Temperature Distribution in a Test Bungalow With Various Heating Devices

BUILDING MATERIALS AND STRUCTURES REPORT BMS108

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Temperature Distribution in a Test Bungalow With Various Heating Devices

by

RICHARD S. DILL and PAUL R. ACHENBACH

ISSUED FEBRUARY 28, 1947

Building Materials and Structures Report BMS108

UNITED STATES DEPARTMENT OF COMMERCE • W. Averell Harriman, *Secretary*

NATIONAL BUREAU OF STANDARDS • E. U. Condon, *Director*

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Foreword

Uniformity of temperature throughout houses is a tacitly accepted American ideal of heating. Probably it is never attained in practice, and departures from it depend upon the design and construction of the house and upon the characteristics of the heating system or devices used. Distribution of warmth in houses has usually been judged only qualitatively by individual engineers on the basis of personal experience or observation. Quantitative data have been limited almost entirely to laboratory tests on parts of the system. Tests described in this report were made for the purpose of obtaining such data on the temperature distribution in a house heated successively with each of several types of heating systems.

E. U. Condon, *Director.*

Temperature Distribution in a Test Bungalow with Various Heating Devices

by **Richard S. Dill** *and* **Paul R. Achenbach**

ABSTRACT

The temperature distributions attained with various types of heating devices or systems were determined in the test bungalow at the National Bureau of Standards. The heating appliances tested included a hot-water heating system, floor furnaces located in several different positions, space heaters with fans, and electric and oil-burning warm-air furnaces. Each heating device was observed under a variety of weather conditions. The conditions inside and the weather outside the laboratory were recorded for comparison. Vertical temperature differences were computed for 32° F outside on the assumption that such differences are proportional to the inside-outside temperature difference.

I. INTRODUCTION

Performance of heating systems has usually been judged from data gathered during laboratory tests of individual parts of the heating device alone or by the experience of heating engineers.

The desirability of a heating system depends on its first cost and economy of operation, on the amount of smoke, soot, or dirt occasioned by its operation, on the amount of care and attention it requires, and on the temperature distribution it yields throughout a house. The last characteristic might be called the quality of its performance.

Information on efficiency, soot deposition, and attention requirements of a heating device can be obtained by laboratory tests, but quality of performance, as defined above, can only be determined by actual trial in a house. Therefore, a full-scale house was constructed at the National Bureau of Standards in which entire heating systems could be installed.

One of the main purposes of the work in this house was to obtain data on temperature distribution attained with various heating devices intended for low-cost houses so that estimates could be made of the performance of these heating methods in similar houses designed for occupancy. The house is a one-story bungalow designated as the test bungalow in this report. An exterior view of the test bungalow is shown in figure 1.

It is now commonly accepted that dry-bulb temperature is not the only important factor affecting human comfort. It is known that such factors as relative humidity, air velocity, and the amount of radiant heat present in an environment affect the degree of comfort at any given dry-bulb temperature. However, these several factors are frequently not subject to independent control in the present conventional heating systems and especially for those in the lower cost range. Consequently, for many systems the possible combinations of these several factors that determine the comfort are very limited. Various instruments intended to include radiant heat and other factors in evaluating the comfort of environments have been developed through the years, but no such device has yet attained general usage.

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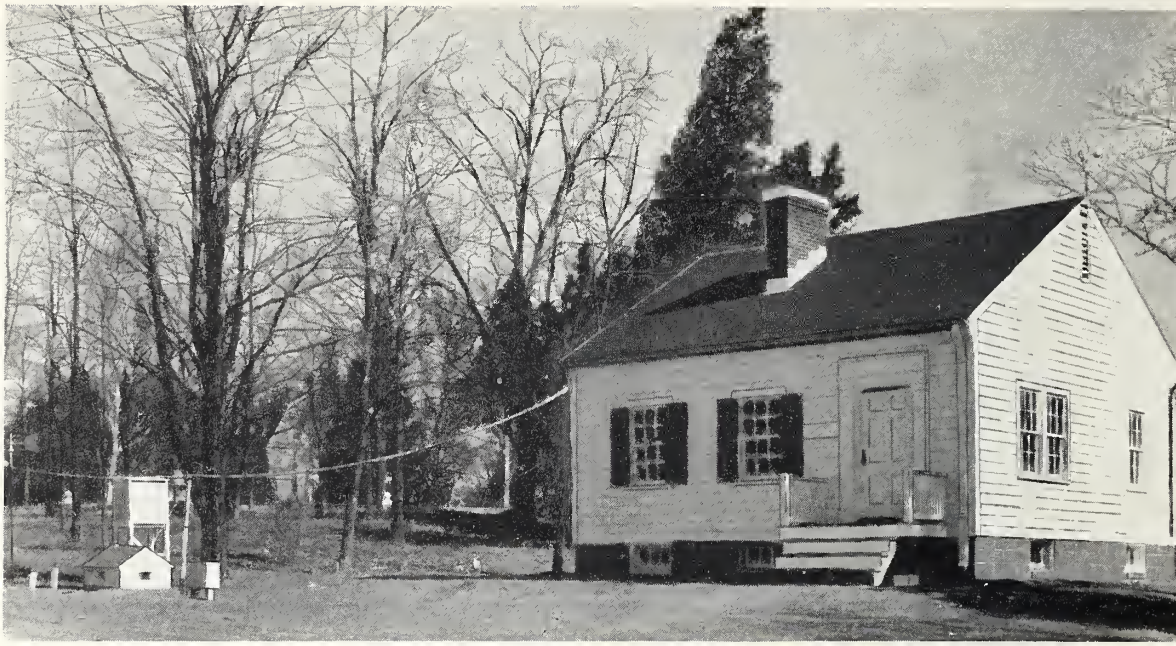

FIGURE 1.—*Exterior view of test bungalow*

Whether or not some other factor more accurately indicates comfort conditions in heated buildings, uniform dry-bulb temperature throughout the building appears to be the generally accepted standard. Uniformity of temperature is never quite achieved in practice, and the data presented herein indicate what departures from uniformity are to be expected in houses similar to the test bungalow when heated with different types of heating devices. Data in this report are intended to assist in determining the degree of variability in temperature distribution that can be or should be tolerated.

Appliances tested include a hot-water heating system, floor furnaces located in several different positions, oil and gas space heaters with fans, and electric and oil-burning warm-air furnaces.

II. TEST EQUIPMENT

The test bungalow at the National Bureau of Standards is similar to house B, described in Technical Bulletin No. 4, Principles of Planning Small Houses, issued by the Federal Housing Administration. This bungalow has four rooms and bath, floor plan of which is shown in figure 2. A small hallway in approximately the middle of the house connects the rooms. Adjacent to the hallway is a utility closet, intended to accommodate the heating equipment. All rooms except the bath, including the hallway, are provided with movable ceilings that can be adjusted to any height between 7 ft and 9 ft by permanently installed overhead screw jacks. During the tests described in this report, the ceiling height was 8 ft. The bungalow is provided with a full basement in which heating systems can be installed for comparison with devices located on the first floor.

The outside walls of the test bungalow are conventional in construction and consist of 2- by 4-in. studding with sheathing and lap siding on the outside, separated by a layer of building paper, and ½-in. gypsum board on the inside. The walls are not insulated. The bungalow has a double floor of 1-in. pine. Building paper is laid between the subfloor and the finish floor in the conventional manner. The ceiling consists of ¼-in. plywood supported by a framework of 2- by 4-in. timbers. A blanket of wood-fiber insulating material 2 in. thick was placed on top of the plywood. The windows are double hung except the one in the bathroom and one of those in the kitchen. Window frames and sash are of wood. There is no weatherstripping around windows or doors.

Data on temperature conditions inside the bungalow were recorded by various types of instruments. Heat-transfer coefficients for floors, side walls, and ceilings were measured by fastening heat-flow meters of the Nicholls type to the surfaces. Coefficients were expressed in terms of Btu per sq ft per hr per deg F difference, and were obtained with an outside wind velocity of approximately 3 mph. Expressed in these units, the coefficients were: for side walls from inside to outside, 0.276; for floor from upper floor surface to basement air, 0.363; and for ceiling from under surface of ceiling to attic air, 0.166.

Thermocouples suspended from the ceiling by strings were used to measure air temperatures in the test bungalow. Five strings were hung in each room, one at the center and one midway between the center and each corner of the room. Five thermocouples were attached to each string, at points 2, 30, 60, 78, and 94 in. above the floor. These thermocouples were insulated to minimize the effect of cycles of the heater and were wrapped in aluminum foil to reflect radiant heat. Additional thermocouples were used to determine temperatures of top and bottom surfaces of the floor, inside of exterior walls, outside of exterior walls, basement air, and attic air.

A multiple-point resistance thermometer recorder was used to obtain a continuous record of the temperature at the center of each room, 30 in. above the floor.

A room thermostat having a bimetallic temperature-sensitive element controlled the operation of automatic heating devices. The thermostat was located on the inside wall of the living room, 30 in. above the floor.

Outdoor conditions in the vicinity of the test bungalow were recorded by the type of instruments employed by the United States Weather Bureau. These instruments included a hygrothermograph for recording temperature and relative humidity, a mercury-in-glass thermometer for registering the temperature, a three-cup anemometer with integrating dial for indicating the wind velocity and integrating the total air movement, and a weather vane for indicating the wind direction.

III. TEST SPECIMENS

Temperatures in the test bungalow were observed when heat was being supplied in turn by an experimental electric heater, an oil-burning warm-air furnace, a jacketed gas-fired space heater, a jacketed oil-fired space heater, a single gas-burning gravity floor furnace, two gas-burning gravity floor furnaces, a gas-burning floor furnace with forced circulation, an oil-burning gravity floor furnace, and a conventional gravity flow hot-water heating system.

1. Electric Heater

The experimental electric heater consisted of a vertical rectangular metal duct, 17 by 23 in.

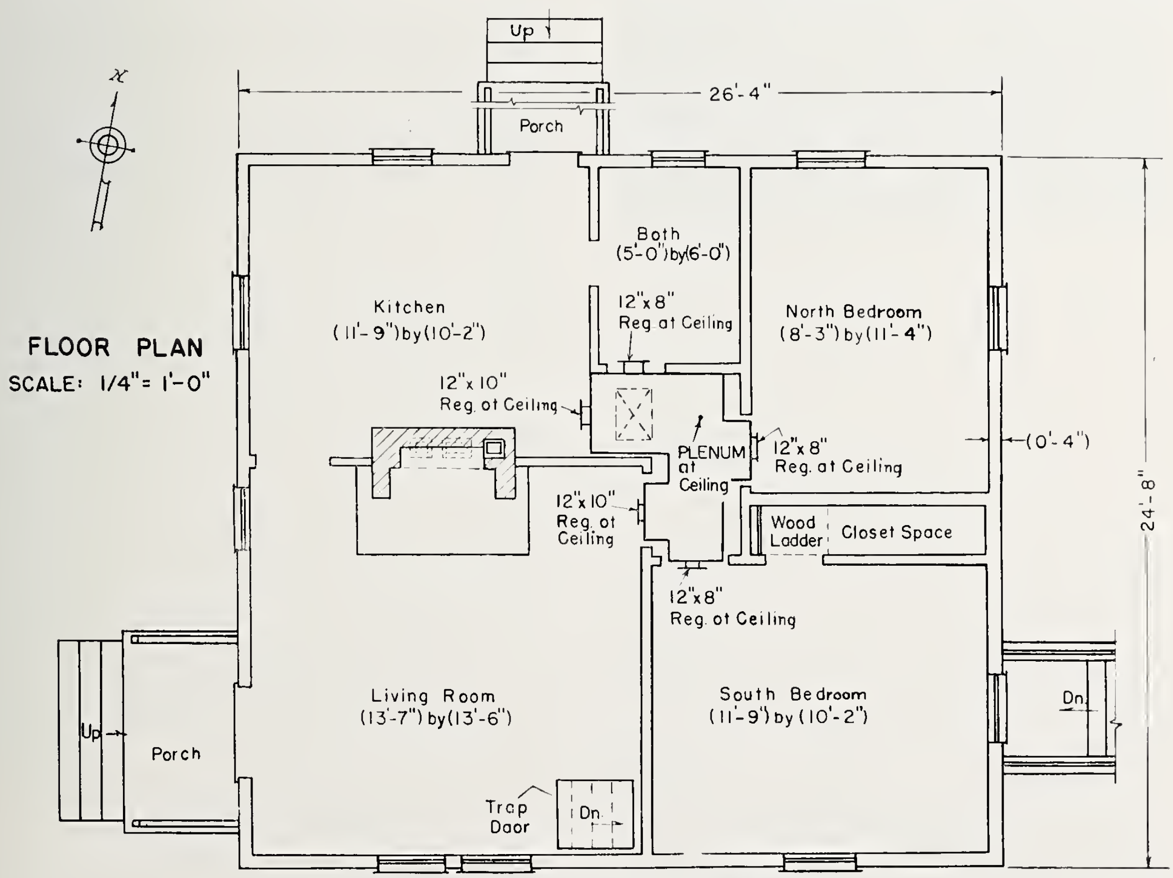

FIGURE 2.—*Floor plan of test bungalow.*

in cross section, lined with transite board, having 30 socket-type electric heaters, each of 660-watt capacity, mounted on the inside. The bottom of the heater was open to receive return air from the house, and the device was supported 12 in. from the floor by legs. The warm-air outlet of the heater was connected by a sheet-metal duct to a plenum chamber overhead.

The plenum chamber was approximately 11 in. high by 24 in. square. Warm air was supplied to each room from the plenum by a short duct. The plenum and ducts occupied the space in the hallway between 7 ft and 8 ft above the floor. The shape and location of the plenum chamber and ducts are shown on figure 2.

The results obtained on this heating device are summarized in tables 1 to 4 of this report.

For tests with forced circulation, the heater was raised to accommodate a centrifugal blower that was installed underneath it. A magnetic switch with a suitable relay permitted the thermostat to start and stop both the electric heater and the blower. The blower circulated air through the heater, plenum chamber, ducts, and rooms. A photograph of the experimental electric heater with the blower attached is shown in figure 3.

The electric heater was used for tests with gravity circulation, with intermittent forced circulation of air at rates of 780 cfm and 1,460 cfm, and with continuous forced circulation of air at a rate of 1,460 cfm.

2. Oil-Burning Warm-Air Furnace

The oil-burning warm-air furnace was of the cabinet type having a top outlet and a side inlet above the floor. A disk fan capable of delivering about 650 cfm against a static pressure of 0.12 in. of water, circulated air around a single heat-transfer cylinder. The furnace had a natural-draft, pot-type burner 13 in. in diameter, operating on high and low fire as required. The operation of the furnace was completely automatic, with the room thermostat controlling the fuel supply to the burner, and the bonnet temperature controlling the operation of the circulating fan. The rate of oil supply to the burner on high fire was 0.55 gal/hr, and the manufacturer's output rating

Table 1.—*Temperature distribution in a test bungalow heated by electric warm-air heater located in utility space with air distributed by gravity circulation through plenum chamber*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
Room Temperature (Outside Temperature 12° to 14° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	58	54	60	58	59	58	6
30	67	64	65	65	69	66	5
60	78	75	78	77	79	77	4
78	97	80	93	85	93	90	17
94	114	86	109	96	119	105	33
Basement	--------	--------	--------	--------	--------	40	--------
Attic	--------	--------	--------	--------	--------	--------	--------
Temperature Difference							
2 to 60	20	21	18	19	20	19	--------
2 to 94	56	32	49	38	60	47	--------
Room Temperature (Outside Temperature 28° to 32° F)							
2	64	60	66	65	65	64	6
30	72	70	72	71	74	72	4
60	81	78	80	79	82	80	4
78	96	82	94	87	95	91	14
94	111	81	106	97	120	103	39
Basement	--------	--------	--------	--------	--------	42	--------
Attic	--------	--------	--------	--------	--------	--------	--------
Temperature Difference							
2 to 60	17	18	14	14	17	16	--------
2 to 94	47	21	40	32	55	39	--------

Table 2.—*Temperature distribution in a test bungalow heated by electric warm-air heater located in utility space with air distributed by intermittent forced circulation through plenum chamber (780 cfm)*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
Room Temperature (Outside Temperature 8° to 10° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	53	52	57	58	53	55	6
30	70	70	69	70	69	70	1
60	82	81	79	82	82	81	3
78	85	83	82	89	103	88	21
94	97	87	79	90	115	94	36
Basement	--------	--------	--------	--------	--------	35	--------
Attic	--------	--------	--------	--------	--------	--------	--------
Temperature Difference							
2 to 60	29	29	22	24	29	26	--------
2 to 94	44	35	22	32	62	39	--------
Room Temperature (Outisde Temperature 28° to 32° F)							
2	60	57	61	60	59	59	4
30	70	68	69	69	70	69	2
60	78	75	76	79	78	77	4
78	82	78	81	84	95	84	17
94	91	82	80	86	108	89	28
Basement	--------	--------	--------	--------	--------	48	--------
Attic	--------	--------	--------	--------	--------	--------	--------
Temperature Difference							
2 to 60	18	18	15	19	19	18	--------
2 to 94	31	25	19	26	49	30	--------

TABLE 3.—*Temperature distribution in a test bungalow heated by electric warm-air heater located in utility space with air distributed by intermittent forced circulation through plenum chamber (1,460 cfm)*

Height above floor	Kitchen	Living room	North bed-room	South bed-room	Bath	Aver-age	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 16° TO 20° F)							
in.	*° F*	*° F*	*° F*	*° F*	*° F*	*° F*	*° F*
2	58	58	62	61	54	59	8
30	71	71	69	72	68	70	4
60	77	75	73	78	77	76	5
78	79	77	76	82	88	80	12
94	88	79	75	82	99	85	24
Basement						36	
Attic							
TEMPERATURE DIFFERENCE							
2 to 60	19	17	11	17	23	17	
2 to 94	30	21	13	21	45	26	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 22° TO 26° F)							
2	59	55	60	60	59	59	5
30	69	70	69	67	70	69	3
60	75	74	73	74	76	74	3
78	77	76	75	75	79	76	4
94	86	79	75	76	81	79	11
Basement						38	
Attic							
TEMPERATURE DIFFERENCE							
2 to 60	16	19	13	14	17	15	
2 to 94	27	24	15	16	22	20	

TABLE 4.—*Temperature distribution in a test bungalow heated by electric warm-air heater located in utility space with air distributed by continuous forced circulation through plenum chamber (1,460 cfm)*

Height above floor	Kitchen	Living room	North bed-room	South bed-room	Bath	Aver-age	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 34° TO 38° F)							
in.	*° F*	*° F*	*° F*	*° F*	*° F*	*° F*	*° F*
2	62	64	61	64	60	62	4
30	70	69	68	70	68	69	2
60	72	70	69	72	72	71	3
78	75	71	70	73	77	73	7
94	75	71	68	73	76	73	8
Basement						45	
Attic							
TEMPERATURE DIFFERENCE							
2 to 60	10	6	8	8	12	9	
2 to 94	13	7	7	9	16	11	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 40° TO 45° F)							
2	64	70	64	65	62	65	8
30	71	72	68	71	69	70	4
60	73	73	69	72	72	72	4
78	74	74	70	72	73	73	4
94	74	73	70	72	72	72	4
Basement						44	
Attic						68	
TEMPERATURE DIFFERENCE							
2 to 60	9	3	5	7	10	7	
2 to 94	10	3	6	7	10	7	

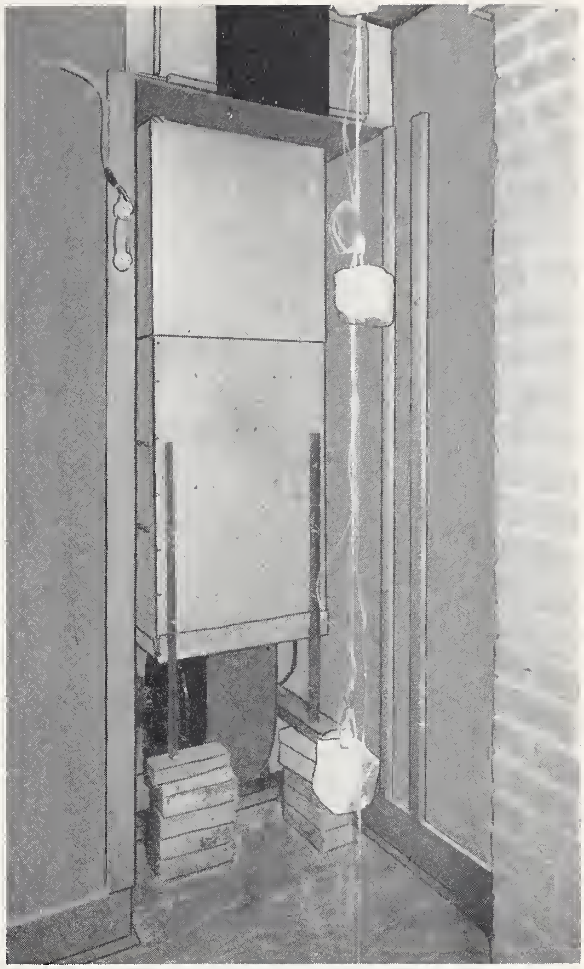

FIGURE 3.—*Electric heater with blower attached.*

on high fire was 55,000 Btu/hr. This heater was connected to the plenum chamber and duct system described above. A view of the furnace in the position used for the tests is shown in figure 4.

The results obtained on this heating device are summarized in table 5.

3. JACKETED GAS-FIRED SPACE HEATER

The gas-fired space heater was jacketed and was equipped with a disk fan 18 in. in diameter mounted on the back. The fan forced air through openings in a cast-iron heat-transfer element and a circular grille 21½ in. in diameter with deflecting vanes. The grille was located in front of the jacket and could be rotated in the jacket to deliver warm air in a desired direction.

The burner was controlled by a room thermostat, and the fan operation was controlled by the temperature of the heat-transfer element. The heater was placed in the living room in front of the fireplace opening for the test. The

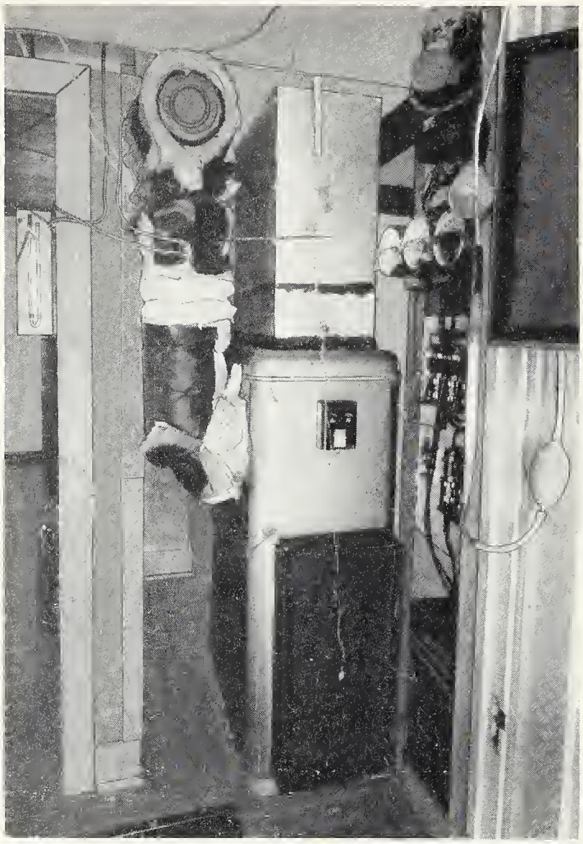

Figure 4.—*Oil-burning warm-air furnace in the position used for the tests.*

movement of air to and from the other rooms took place through the open doorways. The specimen heater is shown in figure 5, in the position used for the tests.

The results obtained on this heating device are summarized in table 6.

4. Jacketed Oil-Fired Space Heater

The oil-fired space heater was jacketed. It was equipped with a disk fan to circulate air downward around the combustion drum and deliver it near the floor through a grille in the front and one in the side of the heater. The heater was also used to heat the bungalow by gravity circulation, with the warm air being delivered from the top of the heater. The unit was equipped with a natural-draft pot-type burner with a diameter of 13 in. The oil supply to this unit was manually controlled. It had a maximum output of about 35,000 Btu/hr. This heater also was placed in the living room in front of the fireplace opening, and the heat was permitted to flow into the other rooms through the open doorways.

The results obtained on this heating device are summarized in tables 7 and 8.

Table 5.—*Temperature distribution in a test bungalow heated by oil-fired furnace located in utility space with air distributed by intermittent forced circulation through plenum chamber*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
Room Temperature (Outside Temperature 22° to 26° F)							
in.	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*
2	57	60	59	63	55	59	8
30	70	71	70	71	69	70	2
60	82	83	83	83	83	83	1
78	89	88	93	90	97	91	9
94	97	94	97	92	101	96	9
Basement						45	
Attic						56	
Temperature Difference							
2 to 60	25	23	24	20	28	24	
2 to 94	40	34	38	29	46	37	
Room Temperature (Outside Temperature 34° to 38° F)							
2	62	62	63	64	60	62	4
30	70	70	70	70	71	70	1
60	77	76	78	78	80	78	4
78	83	81	85	82	86	83	5
94	87	84	89	84	92	87	8
Basement						47	
Attic						58	
Temperature Difference							
2 to 60	15	14	15	14	20	16	
2 to 94	25	22	26	20	32	25	

Table 6.—*Temperature distribution in a test bungalow heated by a jacketed gas-fired space heater located in living room with air distributed by disk fan inside heater jacket*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
Room Temperature (Outside Temperature 23° F)							
in.	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*
2	56	60	55	57	52	56	8
30	69	68	67	66	65	67	4
60	80	91	76	76	74	79	17
78	84	94	80	79	79	83	15
94	87	98	82	80	79	85	19
Basement						43	
Attic						43	
Temperature Difference							
2 to 60	24	31	21	19	22	23	
2 to 94	31	38	27	23	27	29	
Room Temperature (Outside Temperature 37° F)							
2	59	65	58	62	57	60	8
30	69	70	68	69	66	68	4
60	76	85	74	74	72	76	13
78	80	89	78	77	76	80	13
94	82	91	79	78	77	81	14
Basement						47	
Attic						61	
Temperature Difference							
2 to 60	17	20	16	12	15	16	
2 to 94	23	26	21	16	20	21	

Table 7.—*Temperature distribution in a test bungalow heated by jacketed oil-fired space heater located in living room with air distributed by gravity circulation*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 43° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	63	70	63	66	58	64	12
30	69	73	70	72	68	70	5
60	77	81	76	77	74	77	7
78	87	112	82	82	80	89	32
94	96	123	86	87	84	95	39
Basement						52	
Attic						67	
TEMPERATURE DIFFERENCE							
2 to 60	14	11	13	11	16	13	
2 to 94	33	53	23	21	26	31	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 48° F)							
2	70	75	69	70	67	70	8
30	76	78	75	75	75	76	3
60	83	86	81	82	81	83	5
78	92	112	87	86	86	93	26
94	98	123	89	90	89	98	34
Basement						54	
Attic						70	
TEMPERATURE DIFFERENCE							
2 to 60	13	11	12	12	14	12	
2 to 94	28	48	20	20	22	28	

Table 8.—*Temperature distribution in a test bungalow heated by jacketed oil-fired space heater located in living room with air distributed by a disk fan inside heater jacket (downward flow)*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 48° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	66	87	64	66	62	69	25
30	77	87	76	77	75	78	12
60	85	91	81	82	81	84	10
78	87	94	84	85	85	87	10
94	90	101	85	86	85	89	16
Basement						52	
Attic						66	
TEMPERATURE DIFFERENCE							
2 to 60	19	4	17	16	19	15	
2 to 94	24	14	21	20	23	20	

5. Single Gas-Burning Gravity Floor Furnace

The single gas-burning floor furnace of the gravity type was installed in the floor of the hall in the conventional manner. It had a rated input of 70,000 Btu/hr. The warmed air was discharged from the furnace and the cold air was returned to the furnace through a grille measuring 26 by 38 in. The return air passed over the floor and entered the hall from all the rooms through open doorways.

Figures 6 and 7 show views of the furnace from under the floor and above the floor, respectively. Figure 7 is typical of the installation of all the floor furnaces tested in the hall.

The results obtained on this heating device are summarized in table 9.

6. Two Gas-Burning Gravity Floor Furnaces

The two gas-burning gravity floor furnaces were operated simultaneously in the bungalow. Each had a rated input of 35,000 Btu/hr. The hot-air outlet and the cold-air return of each furnace were at floor level and were incorporated in a single register measuring 18 by 32 in. One furnace was installed in the hall, and the other in the living room under the south windows 15 in. from the wall. Both furnaces were controlled during the tests by one room thermostat, located on an inside wall of the living room.

The results obtained on these heating devices are summarized in table 10.

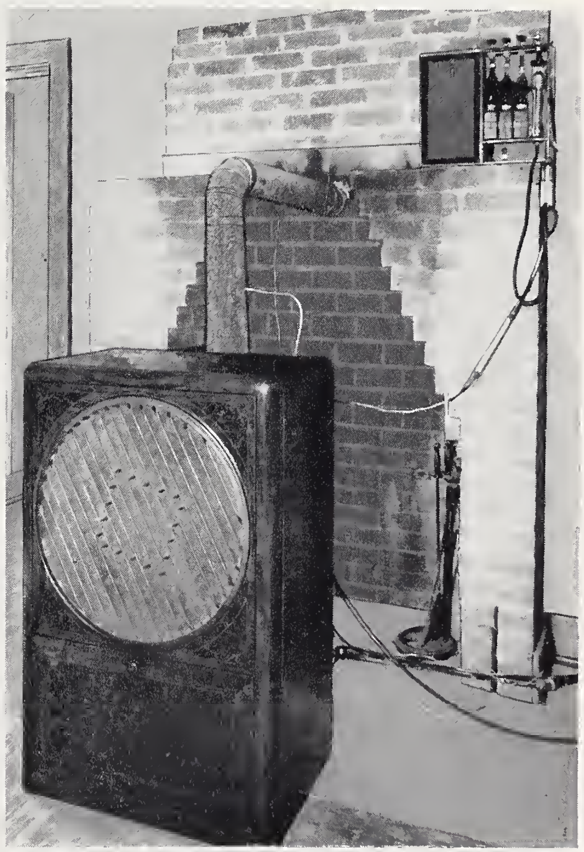

Figure 5.—*Jacketed gas-fired space heater in the position used for the tests.*

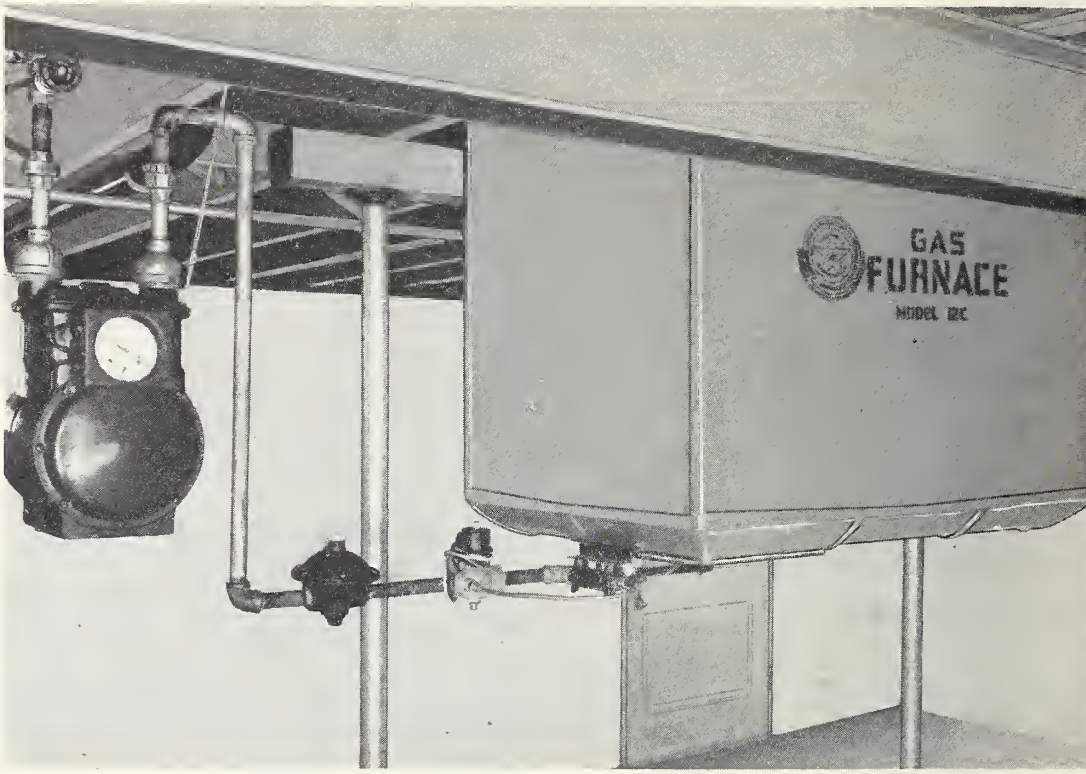

FIGURE 6.—*Single gas-burning floor furnace, gravity type, shown from under the floor.*

TABLE 9.—*Temperature distribution in a test bungalow heated by gas-fired floor furnace with air distributed by gravity circulation*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 34° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	60	60	60	61	57	60	4
30	69	68	69	70	67	69	3
60	75	76	78	78	76	77	3
78	79	79	83	80	83	81	4
94	82	82	83	81	84	82	3
Basement						50	
Attic						49	
TEMPERATURE DIFFERENCE							
2 to 60	15	16	18	17	19	17	
2 to 94	22	22	23	20	27	22	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 42° F)							
2	61	61	62	64	59	61	5
30	69	69	70	71	68	69	3
60	75	75	78	77	76	76	3
78	79	78	82	79	82	80	4
94	82	80	82	80	83	81	3
Basement						49	
Attic						57	
TEMPERATURE DIFFERENCE							
2 to 60	14	14	16	13	17	15	
2 to 94	21	19	20	16	24	20	

TABLE 10.—*Temperature distribution in a test bungalow heated by two gas-fired floor furnaces, one located in living room, the other in hallway, with air from both distributed by gravity circulation*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 27° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	60	62	59	61	58	60	4
30	68	69	67	69	66	68	3
60	74	78	73	75	72	74	6
78	77	80	76	76	75	77	5
94	77	81	76	76	75	77	6
Basement						53	
Attic						44	
TEMPERATURE DIFFERENCE							
2 to 60	14	16	14	14	14	14	
2 to 94	17	19	17	15	17	17	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 38° F)							
2	61	63	60	62	59	61	4
30	69	70	68	69	67	69	3
60	73	77	72	74	72	74	5
78	75	78	75	74	74	75	4
94	75	79	75	75	74	76	5
Basement						52	
Attic						50	
TEMPERATURE DIFFERENCE							
2 to 60	12	14	12	12	13	13	
2 to 94	14	16	15	13	15	15	

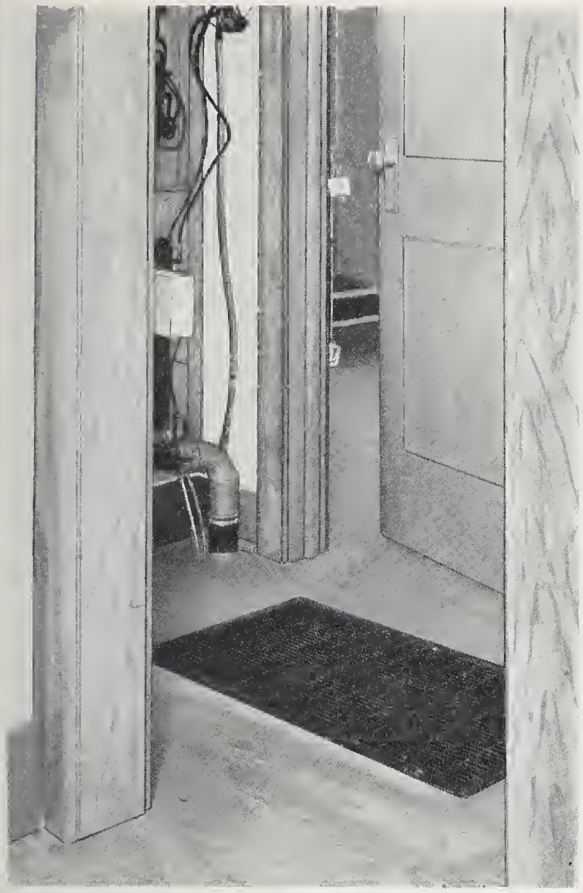

FIGURE 7.—*Single gas-burning floor furnace, gravity type, shown from above the floor.*

7. GAS-BURNING FLOOR FURNACE (WITH CIRCULATING FAN)

The gas-burning floor furnace with the circulating fan was installed in the hall. A plenum chamber 6 in. high was built over the furnace above the floor level and suitable openings permitted the warmed air to be forced toward the doorways of the surrounding rooms just above the floor. In practice, the furnace and its plenum would be placed in a closet or under a stairway adjacent to the hall, but this location was only simulated in the test bungalow to eliminate excessive changing of partitions. The circulating fan was of the propeller type. It was mounted in a vertical position under the heat-transfer element and was used to circulate the air through the heater and the house.

Cold-air return ducts under the floor connected the furnace casing to a floor register near an outside wall in each room except the bath. The ducts serving the two bedrooms were 9 in. in diameter while those serving the living room and kitchen were 12 in. in diameter. The furnace was automatically controlled by a room thermostat and a bonnet switch in the conventional way.

Figure 8 shows the manner in which the cold-air returns were connected to the furnace casing.

The results obtained on this heating device are summarized in table 11.

TABLE 11.—*Temperature distribution in a test bungalow heated by gas-fired floor furnace located in hallway with air distributed by disk fan inside furnace casing and with connected returns under the floor*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 35° F)							
in.	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*	°*F*
2	62	62	65	64	62	63	3
30	67	68	70	69	69	69	3
60	69	71	72	71	71	71	3
78	69	71	72	72	72	71	3
94	70	73	73	72	71	72	3
Basement						55	
Attic						47	
TEMPERATURE DIFFERENCE							
2 to 60	7	9	7	7	9	8	
2 to 94	8	11	8	8	9	9	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 46° F)							
2	63	65	65	65	62	64	3
30	67	69	70	71	68	69	4
60	69	71	71	72	70	71	3
78	69	72	72	72	70	71	3
94	70	73	72	72	70	71	3
Basement						56	
Attic						52	
TEMPERATURE DIFFERENCE							
2 to 60	6	6	6	7	8	7	
2 to 94	7	8	7	7	8	7	

8. OIL-BURNING GRAVITY FLOOR FURNACE

The oil-burning gravity floor furnace was installed in the floor of the hall. The warm-air discharge and the cold-air return were incorporated in a single register measuring 22 by 30 in. A pot-type vaporizing burner with automatic electric ignition was used in the furnace. The operation was automatically controlled by the room thermostat during the tests. The input rating of the furnace was 70,000 Btu/hr.

The results obtained on this heating device are summarized in table 12.

9. GRAVITY HOT-WATER HEATING SYSTEM

The gravity hot-water heating system was of the conventional type and was designed in cooperation with the Heating, Piping, and Air Conditioning Contractors National Association. The boiler was a rectangular, cast-iron boiler

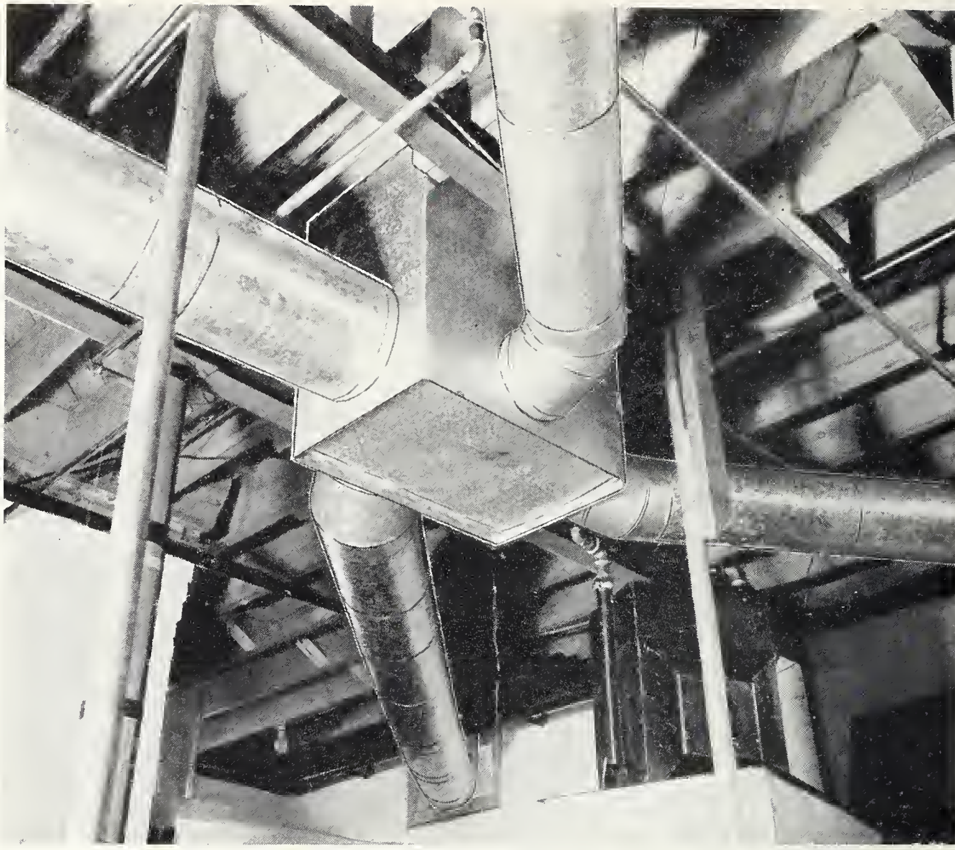

FIGURE 8.—*Manner in which cold-air returns were connected to the casing of the gas-burning floor furnace with circulating fan.*

TABLE 12.—*Temperature distribution in a test bungalow heated by an oil-fired floor furnace located in hallway with air distributed by gravity circulation*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 31° F)							
in.	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*
2	60	60	62	63	60	61	3
30	69	69	69	69	68	69	1
60	77	77	78	78	78	78	1
78	82	80	82	80	84	82	4
94	84	82	83	81	85	83	4
Basement						50	
Attic						59	
TEMPERATURE DIFFERENCE							
2 to 60	17	17	16	15	18	17	
2 to 94	24	22	21	18	25	22	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 36° F)							
2	62	62	63	63	61	62	2
30	69	69	70	69	68	69	2
60	76	75	77	77	77	76	2
78	80	78	81	79	84	80	6
94	83	80	82	81	85	82	5
Basement						51	
Attic						55	
TEMPERATURE DIFFERENCE							
2 to 60	14	13	14	14	16	14	
2 to 94	21	18	19	18	24	20	

TABLE 13.—*Temperature distribution in a test bungalow heated by oil-fired hot-water boiler located in basement with heat distributed by gravity circulation through cast-iron radiators*

Height above floor	Kitchen	Living room	North bedroom	South bedroom	Bath	Average	Maximum temp difference between rooms
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 19° F)							
in.	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*	° *F*
2	66	66	66	66	64	66	2
30	70	69	69	69	68	69	2
60	76	75	74	74	73	74	3
78	79	77	76	75	76	77	4
94	81	79	77	77	76	78	5
Basement						75	
Attic						39	
TEMPERATURE DIFFERENCE							
2 to 60	10	9	8	8	9	8	
2 to 94	15	13	11	11	12	12	
ROOM TEMPERATURE (OUTSIDE TEMPERATURE 32° F)							
2	67	68	67	67	66	67	2
30	70	70	69	69	68	69	2
60	74	73	72	72	71	72	3
78	76	75	73	72	73	74	4
94	78	76	74	74	73	75	5
Basement						75	
Attic						50	
TEMPERATURE DIFFERENCE							
2 to 60	7	5	5	5	5	5	
2 to 94	11	8	7	7	7	8	

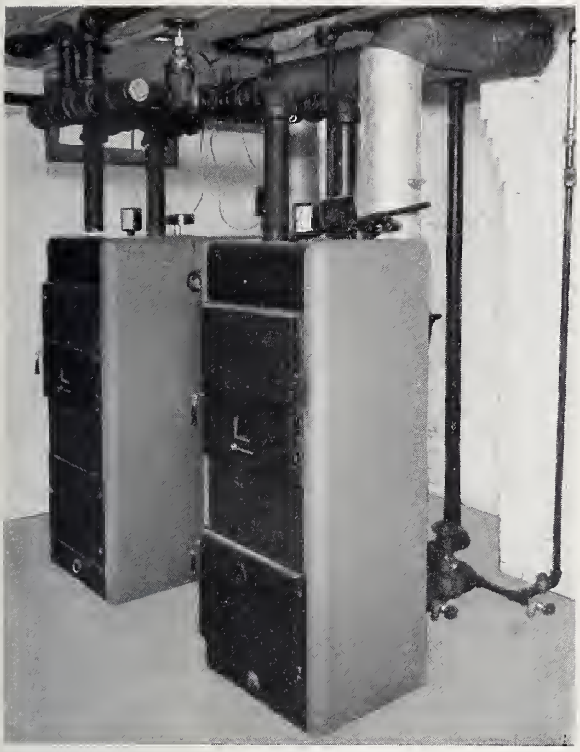

FIGURE 9.—*Oil-fired boiler and a companion coal-fired boiler of the same model.*

of three sections, with a wet base. It was fired with a gun-type oil burner. The burner was controlled by a room thermostat and an immersion aquastat connected in series. Small-tube radiators were used to warm the rooms.

Figure 9 shows a view of the oil-fired boiler and a companion coal-fired boiler of the same model that was installed for making comparisons in performance. No data on the coal-fired boiler are presented in this report.

The results obtained on this heating device are summarized in table 13.

IV. TEST PROCEDURE

Each heating system was operated for several days to assure temperature distribution characteristic of the heater. The automatic devices were controlled by a room thermostat placed 30 in. above the floor on an inside wall of the living room. The setting of the thermostat remained at 70° F continuously during these tests. The manually controlled units were adjusted to maintain approximately 70° F at the 30-in. level. Each heater, when installed, was adjusted in accordance with the manufacturer's instructions.

Continuous records of the outdoor weather conditions and of the temperature at the 30-in. level in the center of each room were obtained with the recording instruments described above. The temperatures indicated by the thermocouples in each room, by those on the floor and wall surfaces, and by those in the basement and attic were observed at intervals throughout the day.

V. VERTICAL TEMPERATURE DIFFERENCES

The average temperatures obtained at five levels in the rooms with the various devices tested are presented in tables 1 to 13. The temperatures shown are those obtained for a typical observation at the given outdoor temperature rather than an average of all the observations taken at the same outdoor temperature. The average difference in temperature between the 2-in. level and the 60-in. level above the floor and that between the 2-in. level and the 94-in. level are tabulated for each room and also for the entire house for each device. The 94-in. level was 2 in. below the ceiling.

The data presented for each device are (a), those that were obtained during the coldest weather that occurred while the device was under test, and (b), those that were obtained when the outdoor temperature was as near to 32° F as occurred during the test period.

From the standpoint of comfort, the temperatures from the floor to 5 feet above the floor are more significant than the temperatures at higher levels. However, an appreciable amount of heat will be radiated from the ceiling when it reaches a high temperature; this radiation may be of importance in maintaining warm floors, depending upon the conditions. High temperatures in the upper parts of the rooms will affect the heat loss from the building materially, especially if the ceiling is not insulated from the attic.

Tables 4, 11, and 13, show that the average temperature differences produced in the test bungalow between the 2-in. level and the 60-in. level with continuous forced circulation of air through a plenum chamber, with a forced-circulation gas floor furnace, and with a gravity hot-water heating system, respectively, were less than 10 deg F for outside temperatures in the range from 32° to 38° F. The temperature differences produced in this same zone by all the other devices tested ranged from 14 to 18 deg F between the level 2 in. above the floor and 60 in. above the floor at comparable outside temperatures. These devices included: gravity circulation of air through a plenum, intermittent forced circulation of air through a plenum with either the electric heater or the oil furnace, gravity floor furnaces, and a gas space heater with a disk fan.

The same heating devices or heating systems that produced the lower temperature differ-

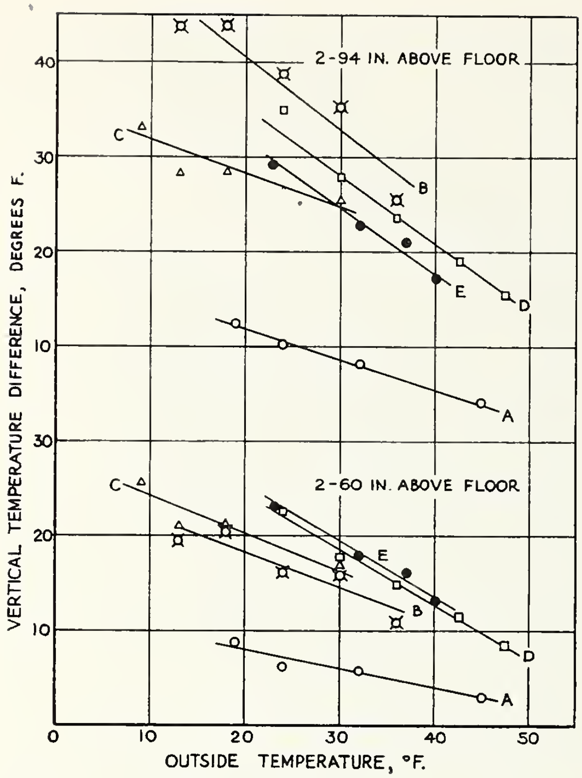

Figure 10.—*Vertical temperature differences attained with various heating devices in the test bungalow at the National Bureau of Standards.*

A, Gravity hot water heating system with radiators; *B*, electric heater with gravity circulation through a plenum chamber; *C*, electric heater with forced circulation (780 cfm) through a plenum chamber; *D*, oil furnace with forced circulation through a plenum chamber; *E*, gas space heater with a disk fan.

ences from the 2-in. to the 60-in. levels, also produced lower temperature differences from the 2-in. level to the 94-in. level. Except for the case of the electric heater when used with a continuous circulation of 1,460 cfm of air (reported in table 4), the heating devices operating with the plenum chamber at the ceiling in the hall produced higher temperature differences between the floor and the ceiling than the other devices tested. This condition was to be expected since the method of introducing the warm air did not diffuse heat throughout the lower parts of the room.

A comparison of tables 7 and 8 shows that, at an outside temperature of 48° F, the use of a disk fan to force air downward through a space heater and then across the living room near the floor caused the zone below the 60-in. level in that room to be warmer than it was with gravity circulation and that the fan caused the air 2 in. above the floor in the other rooms to average 4.5 deg F lower than was the case when gravity circulation was used. The air in the lower 60 in. of the living room was warm heater and the oil-burning furnace, when attached to the plenum chamber, were nearly as enough for comfort with gravity circulation of air through the space heater jacket.

The vertical temperature differences between levels increased as the outside temperature decreased with all the heating devices tested. The variation in the vertical temperature differences with outside temperature for five heating systems is shown in figure 10. Data were obtained for a sufficient range of outside temperatures to show the trend. It will be noted that the gravity hot-water heating system yielded the smallest temperature differences between levels throughout the range of outside temperatures shown. The heat released in the basement by the boiler, piping, and smokepipe was probably influential in keeping the temperature differences small. Table 13 shows that when the gravity hot-water system was used, the temperature in the basement under the floor joists was 75° F when the outside temperature was 19° F. The heat transfer through the wood floor was in an upward direction for this system.

Two other interesting results are shown in figure 10. The vertical temperature difference was less between the 2-in. level and the 60-in. level for outside temperatures of 35° F, or lower with the electric heater having gravity circulation of air through a plenum, than with either the electric heater or the oil-burning furnace having forced circulation through the same plenum.

Vertical temperature differences between the 2-in. and 60-in. levels for the gas space heater with a disk fan were substantially equal to those observed for the oil-burning furnace with the plenum distribution system.

VI. HORIZONTAL TEMPERATURE DIFFERENCES

The maximum temperature difference occurring between any two rooms at each of the five levels is also evaluated for each device in tables 1 to 13. The temperature recorded at each level for each room is the average of all the temperatures observed at that level in each room.

The horizontal temperature difference has no direct relationship to the vertical temperature difference. The comparison indicates, rather, the effect of the heater location for gravity circulation devices and, to some extent the effect of register or damper adjustments for forced circulation devices.

The results show that the average of the horizontal temperature differences at all levels of measurement ranged from 2 to 4 deg F for the several floor furnaces and for the gravity hot-water system. The horizontal temperature differences obtained with the electric small for the levels 2-, 30-, and 60-in. above the floor as for the above-mentioned devices, but they were substantially greater in the upper levels in the house.

As would be expected, the temperature difference between rooms was greater for the space heaters located in the living room than for the other heaters tested. This effect can probably be attributed to the fact that the rooms other than the one containing the heater are warmed by the overflow of heat from the living room through the doorways. If there were no temperature differences between rooms, there would be no motivating force for air circulation. In some instances, the temperature differences between rooms can be decreased by the use of a fan on or near the space heater. However, a comparison of tables 7 and 8 shows that the fan increased the horizontal temperature difference between rooms at the 2-, 30-, and 60-in. levels for the oil-burning heater.

The results in tables 1 to 13 show that, except for the space heaters, the average horizontal temperature differences from 2 to 60 in. above the floor did not increase with lower outside temperatures. When the bungalow was heated with a space heater located in the living room, the temperature difference between rooms usually increased somewhat with decreasing outside temperature.

VII. DISCUSSION

It was noted that the vertical temperature difference inside the test bungalow increased as the outside temperature decreased. To determine whether or not the temperature difference between the 2- and the 60-in. levels was proportional to the difference between the inside and outside temperature, table 14 was prepared evaluating the ratio of these factors for several days of operation with some of the heating devices tested. The observed temperature difference between the outside air and the air inside the building at the 30-in. level is represented by DT_1 in table 14. The 30-in. level was chosen because the room thermostat was located at that height and because it was the midpoint between the 2- and 60-in. levels. The observed temperature difference between the air 2 in. above the floor and 60 in. above the floor is represented by DT_2. The third column in table 14, $(DT_2/DT_1)\times 38$, represents the calulated temperature difference between the 2- and 60-in. levels for a 38-degree temperature difference between inside and outside, i. e. for an outside temperature of 32° F and an inside temperature of 70° F.

If the temperature difference between the 2- and 60-in. levels was directly proportional to the difference between interior and exterior temperatures, the ratio of DT_2 and DT_1 would be a constant. Then the value for the tempera-

Table 14.—*Temperature difference from 2 to 60 in. above floor for an inside temperature of 70° F and an outside temperature of 32° F*

DT_1	DT_2	$\frac{DT_2}{DT_1}\times 38$	Weather	Wind velocity and direction
ELECTRIC HEATER—GRAVITY CIRCULATION				
°F	°F	°F		mph
34.8	11.9	13.0	Clear	5 N.
41.5	18.7	17.1	do	5 N.
48.9	18.3	14.2	do	15 NW.
51.0	20.3	15.1	do	Quiet.
38.6	13.4	13.2	do	6 NW.
42.5	16.1	14.4	do	6 NW.
42.5	15.4	13.8	Cloudy	5 NW.
46.9	18.1	14.7	do	3 NW.
40.3	11.1	10.5	Clear	3 NW.
49.3	18.7	14.4	do	2 NW.
Average		14.0		
ELECTRIC HEATER—INTERMITTENT FORCED CIRCULATION (780 cfm)				
60.8	25.7	16.1	Clear	6 NW.
54.6	21.1	14.7	do	7 NW.
55.4	24.9	17.1	do	6 NW.
39.5	17.8	17.1	Cloudy	2 SE.
36.3	12.9	13.5	Clear	5 N.
49.1	21.0	16.3	do	12 NW.
Average		15.8		
ELECTRIC HEATER—INTERMITTENT FORCED CIRCULATION (1,460 cfm)				
52.0	16.7	12.2	Clear	10 NW.
54.1	17.1	12.0	do	9 NW.
43.0	13.8	12.2	do	5 NE.
38.9	13.6	13.3	do	2 N.
35.5	13.9	14.9	do	5 NW.
27.3	11.1	15.4	do	3 S.
46.6	13.8	11.3	Cloudy	10 NW.
41.6	17.4	15.9	Clear	9 NW.
Average		13.4		
ELECTRIC HEATER—CONTINUOUS FORCED CIRCULATION (1,460 cfm)				
29.8	10.3	13.1	Partly cloudy	3 NW.
25.4	5.7	8.6	do	2 NW.
34.8	9.1	9.9	Cloudy	2 NW.
31.2	8.4	10.2	do	1 NW.
29.5	8.3	10.7	do	5 NW.
29.1	7.8	10.2	do	7 NW.
Average		10.5		
OIL FLOOR FURNACE—GRAVITY CIRCULATION				
37.9	16.2	16.2	Cloudy	2 NW.
33.9	14.3	16.0	do	3 SE.
36.5	15.6	16.2	do	1 SE.
33.6	13.9	15.7	do	2 E.
35.8	13.8	14.7	Clear	7 NW.
34.0	15.6	17.4	Cloudy	4 S.
37.3	15.6	15.9	do	5 NW.
Average		16.0		
GRAVITY HOT-WATER SYSTEM WITH RADIATORS				
50.4	9.0	6.8	Clear	15 NW.
44.0	6.7	5.8	do	12 NW.
37.0	5.7	5.9	Cloudy	9 NE.
24.4	2.8	4.4	Partly cloudy	9 NW.
Average		5.7		
OIL FURNACE—FORCED CIRCULATION THROUGH PLENUM				
32.8	13.1	15.2	Clear	2 N.
23.0	15.1	24.9	do	4 W.
8.3	7.9	36.2	do	5 W.
18.8	11.0	22.2	Cloudy	3 NW.
21.3	8.3	14.7	Partly cloudy	3 NE.
35.8	13.4	14.2	Raining	10 NW.
41.5	16.6	15.2	Snowing	11 NW.
42.3	20.9	18.8	Clear	8 NW.
34.3	15.4	17.1	do	8 NW.
38.8	20.0	19.6	do	6 NW.
33.6	18.4	20.8	do	4 N.
25.0	14.0	21.3	Cloudy	2.5 NE.
25.8	11.5	16.9	do	2 NE.
33.4	15.0	17.1	do	2 N.
33.0	14.9	17.2	do	2.5 N.
34.8	16.7	18.2	Clear	5 N.
30.4	13.1	16.4	do	6 NW.
32.6	19.2	22.4	do	6.5 N.
28.6	11.1	14.8	do	7.5 N.
33.0	18.5	21.3	do	4.5 S.
46.3	22.8	18.7	do	6 NW.
40.3	17.7	16.7	do	5 N.
Average		19.1		

ture between the 2- and 60-in. levels corrected to an outside temperature of 32° F would be the same no matter what the outside temperature was when the observations were made. The results obtained by these calculations show that the quantity $(DT_2/DT_1)\times 38$ was not strictly constant, but that with some exceptions its value remained reasonably steady during the use of any one heating device.

For the electric heater, the value of the quantity $(DT_2/DT_1)\times 38$ averaged 10.5 deg F with continuous forced circulation of 1,460 cfm of air; for the hot-water heating system it averaged 5.7 deg F, and for the oil-fired warm-air furnace, 19.1 deg F. It will be noted that the averages for the ratio $(DT_2/DT_1)\times 38$ in table 14 agree closely with the values for the temperature difference between the 2- and 60-in. levels at an outside temperature of 32° F indicated by the curves on figure 10 for the corresponding system.

A study of the data in table 10 shows no significant correlation between the value of the quantity $(DT_2/DT_1)\times 38$ and the prevailing weather nor with the wind direction or velocity even though it was expected that a strong wind would produce a greater temperature difference between levels in the structure because more heat was required.

Consideration of the methods of heat transmission from a house suggests that the temperature distribution attained in a house with a heating system depends not only on the design of the heater and the distribution system, but also on the construction of the house. It is considered probable that the vertical temperature differences and, to some extent, the horizontal temperature differences attained with a given type heater and heating system will depend on the materials used in the walls, ceiling, and floor, the amount of insulation used in these elements, the amount of window area in the house, whether a basement or crawl space is used under the house, whether or not all of the rooms are on one floor, the arrangement of the rooms, and perhaps other factors.

Certain types of heaters may be suitable for houses of one construction and not suitable for other constructions. For example, a high temperature near the ceiling would not cause much additional heat loss if the ceiling were well insulated, or an insulated floor might permit the use of heaters that do not deliver warmed air at or near the floor level. Furthermore, some types of heaters that provide comfort in areas where extremely low temperatures do not occur, may not provide comfort in colder climates.

The data reported herein were all obtained with the same wall construction, the same degree of insulation, and the same arrangement of interior partitions, so that the data are directly comparable. Data on the effect of wall insulation, floor insulation, weatherstripping, storm windows, and other variables on the temperature distribution, are needed to provide a more nearly complete study of temperature distribution, but these phases of the subject were not taken into consideration during the present program. It is probable that lower temperature differences than those reported herein can be attained with the same heaters in houses of different construction and that a wider variation in temperature might be produced in other houses.

While no standards of performance in the field of vertical or horizontal temperature differences in residences have been established, these tests indicate that the air temperatures in the living zone of all rooms should range from 65° to 80° F for comfort when heated by the conventional types of heating systems.

A floor temperature of 60° F, when continued for 1 hour or more, was found to be too low for foot comfort; when a floor temperature of 65° F was continued for the same period, discomfort was no longer apparent. It was further observed that air temperatures of approximately 85° F around the level of the head became oppressive, especially if the air had an appreciable velocity. Of course, variations in the humidity of the air and the presence of a large amount of radiant heat or a large amount of cold window surface might alter these observations on comfort.

The test results obtained with the devices used in the test bungalow indicate that further improvement in the design of house construction and heating systems is necessary in order to provide comfort in all rooms of basementless houses. A more nearly uniform temperature distribution can probably be obtained either by the use of more insulation in the house elements, by improving the heat-distribution systems, or by a combination of both.

VIII. REFERENCES

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WASHINGTON, January 16, 1946.

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