for the storage type heater during the nine months of the heating season.

During the three summer months, a daily fuel consumption of 165 cu ft can be estimated from Fig. 35. Since there are 92 days during the months of June, July and August, the total fuel consumption for the summer months would be 165 × 92 = 15,180 cu ft of gas. The yearly total for the storage-type heaters under the conditions shown would be 16,380 + 15,180 = 31,560 cu ft of gas. At a cost of 6 cents per therm (1 therm = 100,000 Btu or 100 cu ft of the gas used in the tests) this estimated fuel consumption gives a total cost of $18.94 per year or an average cost of $1.58 per month. At an average cost of 10 cents per therm for the gas the monthly cost of operation would be $2.63.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Distribution of Average Outdoor Temperatures and Corresponding Fuel Consumption Chargeable to Heating Water</th>
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<tr>
<td>Average Outdoor Temperature</td>
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<td>−10 to −5</td>
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Similar data are shown for the external tankless heater in Columns 6 and 7 of Table 5. The total yearly fuel consumption of the tankless heater is shown as 25,410 cu ft. At a cost of 6 cents per therm, the yearly cost of this quantity of gas would be $15.25 or an average of $1.27 per month. At 10 cents per therm the average monthly cost would be $2.12.

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* Based on records of United States Weather Bureau Station at the University of Illinois. Includes months of January, February, March, April, May, September, October, November, and December from September, 1936, through May, 1941.
†Temperature of water drawn = 140 F; temperature of cold water = 60 F.
It will be noted in Columns 4 and 6, Table 5, that for days during the heating season with outdoor temperatures high enough that no house heating was required, the daily fuel consumption charged to heating water was less than during the summer months. This was because the gas consumption of the pilot, amounting to about 35 cu ft per day, was charged to water heating during the summer. Since the principal function of the boiler during the heating season is to supply heat to the house, it seemed logical to charge the pilot fuel consumption to house heating during the heating season. Had the gas consumption of the pilot been charged to water heating for all days for which the average temperature was 65°F or above regardless of the month of the year, the additional cost of heating water would have been only $0.96 per year, or 8 cents per month.

It is worth noting at this time that year-around use of the boiler to supply domestic hot water eliminates one of the main causes of boiler damage — namely, sweating and the resulting corrosion of boiler surfaces during hot, humid weather. In fact, some home owners leave the gas pilot burning the
year around in order to be sure that the temperature of the water in the boiler on hot, humid days will be high enough to prevent sweating. Since the pilot consumption accounts for 20 to 50 percent of the fuel consumption needed to maintain summer stand-by conditions on indirect heaters, to these owners the additional cost of using the boiler to supply domestic hot water would be somewhat less than shown in this bulletin.

The average monthly cost of heating water as described in the first part of this section was determined for several water usage schedules and hot water temperatures, and from these data Figs. 36 and 37 were drawn. Figure 36 shows the average monthly cost of heating water for the storage and tankless heaters with a water usage of 50 gal per day plotted against the unit cost of fuel. Curves 1 and 2 are for a hot water temperature of 180 F, and Curves 3 and 4 represent a hot water temperature of 140 F. Water temperatures between these values may be interpolated linearly between the appropriate curves. Thus, a hot water temperature of 160 F, obtained with a storage-type heater, would fall midway between Curves 1 and 3. Similarly, a temperature of 160 F obtained with a tankless heater would be midway between Curves 2 and 4.

In order to determine a cost correction factor for water usages other than 50 gal per day, the ratio of the fuel consumption for any water usage and that for a daily water usage of 50 gal was obtained for each combination of heater, storage tank, and hot water temperature included in the test program. It was found that the curve shown in Fig. 37 represented all conditions within ±6 percent, and therefore could be used to determine the multiplying factor to be applied to the costs obtained from the curves of Fig. 36 to correct them to water usages other than 50 gal per day.

The use of Figs. 36 and 37 can be illustrated by the following example:

Determine the average cost of heating water for the following conditions:

| Type of heater          | external tankless                        |
| Hot water temperature  | 180 F                                   |
| Draw-off rate          | 3 gpm                                   |
| Hot water usage        | 75 gal per day                          |
| Fuel                   | Natural gas, 1000 Btu per cu ft          |
| Cost of fuel           | 10 cents per therm (100,000 Btu)         |

Find cost of gas, 10 cents per therm, on horizontal axis; go vertically upward until Curve 2 (tankless heater, water temperature 180 F) is intersected, then horizontally to the left. The average monthly cost of supplying 50 gal of hot water per day is found to be $3.08. Since the quantity of hot water used was not 50 gal per day, but 75 gal, Fig. 37 must be used to find the cost correction factor to be applied to the above value. For a daily usage of 75 gal the cost correction factor is 1.16. Therefore, the cost of heating water for the conditions stated is $3.08 \times 1.16 = $3.57 per month.
XI. SUMMARY OF RESULTS

The following is a summary of the results of this investigation:

(1) The temperature gradient from the top to the bottom of the boiler differed for each test setup. The maximum value was about 30 F, obtained with no water heater attached; the minimum was 2 to 3 F, obtained when the internal storage-type heater was attached. The magnitude of the temperature gradient depended on the manner in which heat was removed from the water and on the rate of water circulation. With no water heater attached, the boiler water cooled more rapidly near the bottom of the boiler. This produced a minimum of circulation, and the large temperature gradient noted. On the other hand, when a heater was used, the boiler water cooled most rapidly around the heater. This created a circulation which tended to equalize the temperature of the water throughout the boiler.

(2) For the setup used during the tests on the storage-type heaters, it was found that the control setting and the average water temperature in the storage tank were the same, while the corresponding average boiler water temperature at the control level was approximately 15 F higher. For example, with a control setting of 140 F, the temperature of the water in the hot water storage tank was 142 F, and the average temperature of the boiler water at the control level was 153 F.

(3) For any low-limit control setting, the external and internal storage-type heaters used in conjunction with either 30- or 66-gal storage tanks produced the same water temperature in the storage tanks during summer stand-by operation.

(4) For winter operation with the internal heater there was always an increase in storage tank temperature with the increase in boiler water temperature demanded to satisfy the house heating load when outdoor temperatures were low. This did not hold true for tests on the external heater when, under these same conditions, the temperature of the water in the storage tank dropped off slightly. The test data showed some evidence that circulator operation retarded the flow of boiler water through the external heater, and that this may have been sufficient in cold weather, with long periods of circulator operation, to cause a slight drop in the temperature of the water in the storage tank. One method of correcting this condition is to provide separate circuits for the house heating and the water heating system. The two circuits may have a common supply, but each should have its own return connection to the boiler. If a common return must be used, a “Y” or a special aspirating tee should be provided at the point where the water heater and the house heating circuits join.

(5) When 75 gal of water was used per day, the capacity of the storage heater and 30-gal tank was heavily taxed, resulting in wide variations in temperature between draws and as much as a 20 F drop in temperature during any particular draw. The temperature of the water drawn off at various times during the day varied from 186 F to 147 F. The storage heater and 66-gal tank were a much more stable combination, both as to temperature variation between draws and temperature drop during a draw. The maximum temperature drop during any draw was 12 F, and the water temperature during the day remained between 165 F and 185 F.

(6) At the rather low usage of 30 gal of hot water per day, the storage heater and 30-gal tank were well able to meet the demands, and there was little to choose between the 30- and 66-gal tanks, although the temperature remained a little more uniform in the case of the larger tank.

(7) When using the tankless heater the average temperature of the water drawn did not vary greatly between the individual draws of a 75-gal-per-day service draw-off test, but the temperature drop during any particular draw was large, generally running about 45 F. The drop in temperature experienced with the tankless heater would have been reduced had a fast acting water temperature
control been used to start the burner as soon as possible after the start of a draw.

(8) The rate of heating the water in the storage tank was dependent upon the difference between the boiler water temperature and the temperature of the water entering the heater, but was independent of the control setting. The output of the heater in Btuh was essentially unaffected by the tank size.

(9) The recovery rate of an indirect storage-type heater may be greatly reduced if rust or sediment is permitted to accumulate in the heater or piping. After four weeks operation without flushing, the recovery rate of the heater was reduced by 27 percent and after eight weeks by 40 percent. Possibly the observed reduction in recovery rate with continued operation without flushing would not have occurred had the water supply been soft; however, the tests did indicate that at least under certain conditions, the recovery rate of an indirect storage-type heater may be greatly reduced unless the piping and heater areflushed at regular intervals to remove any accumulation of foreign material.

(10) There was no limit on the number of wash cycles for automatic washing machines which could be made in succession when using the tankless heater as long as the low-limit control setting was above about 150 F. However, the variation in water temperature during any draw was 46 F to 50 F.

When using a storage heater and 30-gal tank with the low-limit control set at 185 F, only one automatic wash cycle could be completed before the water temperature dropped to 140 F, while for the same conditions using the 66-gal tank as many as four cycles were completed.

(11) The storage tank should be placed as high above the heater as possible in order to obtain the hottest possible water for a given control setting.

(12) As far as the quantity of hot water available at a single draw was concerned, no difference was observed between the external and internal heaters, but the size of the storage tank and the initial temperature of the water in the storage tank did have an appreciable effect on the quantity of water available. For an initial water temperature of 180 F, it was possible to draw 335 lb (64 gal) before the water temperature dropped to 125 F. Only 210 lb (25 gal) could be drawn from the 30-gal tank.

(13) With an initial water temperature of 180 F and using the tankless water heater with the draw-off rate set at 2 gpm, 180 lb (21 1/2 gal) of water could be drawn at a temperature of 130 F or over.

(14) The results of the continuous draw-off tests on the tankless heaters are somewhat limited in value because of the type of low-limit control used. In the continuous draw-off tests, some 6 or 7 min elapsed between the start of the draw-off and the time the burner started to operate. The quantity of hot water available at a single draw-off would have been increased materially had a fast acting low-limit control capable of starting the burner within 1/2 to 1 min after the start of the draw been used.

(15) The maximum load imposed by the storage-type water heater under the severe service conditions imposed by the 75-gal daily demand schedule was about 8,000 Btuh, and the duration of this peak load was for very short periods of time. The usual allowance made for pick-up and piping losses is more than adequate to provide for the small additional load imposed by heating domestic hot water during the winter, and hence, no water heating allowance need be added to the house heating load in selecting a boiler to be used with a storage-type water heater.

(16) In the case of the tankless heater, there is no water heating load during periods in which there is no hot water demand. However, the moment hot water is needed, the load on the boiler is instantaneous and severe, often exceeding 150,000 Btuh. For a tankless water heater to operate in a satisfactory manner, the heat removed from the boiler during any draw-off must not exceed the sum of the heat supplied to the boiler by the burner during the draw, the heat stored in the boiler water previous to the draw, and the heat stored in the metal of which the boiler is made.

(17) During the winter, the main load on the boiler is the house heating load, and a large portion of the heat escaping from the surfaces of the boiler, the chimney, the storage tank and the piping (which is lost heat as far as summer operation is concerned) is utilized in supplying heat to the house. On the other hand, in the summer the only function of the boiler is to supply heat for domestic water heating, and, therefore, all summer fuel consumption is chargeable to the cost of providing hot water.
The total daily fuel consumption for winter operation chargeable to water heating was dependent upon the indoor-outdoor temperature difference, but, within the scope of the tests, appeared to be independent of the type of water heater used, the size of the storage tank, the setting of the low-limit control, and the temperature of the cold water, or the quantity of hot water used.

The fuel consumption chargeable to water heating in winter using the storage heater ranged from 130 cu ft of gas per day at an outdoor temperature of 65 F and over to 0 cu ft per day at outdoor temperatures of 30 F or lower. Using the tankless heater the corresponding range of fuel consumptions was from 90 cu ft per day to 0.

For summer operation the required heat input for the tankless heater was from 20 to 25 percent less than for the storage heaters over the whole range of test conditions.

In summer the stand-by heat input was from 47 to 62 percent of the total heat input required when supplying 75 gal of hot water daily.

At a cost of 6 cents per therm (1 therm = 100,000 Btu, or 100 cu ft of the gas used in the tests) the estimated annual fuel consumption chargeable to the storage heater represents a total cost of $18.94 per year, or an average of $1.58 per month. At a cost of 10 cents per therm for the gas, the average monthly cost of operation would be $2.63. At a cost of 6 cents per therm, the yearly cost of the estimated fuel consumption chargeable to the tankless heater would be $15.25, or an average of $1.27 per month. At 10 cents per therm the average monthly cost would be $2.12.
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