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# Piping and Pick-up Factors for Automatically Fired One-Pipe Hot-Water and Steam Systems

by

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UNIVERSITY OF ILLINOIS BULLETIN

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# Piping and Pick-up Factors for Automatically Fired One-Pipe Hot-Water and Steam Systems

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## SUMMARY

In designing hydronic* systems, it is common practice to select a boiler with a gross output larger than the load to be connected to it. This is to ensure sufficient boiler capacity to take care of the piping loss of the system and to bring the system up to its maximum output in a reasonable time after a period of idleness. The ratio of the gross boiler output to the total connected load is called the piping and pick-up factor. The factors used in past years for automatically fired boilers have ranged from about 1.25 to as high as 1.56. In the interest of economical installations, it is desirable to use as low a piping and pick-up factor as possible consistent with proper performance of the system.

This investigation was undertaken to supply data on the effect of the size of the piping and pick-up factor on the performance of hydronic systems and to provide a logical basis for determining the minimum usable piping and pick-up factor.

A common method of operation requiring an adequate piping and pick-up factor is that of operating with reduced room-air temperature at night. The smaller the factor used, the longer the time required for the system to raise the house temperature to normal from the reduced temperature. Therefore, the length of the warm-up period was used as the criterion for the adequacy of the piping and pick-up factor.

A room air temperature of approximately 72 F from 5:30 a.m. to 10:00 p.m. and 66 F from 10:00 p.m. to 5:30 a.m. was maintained. The time required to raise the house temperature from 66 F to 72 F was observed each day and related to the outdoor temperature and the piping and pick-up factor. The size of the load was determined by the amount of radiation installed in the house. The gross output of the boiler was changed by changing the gas burning rate. Three gas burning rates, resulting in three piping and pick-up factors which ranged from about 0.9 to 1.6, were used for each system tested. Tests were made on a one-pipe steam system, and two forced circulation, one-pipe, hot-water systems.

From the results of these tests, it was concluded:

(1) The same piping and pick-up factor may be used for both steam and hot-water heating systems which are automatically fired.

(2) A piping and pick-up factor as low as 1.1 may be used for selecting the boiler for a system designed to maintain room-air temperature at a constant value at all times; however, this low a factor will not provide sufficient reserve for operation with reduced room-air temperature at night.

(3) A piping and pick-up factor of 1.3 is adequate for the successful operation of automatically fired steam or hot-water residential heating systems.

The following is a summary of test results:

When the outdoor temperature was near the design temperature, the method of operation had no measurable effect on the length of the warm-up period.

For each piping and pick-up factor the rate of warming the room air when operating at design indoor-outdoor temperature difference was the same regardless of the type or size of the system.

At a piping and pick-up factor of approximately 1.1 the heating capacities of the systems were not sufficient to raise the room-air temperature at the end of a night setback period to the normal daytime value.

As the piping and pick-up factor was reduced below 1.3 there was a marked increase in the length of the warm-up time. On the other hand, the decrease in warm-up time was relatively small as the piping and pick-up factor was increased above 1.3.

Oversizing both the boiler and radiation in the hot-water system by 12% reduced the length of the warm-up time by as much as 50%. Oversizing the boiler only (use of large piping and pick-up factor) resulted in only a slight reduction in the length of the warm-up time.

Due to the small heat storage capacity of a steam system, the rate at which the room-air temperature decreased at the start of a night setback period was about 40% greater when the steam system was being used than when using the hot-water system.

Normal daytime temperatures were attained at least an hour before the time the thermostat was satisfied, and, due to radiation from the warmer


* "Hydronic system" is a term used in the heating industry as a substitute for "steam and hot-water heating systems."

than normal ceilings during the warm-up period, the house felt comfortably warm even before the room-air temperature attained normal.

The average overrun in the living room-air temperature was approximately 2 F when the hot-water system was being used and about 1 F when using the steam system.

Neither oversizing the system nor increasing the piping and pick-up factor decreased the daily fuel consumption. On the contrary, they probably resulted in some increase.

The heat output from the hot-water system to the rooms began to increase as soon as the burner started to operate. However, the rate of increase was comparatively slow and about 4 hours were required to raise the output of the system to its maximum value for any of the three piping and pick-up factors used in these tests. The maximum output of the water system increased as the piping and pick-up factor was increased up to a factor of about 1.3. When a higher piping and pick-up factor was used, the high limit control prevented further increase in the water temperature and thus limited the maximum heat output of the system.

The heating-up characteristics of the steam system were quite different. Until the water temperature in the boiler had reached the boiling point and at least part of the air was expelled, there was no useful heat output. The length of time required to do this was dependent upon the water temperature at the time the burner started to operate and the rate of heat input to the boiler. In the three warm-up tests reported in this bulletin approximately 5 minutes were required to start boiling. It took an average of another 12 to 17 minutes for steam to reach the radiators. The time required to free the system of air, fill the system with steam, and thus obtain the maximum heat output from the system depended upon the piping and pick-up factor used, but even at the lowest piping and pick-up factor this was accomplished in an average time of about 90 minutes as compared to about 4 hours for the hot-water system.

Since the steam temperature could vary only between 212 F and about 220 F, the maximum output of the system was practically independent of the piping and pick-up factor used as long as the firing rate was sufficient to generate steam as fast as it was being condensed in the radiators and piping.

The normal operating cycle of the steam system was too short to obtain complete venting of the system and, therefore, uniformity of heating the different rooms was dependent upon the venting rate of the valves on the radiators. If for any reason the venting rate of one or more of these valves should change with respect to the others, the balance of the system may be destroyed.

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# I. INTRODUCTION

## 1. Preliminary Statement

This is the sixteenth publication prepared under a cooperative agreement between the Institute of Boiler and Radiator Manufacturers and the University of Illinois. Under the terms of this agreement the Institute is represented by a Research Committee consisting of eight members. This committee, working with the Engineering Experiment Station staff assigned to the I=B=R research project, develops the research program considered to be of greatest interest to the manufacturers, installers, and users of steam and hot-water heating equipment. The Institute provides funds for defraying the major portion of the expense of this research.

In designing hot-water or steam systems, it is common practice to select a boiler with a gross output in excess of the actual load to be connected to the boiler. This is to ensure that the boiler will have sufficient capacity to take care of the piping loss of the system and to bring the system up to its maximum output within a reasonable time following a period of idleness. The ratio of the gross boiler output to the total connected load is called the *piping and pick-up factor*. The piping and pick-up factors used in past years for automatically fired boilers have ranged from about 1.25 to as high as 1.56. In the interest of economical installation, it is desirable to use as low a factor as possible consistent with proper performance of the system.

This investigation was undertaken to supply data concerning the effect of the size of the piping and pick-up factor on the performance of hot-water and steam heating systems and to provide a logical basis for determining the minimum piping and pick-up factor which should be used.

The experimental work on hot-water systems was done in the I=B=R Research Home during the winters of 1950-51 and 1956-57. Investigations on the steam system were made during the winter of 1957-58.

## 2. Objects of Investigation

The tests herein reported were undertaken primarily to determine the minimum practical piping and pick-up factor for automatically fired, one-pipe, hot-water and steam systems. Other objectives were to compare the operating characteristics of one-pipe steam and hot-water systems when operating under actual use conditions.

## II. DESCRIPTION OF EQUIPMENT

### 3. I=B=R Research Home

The Research Home, shown in Figs. 1 through 4, and described in detail in earlier reports,[1, 2]* was a two-story building typical of the small, well-built American home of 1940. The construction was brick veneer on wood frame. All of the outside walls and the second-story ceiling were insulated with mineral wool batts 3⅝ in. thick. A vapor barrier between the plaster base and the insulation prevented condensation on the sheathing by retarding the passage of water vapor from the rooms into the insulation in the walls. The calculated coefficient of heat transmission, $U$, for the wall section was 0.074 Btu per sq ft per hr (F) temperature difference. All windows and the two outside doors were weatherstripped. Two storm doors were used. The total calculated heat loss for the house, excluding the basement, was 43,370 Btuh at design temperatures of −10 F outdoors and 70 F indoors. A summary of room volumes and calculated heat losses is given in Table 1.

* Superscripts in parentheses refer to entries in the References.

### 4. Heating Systems

*1950-51 Hot-Water System:* A gas fired, one-pipe forced circulation, hot-water system, designed in accordance with I=B=R Installation Guide No. 5, was used in the Research Home during the

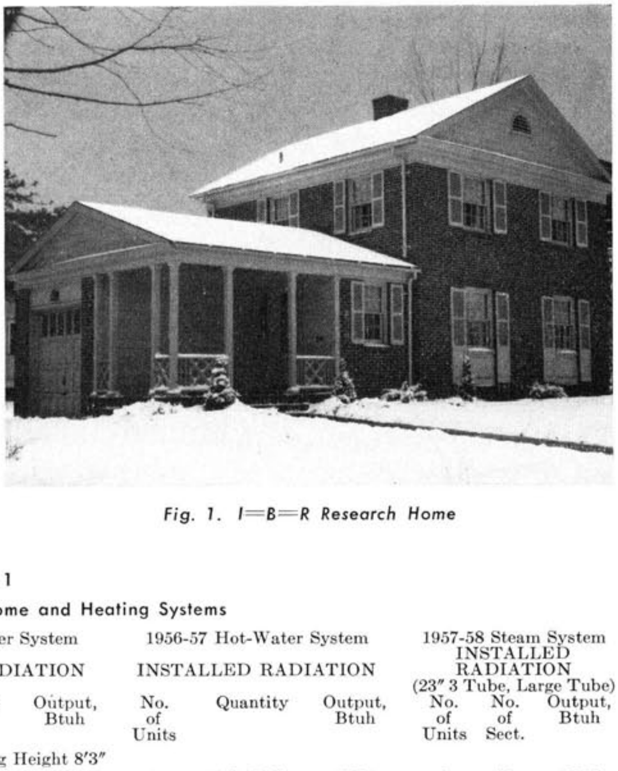


*Fig. 1. I=B=R Research Home*

Table 1

Data on I=B=R Research Home and Heating Systems

| Rooms | Dimensions | Heated Space, Cu Ft | Calc. Heat Loss, Btuh[a] | 1950-51 Hot-Water System INSTALLED RADIATION | | | 1956-57 Hot-Water System INSTALLED RADIATION | | | 1957-58 Steam System INSTALLED RADIATION (23″ 3 Tube, Large Tube) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | No. of Units | Quantity | Output, Btuh | No. of Units | Quantity | Output, Btuh | No. of Units | No. of Sect. | Output, Btuh |
| | | | | First Floor Ceiling Height 8′3″ | | | | | | | | |
| Living Room | 24′0″ x 13′4″ | 2641 | 5749 | 1 | 11 ft RC[b] | 5335 | 1 | 13 ft RC[b] | 6305 | 2 | 13 | 6240 |
| Dining Room | 13′1″ x 11′3″ | 1183 | 8742 | 1 | 11 ft RC[b] | 5335 | 1 | 13 ft RC[b] | 6305 | 1 | 14 | 6720 |
| Kitchen | 10′5″ x 11′3″ | 799 | 3199 | 1 | 10 Sect ST[c] | 3360 | 1 | 11 Sect ST[c] | 3696 | 1 | 7 | 3360 |
| Lavatory | 7′0″ x 2′8″ | 152 | 1484 | 1 | 8 Sect ST[c] | 2688 | 1 | 9 Sect ST[c] | 3025 | 1 | 2 | 960 |
| Vestibule | 7′5″ x 5′4″ | 284 | 4848 | 1 | 14 Sect ST[c] | 4704 | 1 | 16 Sect ST[c] | 5376 | 1 | 8 | 3840 |
| Vest. Closet | | 54 | | | | | | | | | | |
| Total, First Floor | | 5113 | 24022 | 5 | | 21422 | 5 | | 24707 | 6 | 44 | 21120 |
| | | | | Second Floor Ceiling Height 7′9″ | | | | | | | | |
| NE Bedroom | 10′7″ x 9′9″ | 800 | 4393 | 2 | 9 ft RC[b] | 4365 | 2 | 10 ft RC[b] | 4850 | 1 | 9 | 4320 |
| NW Bedroom | 10′6″ x 13′4″ | 1148 | 4944 | 2 | 10 ft RC[b] | 4850 | 2 | 12 ft RC[b] | 5820 | 1 | 11 | 5280 |
| SW Bedroom | 13′0″ x 11′4″ | 1108 | 5250 | 2 | 10 ft RC[b] | 4850 | 2 | 11 ft RC[b] | 5335 | 1 | 11 | 5280 |
| Bathroom | 6′6″ x 7′6″ | 374 | 2606 | 1 | 8 Sect ST[c] | 2688 | 1 | 9 Sect ST[c] | 3025 | 1 | 5 | 2400 |
| Stairway | | 505 | 2155 | 1 | 6 Sect ST[c] | 2015 | 1 | 7 Sect ST[c] | 2353 | 1 | 3 | 1440 |
| Closets | | 345 | | | | | | | | | | |
| Total, Second Floor | | 4280 | 19348 | 8 | | 18768 | 8 | | 21383 | 5 | 39 | 18720 |
| Total, First and Second Floors | | 9393 | 43370 | 13 | 51 ft and 46 Sect | 40190[d] | 13 | 59 ft and 52 Sect | 46090[e] | 11 | 83 | 39840[f] |

[a] No storm sash. Outdoor temperature = −10 F, indoor temperature = 70 F. Infiltration based on crackage.
[b] 7 in. RC radiant baseboard.
[c] 19 in. 4 tube, small tube.
[d] Equivalent to a design temperature difference of 74° or a design O.D.T. of −4 F.
[e] Equivalent to a design temperature of 85° or a design O.D.T. of −15 F.
[f] Equivalent to a design temperature difference of 73.5 F or a design O.D.T. of −3.5 F.

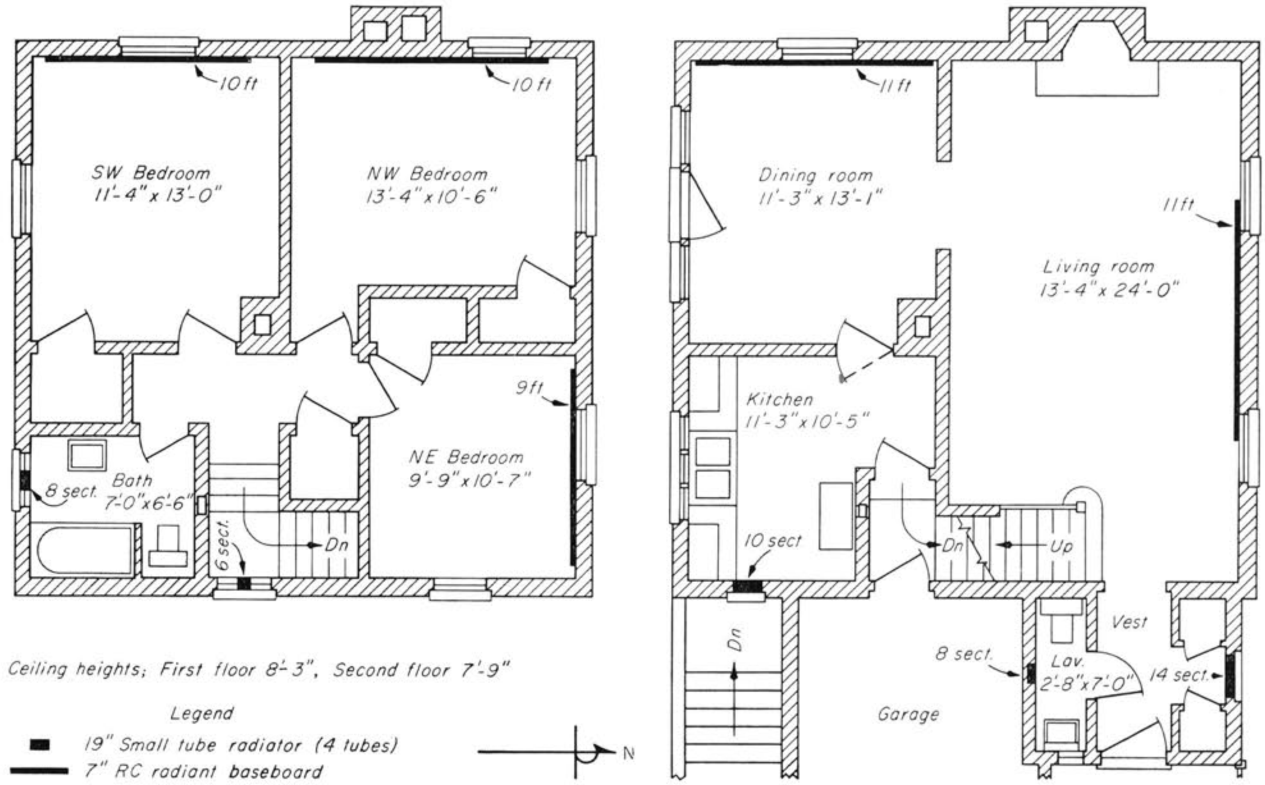



Fig. 2. 1950-51 Hot-Water System

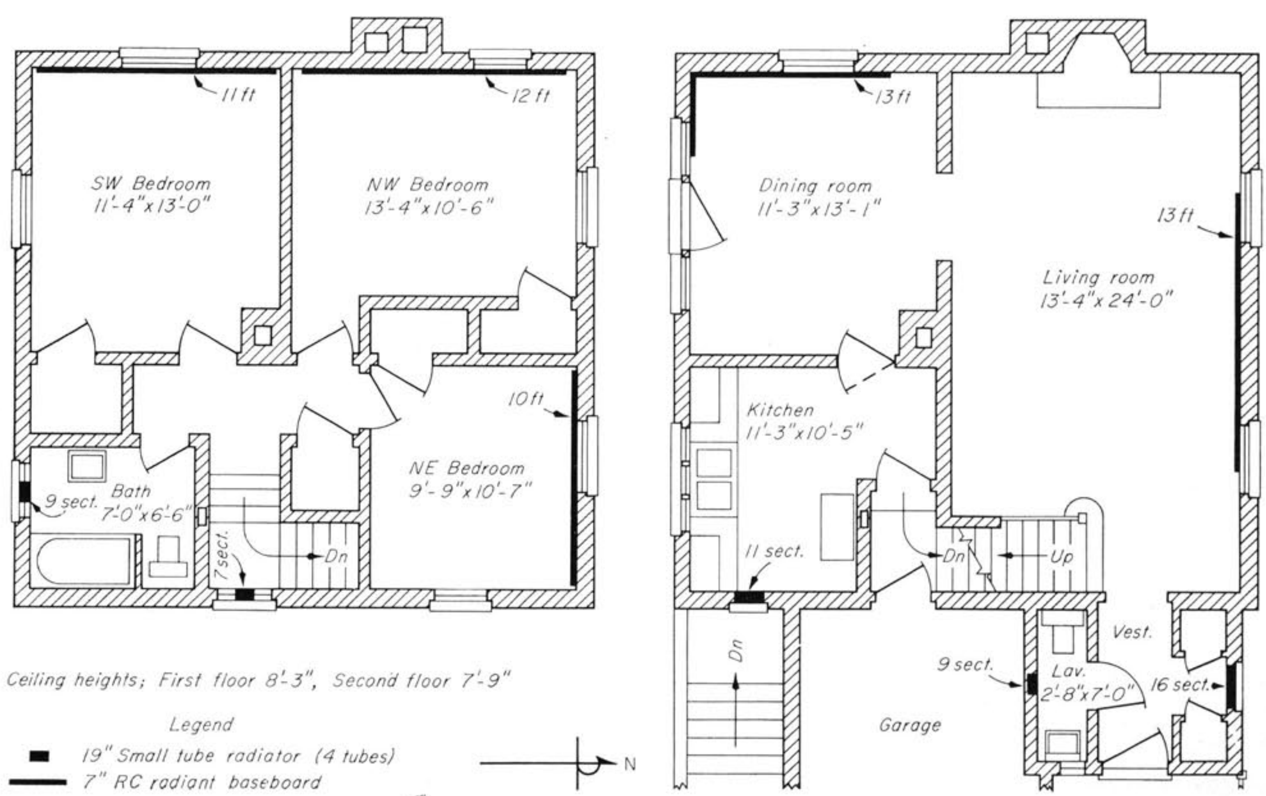



Fig. 3. 1956-57 Hot-Water System

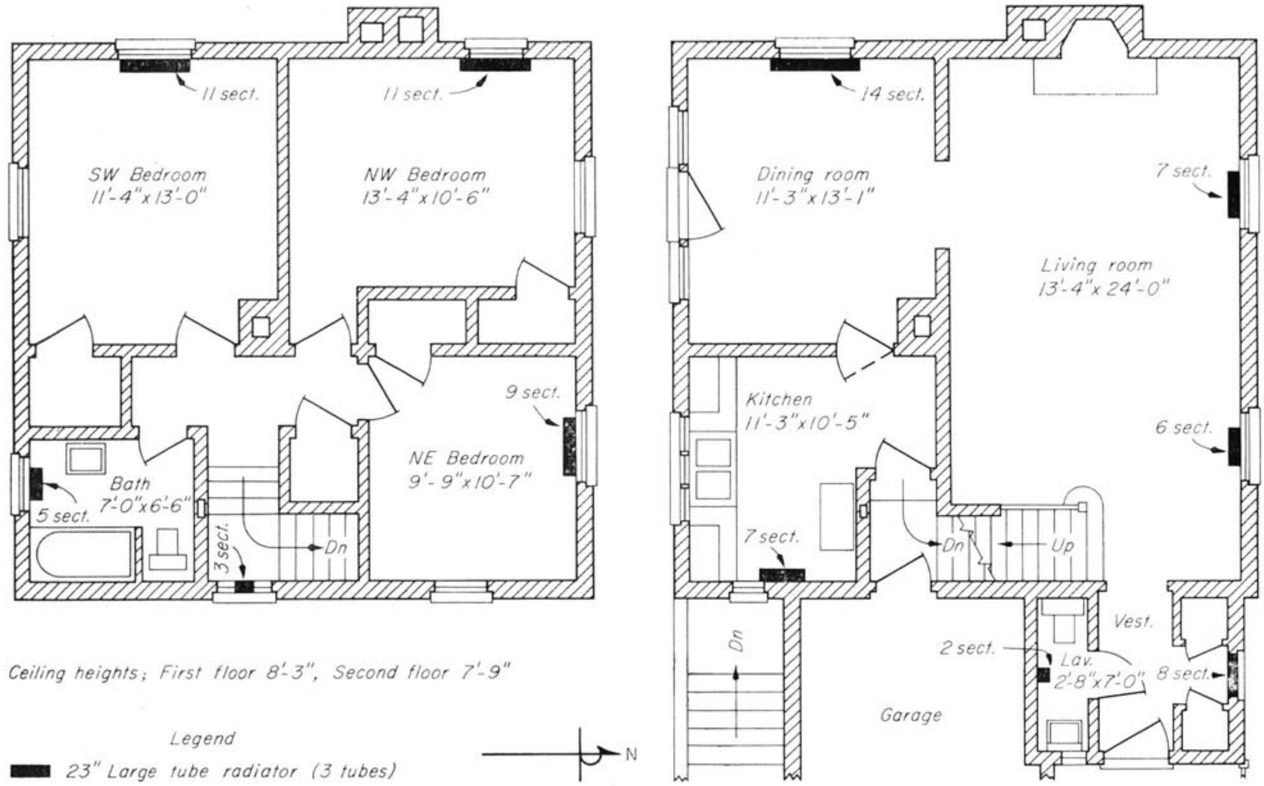



Fig. 4. 1957-58 Steam System

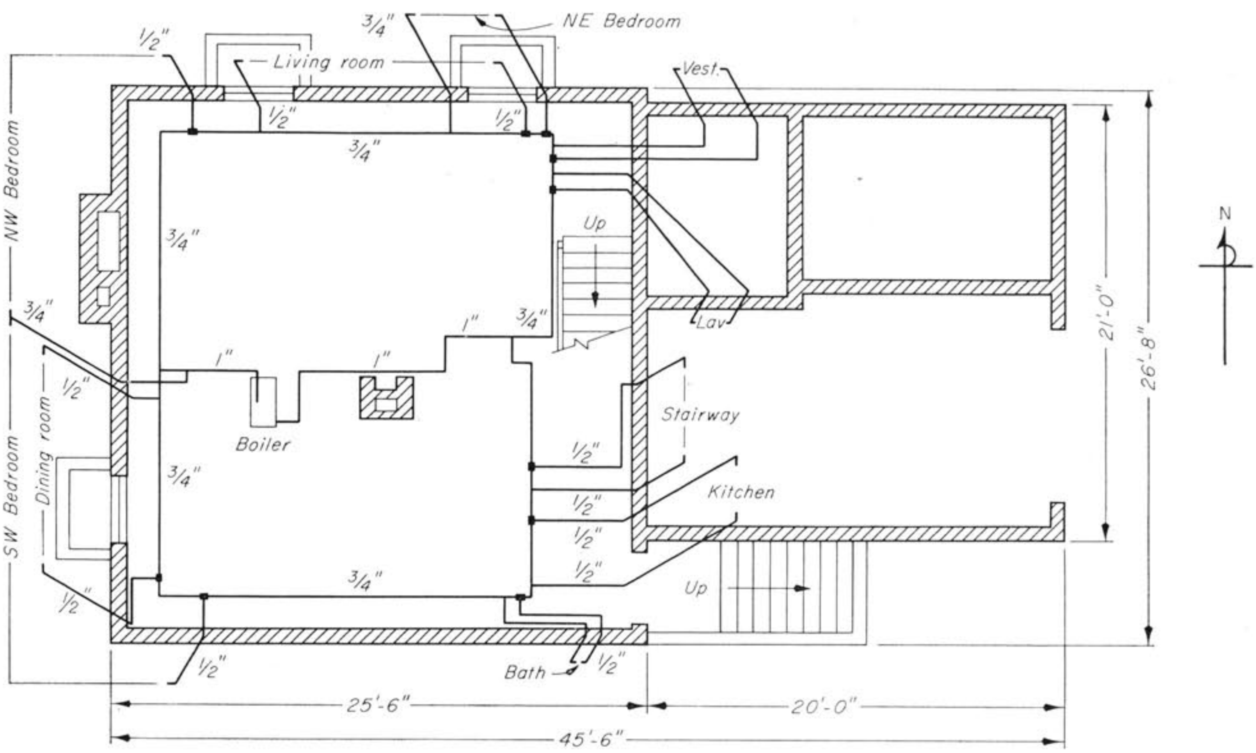
1950-51 heating season. The capacity of the installed radiation was equal to 40,190 Btuh at a design water temperature of 215 F. This capacity was equivalent to the calculated heat loss of the house at an indoor-outdoor temperature difference of 74 F or to a design outdoor temperature of −4 F and a design indoor temperature of 70 F. The radiation consisted of five units of 19-in. 4 tube, small tube radiators, totalling 46 sections, and eight units of 7-in. type RC radiant baseboard totalling 51 ft in length. The arrangement of the radiation and piping system is shown in Figs. 2 and 5 and in Table 1.

A wet bottom, cast iron boiler composed of two 6-in. sections and one 4-in. section was used in the tests. This boiler was insulated on top, sides and back with an air cell insulation approximately 1 in. thick and was completely enclosed in an enameled sheet metal jacket. All cracks between sections were sealed with asbestos cement. The boiler was equipped with a conversion type gas burner. The net I=B=R rating of the boiler was 55,000 Btuh, the gross I=B=R output was 84,000 Btuh; however, during the tests reported here several different firing rates were used to obtain different gross outputs.

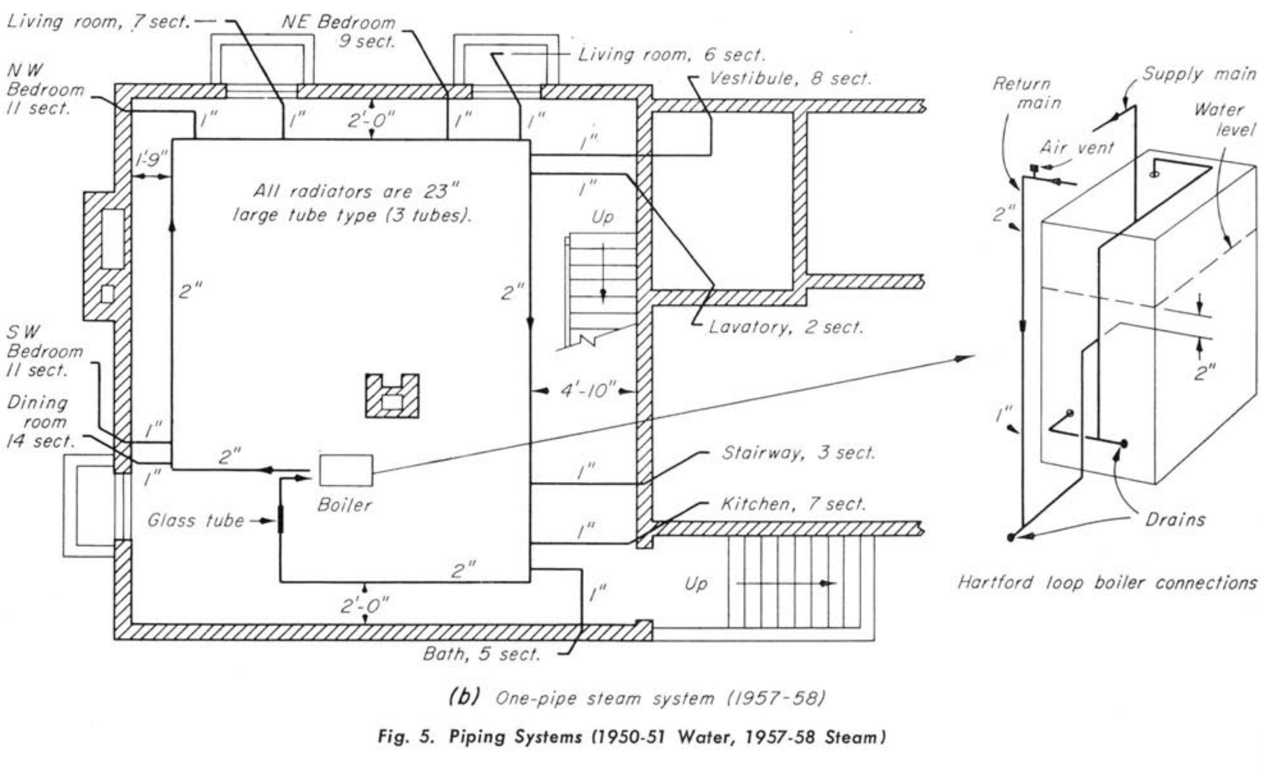
*1956-57 Hot-Water System:* The hot-water system used during the 1956-57 heating season was the same as that used during 1950-51 except that the installed radiation was increased by about 12%, equivalent to using a design indoor-outdoor temperature difference of 85 F. The amount of radiation installed in each room is shown in Table 1.

*1957-58 Steam System:* A gas fired, one-pipe steam heating system was used in the Research Home for all tests made during the 1957-58 heating season. The capacity of the installed radiation (Table 1) was equivalent to the calculated heat loss of the house at an indoor-outdoor temperature difference of 73.5 F. The radiation consisted of 23-in. 3 tube, large tube radiators set under windows. All radiator venting valves and the main vent valves were of the non-vacuum type. The venting rates of the valves were adjustable. The sizes and locations of the radiators are indicated in Table 1 and on the floor plans of the house in Fig. 4. The piping system is shown in Fig. 5.

A dry base, 4-section, cast iron steam boiler




*(a)* One-pipe hot-water system (1950-51 and 1956-57)




*(b)* One-pipe steam system (1957-58)

**Fig. 5. Piping Systems (1950-51 Water, 1957-58 Steam)**

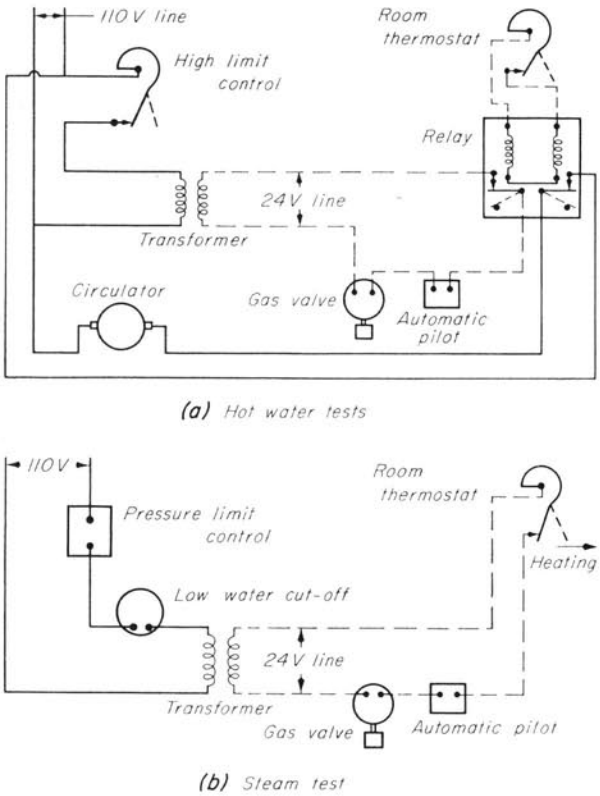



*Fig. 6. Control Arrangements (Hot-Water and Steam Systems)*

designed for gas firing was used in the tests. The boiler was insulated on the top, sides, front and back with glass wool insulation approximately 1 in. thick and was completely enclosed in an enameled sheet metal jacket. The net I=B=R rating was 40,000 Btuh, but, as was the case with the hot-water boiler, several gas burning rates were used to obtain a range of gross outputs.

## 5. Controls

The same basic control arrangement was used in all three heating systems. The room thermostat, located at the 30-in. level in the living room, was of the heat-anticipating type and turned the gas burner on and off according to the heat requirements of the room. On the hot-water system the room thermostat also controlled the operation of the circulator. The safety control consisted of an immersion thermostat set to stop the burner, but not the circulator, when the temperature of the water in the boiler exceeded 225 F. The burner would re-start when the water temperature dropped to about 185 F.

The safety controls on the steam system consisted of a low water cut-off, set to turn off the burner at any time the water level in the boiler dropped 5 in. below normal, and a steam pressure control, set to stop the burner when the steam pressure attained 2.5 lb per sq in. gage.

Both the steam and water boilers were equipped with safety valves set to open at the maximum allowable working pressure for the system. Schematic diagrams of the control arrangements are shown in Fig. 6.

## 6. Testing Apparatus

Instrumentation in the Research Home has been described in detail in an earlier report.[1] It suffices here to say that thermocouples for the measurement of room-air and basement-air temperatures were installed at levels of 3 in., 30 in., and 60 in. above the floor as well as 3 in. below the ceiling. Other thermocouples were used to measure the temperature of the water or steam leaving the boiler and the temperature of the water returning to the boiler. A differential pressure recorder attached to an elbow meter,[3] calibrated in place, supplied a continuous record of the rate of water circulation through the boiler for all tests with the hot-water system.

Recording thermometers were used to make continuous records of the air temperatures in each of the six rooms and the attic space at 3 and 30 in. above the floor and 3 in. below the ceiling. Similar thermometers recorded the temperature of the outdoor air and the temperature of the flue gases at the flue outlet of the boiler. The $CO_2$ content of the flue gas was obtained by use of an Orsat apparatus, and the fuel consumption was measured by a dry test meter. The moisture content of the air was measured by four humidity indicators and one hygrometer. A thermocouple-type surface pyrometer was used to measure the temperature of radiator surfaces during special studies.

# III. METHOD AND PROCEDURE OF TESTING

## 7. General Method

Operating a heating system with reduced temperature at night is one of the more common methods of operation requiring an adequate piping and pick-up factor. The smaller the factor used, the longer the time required for the system to raise the house temperature to normal following a period of operation with reduced temperature. Hence, the length of this warm-up period was used as the criterion for the adequacy of the piping and pick-up factor.

The thermostat was set to maintain a room-air temperature of approximately 72 F from 5:30 a.m. to 10:00 p.m. and 66 F from 10:00 p.m. to 5:30 a.m. The time required to raise the house temperature from 66 F to 72 F was observed each day and related to the outdoor temperature and the piping and pick-up factor.

By definition, the piping and pick-up factor is the ratio of the gross output of the boiler to the connected load. The size of the connected load was determined by the amount of radiation installed in the house. Different gross outputs of the boiler were obtained by the use of different burning rates. Three gas burning rates, resulting in three piping and pick-up factors, were used for each system tested. These factors ranged from about 0.9 to 1.6. The fuel used in all tests was natural gas supplied by the Texas-Oklahoma pipe line. The heating value of the gas was 1000 Btu per cu ft.

At all times during the tests the doors between rooms were open, and the windows were closed. Observations of room-air temperature as determined by the thermocouples located 3, 30 and 60 in. above the floor and 3 in. below the ceiling were recorded at 7:30 a.m., 11:00 a.m., 4:00 p.m. and 10:30 p.m. The temperature of the air in the basement and in the attic and the relative humidity in the heated portions of the house were also observed at these times. Complete daily records were made of the operating time, the number of cycles of the gas burner, the power consumption of the circulator and the cubic feet of gas consumed. Recording instruments were used to obtain a continuous record of the temperature of the water returning to the boiler and the temperature of the water or steam at the boiler outlet.

Table 2

Operating Conditions — Hot-Water Tests

| Test Series | High Limit Control Setting, F | Low Limit Control Setting, F | Flow Control Valve | Water Heater Operation | Thermostat Setting, F | Installed Radiation, Btuh | Gas Burning Rate, cfh |
|---|---|---|---|---|---|---|---|
| B–50 | 225 | 185 | Used | 75 gal serv. | 72–66 | 40,190 | 100 |
| C–50 | 225 | 185 | Used | Standby | 72–66 | 40,190 | 100 |
| F–50 | 225 | Off | Not Used | Drained | 72–66 | 40,190 | 100 |
| G–50 | 225 | Off | Not Used | Drained | 72–66 | 40,190 | 70 |
| H–50 | 225 | Off | Not Used | Drained | 72–66 | 40,190 | 85 |
| A–56 | 225 | 185 | Used | Standby, Drained | 72–66 | 46,090 | 100 |
| B–56 | 225 | 185 | Used | Standby, Drained | 72–66 | 46,090 | 70 |
| C–56 | 225 | Off | Used | Standby, Drained | 72–66 | 46,090 | 135 |
| I–50 | 225 | 185 | Used | Standby | 72–66 | 40,190 | 70 |
| J–50 | 225 | 185 | Used | 75 gal | 72–66 | 40,190 | 70 |
| K–50 | 225 | 185 | Used | Standby | 72–66 | 40,190 | 85 |
| N–50 | 225 | Off | Used | Drained | 72 | 40,190 | 100 |

## 8. Hot-Water Tests

The operating conditions employed in tests on the hot-water heating systems are shown in Table 2. For each operating condition the gross output of the boiler was obtained by multiplying the rate of water circulation through the boiler in pounds per hour by the temperature rise in degrees F. As a check on this calculation, the gross output was also obtained by multiplying the heat input rate to the boiler by the efficiency of operation. The efficiency of operation was obtained from readings of the temperature and carbon dioxide content of the flue gas. The total heat input rate was equal to the rate of gas burning in cfh multiplied by the heat content of the gas in Btu per cubic foot.

The piping and pick-up factors were obtained by dividing the gross output of the boiler by the connected load, both expressed in Btuh.

## 9. Steam Tests

In testing the steam system, the initial steps were to establish a uniform rate of heating rooms by adjusting the venting rates of the radiator vent valves. After the room-air temperature had been balanced, the room thermostat was set at 72 F from 5:30 a.m. to 10:00 p.m. and at 66 F from 10:00 p.m. to 5:30 a.m. Three series of tests were conducted under these conditions: Series E-57 with a gas burning rate of 85 cfh; Series F-57 with a burning rate of 65 cfh; and Series G-57 with a burning rate of 70 cfh.

For each series of tests, the measured flue gas temperature and the $CO_2$ content of the flue gas determined the boiler efficiency. This efficiency, multiplied by the heat input rate, gave the gross output of the boiler. As before, the piping and pick-up factor was obtained by dividing the gross output of the boiler by the installed radiation.

### 10. Special Tests

Some special tests were made to determine the rate of heating when starting with the entire system cold. Operating conditions and test methods used for these tests are described along with the discussion of results.

## IV. BOILER OUTPUT AND RATE OF WARM-UP

### 11. Effect of Indirect Water Heater Operation on Length of Warm-up Period

Preliminary tests were made at the start of the hot-water studies to determine the effect of the operation of an indirect water heater on the length of the warm-up period. The three conditions considered were: operation with the low limit control and with no water heater in use; operation with the water heater attached but no hot water used; and operation with a daily hot-water consumption of 75 gal. A summary of all operating conditions is given in Table 2. Figure 7 shows the warm-up time plotted against the outdoor temperature during the warm-up period for Series G-50, J-50 and I-50. These tests were made with a firing rate of 70 cfh, the lowest used with this heating system. The capacity of the installed radiation was equivalent to the calculated heat loss of the house at 70 F and −4 F indoor and outdoor temperatures, respectively. It can be seen that when the outdoor temperature was near the design temperature, the method of operation had no measurable effect on the length of the warm-up period. In mild weather, operation with no water heater attached to the boiler resulted in the longest warm-up time. While the curves are not shown for Series B-50, C-50 and F-50, in which the firing rate was increased to 100 cfh, these three series of tests confirmed the results shown in Fig. 7.

The piping and pick-up factor is most critical when the system is operating at or near design conditions. This being the case, these preliminary tests indicated that the method of operation should have no effect on the results of the tests; however, practically all subsequent tests to determine the minimum piping and pick-up factor were made by operating the boiler with no low limit control and without an indirect water heater attached.

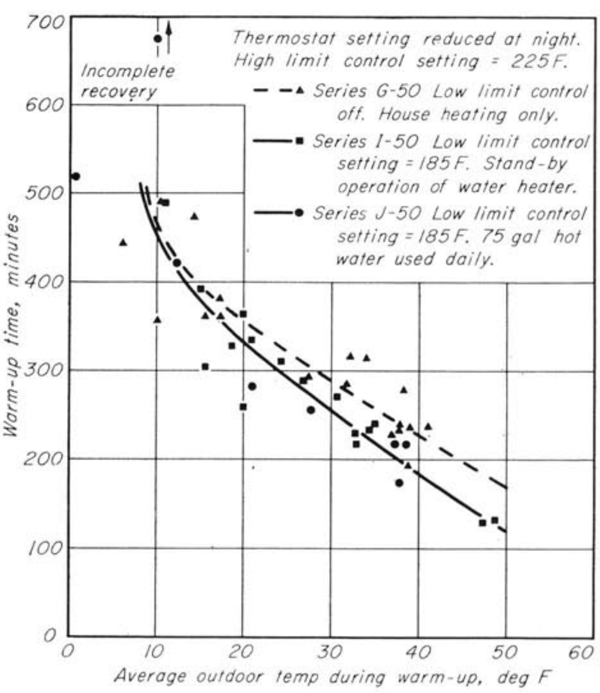



**Fig. 7. Effect of Operating Conditions on Length of Warm-up Period**

### 12. Effect of Burning Rate on Gross Output and Piping and Pick-up Factor

The curves of Fig. 8 show the effect of burning rate on the piping and pick-up factor and the gross boiler output. It can be observed that as the firing

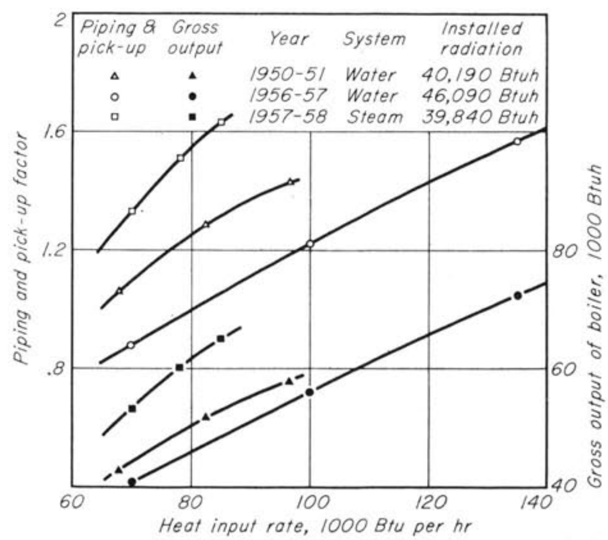



**Fig. 8. Gross Outputs of Boiler and Piping and Pick-up Factors**

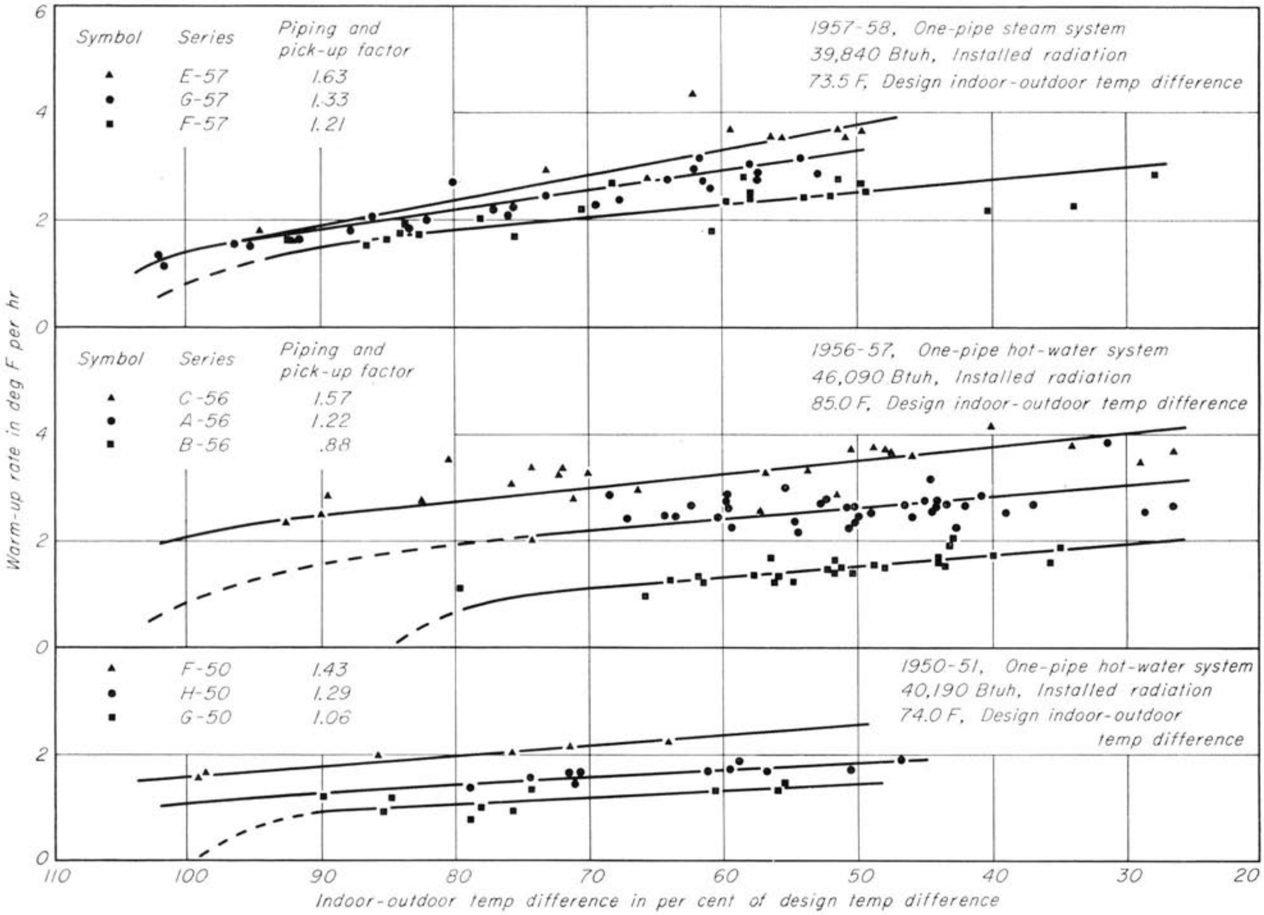



*Fig. 9. Effect of Indoor-Outdoor Temperature Difference on the Warm-up Rate*

rate increased, the boiler output increased, and, consequently, the piping and pick-up factor increased. Thus, the three firing rates used for each heating system represented three boiler outputs and three piping and pick-up factors. The latter were the ratios of gross boiler outputs to the installed radiation, both expressed in Btuh.

### 13. Effect of Percent of Design Indoor-Outdoor Temperature Difference on Warm-up Rate

Relating the length of the warm-up period to the average outdoor temperature and fuel burning rate, as was done in Fig. 7, was found to be unsatisfactory when trying to compare the different systems as, from test to test, there was some variation in the number of degrees the room-air temperature was raised. Furthermore since the amount of installed radiation differed in each system, a given firing rate did not result in the same piping and pick-up factor for all three systems.

To place all data on a common basis, the average rate of warming the room air in degrees F per hour was correlated with the observed indoor-outdoor temperature difference during the test, expressed in percent of the design temperature difference, and with the piping and pick-up factor. The design temperature difference was taken as that at which the calculated heat loss of the house would be equal to the capacity of the installed radiation. The observed indoor-outdoor temperature difference was assumed equal to the difference between the average daytime indoor air temperature and the average outdoor air temperature during the warm-up period.[1, 4] The piping and pick-up factor was obtained from the heat input rate during the test and Fig. 8.

Figure 9 is a plot of all test data using the method just described. These curves show the obvious fact that for any piping and pick-up factor the rate of warm-up decreases as the indoor-outdoor temperature difference increases, and at any given indoor-outdoor temperature difference, the rate of warm-up increases as the piping and pick-up factor is increased. It appeared that the indoor-outdoor

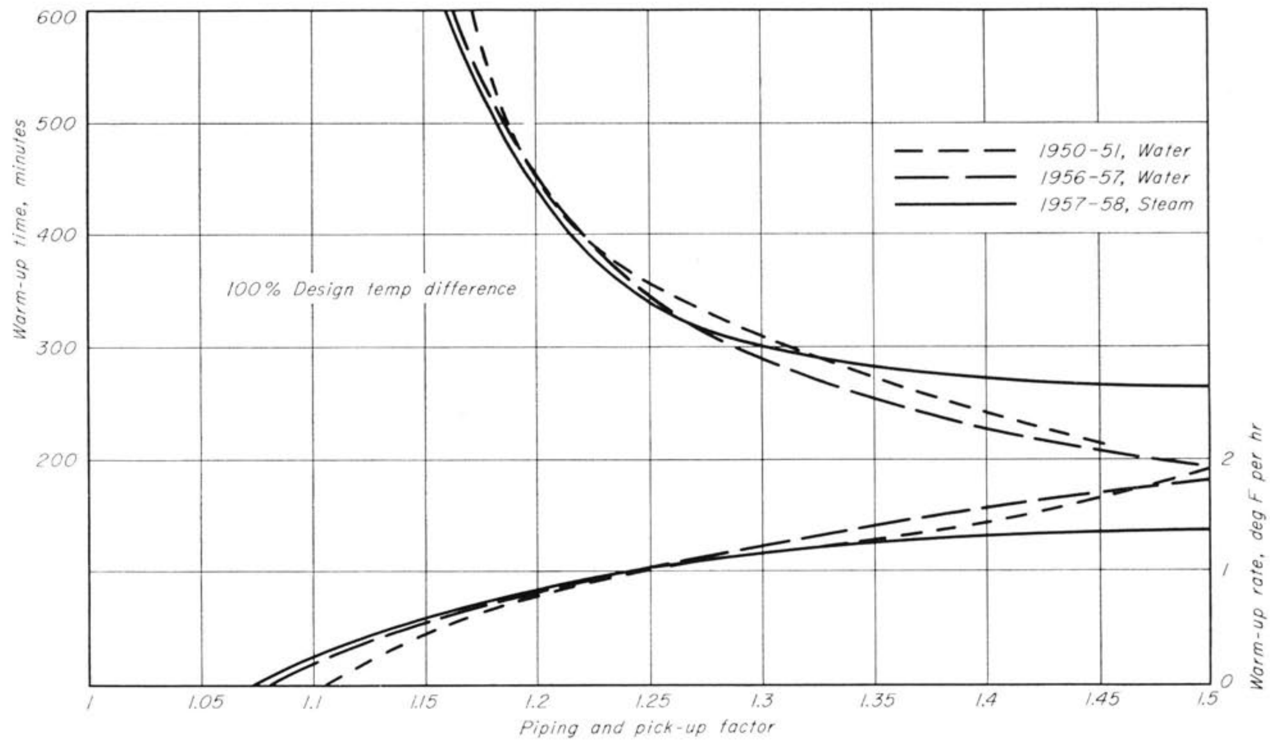



*Fig. 10. Effect of Piping and Pick-up Factor on the Warm-up Rate*

temperature difference had a greater effect on the warm-up rate when using the steam system than when using the hot-water system. Also, as the size of the hot-water system was increased, the effect of the indoor-outdoor temperature difference on the warm-up rate became more pronounced.

### 14. Effect of Piping and Pick-up Factor on Warm-up Time

The warm-up rate at the design indoor-outdoor temperature difference is most important, since the boiler size must be adequate to ensure satisfactory operation at these conditions. The lower group of curves in Fig. 10 shows the relationship between the warm-up rate and the piping and pick-up factor for each of the three systems when operated at design conditions. These curves were derived directly from those in Fig. 9.

For each piping and pick-up factor, the rate of warming up the room air when operating at design indoor-outdoor temperature difference was essentially the same regardless of the type or size of the system. At a piping and pick-up factor of approximately 1.1, the heating capacity of the system was not sufficient to raise the room-air temperature at the end of a night setback period. Thus a factor of 1.1 might be used on a system where the room-air temperature was to be maintained at a constant value at all times, but it would not be adequate if the room-air temperature was to be periodically reduced below the normal operating value. In Fig. 10 a clearer picture of the effect of the size of the piping and pick-up factor on the length of the warm-up time is obtained from the upper group of curves which show the time required to raise the room-air temperature 6 F. As the piping and pick-up factor was reduced below about 1.3, there was a marked increase in the length of the warm-up time. On the other hand, as the piping and pick-up factor was increased above 1.3, the decrease in warm-up time was relatively small. For example, increasing the piping and pick-up factor from 1.3 to 1.56 (a 12% increase in the gross boiler output) made almost no reduction in the length of the warm-up time when using the steam system, and about a 30% reduction in the case of the hot-water system. A 12% reduction in the gross output of either the steam or hot-water boiler resulted in a warm-up time of over 10 hours.

The results of these tests indicate that a piping and pick-up factor of 1.3 is adequate for the successful operation of both automatically fired steam and hot-water residential heating systems. The use of larger factors results in the selection of larger boilers but offers little or no improvement in overall performance.

### 15. Effects of Outdoor Temperature and System Size on Warm-up Time

The length of the warm-up period shown in Fig. 10 may seem large. However, this is for design outdoor temperature difference and, for a greater part of the winter, outdoor temperatures are well above design. In Urbana the average outdoor temperature for the winter is 38 F and for only about one day out of every two years does the outdoor temperature average zero or less. Furthermore, due to the radiant effect of the hot radiators and the warmer than normal ceiling, the house felt comfortably warm 60 to 90 minutes before the actual end of the pick-up cycle.

Table 3 has been developed from the same data as Fig. 10 and is arranged to show the effect of outdoor temperature and system size on warm-up time. For all systems, an increase in the outdoor temperature resulted in a marked decrease in warm-up time. This was especially true in the 1957-58 tests using the one-pipe steam system. Whereas the length of the warm-up period at design indoor-outdoor temperature difference was about 300 minutes, at an outdoor temperature of 30 F it was only 115 to 195 minutes.

A hot-water heating system inherently requires a relatively long time to raise the house temperature from one value to a higher one. By increasing both the amount of installed radiation and the gross output of the boiler by 12%, thus making no change in the piping and pick-up factor, the length of the pick-up time when using a hot-water system at an outdoor temperature of −10 F was reduced from 435 minutes to 225 minutes, a reduction of approximately 50%. At an outdoor temperature of 30 F the reduction in warm-up time was approximately 35%.

The results of these tests indicate that the warm-up time for a hot-water system may be decreased to some extent by the use of an oversized boiler, but if minimum warm-up times are desired, the entire system must be increased in size. Almost no decrease in the warm-up time results from the use of an oversized steam boiler.

While the use of an oversized system will reduce the warm-up time, caution should be used, since carrying such a practice to extreme may result in such control problems as overrun of room-air temperature above the setting of the thermostat.

**Table 3**

**Effects of Outdoor Temperature and System Size on Length of Warm-up Time**

Indoor Temperature = 70 F
Piping and Pick-up Factor = 1.3
House Temperature Raised 6 F

| Outdoor Temp., F | 1950-51 Percent of Design In-Out Temp. Diff. | 1950-51 Warm-up Time, Minutes | 1956-57 Percent of Design In-Out Temp. Diff. | 1956-57 Warm-up Time, Minutes | 1957-58 Percent of Design In-Out Temp. Diff. | 1957-58 Warm-up Time, Minutes |
|---|---|---|---|---|---|---|
| −20 | 122 | Inf. | 106 | 500 | 121 | Inf. |
| −10 | 108 | 435 | 94 | 225 | 107 | 510 |
| 0 | 95 | 272 | 83 | 172 | 94 | 233 |
| 10 | 81 | 227 | 71 | 146 | 81 | 167 |
| 20 | 68 | 204 | 59 | 130 | 67 | 133 |
| 30 | 54 | 195 | 47 | 125 | 54 | 115 |
| 40 | 41 | 195 | 35 | 125 | 40 | 105 |
| Installed Radiation | 40,190 Btuh | | 46,090 Btuh | | 39,840 Btuh | |
| Design In-Out Temp. Diff. | 74.0 F | | 85.0 F | | 73.5 F | |
| System | Hot-Water | | Hot-Water | | Steam | |

# V. ROOM-AIR TEMPERATURES

## 16. Average Room-Air Temperature During Setback Period

Both the steam and hot-water systems produced a variation in room-air temperature during the night setback period. These variations are shown in the curves of Fig. 11, which were drawn from the data of two selected testing days, each having an average indoor-outdoor temperature difference approximating design conditions.

Even though the outdoor temperature was about the same during the period represented by each of the curves in Fig. 11, the rate at which the house cooled down was about 40% faster when the steam system was in use. Since there were no changes in the house which would affect the heat loss, it is evident that the different rates of cooling must be attributed to the heating systems. The water content of the hot-water system exceeded that of the steam system by about 250 lb. The average temperature of the water at the start of the setback period was about 200 F and during the setback period this water was cooled to about 80 F, a drop of 120 F. This represented a heat release from the hot-water system of approximately 30,000 Btu (equivalent to the calculated heat loss of the house for about one hour at the indoor-outdoor temperature difference existing during the setback period) which was not present when the steam system was used. Since there were heat gains in the house from such other sources as gas burned in the water heater, electricity used, occupancy and heat from the chimney, the heat released by cooling the water in the heating system did not have to supply the entire heat loss of the house and it is evident that the 30,000 Btu from the water would be sufficient to increase the length of the cooling period by 90 minutes as indicated in Fig. 11.

In mild weather the cooling rate of the house was correspondingly longer. In fact, at an outdoor temperature of about 35 F there was no operation of the burner during the entire night and the temperature of the water in the heating system was between 70 F and 80 F at the start of the pick-up period. In this case an additional 30,000 Btu had to be supplied to the water in the hot-water system as compared to the steam system to obtain the full

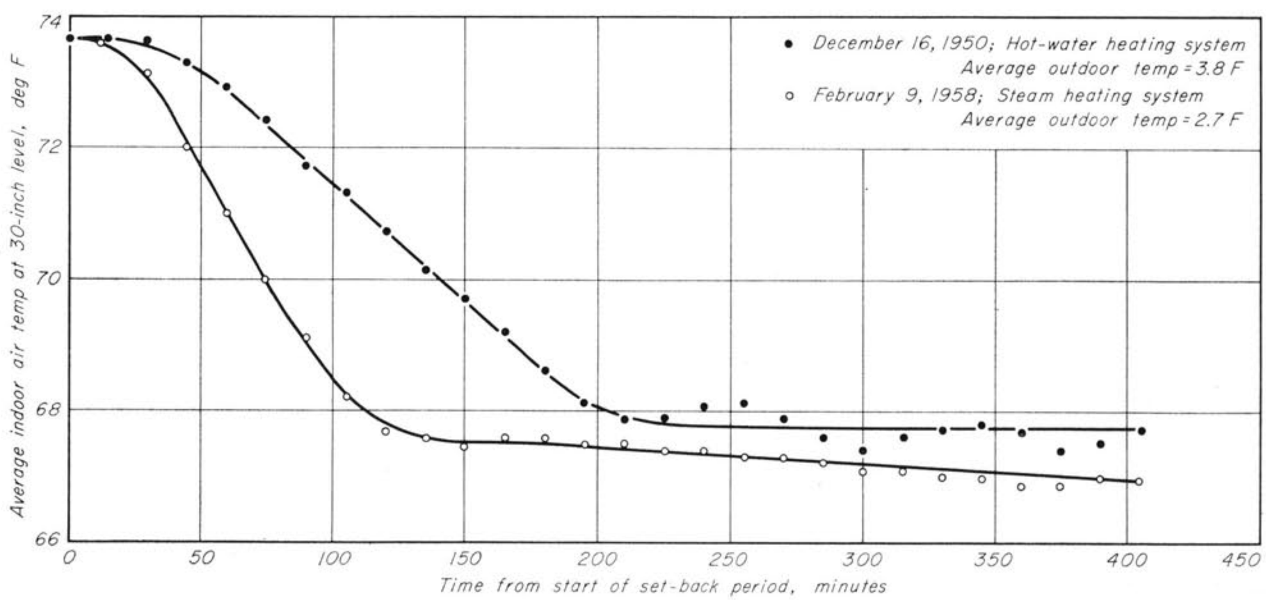



**Fig. 11. Room-Air Temperature During Setback Period**

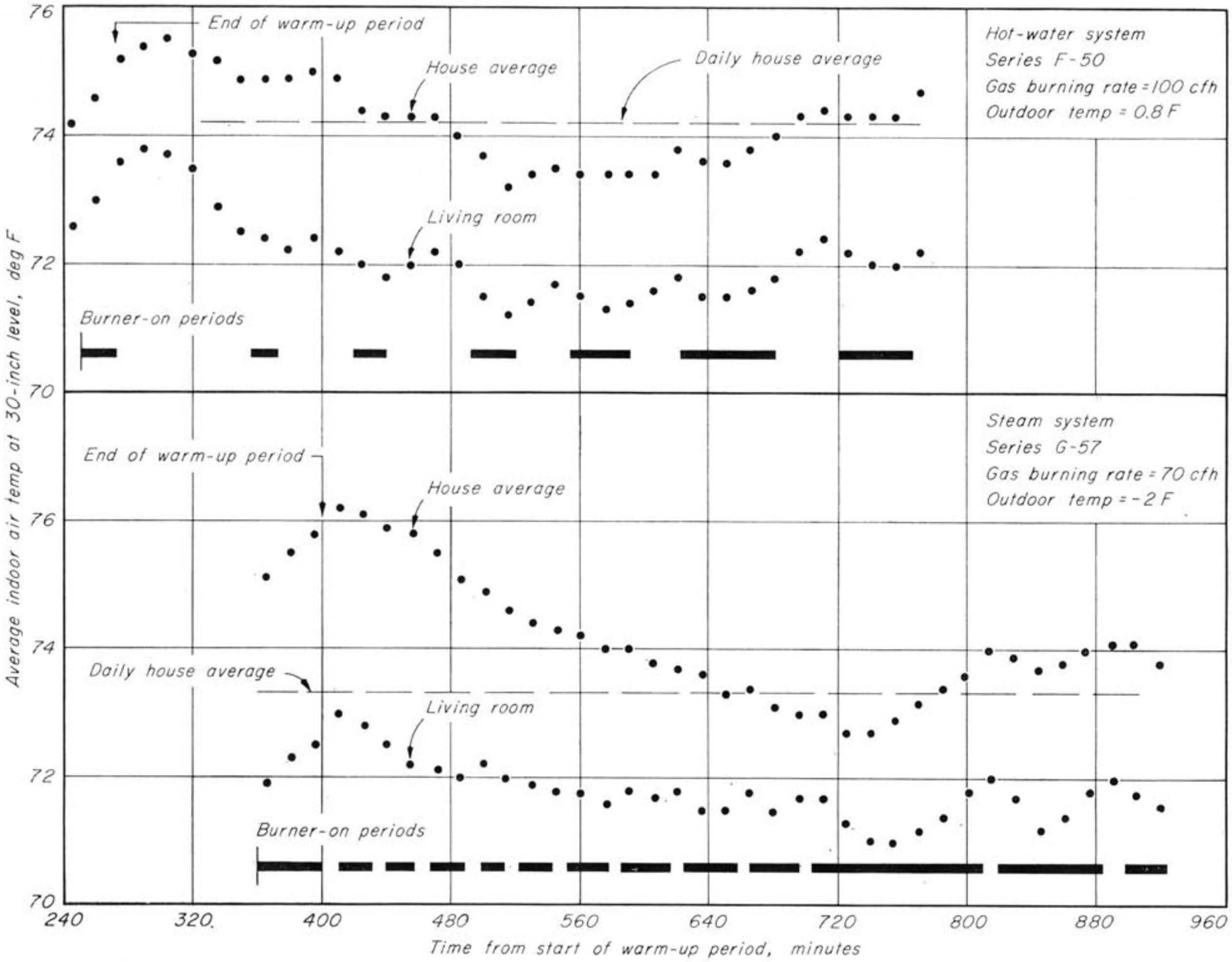



*Fig. 12. Room-Air Temperature at End of Warm-up Period*

output of the installed radiation. Thus the warm-up time for the hot-water system in mild weather was longer than for the steam system. In colder weather, the heating systems would operate during the night so that at the start of the pick-up period the water temperature was nearer the design value. At design outdoor temperature, operation of the systems at night was sufficient to bring the water temperature close to the maximum temperature required and hence the warm-up time was about the same for both the steam and water system (see Table 3).

## 17. Average Room-Air Temperature Following Warm-up Period

Average room-air temperatures and the temperature of the air in the living room near the end of, and immediately following, the warm-up period are shown in Fig. 12. The living room air temperature was about 2 F lower than the house average but otherwise the two exhibited the same characteristics. During the warm-up periods, the temperature of the room air was increasing. The change in the temperature of the walls and thermostat body naturally lagged behind the air temperature change. The heat input from the anticipator was insufficient to overcome this lag completely; hence there was a 1 F overrun in air temperature at the time the thermostat ceased to call for heat (end of warm-up period). This represents the amount that the temperature of the thermostat lagged the air temperature during the warm-up period. There was some additional overrun immediately following the end of the warm-up period resulting from heat stored in the system. The lag of the thermostat behind the room-air temperature made the warm-up periods (time the thermostat called for heat) quite long. However, normal daytime temperatures were attained at least an hour before the end of the

Table 4

Room Air Temperatures at End of Warm-up Period

| Test Series | Gas Burning Rate, cfh | Piping and Pick-up Factor | Warm-up Period, Minutes | Time to Raise Room-Air Temp. to Normal, Minutes | Overrun in Living Room: Time, Minutes | Overrun in Living Room: Temp., F | Outdoor Air Temp., F |
|---|---|---|---|---|---|---|---|
| Water System | | | | | | | |
| F–50 | 100 | 1.43 | 273 | 220 | 53 | 1.8 | 0.8 |
| F–50 | 100 | 1.43 | 198 | 148 | 50 | 2.5 | 26.0 |
| G–50 | 70 | 1.06 | 310 | 256 | 54 | 1.7 | 32.0 |
| Average, Water System | | | | | | 2.0 | |
| Steam System | | | | | | | |
| F–57 | 65 | 1.21 | 170 | 158 | 12 | 0.7 | 33.0 |
| G–57 | 70 | 1.33 | 400 | 353 | 47 | 1.5 | −2.0 |
| E–57 | 85 | 1.63 | 145 | 110 | 35 | 1.2 | 32.0 |
| Average, Steam System | | | | | | 1.1 | |

warm-up period, and the house felt comfortably warm even before the room-air temperature attained normal due to radiation from the warmer than normal ceilings during the warm-up period.

Following the peak temperature, attained a few minutes after the end of the warm-up period, the room-air temperatures declined. Even during this period there was some operation of the burner, apparently due to the effect of wall surface temperature which lagged behind the room-air temperature during the warm-up period.

The curves in Fig. 12 are for two tests only. Table 4 presents similar data for several firing rates and outdoor temperatures. The overrun at the end of the warm-up period tended to be a little greater for the hot-water system than for the steam system. This was particularly true at the warmer outdoor temperatures, under which conditions the additional heat stored in the water system was sufficient to cause additional overrun after the thermostat was satisfied.

The overrun increased with increasing outdoor temperatures and with increasing firing rates. The average overrun in the living room air temperature was approximately 2 F when the hot-water system was being used and about 1 F when the steam system was being used.

## 18. Average Room-Air Temperature During Normal Daytime Operation

The average room-air temperature at the 30-in. level in each room of the house and for each test series is shown in Table 5. In all tests there was a slight difference in the individual room-air temperatures because the capacity of the installed radiation was not exactly matched to the actual heat loss of the room. With the exception of the first story lavatory, this unbalance in room-air temperature was generally less than 3.0 F.

The data in Table 5 indicate that the piping and pick-up factor had little if any effect on the distribution of heat to the rooms. In Test Series A-56, B-56 and C-56 it appeared that as the piping and pick-up factor was increased, a slightly greater proportion of the total heat output was delivered to the second-story rooms (bedrooms). However, the resulting change in the unbalance of room-air temperature was slight, amounting to about 2 F at most. Changing the piping and pick-up factor from 1.21 to 1.63 did not affect the distribution of heat by the steam system.

Table 5

Room Air Temperatures — Normal Daytime Operation

| Test Series | G-50 | | H-50 | | F-50 | | B-56 | | A-56 | | C-56 | | F-57 | | G-57 | | E-57 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| System | Water | | | | | | Water | | | | | | Steam | | | | | |
| Piping and Pick-up Factor | 1.06 | | 1.29 | | 1.43 | | 0.88 | | 1.22 | | 1.57 | | 1.21 | | 1.33 | | 1.63 | |
| | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. | Avg. Air Temp. | Diff. from Living Room Temp. |
| Living Room | 72.0 | 0 | 72.0 | 0 | 72.0 | 0 | 71.8 | 0 | 72.5 | 0 | 72.3 | 0 | 71.8 | 0 | 71.1 | 0 | 72.6 | 0 |
| Dining Room | 73.3 | 1.3 | 73.0 | 1.0 | 73.5 | 1.5 | 72.1 | 0.3 | 73.0 | 0.5 | 72.9 | 0.6 | 73.3 | 1.5 | 73.2 | 2.1 | 73.3 | 0.7 |
| Kitchen | 72.3 | 0.3 | 72.6 | 0.6 | 73.1 | 1.1 | 71.3 | −0.5 | 72.8 | 0.3 | 72.3 | 0 | 71.9 | 0.1 | 71.9 | 0.8 | 72.2 | −0.4 |
| NE Bedroom | 73.3 | 1.3 | 73.1 | 1.1 | 73.6 | 1.6 | 71.9 | 0.1 | 73.1 | 0.6 | 73.6 | 1.3 | 75.8 | 4.0 | 76.0 | 4.9 | 76.0 | 3.4 |
| NW Bedroom | 73.4 | 1.4 | 73.5 | 1.5 | 73.9 | 1.9 | 71.5 | 0.3 | 72.9 | 0.4 | 73.6 | 1.3 | 73.4 | 1.6 | 73.6 | 2.5 | 75.0 | 2.4 |
| SW Bedroom | 73.3 | 1.3 | 73.3 | 1.3 | 74.1 | 2.1 | 72.3 | 0.5 | 73.7 | 1.2 | 74.6 | 2.3 | 74.0 | 2.2 | 74.1 | 3.0 | 75.3 | 2.7 |
| Bathroom | 73.9 | 1.9 | 73.2 | 1.2 | 74.2 | 2.2 | 72.5 | 0.7 | 74.1 | 1.6 | 74.2 | 1.9 | 72.4 | 0.6 | 72.3 | 1.2 | 73.0 | 0.4 |
| Lavatory | 68.0 | −4.0 | 67.1 | −4.9 | 67.3 | −4.7 | 69.7 | −2.1 | 68.8 | −3.7 | 68.1 | −4.2 | 64.4 | −7.4 | 63.0 | −8.1 | 63.5 | −9.1 |

# VI. FUEL CONSUMPTION

### 19. Daily Fuel Consumption

The daily gas consumption was determined for each test. The average daily gas consumption for each series at outdoor temperatures of 0 F and 30 F are shown in Fig. 13. In comparing the 1950-51 and 1956-57 tests on hot-water systems, there is an indication that the fuel consumption was slightly higher for the 1956-57 tests, although, considering the 95% confidence interval,* it is doubtful that the difference is significant at an outdoor temperature of 30 F. At least a part of any increase there may have been in the daily fuel consumption in the 1956-57 tests resulted from the lower boiler efficiency obtained in those tests (see Fig. 8). As an outdoor temperature of 30 F approximates average winter conditions at Urbana, Illinois, the fuel consumption at this temperature is an excellent index of seasonal fuel consumption. While the difference in daily gas consumption does appear to be significant at an outdoor temperature of 0 F, the very large confidence interval indicates that additional tests at low temperature are required to establish accurate values. During the winter of 1956-57 there were very few days with average temperatures below 15 F and as a result the fuel consumptions at 0 F for Series A-56, B-56 and C-56 shown in Fig. 13 had to be extrapolated beyond the range of actual test data. This practice in itself introduced some doubt as to the accuracy of the values.

While there was no clear-cut indication that the fuel burning rate had any effect on the daily fuel consumption in the 1950-51 tests, there was a definite increase in the daily fuel consumption as the fuel burning rate was increased in the 1956-57 tests. The range of fuel burning rates was larger in 1956-57 than in 1950-51 and at the higher burning rates the boiler was being over-fired.

Making allowance for the unfavorable winter in 1956-57 and the over-firing of the boiler in Series C-56, the fact still remains that neither oversizing the system nor increasing the piping and pick-up factor decreased the daily fuel consumption. On the contrary, they probably resulted in some increase.

The fuel consumptions obtained with the steam system in 1957-58 were approximately the same as those obtained on the hot-water system in 1950-51. However this comparison may be misleading, since

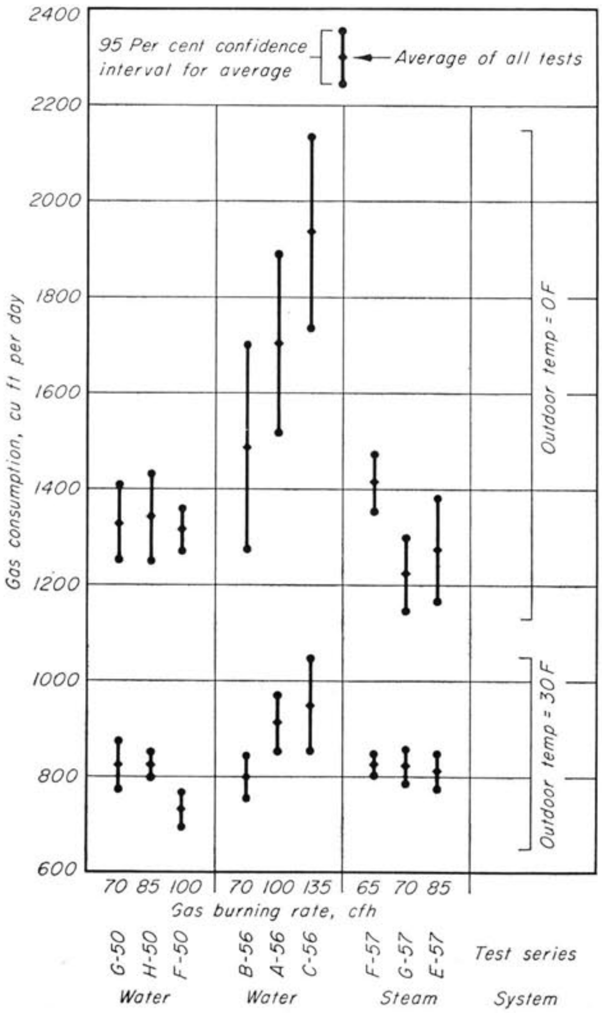



Fig. 13. Average Daily Gas Consumption

* Confidence interval is a term used in statistical analysis to define the certainty of a value. As used here, it means that if the tests were repeated under the same conditions, the chances would be 95 out of a hundred that the new average fuel consumption would fall within the confidence interval indicated in Fig. 12.

the boiler used for the steam tests was designed for gas and was 10 to 15% more efficient than the all purpose boiler equipped with a conversion gas burner which was used on the hot-water system during the winters of 1950-51 and 1956-57. Had the same all purpose boiler been used on all tests, the daily fuel consumption for the steam tests would probably have been some 10 to 15% higher than those shown in Fig. 13 and would closely approximate earlier test results.[2]

## VII. SYSTEM WARM-UP TESTS

### 20. Method of Testing

Tests were made on both the hot-water and the steam systems to determine how changes in the firing rate would affect the warming-up characteristics of the system itself. In preparation for these tests the system was allowed to cool to an average water temperature of about 130 F. After the system had cooled, the burner was started and operated continuously until the system was operating at its maximum output. During tests on the hot-water system the circulator was in continuous operation. Observations included the temperature of the water in the boiler and the rate of water circulation for the hot-water system; observations for the steam system included the boiler water temperature, boiler pressure, time required for the boiler to start steaming, time required for steam to reach each radiator and the time required for each radiator to become filled with steam. Other observations included the firing rate and flue gas temperature.

### 21. Rate of Water Temperature Rise — Hot-Water System

Warm-up tests were made on the hot-water system during the winter of 1950-51. System water temperatures were observed throughout each test and plotted in Fig. 14. At all three burning rates it took approximately 4 hours to attain the maximum water temperature. At a burning rate of 70 cfh (piping and pick-up factor = 1.06), the maximum water temperature was about 180 F, 35 F lower than the design water temperature. At firing rates of 85 cfh and 100 cfh (piping and pick-up factors of 1.29 and 1.43 respectively), the corresponding maximum water temperatures were 205 and 220 F.

The output of a baseboard radiator is proportional to the 1.4 power of the difference between average water temperature and ambient air temperature. Assuming the average water temperature in the radiation to be the same as the average water temperature in the boiler and the ambient air temperature to be 70 F, the curves of Fig. 14 indicate that the hot-water system was operating at 30 to 40% of its maximum output at the start of the system warming-up tests. In 40 minutes the output had risen to about 60% of maximum and in 80 minutes the system was operating at about 80% of maximum output.

Since 215 F was the design water temperature, it is apparent that the system was unable to operate at design capacity during tests in Series G-50 and H-50. The maximum output of the system during test H-50 was about 90% of design output and only about 70% of design output for test G-50.

In summary, the firing rate (piping and pick-up factor) apparently had no effect on the length of time required to heat the water in the hot-water system to the maximum temperature attainable. It did, however, have a distinct effect on the value of the maximum temperature and on the maximum output of the system. About four hours were required to attain maximum water temperatures in the system, and at any piping and pick-up factor less than about 1.3 the system was unable to develop its full design output capacity.

### 22. Temperature of Steam Leaving and Condensate Returning to Boiler — Steam System

The temperatures of the steam leaving the boiler and of the condensate returning to the boiler were recorded at 1-minute intervals during each test. The variations in these temperatures were about the same for all three firing rates. The boiler started to steam about 5 minutes after the start of the test. In all except Series E-57 the steam temperature remained at a constant value of approximately 212 F throughout the remainder of the test. In Series E-57 the steam temperature began to increase above 212 F approximately 60 minutes after the start of the test and reached a maximum of about 220 F 15 minutes later, at which time the burner was stopped by action of the high limit control.

The first condensate was returned to the boiler

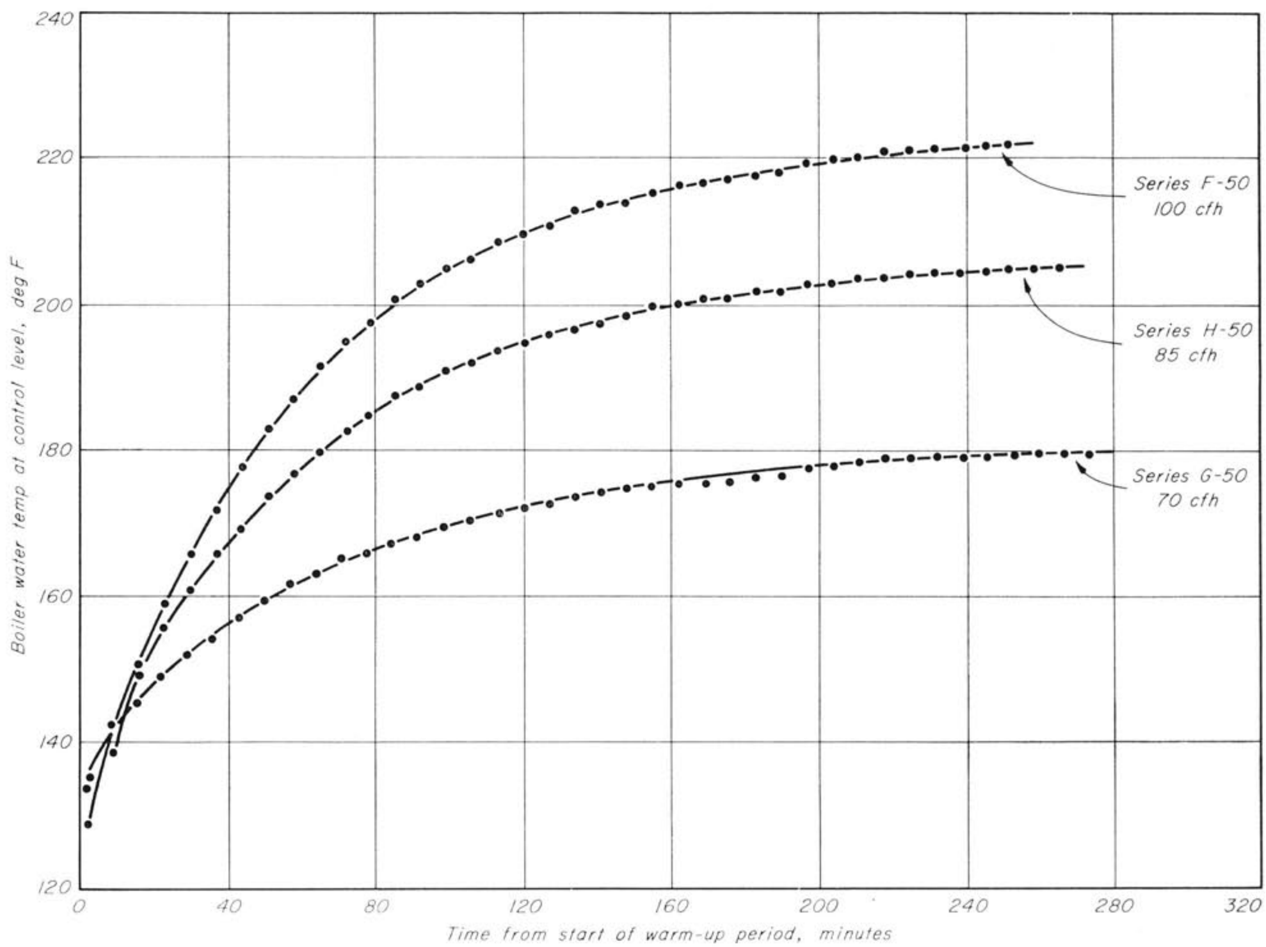



*Fig. 14. Effect of Burning Rate on the Boiler Water Temperature (Hot-Water System)*

about 10 minutes after the start of the test. The temperature of the condensate was about 166 F at the start and gradually increased to a steady state temperature of 198 F, about 15 F less than the average steam temperature.

### 23. Boiler Pressure — Steam System

In Test E-57 (piping and pick-up factor = 1.63) the boiler pressure was raised to 2.5 psig, the setting of the pressure control, in 75 minutes. Over 3 hours were required to do this in Test G-57 (piping and pick-up factor = 1.33) and in Test F-57 (piping and pick-up factor = 1.21) the boiler pressure could not be increased above about 0.7 psig regardless of how long the burner was operated. Operation of the burner can cause an increase in the boiler pressure only if the gross output of the boiler exceeds the rate at which steam is condensed in the radiation and piping making up the system. Since steady state conditions existed in Test F-57, the gross output of the boiler must have exactly equalled the steam condensing capacity of the pipe and connected radiation or, in other words, the steam condensing capacity of the system piping was about 21% of the condensing capacity of the connected radiation.

At any time the gross output of the boiler is equal to or less than the steam condensing capacity of the piping and connected radiation there is danger that the system will not be completely freed of air and therefore one or more of the radiators in the system may fail to heat properly.

### 24. Time Required to Generate Steam and Distribute It to Radiation — Steam System

The intervals between the times the boiler started to steam and (1) steam first entered each radiator and (2) each radiator was filled with steam are tabulated in Table 6. In each series approximately 5 minutes were required to raise the

**Table 6**

**Rate of Heating of Radiators — Steam System**

| Radiator Location | Series F-57 (65 cfh) Time First Steam Enters Radiator, Minutes[a] | Series F-57 (65 cfh) Time Radiator Is All Hot, Minutes[a] | Series G-57 (70 cfh) Time First Steam Enters Radiator, Minutes[a] | Series G-57 (70 cfh) Time Radiator Is All Hot, Minutes[a] | Series E-57 (85 cfh) Time First Steam Enters Radiator, Minutes[a] | Series E-57 (85 cfh) Time Radiator Is All Hot, Minutes[a] |
|---|---|---|---|---|---|---|
| Kitchen | 24 | 82 | 23 | 76 | 23 | 51 |
| Dining Room | 4 | 69 | 3 | 74 | 2 | 44 |
| Living Room, W | 26 | 149 | 5 | 63 | 4 | 50 |
| Living Room, E | 8 | 66 | 8 | 72 | 6 | 39 |
| Vestibule | 18 | 89 | 18 | 68 | 14 | 57 |
| Lavatory | 21 | 51 | 20 | 41 | 15 | 33 |
| Bathroom | 32 | ..[b] | 31 | ..[b] | 24 | 67 |
| SW Bedroom | 6 | 152 | 6 | 53 | 6 | 36 |
| NW Bedroom | 16 | 88 | 25 | 121 | 16 | 45 |
| NE Bedroom | 16 | 69 | 16 | 71 | 15 | 44 |
| Landing | 28 | 106 | 79 | 103 | 21 | 35 |
| Average, All Units | 18.1 | 92.1[c] | 21.3 | 74.2[c] | 13.3 | 45.5 |
| Average, Omitting Units in NW Bedroom and Stair Landing | 17.2 | 90.9[c] | 14.4 | 64.8[c] | 12.1 | 46.8 |

[a] Measured from time boiler started to steam.
[b] Not completely vented in length of test (180 minutes).
[c] Bathroom radiator not included.

boiler water temperature from 130 F to 212 F. In Series E-57, the average time required for steam to reach the radiators after the boiler started to steam was 13.3 minutes. For Series G-57 and F-57 an average of 21.3 and 18.1 minutes, respectively, were required. The average time required to free the radiators of air and fill them with steam was 45.5, 74.2 and 92.1 minutes for Series E-57, G-57 and F-57 respectively.

The average time for steam to first enter each radiator normally should be less in Series G-57 than in Series F-57. Due to operating difficulties it was necessary to replace the air vents on the radiators in the northwest bedroom and stairway prior to making the tests in Series G-57. The new vents obviously had different characteristics than did the vents which they replaced. If the average values for nine radiators (excluding radiators in the northwest bedroom and stairway) are calculated, the results are 17.2, 14.4 and 12.1 minutes for steam to first enter the radiators in Series F-57, G-57 and E-57, respectively, and 90.9, 64.8 and 46.8 minutes, respectively, for the average time required for the radiators to fill with steam.

## 25. System Warm-up Characteristics — Steam vs. Water

The heat output from the hot-water system to the rooms began to increase as soon as the burner started to operate. However, the rate of increase was comparatively slow, about 4 hours were required to raise the output of the system to its maximum value at any of the three firing rates used in the tests. The maximum output of the water system increased as the firing rate was increased up to a firing rate of approximately 100 cfh. At firing rates higher than 100 cfh, the high limit control prevented further increase in the water temperature and thus limited the maximum heat output of the system.

The heating up characteristics of the steam system were quite different. Until the water temperature in the boiler had reached the boiling point and at least part of the air had been expelled from the radiation, there was no useful heat output. The length of time required to do this was dependent on the water temperature at the time the burner started to operate and the rate of heat input to the boiler. In the three warm-up tests reported here, approximately 5 minutes were required to start the water boiling. An additional 12 to 17 minutes were needed for steam to reach the radiators. The time required to free the system of air, fill it with steam, and thus obtain the maximum heat output depended on the firing rate, but even at the lowest firing rate this was accomplished in an average time of about 90 minutes as compared to about 4 hours required to obtain maximum output when using the hot-water system. Since the steam temperature could vary only between 212 F and about 220 F, the maximum output of the steam system was practically independent of the firing rate as long as the firing rate was sufficient to generate steam as fast as it was being condensed in the radiation and piping.

It should be noted that even at the highest firing rate about $\frac{3}{4}$ hour was required to fill the system with steam. Data in a previous bulletin[2] show that the normal "on-period" of the burner is of the order of magnitude of 20 minutes. Therefore, except in very cold weather, it is unlikely that a one-pipe steam system in a residence will ever be completely filled with steam and uniformity of heating the different rooms will be dependent on the venting rate of the radiator valves. If for any reason the venting rate of one or more valves should change with respect to the others, the balance of the system may be destroyed.

## VIII. REFERENCES

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