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A STUDY OF RADIANT BASEBOARD HEATING IN THE I=B=R RESEARCH HOME

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COOPERATION WITH

THE INSTITUTE OF BOILER AND
RADIATOR MANUFACTURERS

BY

ALONZO P. KRATZ

AND

WARREN S. HARRIS

PRICE: THIRTY-FIVE CENTS

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ABSTRACT

This is the fourth bulletin to be published under a cooperative agreement between the Institute of Boiler and Radiator Manufacturers and the University of Illinois. The agreement was formally approved January 2, 1940. Results are presented of tests made during the heating seasons of 1943-44 and 1944-45 on a hot-water heating system in which an unusual design of radiation was employed. Both a one-pipe, forced-circulation, hot-water system and a gravity, two-pipe, reversed-return, hot-water system were used. The tests were undertaken to determine the effect of introducing heat into the rooms by means of long, low panels, heated by means of hot water. These panels were placed near the floor and extended along the exposed walls of the rooms. A second object was to compare the operating characteristics of the panels with the operating characteristics of conventional, small-tube radiators.

A one-pipe, forced-circulation, hot-water system was used during the 1943-44 heating season. For the first part of the season small-tube type, 19-in., 4-tube, cast-iron radiators set in open recesses below the windows were used in all rooms of the house. For the remainder of the season the radiators in the living room, dining room, and all three bedrooms were replaced with wrought steel pipe extending along the exposed walls of the rooms near the floor. The steel pipe was used in place of conventional radiation in order to obtain preliminary data on the effect of introducing heat into the rooms at the floor level without having to make up special radiator sections. During the season of 1944-45 the radiators used in the living room, dining room, all three bedrooms, and the lavatory were of an experimental design made in the form of a hollow cast-iron baseboard approximately 6 in. high. The radiators, designated as "radiant baseboards," were installed along the outside walls of the rooms, replacing the baseboard, and were used in conjunction with a two-pipe, gravity, hot-water system.

At an outdoor temperature of zero deg. F. and an indoor temperature of 72 deg. F. at the 30-in. level, when the rooms were heated by the radiant baseboards, the average floor to ceiling temperature difference was only about 2 deg. F. as compared with 5½ deg. F. obtained when the rooms were heated by conventional recessed radiators. The average temperature obtained 3 in. above the floor with the radiant baseboards was about 1.4 deg. F. higher than that obtained with con-

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A one-pipe, forced-circulation, hot-water system was used during the 1943-44 heating season. For the first part of the season small-tube type, 19-in., 4-tube, cast-iron radiators set in open recesses below the windows were used in all rooms of the house. For the remainder of the season the radiators in the living room, dining room, and all three bedrooms were replaced with wrought steel pipe extending along the exposed walls of the rooms near the floor. The steel pipe was used in place of conventional radiation in order to obtain preliminary data on the effect of introducing heat into the rooms at the floor level without having to make up special radiator sections. During the season of 1944-45 the radiators used in the living room, dining room, all three bedrooms, and the lavatory were of an experimental design made in the form of a hollow cast-iron baseboard approximately 6 in. high. The radiators, designated as "radiant baseboards," were installed along the outside walls of the rooms, replacing the baseboard, and were used in conjunction with a two-pipe, gravity, hot-water system.

At an outdoor temperature of zero deg. F. and an indoor temperature of 72 deg. F. at the 30-in. level, when the rooms were heated by the radiant baseboards, the average floor to ceiling temperature difference was only about 2 deg. F. as compared with $5\frac{1}{2}$ deg. F. obtained when the rooms were heated by conventional recessed radiators. The average temperature obtained 3 in. above the floor with the radiant baseboards was about 1.4 deg. F. higher than that obtained with con-

ventional recessed radiators, and the use of a radiant baseboard in the lavatory, which had a concrete floor laid directly on the ground, raised this temperature 6 deg. F. A cold floor is a major factor in contributing to discomfort in otherwise well-heated rooms, hence the tendency to produce a warm floor may be regarded as an important attribute of radiant baseboards. This attribute is most important in the case of the basementless house in which cold floors are particularly prevalent. Therefore, the use of radiant baseboards is especially adaptable to this type of construction.

The temperature of the entire wall below the 60-in. level was higher than that of the room air at the 30-in. level when radiant baseboards were used, whereas with the conventional recessed radiators the temperature of this portion of the wall surface was from 0.2 to 1.6 deg. F. lower than the temperature of the air at the 30-in. level.

When operating with reduced air temperatures at night, the performance obtained with radiant baseboards was, in general, the same as that obtained with the conventional recessed radiators. However, in the case of the radiant baseboards, the overruns in the temperature of the air 3 in. below the ceiling during the warming-up period were somewhat less than those obtained with the conventional recessed radiators.

No material difference in fuel consumption could be attributed to the inherent characteristics of the radiant baseboards.

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A STUDY OF RADIANT BASEBOARD HEATING IN THE I=B=R RESEARCH HOME

I. Introduction

1. *Preliminary Statement.*—This is the fourth 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 an Advisory Research Committee consisting of five members. Since the inception of the program the following members of the Institute have served on this Committee:

J. P. Magos,* Crane Co., Chicago, Illinois, 1940-1945

L. N. Hunter,† National Radiator Company, Johnstown, Pennsylvania, 1940-1945

J. F. McIntire, United States Radiator Corporation, Detroit, Michigan, 1940-1945

H. F. Randolph, International Heater Company, Utica, New York, 1940-1945

S. K. Smith,‡ H. B. Smith Company, Inc., Westfield, Massachusetts, 1940-1945

G. L. Cheasley, Thatcher Furnace Company, Garwood, New Jersey, 1945.

It is the function of this committee to propose such problems for investigation as are of the greatest interest 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 this research work.

Since January 1941 the I=B=R Research Home has been used continuously in studies on hot-water heating systems. An earlier bulletin¶ contains a discussion of the results of tests made on a one-pipe, forced-circulation, hot-water heating system using conventional small-tube radiators. The present bulletin contains a discussion of the results of tests made during the heating seasons of 1943-44 and 1944-45 on a hot-water heating system in which an unusual design of

* Chairman of Committee, 1941-1944.
† Chairman of Committee, 1940.
‡ Chairman of Committee, 1945.
¶ "Performance of a Hot-Water Heating System in the I=B=R Research Home at the University of Illinois." Univ. of Ill. Eng. Exp. Sta. Bul. 349.

radiation was employed. In these tests both a one-pipe, forced-circulation, hot-water system and a two-pipe, gravity, reversed-return, hot-water system were used.

2. *Acknowledgments.*—The results presented in this bulletin were obtained in connection with a cooperative investigation sponsored jointly by the Engineering Experiment Station of the University of Illinois and the Institute of Boiler and Radiator Manufacturers. The investigation has been carried on as a project of the Department of Mechanical Engineering, and was conducted under the general administrative direction of DEAN M. L. ENGER, Director of the Engineering Experiment Station, and of PROFESSOR O. A. LEUTWILER, Head of the Department of Mechanical Engineering. Acknowledgment is hereby made to various manufacturers who cooperated by furnishing materials and equipment used in the investigation.

3. *Objects of Investigation.*—These tests were undertaken to determine the effect of introducing heat into the rooms by means of long, low panels, heated by means of hot water. These panels were placed near the floor and extended along the exposed walls of the rooms. A second object was to compare the operating characteristics of the panels with the operating characteristics of conventional, small-tube radiators.

II. DESCRIPTION OF EQUIPMENT

4. *Research Home.*—The Research Home, described in detail in Engineering Experiment Station Bulletin No. 349, is a two-story building, typical of the small, well-built American home. The construction is brick veneer on wood frame, and all of the outside walls and the second-story ceiling are insulated with mineral wool bats 3⅝ in. thick. A vapor barrier placed between the studs and the plaster base prevents 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 is 0.074 B.t.u. per sq. ft. per hr. per deg. F. temperature difference. All windows and the two outside doors are weather-stripped. Two storm doors were used. The total calculated heat loss under design conditions, with temperatures of − 10 deg. F. outdoors and 70 deg. F. indoors, is 43,370 B.t.u. per hr. for the house, excluding the basement.

5. *Heating System.*—A wet-bottom, cast-iron boiler composed of two 6-in. sections and one 4-in. section was used on the tests. This

boiler was insulated on top, sides, and back with an air cell insulation approximately 1 in. in thickness, and was completely enclosed in an enameled sheet-metal jacket. All cracks between sections were sealed with asbestos cement. The net I=B=R rating was 55,000 B.t.u. per hr. and the gross I=B=R output was 84,000 B.t.u. per hr. The boiler was supplied with a conversion-type gas burner, adjusted to a burning rate of approximately 100 cu. ft. per hr. of natural gas having a heating value of 1000 B.t.u. per cu. ft.

A one-pipe, forced-circulation, hot-water system was used during the 1943-44 heating season. For the first part of the season, small-tube type, 19-in., 4-tube, cast-iron radiators, set in open recesses below the windows, were used in all rooms of the house. For the remainder of the season the radiators in the living room, dining room, and all three bedrooms were replaced with wrought steel pipe extending along the exposed walls of the rooms near the floor. The steel pipe was used in place of conventional radiation in order to obtain preliminary data on the effect of introducing heat into the rooms at the floor level without having to make up special radiator sections. However, it is quite conceivable that such pipes might be used as the radiator in the case of some of the low-cost housing, where it is essential to keep the first cost of the heating system to a minimum. The pipe is not too noticeable if it is painted to match the baseboard, as is shown in Fig. 1.

The sizes and lengths of the pipes were selected so that the total heat emission was equal to that from the conventional radiators which they replaced. The heat emission from the pipe was calculated in accordance with the data in Table 1, Chapter 43, page 777 of the 1943 ASHVE Guide. The amounts of both types of radiation, together with the size, amount, and arrangement of the basement mains and piping, are shown in Tables 1 and 2 and Figs. 2 and 3. The locations of the radiators in each room are shown in Figs. 4 and 5.

During the season of 1944-45 the radiators used in the living room, dining room, all three bedrooms, and the lavatory were of an experimental design made in the form of a hollow cast-iron baseboard approximately 6 in. high. These radiators were designated as "radiant baseboards" and were installed along the outside walls of the rooms replacing the wooden baseboard, as indicated in Fig. 6. A photograph of a typical installation is shown in Fig. 7, and a close-up view of the end of the radiator with access door removed, illustrating the method of making the pipe and vent connections, is presented in Fig. 8. A cross-section through the wall and radiator showing the method of in-

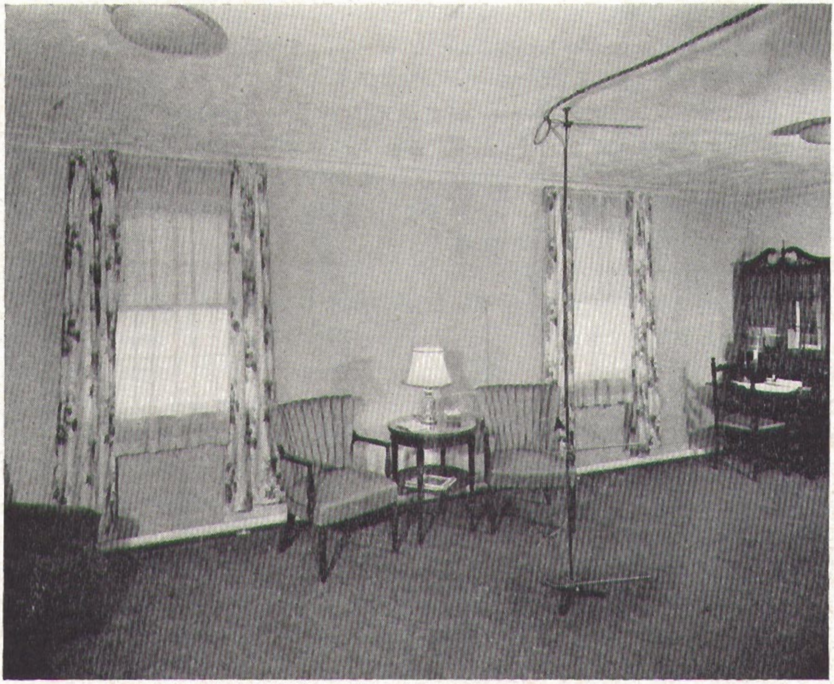

Fig. 1. Typical Installation of Pipe Along Outside Wall of Room Near Floor for Radiator

stallation is presented in Fig. 6. Rice paper served as a dust seal to prevent the possibility of streaking the walls. Small-tube type, 19-in., 4-tube, cast-iron radiators, shown by blackened rectangles in Fig. 6, were used in the vestibule, the kitchen, the bath, and on the stair landing. The total heat emission from the radiators used in each room for the 1944-45 season was approximately the same as that used during the previous season. During the 1944-45 season the same boiler was used in connection with a two-pipe, reversed-return system. This system was designed to operate with a mean water temperature of 215 deg. F. and a 30 deg. F. drop through the radiators. The amount of radiation, together with the size, amount, and arrangement of the basement mains and piping, are shown in Table 3 and Fig. 9.

6. *Controls.*—Except for the fact that the circulator was omitted from the gravity system, the same controls were used for all the tests. The control system, shown in Fig. 10, included a room thermostat located in the living room, an electric clock with a self-contained time

TABLE 1

RADIATION, PIPE, AND FITTINGS FOR ONE-PIPE, FORCED-CIRCULATION, HOT-WATER HEATING SYSTEM USED IN SERIES S, 1943-44 HEATING SEASON

Section	Installed Radiation	Pipe		Elbows		Tees		Specialties
	19-in. Small Tube sq. ft.	Size in.	Length ft.	Size in.	Number	Size in.	Number	
Basement Main								
North Loop		½	43.6	½	6	½	12	
				½–45°	1			
South Loop		½	35.5	½–45°	1	½	10	
Supply Trunk		¾	6.1	¾	2	¾ x ½ x ½	1	1-in. Flow Control Valve
Return Trunk		¾	18.1	¾	2	½ x ½ x ¾	1	
		2½	0.6			2½ x 2½ x ¾	1	1-in. Circulator
RISERS AND RADIATORS								
S.W. Bedroom	12.8	½	31.3	½	9			
N.W. Bedroom	16.0	½	32.5	½	7			
N.E. Bedroom	16.0	½	32.0	½	7			
Bath	17.6	½	42.3	½	12			
Stairway	11.2	½	38.1	½	10			
Kitchen	17.6	½	18.9	½	9			
Dining Room (W)	22.4	½	11.7	½	9			
Living Room (W)	14.4	½	14.5	½	7			
Living Room (E)	12.8	½	13.9	½	7			
Vestibule	25.6	½	28.6	½	12			
Lavatory	14.4	½	28.6	½	9			

PIPE TOTALS	
2½ in.	0.6 ft.
¾ in.	24.2 ft.
½ in.	371.5 ft.

ELBOW TOTALS	
¾ in.	4
½ in.	104
½ in.-45°	2

TEE TOTALS	
2½ x 2½ x ¾ in.	1
¾ x ½ x ½ in.	1
½ x ½ x ¾ in.	1
½ in.	22

TABLE 2
RADIATION, PIPE, AND FITTINGS FOR ONE-PIPE, FORCED-CIRCULATION, HOT-WATER HEATING SYSTEM USED IN SERIES R, 1943-44 HEATING SEASON

Section	Installed Radiation			Pipe		Elbows		Tees		Specialties
	19-in. Small Tube	Wrought Steel Pipe		Size	Length	Size	Number	Size	Number	
	sq. ft.	Size in.	Length ft.	in.	ft.	in.		in.		
Basement Main										
North Loop				½	50.6	½	5	½	10	
South Loop				½	41.2	½	6	½	10	
Supply Trunk				¾	9.6	¾	2	¾ x ¾ x ½	1	1-in. Flow Control Valve
								½ x ½ x ¾	1	
Return Trunk				¾	25.8	¾	5	¾	1	1-in. Circulator
								½ x ½ x ¾	1	
Risers and Radiators										
S.W. Bedroom		1¼	11.0	½	18.0	½	5			
		1	9.5			1¼	1	1¼	2	
N.W. Bedroom		1¼	21.0	½	19.1	½	5	½	1	
						1¼	1	1¼	2	
N.E. Bedroom		2	17.0	½	30.0	½	12			
						2	1	2	2	
Bath	17.6			½	38.9	½	12			
Stair Landing	11.2			½	34.9	½	11			
Kitchen	17.6			½	16.3	½	9			
Dining Room (W)		2	15.3	½	4.6	½	3			
						2	1	2	2	
Dining Room (S)		2	5.3	½	4.2	½	1			
						2	1	2	2	
Living Room		2	24.0	½	8.1	½	3			
						2	1	2	2	
Vestibule	25.6			½	28.2	½	12			
Lavatory	14.4			½	27.7	½	9			

PIPE TOTALS

2 in.	61.6 ft.
1¼ in.	32.0 ft.
1 in.	9.5 ft.
¾ in.	35.4 ft.
½ in.	321.8 ft.

ELBOW TOTALS

2 in.	4
1¼ in.	2
¾ in.	7
½ in.	93

TEE TOTALS

2 in.	8
1¼ in.	4
¾ in.	1
½ in.	21
¾ x ¾ x ½ in.	1
½ x ½ x ¾ in.	2

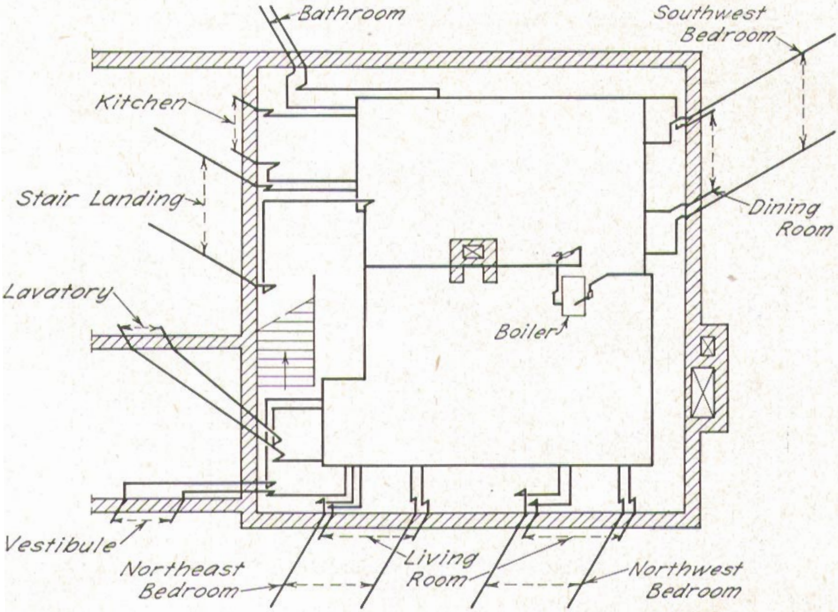

FIG. 2. BASEMENT PIPING SYSTEM FOR ONE-PIPE, FORCED-CIRCULATION, HOT-WATER HEATING SYSTEM USED IN SERIES S, 1943-44 HEATING SEASON

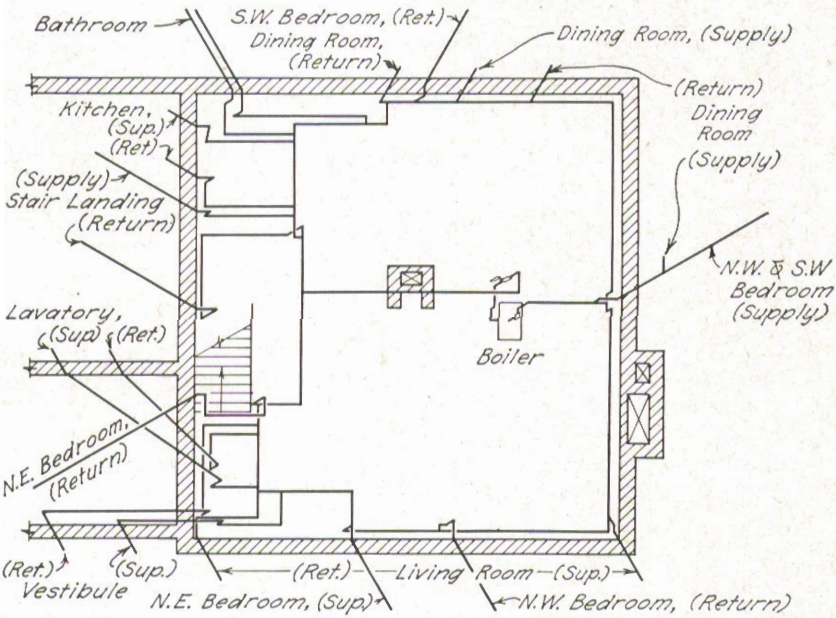

FIG. 3. BASEMENT PIPING SYSTEM FOR ONE-PIPE, FORCED-CIRCULATION, HOT-WATER HEATING SYSTEM USED IN SERIES R, 1943-44 HEATING SEASON

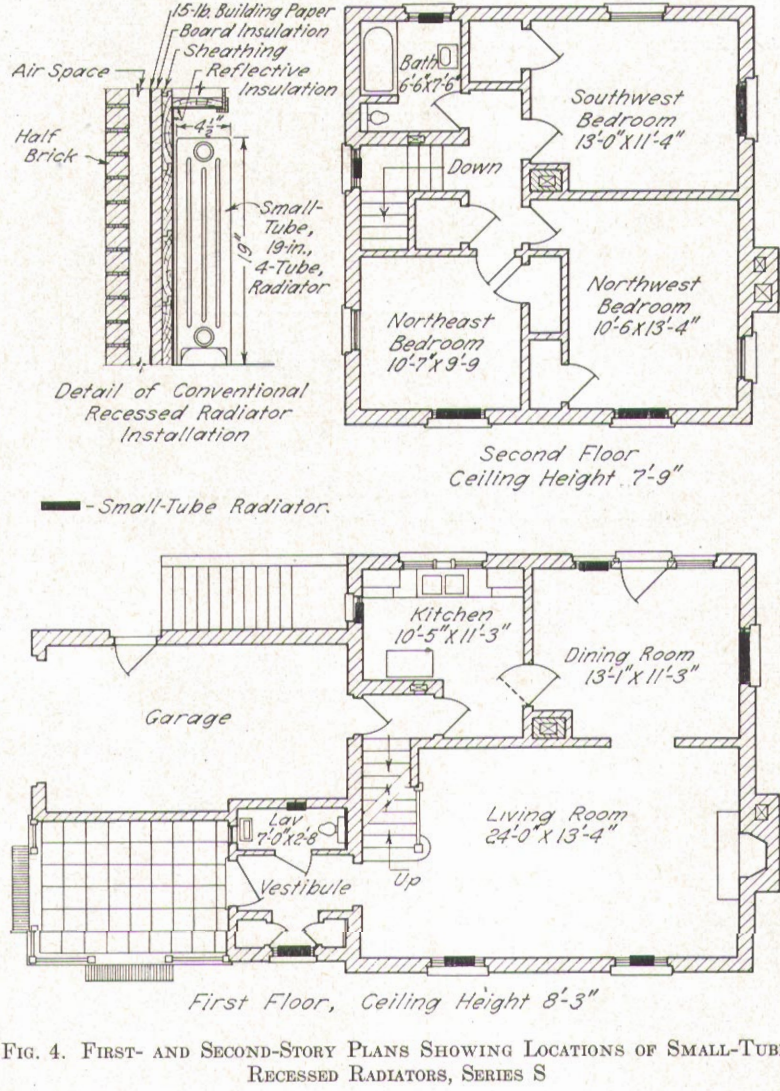

FIG. 4. FIRST- AND SECOND-STORY PLANS SHOWING LOCATIONS OF SMALL-TUBE RECESSED RADIATORS, SERIES S

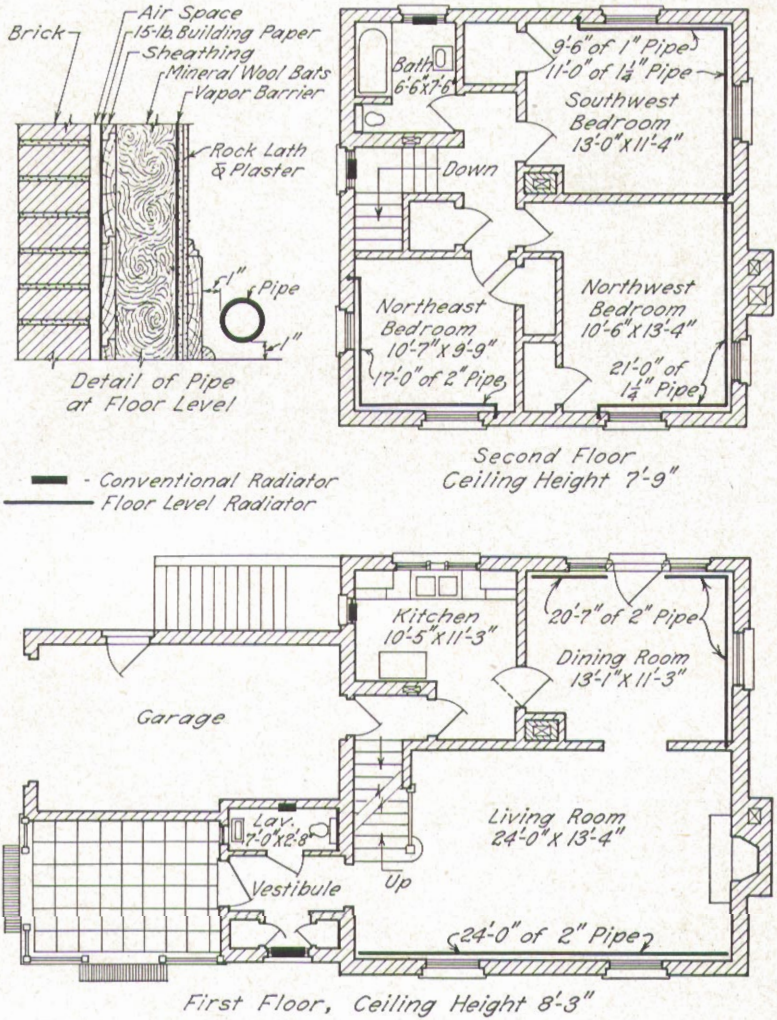

Fig. 5. First- and Second-Story Plans Showing Locations of Pipe at Floor Level, Series R

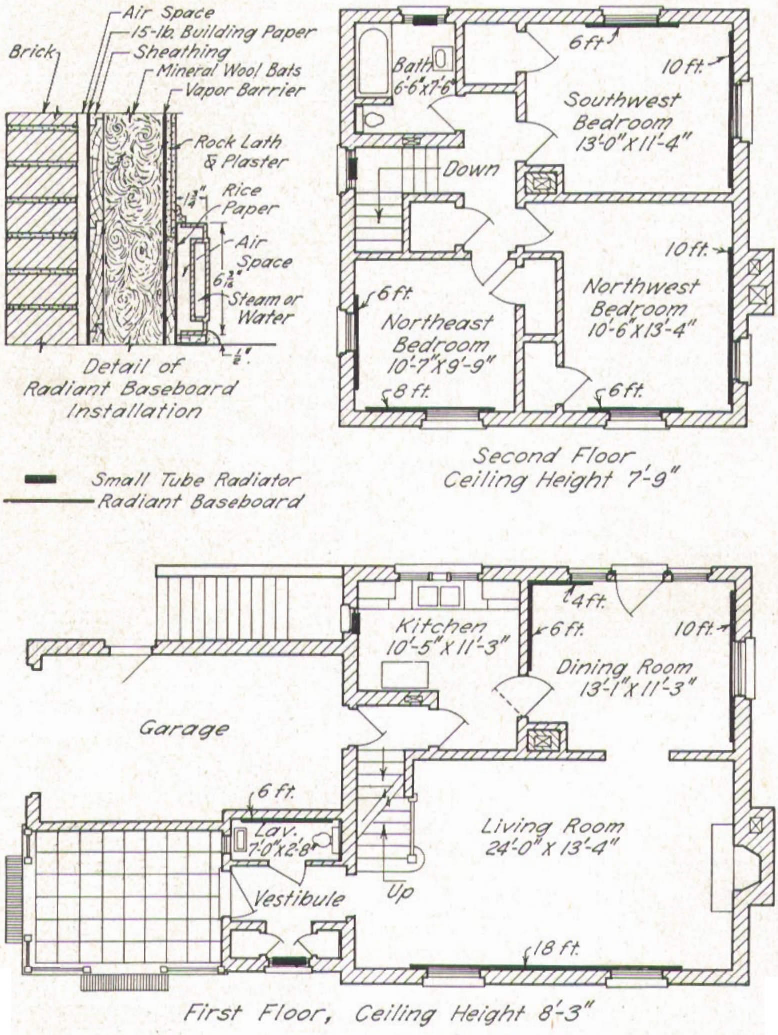

Fig. 6. First- and Second-Story Plans Showing Locations of Radiant Baseboards, Series C-44

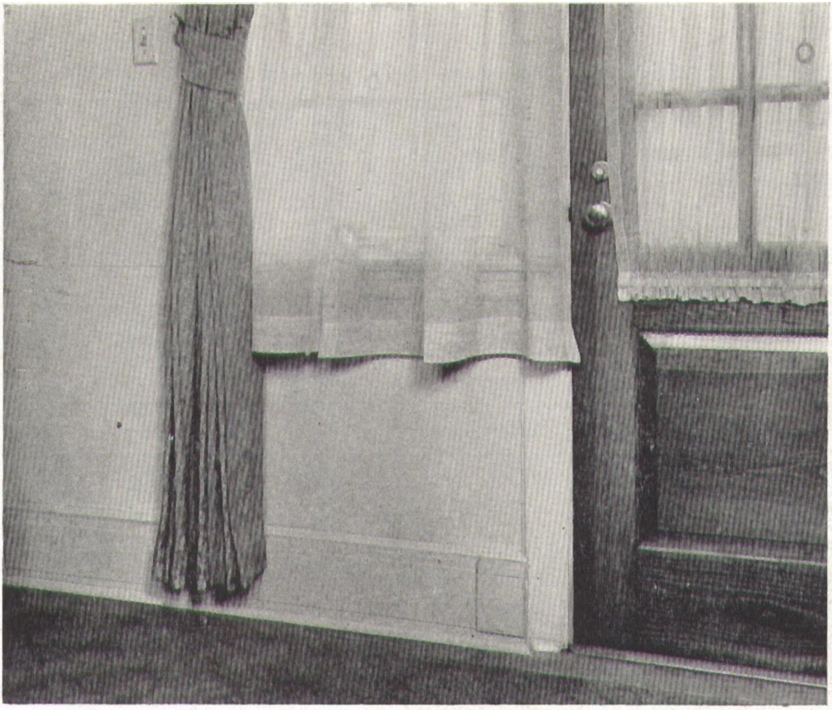

Fig. 7. Typical Installation of Radiant Baseboard

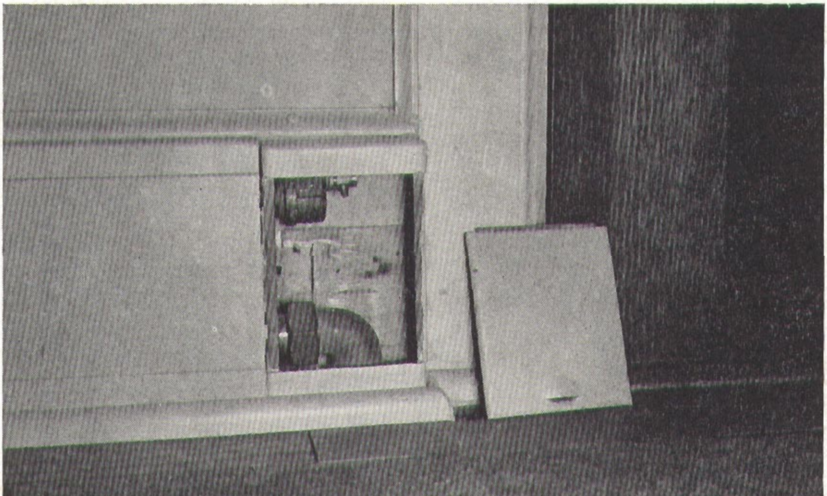

Fig. 8. Close-Up View of Access Box for Radiant Baseboard

TABLE 3

RADIATION, PIPE, AND FITTINGS FOR TWO-PIPE, GRAVITY, HOT-WATER HEATING SYSTEM USED IN SERIES C-44, 1944-45 HEATING SEASON

Section	Installed Radiation		Pipe		Elbows		Union Elbows		Eccentric Reducing Couplings		Tees	
	19-in. Small Tube sq. ft.	Radiant Base-board Length ft.	Size in.	Length ft.	Size in.	Number	Size in.	Number	Size in.	Number	Size in.	Number
Basement Main												
North Loop (Supply)			2	0.6					2 x 1½	1		
			1½	3.4					1½ x 1¼	1	1½	1
			1¼	12.5	1¼	1			1½ x 1	1	1 x 1 x ½	2
			1	21.7	1	2					1¼ x 1 x ¾	1
					1 x ¾	1					1 x ¾ x ¾	1
North Loop (Return)			2	0.8					2 x 1¼	1	1¼ x 1¼ x ¾	2
			1¼	11.7	1¼	1			1¼ x ¾	1	1¼ x 1¼ x ½	1
			¾	9.4	¾	1					1¼ x ¾ x 1¼	1
South Loop (Supply)			2	0.7					2 x 1	1		
			1	23.4	1	1					1 x 1 x ¾	1
			¾	0.3							1 x ½ x ¾	1
			½	5.0	½	1					¾ x ½ x ¾	1
South Loop (Return)			2	0.3					2 x 1¼	1		
			1¼	6.0							1¼ x 1¼ x ½	1
			1	10.9					1 x ¾	1	1¼ x 1 x ¾	1
			¾	9.4	¾–45°	1					1 x ½ x 1	1
											1 x 1 x ½	1
Supply Trunk			2	4.1	2	1					2	1
Return Trunk			2	21.2	2	3					2	2
RISERS AND RADIATORS												
S.W. Bedroom	....	16	½	25.7	½	5	½	1			½	1
					½–45°	4	½–45°	3				
N.W. Bedroom	....	16	½	25.7	½	4	½	1				
					½–45°	6	½–45°	3				
N.E. Bedroom	....	14	½	33.0	½	11	½	1				
					½–45°	4	½–45°	3				
Bath	17.6	..	½	35.6	½	11						
					½–45°	3						
Stair Landing	11.2	..	½	33.0	½	9						
					½–45°	1						

TABLE 3 (CONTINUED)

RADIATION, PIPE, AND FITTINGS FOR TWO-PIPE, GRAVITY, HOT-WATER HEATING SYSTEM USED IN SERIES C-44, 1944-45 HEATING SEASON

Section	Installed Radiation		Pipe		Elbows		Union Elbows		Eccentric Reducing Couplings		Tees	
	19-in. Small Tube sq. ft.	Radiant Baseboard Length ft.	Size in.	Length ft.	Size in.	Number	Size in.	Number	Size in.	Number	Size in.	Number
RISERS AND RADIATORS (Continued)												
Kitchen	17.6	..	¾	15.9	¾	8						
					¾–45°	3						
Dining Room (W)	....	10	¾	7.2	¾	2	¾	2				
					¾–45°	2						
Dining Room (S)	....	10	¾	9.3	¾	3	¾	2				
			½	0.6	¾–45°	2						
					½	1						
Living Room	....	18	¾	8.4	¾	4	¾	2				
					¾–45°	2						
Vestibule	25.6	..	¾	20.2	¾	11						
					¾–45°	1						
Lavatory	....	6	¾	29.2	¾	8	¾	2				
					¾–45°	3						

PIPE TOTALS

2 in.	27.7 ft.
1½ in.	3.4 ft.
1¼ in.	30.2 ft.
1 in.	56.0 ft.
¾ in.	109.3 ft.
½ in.	158.6 ft.

90° ELBOW TOTALS

2 in.	4
1¼ in.	2
1 in.	3
¾ in.	37
½ in.	42
1 x ¾ in.	1

45° ELBOW TOTALS

¾ in.	14
½ in.	18

UNION ELBOW TOTALS

¾ in.	8
½ in.	3
½ in. 45°	9

REDUCING COUPLINGS

2 x 1½ in.	1
2 x 1¼ in.	2
2 x 1 in.	1
1½ x 1¼ in.	1
1½ x 1 in.	1
1¼ x ¾ in.	1
1 x ¾ in.	1

TEES TOTALS

2 in.	3
1½ in.	1
½ in.	1
1¼ x 1¼ x ¾ in.	2
1¼ x 1¼ x ½ in.	2
1¼ x 1 x ¾ in.	2
1¼ x ¾ x 1¼ in.	1
1 x 1 x ¾ in.	1
1 x 1 x ½ in.	3
1 x ¾ x ¾ in.	1
1 x ½ x 1 in.	1
1 x ½ x ¾ in.	1
¾ x ½ x ¾ in.	1

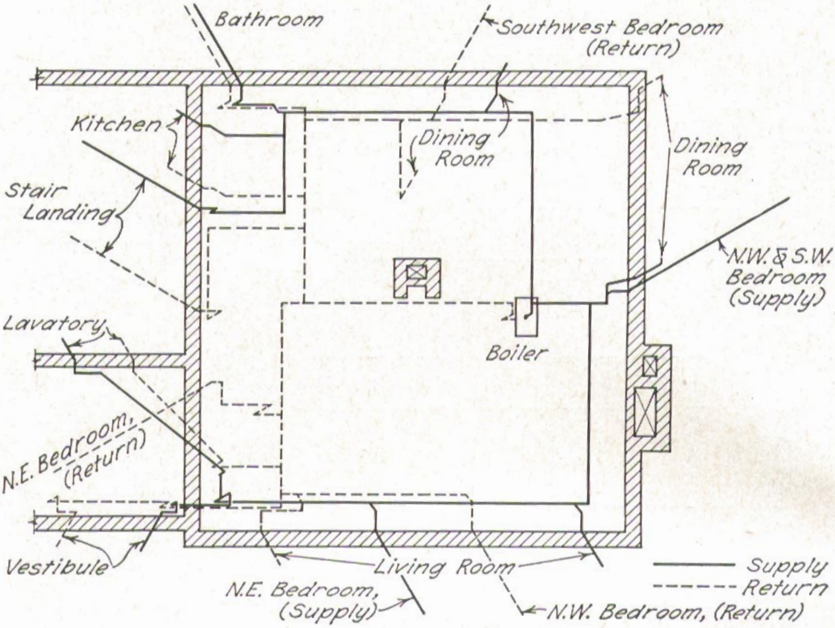

FIG. 9. BASEMENT PIPING SYSTEM USED IN TWO-PIPE, GRAVITY, HOT-WATER HEATING SYSTEM USED IN SERIES C-44, 1944-45 HEATING SEASON

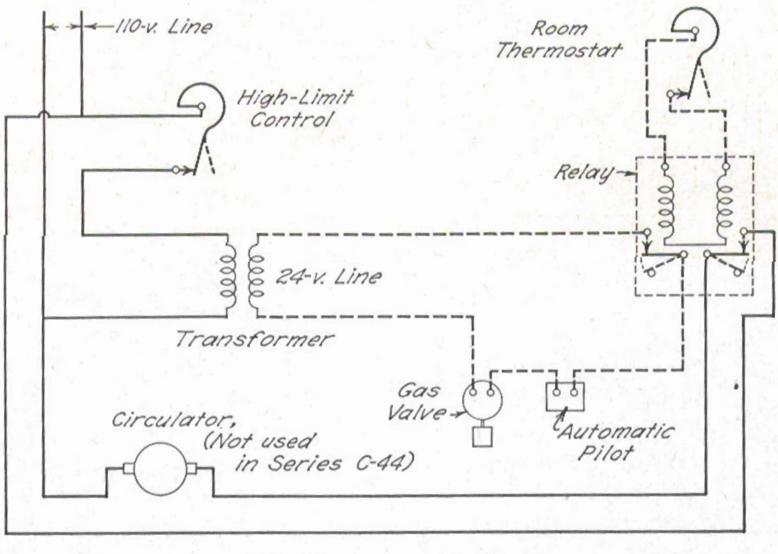

FIG. 10. CONTROL SYSTEM FOR GAS-FIRED BOILER

switch, a high-limit boiler-water temperature control, a magnetic gas valve, a safety pilot, transformer, and relay. The room thermostat was of the heat-anticipating type placed 30 in. above the floor, and provision was made through the action of the clock and time switch to reduce the temperature setting automatically at night and restore it to normal in the morning. The high-limit boiler-water temperature control, which served to prevent overheating of the water in the boiler, was of the immersion type and was located in the top of the back section of the boiler.

III. Test Procedure

7. *General Procedures.*—During all of the tests a burning rate of approximately 100 cu. ft. of gas per hr. was maintained. The burner was adjusted so that a CO_2 content of from 9 to 10 per cent was obtained at the smoke outlet of the boiler. The natural gas used was supplied from the Texas-Oklahoma Pipe Line, and had a high heating value of 1000 B.t.u. per cu. ft.

The doors between rooms were open at all times. Observations of the room air temperatures, as determined by the thermocouples located 3 in., 30 in., and 60 in. above the floor, and 3 in. below the ceiling, were recorded at 7:00 A.M., 11:00 A.M., 5:00 P.M., and 10:00 P.M. The temperatures of the air in the basement and the attic, and the relative humidity in the heated portion of the house were also observed at these times. Complete daily records were made of the operating time, the number of cycles and the power consumption of the gas burner and circulator, and the cubic feet of gas consumed. Recording instruments were used to obtain continuous records of the stack temperature and draft, the CO_2, the temperature of the water at the boiler outlet and return, the outdoor air temperature, the indoor relative humidity, and the air temperature in each room 3 in. and 30 in. above the floor and 3 in. below the ceiling. Other daily observations included the total amount of electricity, gas, and water used in the house, and general weather conditions.

8. *Series S.*—Tests included in series S, in which small-tube radiation was used in all rooms of the house, were conducted during the heating season of 1943-44. The average temperature of the air in the rooms at the 30-in. level was maintained constant at approximately 72 deg. F. both day and night. A forced-circulation system was used. When heat was required, the gas burner and the circulator were started, and both continued to operate until stopped by the room

thermostat. If the period of operation was of sufficient duration to raise the temperature of the water in the boiler to 210 deg. F., corresponding to the setting of the high-limit control, the latter would stop the burner. The circulator, however, would continue to operate.

9. *Series R.*—Tests included in series R were also conducted during the heating season of 1943-44. This series differed from series S only in that the small-tube radiation in the living room, dining room, and all three bedrooms was replaced with standard wrought-steel pipe extending along the outside walls of the rooms near the floor as shown in Fig. 5. The steel pipe was used in place of conventional radiation in order to obtain preliminary data on the effect of introducing heat into the rooms at the floor level without having to make up special radiator sections. However, it is quite conceivable that such pipes might be used as the radiator in the case of some of the low-cost housing, where it is essential to keep the first cost of the heating system to a minimum. The pipe is not too noticeable if it is painted to match the baseboard, as is shown in Fig. 1.

10. *Series T.*—Tests included in series T, made on the same heating system as that used in series R, were conducted during the heating season of 1943-44. The test procedure for series T differed from that for series R, only in that the setting of the room thermostat was reduced to 66 deg. F. at 10:00 P.M. and restored to 72 deg. F. at 5:30 A.M.

11. *Series C-44.*—Tests included in series C-44, made on the two-pipe, gravity, hot-water system, were conducted during the heating season of 1944-45. The high-limit control was set to a temperature of 235 deg. F., in order to make it possible to operate with an average radiator temperature of 215 deg. F., in case such a temperature should be demanded in sub-zero weather. The radiant baseboards shown in Figs. 6 and 7 were used in the living room, the dining room, all three bedrooms, and the lavatory.

IV. Results

12. *Room Temperature Differentials.*—When changes were made for each series of tests, all of the radiators in the second-story bedrooms were replaced while some of those on the first story were left unchanged. Hence, it was considered that only the air temperature differentials observed in the second story should be used in making comparisons of the operating characteristics of the several types of

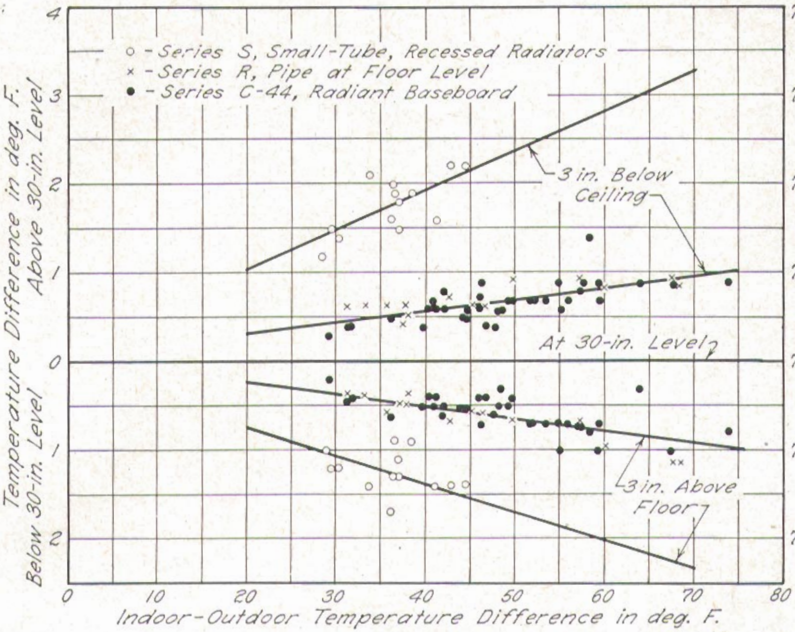

FIG. 11. SECOND-STORY AIR-TEMPERATURE DIFFERENTIALS

radiators used, and therefore the discussion in this section has been confined to data obtained in the three bedrooms. Data obtained in the first-story rooms showed characteristics similar to those obtained in the second-story rooms except that the floor to ceiling temperature difference was from 1 to 2 deg. F. greater.

As shown in Fig. 11, at an outdoor temperature of zero deg. F., when the three bedrooms were heated either by the pipe or by the radiant baseboards, the average floor to ceiling temperature difference was only about 2 deg. F., as compared with 5½ deg. F. obtained when the rooms were heated by conventional recessed radiators. For the sake of clarity, only the temperatures 3 in. below the ceiling, at the 30-in. level, and 3 in. above the floor are shown. However, when either the pipe or the radiant baseboards were used, the temperature at the 60-in. level was the same as that 3 in. below the ceiling. Thus the entire temperature difference occurred within a zone extending from 3 in. above the floor to the 60-in. level. At an outdoor temperature of zero deg. F., the temperature 3 in. above the floor was 71.1 deg. F., the temperature at the 30-in. level was 72.0 deg. F., and the temperatures 60 in. above the floor and 3 in. below the ceiling were each

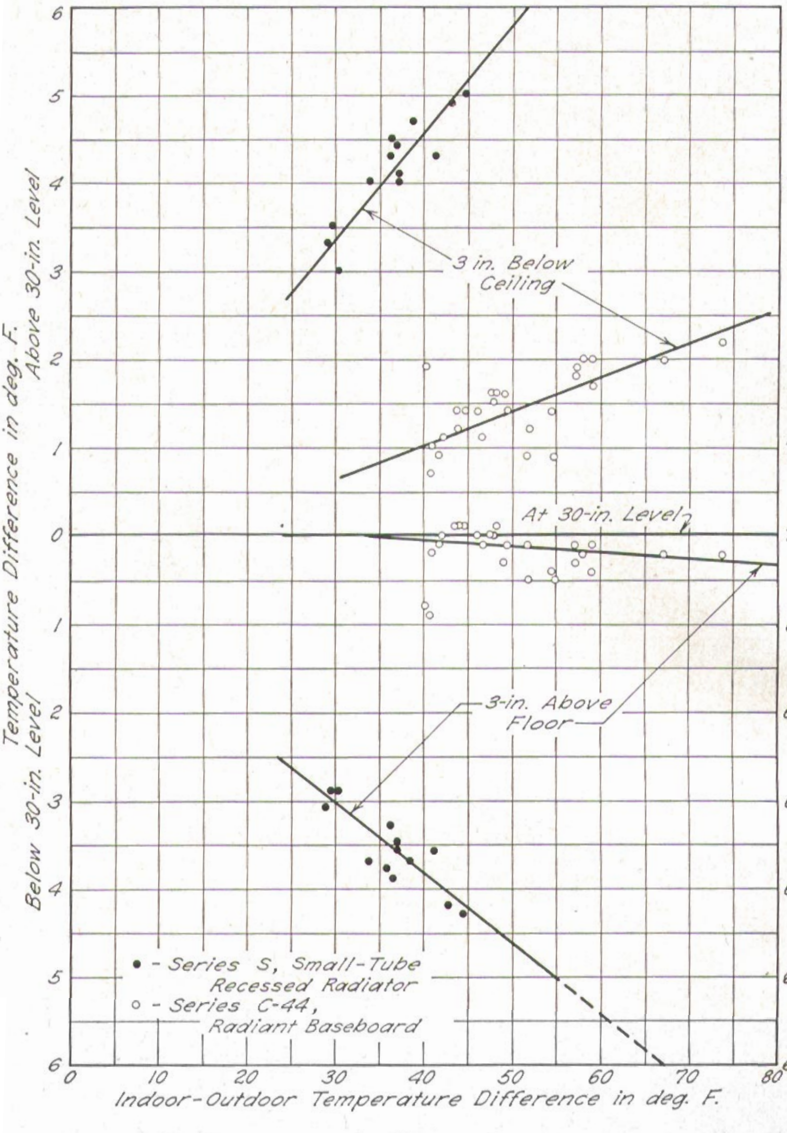

FIG. 12. LAVATORY AIR-TEMPERATURE DIFFERENTIALS

72.9 deg. F., while the corresponding temperatures for series S were 69.7 deg. F., 72.0 deg. F., 73.3 deg. F. and 75.3 deg. F. respectively. Thus it may be observed that the use of either the pipe or the radiant baseboards resulted in a temperature 3 in. above the floor 1.4 deg. F. higher than that obtained with the conventional recessed radiators. It may be further observed from Fig. 11 that this difference between the temperatures at the 3-in. level increased as the outdoor temperature was decreased.

Even more striking evidence of the tendency of the radiant baseboard to produce warm air near the floor is presented in the case of the lavatory on the first story. The floor of this lavatory, which adjoined the unheated garage, was an extension of the concrete floor of the porch and was laid directly on the ground. Conditions in the lavatory, which proved extremely difficult to heat with a conventional recessed radiator, are typical of those encountered in certain types of basementless houses. As shown by Fig. 12, at an outdoor temperature of zero deg. F., and with the same temperature at the 30-in. level, the substitution of the radiant baseboard for the recessed radiator resulted in an increase of 6 deg. F. in the temperature of the air 3 in. above the floor. Furthermore, with the radiant baseboard the temperature of the air at the 3-in. level was essentially the same as that at the 30-in. level.

A cold floor is a major factor in contributing to discomfort in otherwise well-heated rooms, hence the tendency to produce a warm floor may be regarded as an important attribute of radiant baseboards. This attribute is most important in the case of the basementless house in which cold floors are particularly prevalent. Therefore, the use of radiant baseboards is especially adaptable to this type of construction.

13. *Wall Surface Temperatures.*—Figure 13 shows the wall surface temperatures, measured on the inside surface of the plaster on the north wall of the living room, resulting from the use of the conventional recessed radiators, the pipe at the floor level, and the radiant baseboards. At the times that these observations were made, the outdoor temperature was approximately 32 deg. F., and the temperature of the air in the living room at the 30-in. level was 72 deg. F. It may be observed that with the pipe at the floor level and the radiant baseboard the temperature of the entire wall below the 60-in. level was greater than the temperature of the room air at the 30-in. level, whereas with the conventional recessed radiator the temperature of this portion of the wall surface was from 0.2 to 1.6 deg. F. below the temperature of the air at the 30-in. level. Thus, up to a height of 60 in., both the pipe at the floor level and the radiant baseboard warmed the entire surface of the portion of the exposed wall along which they were installed. On the other hand, with the conventional recessed radiator, only the small portion of the wall forming the back of the recess was warmed, and this contributed nothing to comfort because

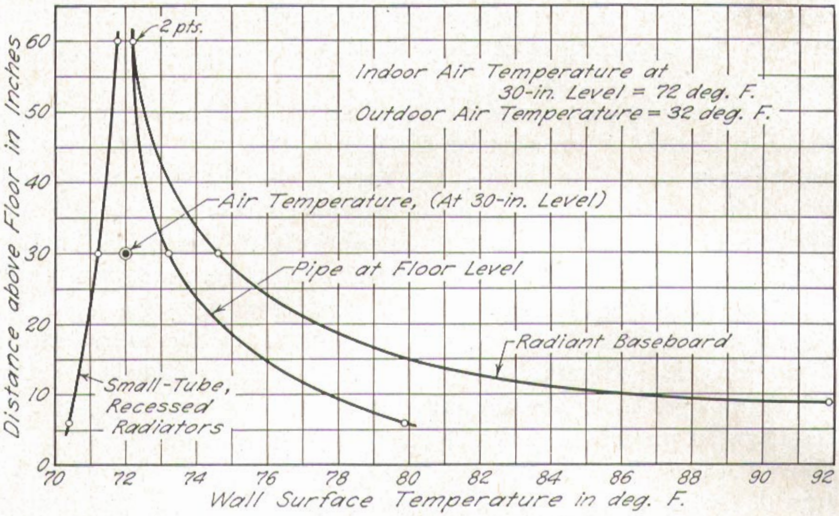

FIG. 13. INSIDE SURFACE TEMPERATURE OF NORTH WALL OF LIVING ROOM

this portion of the wall was hidden by the radiator, which was at a much higher temperature. The radiant baseboard was installed so that in effect it formed part of the wall itself. In this case the warming effect was the greatest because the wall was heated by conduction up through the plaster.

If all other factors except the wall surface temperature remained unchanged, the increase in the wall surface temperatures accompanied by the use of the floor level pipe and the radiant baseboard would result in an increase in the mean radiant temperature in the room. However, measurements made at the 30-in. level by means of both a thermo-integrator and a globe thermometer in five different locations in the living room proved that with conventional recessed radiators the mean radiant temperature was about 1 deg. F. higher than the air temperature and, with the floor level pipe and radiant baseboards the mean radiant temperature was from 0.5 to 1.0 deg. F. lower than the air temperature. This condition is just the reverse of that to be expected from the wall surface temperatures obtained with the three types of radiation. The higher mean radiant temperature obtained with the conventional recessed radiators must have been the result of the higher ceiling temperatures accompanying the use of these radiators. These mean radiant temperature observations indicate that, in an insulated house, even though the use of radiant baseboards results in warmer air near the floor and in warmer inside surfaces for the exposed wall, in order to produce the same degree of comfort it would still be necessary to maintain the same, or even a slightly higher, air temperature at the 30-in. level with the radiant baseboards than would be required with the conventional recessed radiators. Hence the main advantage of the radiant baseboard lies in the fact that the use of this type of radiation insures that warm floors will be obtained.

14. *Operation With Reduced Air Temperatures at Night.*—During part of each heating season the thermostat setting was reduced at night both when operating with the conventional recessed radiators and with the pipe at the floor level. In general, the performance obtained with the pipe did not differ materially from that obtained with the conventional recessed radiators.* However, as shown by Fig. 14, in the case of the pipe the overruns in the temperature of the air 3 in. below the ceiling during the morning warming-up cycle were somewhat less than those obtained with the conventional recessed radiators. Data obtained for the radiant baseboards were incomplete, but indicated that the performance with these baseboards was essentially the same as that obtained with the pipe at the floor level.

15. *Fuel Consumption.*—The fuel consumptions obtained with the three types of radiation are shown in Fig. 15. The points representing all the observed data are shown in this figure. The average curves, however, were obtained by plotting the points for each series on separate sheets, and then drawing the most representative curve for each set of data. It may be observed from the curves for series S and series R that replacing the conventional radiators with the pipe at the floor level resulted in a very slight reduction in fuel consumption. When the radiant baseboards, series C-44, were used a further reduction of approximately 5 per cent occurred in the fuel consumption. In the latter case, however, the radiators were used in connection with a gravity system, and, owing to the large size of the pipes, it was necessary to insulate the basement mains in order to prevent overheating the basement. As a result, an air temperature of about 70 deg. F. was obtained at the basement ceiling as compared with a temperature of approximately 75 deg. F. when the forced-circulation system, with small, uninsulated mains, was used in connection with series R and series S. It is probable that the decrease in fuel consumption should be attributed to this 5 deg. F. decrease in basement temperature which caused a decrease in heat loss from the house. Hence it seems safe to

* The performance with conventional radiators has been fully discussed in Univ. of Ill. Eng. Exp. Sta. Bul. 349.

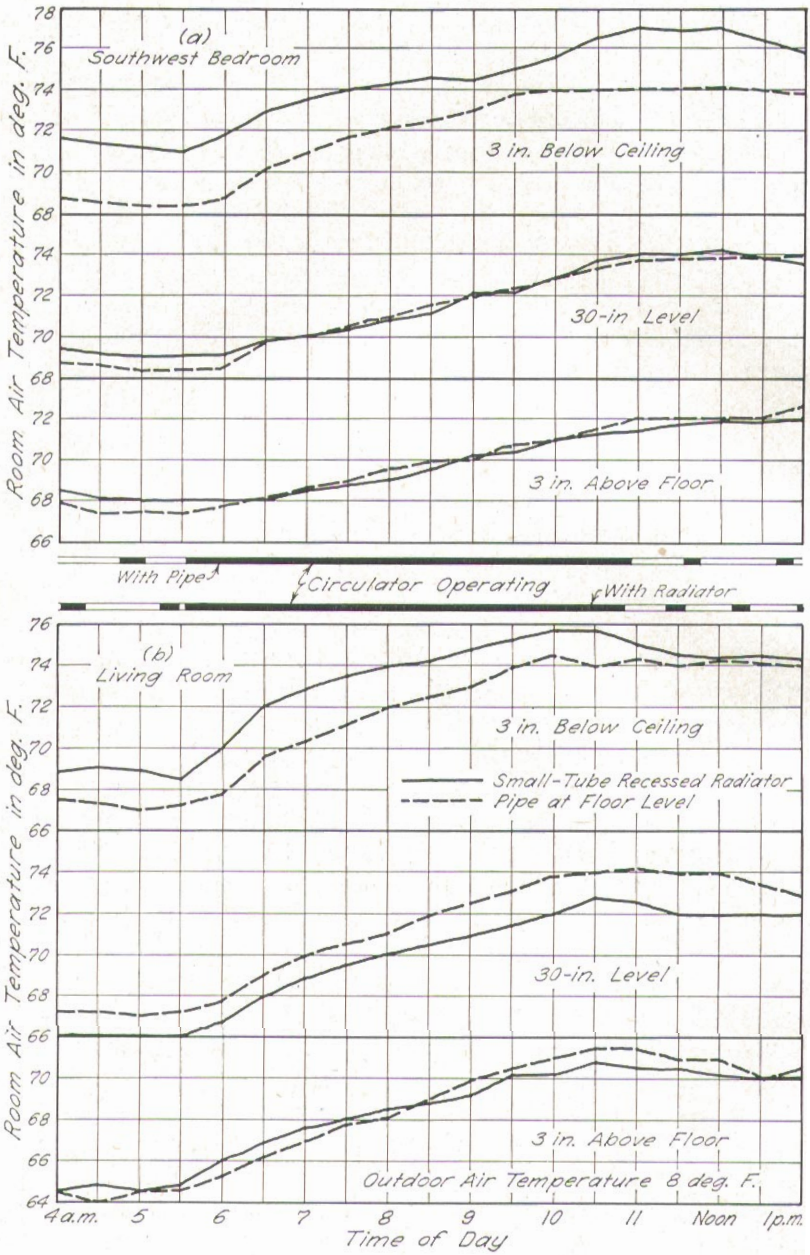

FIG. 14. ROOM AIR TEMPERATURE DURING WARMING-UP PERIOD USING CONVENTIONAL RECESSED RADIATORS AND PIPE AT FLOOR LEVEL

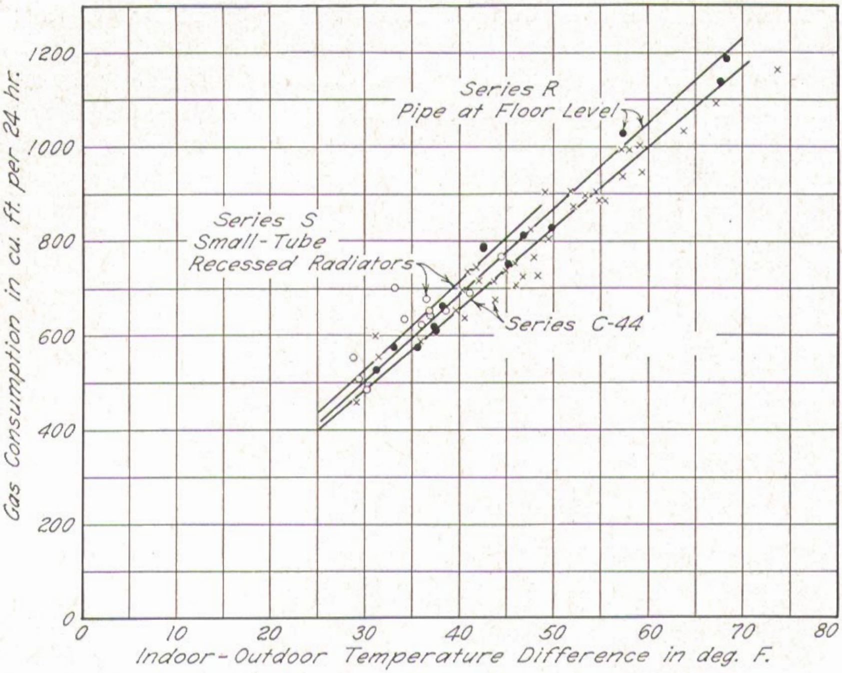

FIG. 15. FUEL CONSUMPTION CURVES

assume that no material difference in fuel consumption can be attributed to the inherent characteristics of the radiators themselves.

In any case, variations in the effect of wind and sunshine are liable to result in deviations of as much as 5 per cent from the averages of the fuel consumptions represented by the plotted curves. For this reason differences in the magnitudes of the order of those shown in Fig. 15 cannot be regarded as significant, and to all intents and purposes the fuel consumptions obtained with all three types of radiators can be considered as practically the same.

16. *Cleanliness of Operation.*—Immediately after installing the radiant baseboards and before any heat was required, all the walls were freshly painted and all curtains and draperies were cleaned. After operating through a complete heating season of approximately nine months no dirt patterns were observed on the walls above the radiant baseboards and there was no evidence that the heat had discolored the paint on the wall. Furthermore, at the end of the heating season, the white curtains at the windows over the radiant baseboards were as

clean as were similar curtains at windows under which no radiators were located. Neither were in need of cleaning. On the other hand, characteristic dirt patterns appeared on the walls above the conventional recessed radiators on the stair landing and in the kitchen and the curtains above these radiators were in need of cleaning long before the end of the heating season.

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