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PERFORMANCE OF A GAS-FIRED WALL HEATER
INSTALLED IN A BASEMENTLESS HOUSE

by

O. N. McDorman
P. R. Achenbach

Report to

Federal Housing Administration
Washington, D. C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Heating and Air Conditioning Section
Building Technology Division

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ABSTRACT

A study was made of the performance of a gas-fired wall heater in a house without a basement with gravity circulation of air through the unit and with a booster fan to increase the air circulation. The results revealed that the heat loss of the structure was not significantly greater than for other heating methods wherein the heating unit is incorporated entirely in the heated space and that the heat loss could be calculated by conventional methods although the uncertainty in the rate of infiltration might result in inaccuracies in some cases. It was shown that insulation was desirable over the ceiling to restrict heat loss upward and also to promote radiation downward from the warm ceiling surface. Wall heaters without ducts employing gravity circulation or a booster fan are likely to produce significant temperature differences between rooms, between different levels in the same room, and between stations at the same level within rooms. These temperature differences were observed to be of such magnitude as to suggest limitations on the size of house, severity of climate, heat loss of the house and number of doorways between the heater and any heated room that could be associated satisfactorily with this type of heat distribution. The test results indicated that no more than one average-size doorway should be interposed between the heater and any room to be heated; a limiting distance of 18 feet, as presently specified in FHA Minimum Property Requirement, is probably too great for all applications; and design winter temperature of 0°F should be a lower limit for this type heating system unless the heat loss of the house in question can be reduced appreciably below 50 Btu/hr per sq ft of floor area at design outdoor conditions.

1. Introduction

At the request of the Federal Housing Administration in a letter dated August 16, 1954 a study was made of the performance

of a typical gas-fired wall heater with gravity circulation of air through the unit and with a booster fan to augment the air circulation within the furnace housing. A wall heater manufactured by Royal Jet Inc. of Alhambra, California was used for this investigation. With gravity circulation the heater was designated as the manufacturer's model FG-3-45 whereas the model number was FF-3-45 when the booster fan was attached to the same heater.

The purpose of this investigation was to study the temperature distribution produced in the Test Bungalow by a wall heater with and without the booster fan with respect to horizontal and vertical temperature gradients as a basis for judging the acceptability of this type heating system for various climates and various sized houses. The observed heat loss of the house was also compared with the heat loss computed by the method described in the Guide of the American Society of Heating and Air Conditioning Engineers to determine whether a gravity warm air furnace should be penalized in capacity when located on the living level of a one-story house.

The noise level produced by the quipment was also observed in the various rooms of the Test Bungalow.

II. Description of the Heater

The Royal Jet Heater employed a raised port burner ignited by a pilot, and a dimpled heat exchanger. The unit was designed for vertical installation within the living area as a gravity heater without discharge ducts. The specimen was rated at 45,000 Btu/hr input and 31,500 Btu/hr output. The casing measured overall 93-inches high, 28 3/4-inches wide and 14-inches deep. Three views of the heater installation in the Test Bungalow are shown in Figs. 1, 2, and 3. Fig. 1 shows the heater as seen from the kitchen, Fig. 2 as seen from the living room and Fig. 3 as seen from the hall. Fig. 4 shows the location of the heater on a floor plan of the house and indicates the location of the supply and return grilles.

The inner liner of the unit could be fitted with different heads to deliver warm air in two, three, or four directions as required by the particular installation. A head that delivered warm air to the living room and hall only was used for some of the tests whereas a head that delivered warm air to the living room, hall, and kitchen was used for the remainder of the tests. The dimensions of the openings in the heads and

the supply and return grilles are summarized below.

Room	Openings in Head, In.	Supply Grilles, In.	Return Grilles, In.
Kitchen	7x6	11 3/4x9 5/8	11 3/4x9 5/8
Living Room	19 3/4x7	26 1/4x11 3/4	26 1/4x11 3/4
Hall	7x6	11 3/4x9 5/8	11 3/4x9 5/8

The booster fan used with the heater carried the following name plate data.

Model 3300, Volts 115, cyc 60, Ser 4Y, Type L, Amp 0.30, RPM 1570, Redmond, Oivosso, Michigan, High Impedance Protected, A App. No. 5319. The booster fan consisted of two squirrel cage motors mounted on the two ends of the blower motor. The blowers were arranged for free discharge of air vertically upward through the heater.

The thermostat used for some of the tests was a wall thermostat manufactured by General Controls Company employing a thermoelectric circuit for actuation of the control.

III. Test Equipment and Procedure

The Test Bungalow remained in the same condition with respect to insulation and construction features, as for other heating systems recently tested. Significant factors were as follows: plastered ceiling, fluorescent illumination, weatherstripped windows and doors, uninsulated outside walls, basement ceiling consisted of 1-inch rigid insulation board nailed directly to the under side of the floor joists. The ceiling was insulated from the attic space with two layers of commercial "double thick" rock wool. The effective thickness was determined to be 5.4 inches. The Test Bungalow was operated as a basementless house for these tests even though it had a full basement. The basement temperature was controlled for similar tests to provide comparative data.

The temperature distribution was ascertained by means of 200 thermocouples enclosed in 3-inch cork spheres located at five stations and five levels in each of the four large rooms and three stations and five levels in the bath and at other suitable stations on the floor, embedded in the ceiling surface, on the sidewalls, and in basement, attic and out-of-doors. Additional thermocouples, of the parallel multiple-junction type were placed at the heater inlets and outlets.

The temperature of the gas supply was measured by means of a thermocouple inserted in the gas stream.

The absolute values of the heat transmitted to the attic were determined with the aid of twenty heat flow meters placed over the first layer of rock wool insulation in the attic.

After steady state conditions had been maintained in outside and inside temperatures for approxiately 8 hours, test periods of about 12 hours commenced, during which observations of the inside temperatures for approximately 150 stations were recorded at 4-hour intervals. Hourly recordings were made of the following temperatures: outside air, 30-inch level at five room centers, 5 positions in basement, 5 locations on furnace, gas supply temperature, and the closet. The accuracy of the measuring circuit was checked hourly using melting ice as a standard. Gas consumption, electrical energy used for lighting the house, electrical energy consumed by fan motors, and gas pressure were recorded hourly.

An auxiliary desk-type fan was used to direct air from the hallway toward the two bedrooms during one test for comparison with similar tests using gravity circulation or the booster fan.

IV Test Results

The temperature distributions observed in the Test Bungalow during nine tests under steady state conditions are summarized in tables 1-9 inclusive. Table 10 summarizes the performance of the heater, the heat loss of the house, and some of the more significant temperatures in the structure. The tests were made at outdoor temperatures ranging from 32°F to -15°F. Some of the tests were made with gravity circulation of the air whereas the booster fan was used for others and an auxiliary desk-type fan was used for air circulation during test 3. Two supply and return grilles were used for a part of the tests whereas three were used for other tests. Test 4 was made with a higher basement temperature than the other tests with the same outdoor temperature. These variations in test conditions are shown in tables 1-10. Table 11 summarizes the results of the noise measurements made in the house.

Temperature Distribution

The averages of the temperatures observed at five levels in each of the five rooms of the house are summarized in tables 1-9. The station at the center of the living room 30-inches above the floor was used as a control point for the tests. In test 1 with an outdoor temperature of about -15°F the Royal heater was able to maintain a temperature of 70.6°F at the control point when operating continuously with gravity circulation of the air through the heater. The average of the temperatures at all stations at the 30-inch level in the living room was 68.8°F and the average of the temperatures at the same level in the four other rooms was 6.6°F lower than the living room average. Table 2 shows that the average of the temperatures observed at the 30-inch level in the living room was raised to 70.8°F when the booster fan was employed at the same outdoor temperature, and the average of the temperature at the same level in the other four rooms was 5.4°F lower than the living room average. Table 3 shows that the auxiliary fan raised the average temperature at the 30-inch level in the two bedrooms above 70°F and also raised the temperature at the same level in the kitchen and bath to near 70°F.

When the outdoor temperature was maintained at about -5°F, as for the tests summarized in tables 5-7, average temperatures above 70°F were produced in the kitchen and living room at the 30-inch level with gravity circulation of the air and the other three room averaged 68.2°F at the same level. When the booster fan was used for circulation of air the average temperatures at the 30-inch level in all rooms were above 70°F with either two or three supply and return grilles on the heater as shown in tables 6 and 7. These two tables show that the principal effects of using a third supply and return grille in the kitchen were to increase the temperatures at all levels in the kitchen and to reduce the temperatures at all levels in the other rooms.

Tables 8 and 9 show that the living room temperature at the 30-inch level averaged 4.0°F higher at an outdoor temperature of 15°F and 3.1°F higher at an outdoor temperature of 31°F than the corresponding average of the other four rooms respectively.

Tables 1-9 show that there was less variation in average temperature between rooms at the 30-inch level than at any other level of observation.

Vertical Temperature Differences

The test results show that the temperature difference in the living zone from 2 to 60 inches above the floor ranged from 7.7°F for an outdoor temperature of 32°F to 16.6°F for an outdoor temperature of -15°F with gravity circulation of air through the heater. The 2 to 94-inch temperature difference ranged from 18.°F to 38.0°F for the same range of outdoor temperature.

The effect of using the booster fan or an auxiliary 16-inch non-oscillating desk-type fan placed in the hall near the warm air outlet is shown in Fig.5 and in Tables 1-3 inclusive. The booster fan raised the temperature from 2 to 5 degrees at all levels in the house but had no beneficial effect on the temperature differences between levels. The booster fan raised the temperature of the floor surface at room centers 5.2°F. The auxiliary fan raised the room temperatures below the 50-inch level and decreased the temperatures above the 65-inch level thus reducing the temperature difference between levels as compared to gravity circulation or booster-fan circulation of the air in the house. As shown in Fig. 5 and table 3 the vertical temperature difference between the 2 and 60-inch levels was 11.3°F whereas that between the 2 and 94-inch levels was 20.8°F for an outdoor temperature of -13°F when the auxiliary fan was used for air circulation.

Fig. 5 shows that the air 2-inches below the ceiling averaged about 10°F warmer than the ceiling surface at room centers for gravity and booster fan circulation of the air whereas this difference was about 7°F when the auxiliary fan was in operation. A temperature difference of only about 1 1/2°F would be required between air and ceiling surface to transfer all of the heat lost through the ceiling to the attic. This indicates that the major portion of the heat transferred to the ceiling by convection was radiated downward to the walls and floor.

Table 4 and test 4 in table 10 show the effect of a higher basement temperature on the temperatures in the living space at an outdoor temperature of -13°F. Raising the basement temperature from 37.5°F as in test 1 to 62.8°F as in test 4 raised the temperature on the floor surface and at all levels between floor and ceiling even though the heat output of the furnace was about 4000 Btu/hr less in test 4. The vertical temperature difference in the living zone from 2 to 60-inches above the floor was 12.8°F with the warmer basement as compared to 16.6°F in test 1.

Horizontal Temperature Differences

The maximum temperature difference between rooms on a room-average basis at each level of observation is shown in tables 1-9. This maximum temperature difference ranged from 7.9°F at an outdoor temperature of -15°F to 3.9°F at an outdoor temperature of 32°F at the 30-inch level with gravity circulation of air through the furnace. The maximum disparity between rooms decreased from 1 to 1 1/2°F when the booster fan was used. The maximum difference between average room temperatures was consistently lower at the 30-inch level than at any other level of observation. The living room was consistently the warmest room and the north bedroom was consistently the coldest room at the 30-inch level except for test 3 when the auxiliary circulating fan forced more warm air through the doorway connecting the hall and north bedroom.

The maximum temperature difference at the 30-inch level between any two of the stations in each room is also shown in tables 1-9. Some of these stations are within 2 feet of the exterior walls in the north bedroom and range up to 3 1/4 feet from the exterior walls in the living room. The average of these maximum temperature differences in the five rooms averaged from 4.1°F at an outdoor temperature of -15°F to 2.1°F at an outdoor temperature of 32°F at the 30-inch level with gravity circulation of air through the furnace. Operation of the booster fan did not affect the temperature variation within rooms at the 30-inch level significantly.

When the horizontal temperature differences between rooms and within rooms are considered together a value can be obtained for the maximum variation in temperature at the 30-inch level between the center of the living room which was the control point for the tests and the coldest station in any other room. The values for the maximum horizontal variation in temperature relative to the center of the living room are plotted in Fig.6. Fig.6 shows a linear relationship between maximum horizontal temperature variation and indoor-outdoor temperature difference for gravity circulation of air through the furnace ranging from 6°F to about 11°F as the indoor-outdoor temperature difference increased from 40°F to 80°F. Use of the booster fan or the auxiliary fan decreased this maximim variation from 1 to 2 degrees at the lowest outdoor temperature used for the tests. As would be expected, warming the basement decreased this variation significantly. The use of three supply and return grilles in tests 5 and 6 appeared to decrease the maximum variation of temperature at

the 30-inch level about 1 degree as compared to operation with two supply and return grilles under similar conditions.

Fig.7-10 inclusive were plotted to show the temperature difference between the center of the living room and the station most distant from the heater in each room for four levels above the floor, namely, 2-in, 30 in, 60 in. and 94 in., as affected by indoor-outdoor temperature difference and the method of air circulation in the house. For the most part the horizontal temperature differences at each level varied linearly with indoor-outdoor temperature difference for gravity circulation of the air through 2 supply and return grilles. Fig. 7-10 show that the remote stations in the bath and two bedrooms which were separated from the heater by an open doorway were consistently colder relative to the living room than were the living room and kitchen for gravity circulation of the air with two supply grilles. Tables 1-3 and 7-9 show that relatively more heat was delivered to the living room than the other rooms with the 2 grille arrangement used for the tests. This disparity in heat delivery to the several rooms was caused partly by the larger grilles in the living room and partly because the bath and two bedrooms had to be heated by flow of air through the doorways connecting these rooms to the hall. This probably accounts for a large part of the disparity shown in Fig.7-10 between the temperature difference in the living room and that shown for the other four rooms of the house.

Fig.7-10 show somewhat greater temperature differences at the 2-inch level than at either the 30 or 60-inch levels. This probably reflects the effect of air infiltration in the lower parts of the rooms and the return of the cold air from the exterior walls to the heater near the floor surface.

The points plotted in Fig.7-10 with the subscript "a" show the results obtained with gravity circulation of air through 3 supply and return grilles: in the living room, hallway, and kitchen. These data show that the temperature difference between kitchen and living room was decreased considerably at all levels by the use of supply and return grilles in the kitchen; the temperature differences between the living room and the two bedrooms and bath were decreased somewhat less; and the living room was affected only slightly.

The points plotted in Fig. 7-10 with the subscript "b" show the results obtained with the booster fan circulating air through the heater and employing 2 supply and return grilles. The use of the booster fan decreased the temperature

differences shown in Fig. 7-10 no more than one degree at the 2-inch level, from 1 to 2 degrees at the 30-inch level. At the 60-inch level the booster fan had little effect on the temperature differences in the living room and two bedrooms and effected a reduction of about one degree in the kitchen and bath.

The points plotted in Fig.7-10 with the subscript "c" show the results obtained with the auxiliary fan circulating air in the house. The auxiliary fan, directed as it was toward the doorways between the hallway and the two bedrooms, had its greatest beneficial effect on these two rooms. Fig. 7-10 show that the auxiliary fan reduced the temperature differences at the 2-inch and 30-inch levels in the two bedrooms to 50 percent or less of the values observed with gravity circulation whereas there was no reduction of the temperature differences at the 60-inch and 94-inch levels in these same rooms. The auxiliary fan had an adverse effect on the temperature differences in the kitchen at the 60-inch level and only small effects on the temperature differences at the other levels of observation. The effect of the auxiliary fan on the temperatures in the living room was small.

A study of Fig. 7-10 shows that the temperature difference between the center of the room containing the temperature control and the station farthest from the heater in the other rooms cannot be directly correlated with the distance from the heater. The temperature difference is more strongly affected by doorways interposed between the heater and the rooms to be heated, by supply and return grilles serving each room to be heated, and by circulating fans that direct the heated air through connecting doorways. The results in the kitchen, living room, and north bedroom offer a comparison of three rooms in which the most remote stations of temperature observation were about equally distant from the heater. For the tests with gravity circulation only the living room of this group was served directly by a supply and return grille and it had significantly lower temperature differences than the other two rooms. In test 5, for which the temperature differences are identified by the subscript "a" in Fig. 7-10 the kitchen was also served directly by supply and return grilles but of smaller size than those serving the living room. In this test the temperature difference for the kitchen was below that for the north bedroom which was connected to the hallway by a doorway; they were also lower than those for the bath in which the most distant station was only 6 ft from the heater but which had an intervening doorway; they were greater than those

for the living room presumably because of the difference in grille size for the two rooms. As noted before the auxiliary fan, which directed air downward toward the two bedroom doors, lowered the temperature differences at the 2-inch and 30-inch levels for the two bedrooms to values approaching those observed in the living room without the auxiliary fan.

Total Temperature Difference

The total temperature difference between the 2-inch and 60-inch levels that would be experienced in the entire area of the house covered by the stations of temperature observation are plotted in Fig. 11. These values are a combination of the horizontal and vertical temperature variations and were determined by subtracting the lowest temperature observed at the 2-inch level from the highest temperature observed at the 60-inch level. The values of total temperature difference ranged from about 14°F for an indoor-outdoor temperature difference of 35°F to about 30°F for an indoor-outdoor temperature difference of 80°F. The booster fan produced about the same values of total temperature difference as gravity circulation and the auxiliary fan reduced the values of total temperature difference about 5°F as compared to gravity circulation.

Heat Loss

The relation between the heat loss of the house and the average indoor-outdoor temperature difference at the 30-inch level is shown in Fig. 12 for the nine tests performed on the heater. The heat loss observed in tests 2, 6 and 7 with circulation of air by the booster fan averaged about 5% less than that for gravity circulation of air for the same indoor-outdoor temperature difference at the 30-inch level. The heat loss of the house with the auxiliary fan was about 10% less than for gravity circulation for the same indoor-outdoor temperature difference at the 30-inch level presumably because the auxiliary fan forced a greater amount of the heat downward into the lower part of the house and decreased the temperatures near the ceiling as shown in Fig. 5. Heating the basement of the house by an auxiliary means as in test 4 decreased the heat loss of the house by approximately 4500 Btu/hr as compared to gravity circulation without basement heating for an indoor-outdoor temperature difference of 80°F. This reduction in heat requirement is considerably greater than the decrease in the heat transmission through the floor caused by raising the basement temperature from 38°F to 63°F. This apparent discrepancy can be accounted for by the probability

that the infiltration air moving from the basement to the living space was also being warmed by the auxiliary heater in the basement.

Measurements of air infiltration were made with gravity circulation of air through the furnace and with the booster fan in operation using the tracer gas technique. Values of 1.55 and 2.33 air changes per hour were observed for gravity circulation and booster fan circulation, respectively, at an outdoor temperature of about -15°F. The only logical explanation that has been suggested for the increase in infiltration with the booster in operation is that it produced a slightly greater static pressure around the draft diverter inlet which was in the bonnet of the heater and thus forced more air out the flue. The change in infiltration rate is not supported by the heat loss data with and without the booster in operation indicating that more study of this relationship is needed.

In addition to the heat output from the Royal heater an average of 0.4 KW of electrical energy for illumination, instrument power and fan operation was dissipated. This electrical energy plus the heat output of one operater contributed from 1540 to 2740 Btu/hr to the heat requirements.

The heat loss from the living space to the attic was measured with 20 heat flow meters distributed over the total area so that each represented approximately an equal area. The observed heat loss through the ceiling, insulated with 5.4 inch of rock wool, averaged about 5% of the total heat loss of the hourse.

Heater Performance

The results obtained on the performance of the heater itself are summarized in table 10. Furnace efficiencies of 66 and 68 percent were observed. The reported furnace efficiencies are based on flue gas analyses and flue gas temperatures observed during continuous operation of the heater. Calculations were made with the values observed below the draft diverter since incomplete mixing of the flue gases and room air above the diverter appeared to make observations at this point less reliable. Heat transfer computations indicated that the heater efficiencies actually were approximately 5 percent higher than those shown in table 10 due to the radiation and convection transfer from the diverter and its components to the heater bonnet and the air circulated through the heater.

Comparisons between tests 1 and 2 and between tests 5 and 6 of the temperature rise of the air as it passed through the furnace indicate that the air circulation was increased from 20 to 30 percent by the use of the booster fan. A comparison of the air temperature at the supply and return grilles in tests 2 and 6 indicates that the total air circulation rate was not increased significantly by the use of 3 grilles as compared to that observed with 2 grilles.

The noise levels observed at the center of three rooms in the Test Bungalow at two different levels above the floor are summarized in table 11.

V. Discussion and Conclusions

Several questions naturally arise as to the effectiveness of a heater such as the Royal heaters when used as a central heating unit for a multi-room house with other gravity circulation of air through the heater or using a booster fan to increase the circulation moderately. Some of these questions might be phrased as follows:

1. Are the vertical temperature differences excessive when the air is circulated by gravity?

2. Are the room-to-room temperature differences excessive because no ducts are used?

3. Is the heat loss of a house equipped with this type heating unit likely to exceed the computed heat loss because of large vertical temperature differences?

4. How big a house is this type unit able to heat satisfactorily?

5. Are there climatic limitations to this type of heating system?

6. Is a booster fan beneficial in extending the application of the unit to larger houses or colder climates or does it increase the comfort attained in a given house?

The test data do not provide specific answers to all of the questions, but do provide information on the temperature distribution produced by this type heating system and some guidance in its application to small houses.

The Royal heaters, with or without a booster fan, deliver a supply of warm air from one or more grilles whose center lines are typically 78 to 80 inches above the floor level. Since practically no ductwork is used the heater can deliver warm air directly into only one, two, or three rooms depending on the heater location, and there may be one or more rooms that must be warmed by air movement in both directions through doorways. In the rooms heated directly by supply grilles the warm air spreads out over the ceiling and warms the ceiling by conduction and convection which in turn radiates significant amounts of heat to the floor, walls, and occupants of a house if the ceiling is adequately insulated. For example, in test 1, the average ceiling surface temperature in the living room was 102°F. Studies of a ciling panel heating system showed that the heat emission from the ceiling surface at that temperature was on the order of 35 Btu/hr (sq ft).

Since the warmest air is near the ceiling and since very little warm air is delivered from the heater below the level of the top of the doorways, the air that can pass to connecting rooms through doorways is at a lower temperature and therefore conveys less heat to these rooms. There is much less radiation from the ceiling of rooms heated through connecting doorways. For example, in test 1, the average ceiling temperatures of the bathroom and two bedrooms ranged from 75°F to 80°F.

With gravity circulation of air through the heater none of the warm air is delivered directly to the lower half of the room. Cooling of the room air at the exterior walls cause a downward convection current at the exterior walls and the temperature of the lower part of the room is determined by the temperature of these downward currents except when appreciable radiation occurs from the ceiling. The air circulation rate through the Royal heater by natural convection was between 200 and 250 cfm. This is probably much less than the total natural downward convection at all the exterior walls of the house. Consequently, the lower portion of the rooms could only be warmed as the downward currents of air at the exterior walls become warmer, except for radiation effects from the ceiling. Since the booster fan increased the air circulation through the heater no more than 20 to 30 percent, it is improbable that the booster fan forced the warm air into the lower part of the room.

The Test Bungalow has a gross floor area of 616 sq ft which approaches the lower limit of acceptable area for detached single-family dwellings. It has a hallway located

very near the center of the building and the heater location was near the center of the house. The distance from the supply grille to the most remote doorway to a connecting room was about 5 feet whereas the distance from the supply grille to the center of the most remote rooms to be heated was about 11.5 ft. There was no more than one doorway between the heater and any room to be heated. Thus, the installation used for the test is considered favorable to good temperature distribution from the standpoint of floor area served, heater location, room arrangement, and distance from the heater to each of the connecting doorways.

The test results in tables 5-7, at an outdoor temperature of about -5°F, show that the Royal heater was able to produce a temperature of 70°F or higher at the 30-inch level in all rooms with either two or three supply grilles when the booster fan was in operation, but did not warm the two bedrooms and bath to 70°F at the 30-inches level with gravity circulation of the air. However, the temperature difference between the 2 and 60-inch levels was about 19°F with the booster fan in operation and 15.5°F with gravity circulation of the air. Experience with this heating system and with other systems, described in BMS 108 and BMS 114, indicates that people begin to experience discomfort if the temperature at the 2-inch level falls below 65°F or if the temperature at the 60-inch level exceeds 80°F corresponding to a vertical temperature difference of 15°F in this zone. By this criterion some of the rooms would be too warm at the 60-inch level with the booster fan operating and some would be too cold at the 2-inch level with gravity circulation for the three tests at an outdoor temperature of -5°F.

In tables 5, 6, and 7 the horizontal temperature differences between rooms on a room-average basis ranged from 5.6°F to 6.5°F at the 30-inch level, from 8.1°F to 9.7°F at the 60-inch level, and from 9.9°F to 10.3°F at the 2-inch level. Fig. 6 shows that the temperature difference at the 30-inch level between the center of the living room and the coldest station was appreciably above the values cited above on the room-average basis, ranging from 8.2°F in test 6 to 9.5°F in test 5. It is common practice among heating engineers to compute heat losses for dwellings on the basis of an indoor temperature of 70°F. However, it is generally recognized that in the United States indoor temperatures ranging up to 75°F are preferred by normally-clothed adults. It is probable that a variation of temperature between rooms of 5°F at the 30-inch level would not be excessive as long as none of the temperatures

was below 70°F or above 75°F and provided the vertical temperature differences in the living zone associated therewith were not excessive. By this criterion the temperature distribution attained in the Test Bungalow with the Royal heaters would hardly be acceptable at an outdoor temperature of -5°F but would be acceptable at an outdoor temperature of 15°F.

The data in tables 1-9 show that the maximum horizontal temperature variation within rooms at the 30-inch level averaged about half as much as the maximum horizontal temperature difference between rooms at the same level on a room-average basis. This indicates that the temperature difference or temperature head at the 30-inch level required to move the warmed air across a room was about half as great as that developed between rooms at the same level when moving warmed air through a 30" by 68" doorway connecting the hall and a remote room. This suggests that a limit of one doorway between the heater outlet and any room to be heated is a valid limitation. It should be noted in tables 1-9 that the maximum horizontal temperature variations within the four larger rooms of the Test Bungalow were of about the same magnitude irrespective of whether the room was heated directly or through a connecting doorway.

The results observed in the Test Bungalow with the Royal heaters, for which the maximum distance between the heater outlet and the center of any room did not exceed 11 1/2 feet, indicate that the limit of 18 feet specified for this distance in the FHA Minimum Property Requirements Revision No. 51 is a liberal limit and probably should be reduced. The distance from the heater outlet to the center of the room in the Test Bungalow that was consistently the coldest room was only 9 ft. Probably few installations would have more favorable characteristics than the test installation for good distribution of heat by this method with respect to floor area, central location of the hallway, and central location of the heater. However, some houses of equal or greater size could have a lower heat loss than the Test Bungalow because more insulation was used which would tend to decrease the temperature difference between levels and between rooms. The computed heat loss of the Test Bungalow is about 51 Btu/hr per sq ft of floor for an indoor-outdoor temperature difference of 70°F.

It is concluded from the results obtained with the Royal heaters in the Test Bungalow that this type of heater should be used only in areas where the winter design temperature is 0°F or higher even with a booster fan except that application

in colder climates might be satisfactory in some cases in houses whose heat loss at design outdoor temperatures is significantly lower than 50 Btu/hr per sq ft of floor area. This conclusion is based on the observations that, at an outdoor temperature of -5°F, the heater was not able to produce a temperature of 70°F at the 30-inch level in the center of all rooms without the booster fan, the vertical temperature differences were as high or higher than the limit considered acceptable, the maximum temperature difference between rooms at the 30-inch level was a little greater than 5°F and considerably greater than 5°F at other levels above the floor, and on the opinion that the test installation is considered generally to be a favorable one for this method of heat distribution.

The heat loss of the Test Bungalow was computed using the methods recommended in the 1954 "Guide" of the American Society of Heating and Air Conditioning Engineers for comparison with the heat loss observed during the tests. The heat transmission through the floor, walls, windows and doors, and ceiling and roof was determined by the conventional formula:

$$H = AU\Delta T$$

using computed or tabulated values of the heat transmission factor, U, after correcting the values for the walls and windows to a wind velocity of 3 mph which was the approximate velocity of air motion over the exterior of the house. The infiltration heat loss was computed on the basis of one air change per hour. A sample computation for an indoor-outdoor temperature difference of 85°F is shown below.

Computed Heat Loss of Test Bungalow

Heating Load Element	Area Sq Ft	U Factor Btu/hr(ft)^2(°F)	Temperature Difference, °F	Heat Loss, Btu/hr
Outside Walls	667	0.243	85	13780
Windows and Doors	138	0.895	85	10500
Floor	616	0.144	38	3370
Ceiling and Roof	616	0.044	85	2300
Infiltration	5000 cu ft x 0.018x85			7650
Total				37600

The heat loss of the Test Bungalow was computed using the method illustrated above for a temperature difference equal to the average indoor temperature at the 30-inch level minus the outdoor temperature for each of the nine tests. These values are reported in table 10. On the average the computed heat loss values are about 5% higher than the observed heat loss. When it is recalled that the heat transmitted to the circulated air by the draft diverter, which was enclosed in the bonnet of the heater, is not included in the observed heat loss values reported, the agreement between computed and observed heat loss is very close.

In an installation, such as this one, where there is a temperature difference between rooms the thermostat might not be set to produce an average house temperature of 70°F at the 30-inch level, If the thermostat were set to produce a temperature of 70°F in the living room, the heat loss of the house might be less than the computed value. On the other hand, if the thermostat were set to produce a temperature of 70°F in the coldest room, the heat loss of the house might be greater than the computed value. In tests 4, 5 and 6 at an outdoor temperature of -5°F, the living room was about 3.5F warmer than the house average and the coldest room was about 2.5°F colder than the house average at the 30-inch level. Thus, the heat required to warm the coldest room to 70°F might be about 4% greater than that required to produce a house average of 70°F whereas the heat required to warm the living room, i.e. the warmest room, to 70°F might be about 5% less than that required to produce a house average of 70°F. Since many people in this country now prefer room temperatures above 70°F, it is perhaps more likely that the thermostat would be set to maintain a temperature of 70°F in the coldest room.

The relation between computed heat loss and required heat output to adequately warm a house would also be affected by the accuracy of the infiltration estimate. In the example shown above, the heat loss corresponding to an infiltration rate of one air change was 7650 Btu/hr or about 20% of the total heat loss. Infiltration measurements showed that the actual air leakage ranged from 1.5 to 2.3 air changes during the tests. The effect of this disparity between assumed and observed air leakage on the heat loss must have been compensated for in the heat loss calculation by other unknown errors, otherwise, the computed and observed heat losses would not be in such good agreement. Similar inaccurate estimates of the air infiltration rate could accur in the field with less

fortuitous compensation by other factors with the result that some cases of underheating might occur.

The test results do not indicate that the heat requirement of a house using a wall heater is significantly greater than the computed heat loss. The tests do indicate the importance of adequate ceiling insulation because the air temperature near the ceiling is high in the rooms warmed directly by this method and because radiation from the ceiling plays an important part in warming the lower part of these rooms. If the ceiling were uninsulated the ceiling surface would be cooler and less heat would be radiated downward toward the floor.

The booster fan increased the efficiency of the heater about 2 percent, raised the temperatures appreciably at the 30-inch level in all rooms, and decreased the maximum temperature difference between rooms from 1 to 1 1/2 degrees at the 30-inch level, but it increased the vertical temperature difference in the living zone from 3 to 4 degrees as compared to gravity circulation. The overall effect of the booster fan was to increase the comfort a little and to make the heat distribution acceptable at somewhat lower outdoor temperatures.

The Royal heaters were considered acceptable from the standpoint of noise.

TABLE 1

Temperature Distribution with Royal Heater, Gravity Flow
Outdoor Temperature 15.2°F 2 Supply Grilles

Height Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	56.3	63.8	57.0	51.5	55.0	56.7	12.3
30	63.6	68.8	62.0	60.9	63.1	63.7	7.9
60	74.3	79.2	72.5	70.0	70.3	73.3	9.2
78	88.0	106.3	83.8	75.9	76.7	84.9	30.4
94	96.7	118.3	90.7	84.0	83.9	94.7	34.4
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITH IN ROOMS							
30	4.4	4.1	2.5	4.7	4.8	4.1	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	18.0	15.4	15.5	18.5	15.3	16.6	
2-94	40.4	54.5	33.7	32.5	28.9	38.0	

Average Basement Temperature	37.5°F
Average Attic Temperature	16.8°F
Average Ceiling Surface Temperature	84.5°F
Average Floor Surface Temperature	54.4°F

TABLE 2

Temperature Distribution with Royal Heater, Forced Flow
Outdoor Temperature - 14.6°F   2 Supply Grilles

Height Above Floor	Average Room Temperature: Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room	Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
Inches	°F	°F	°F	°F	°F	°F	°F
2	58.1	64.9	59.6	53.9	57.2	58.7	11.0
30	65.8	70.8	66.1	64.3	65.5	66.5	6.5
60	80.1	84.5	79.2	74.6	75.0	78.7	9.9
78	90.0	107.9	88.4	79.8	81.5	89.5	28.1
94	95.5	117.2	94.0	84.8	88.5	96.0	32.4
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	3.8	4.2	2.1	4.1	5.6	4.0	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	22.0	19.6	19.6	20.7	17.8	20.0	
2-94	37.4	52.3	34.4	30.9	31.3	37.3	

Average Basement Temperature	35.9°F
Average Attic Temperature	19.6°F
Average Ceiling Surface Temperature	85.5°F
Average Floor Surface Temperature	59.6°F

TABLE 3
Temperature Distribution with Royal Heater with Auxiliary Fan
Outdoor Temperature - 13.2°F 2 Supply Grilles

Height Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	58.8	68.2	61.8	64.5	65.4	63.7	9.4
30	68.6	75.7	69.4	71.3	72.1	71.4	7.1
60	74.3	82.5	72.6	72.6	73.1	75.0	9.9
78	79.5	96.1	73.9	73.4	73.6	79.3	22.7
94	86.8	112.6	75.2	73.9	74.1	84.5	38.7
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	3.5	3.3	1.5	4.7	3.8	3.4	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	15.5	14.3	10.8	8.1	7.7	11.3	
2-94	28.0	44.4	13.4	9.4	8.7	20.8	

Average Basement Temperature	38.6°F
Average Attic Temperature	15.2°F
Average Ceiling Surface Temperature	77.6°F
Average Floor Surface Temperature	59.6°F

TABLE 4

Temperature Distribution with Royal Heater, Gravity Flow
Outdoor Temperature - 13.4°F 3 Supply Grilles

Height Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	65.9	67.9	65.0	58.8	61.5	63.8	9.1
30	69.7	72.6	68.3	66.1	67.3	68.8	6.5
60	78.9	80.7	76.4	73.1	74.1	76.6	7.6
78	95.2	101.7	86.1	78.3	79.4	88.1	23.4
94	105.2	114.6	92.6	86.0	85.6	96.8	29.0
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHON ROOMS							
30	4.9	5.2	3.3	5.8	3.0	4.4	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	13.0	12.8	11.4	14.3	12.6	12.8	
2-94	39.3	46.7	27.6	27.2	24.1	33.0	

Average Basement Temperature	62.8°F
Average Attic Temperature	25.5°F
Average Ceiling Surface Temperature	88.1°F
Average Floor Surface Temperature	66.0°F

TABLE 5

Temperature Distribution with Royal Heater, Gravity Flow

Outdoor Temperature - 4.9°F 3 Supply Grilles

Weight Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	65.1	68.6	63.6	58.3	60.7	63.3	10.3
30	70.6	73.5	68.9	67.0	68.8	69.8	6.5
60	81.0	83.4	78.3	75.3	76.2	78.8	8.1
78	99.0	106.2	89.0	81.3	81.5	90.2	24.9
94	112.1	119.7	95.9	89.3	88.2	101.0	31.5
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	3.8	4.2	2.1	3.8	5.0	3.8	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	15.9	14.8	14.7	17.0	15.5	15.5	
2-94	47.0	51.1	32.3	31.0	27.5	37.7	

Average Basement Temperature	40.1°F
Average Attic Temperature	24.1°F
Average Ceiling Surface Temperature	89.9°F
Average Floor Surface Temperature	64.0°F

TABLE 6

Temperature Distribution with Royal Heater, Forced Flow

Outdoor Temperature - 4.5°F 3 Supply Grilles

Height Above Floor	Average Room Temperature: Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room	Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
Inches	°F	°F	°F	°F	°F	°F	°F
2	67.1	71.2	67.0	61.3	63.5	66.0	9.9
30	74.0	76.9	73.2	71.3	72.5	73.6	5.6
60	87.8	89.8	85.6	81.4	81.8	85.3	8.4
78	100.9	109.8	95.0	86.8	87.3	96.0	23.0
94	105.9	119.4	98.9	91.8	93.5	101.9	27.6
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOM							
30	3.3	4.9	1.5	3.2	4.9	3.6	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	20.7	18.6	18.6	20.1	18.3	19.3	
2-94	38.8	48.2	31.9	30.5	30.0	35.9	

Average Basement Temperature	38.3°F
Average Attic Temperature	27.4°F
Average Ceiling Surface Temperature	93.1°F
Average Floor Surface Temperature	66.9°F

TABLE 7

Temperature Distribution with Royal Heater, Forced Flow
Outdoor Temperature - 5.0°F   2 Supply Grilles

Height Above Floor	Average Room Temperature: Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room	Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
Inches	°F	°F	°F	°F	°F	°F	°F
2	66.0	72.2	67.5	62.3	65.0	66.6	9.9
30	73.2	78.2	74.1	72.3	73.4	74.2	5.9
60	87.7	92.0	86.7	82.3	82.7	86.3	9.7
78	97.4	114.7	95.7	87.6	88.8	96.8	27.1
94	102.7	124.3	101.4	92.5	97.4	103.7	31.8
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	0.6	4.9	2.0	3.8	2.0	2.7	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	21.7	19.8	19.2	20.0	17.7	19.7	
2-94	36.7	52.1	33.9	30.2	32.4	37.1	

Average Basement Temperature 38.0°F
Average Attic Temperature 27.1°F
Average Ceiling Surface Temperature 92.6°F
Average Floor Surface Temperature 66.7°F

TABLE 8

Temperature Distribution with Royal Heater, Gravity Flow
Outdoor Temperature 15.7°F 2 Supply Grilles

Height Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	61.9	66.5	62.4	59.1	60.9	62.2	7.4
30	66.4	69.9	66.1	64.9	66.3	66.7	5.0
60	73.3	76.3	72.2	69.9	70.9	72.5	6.4
78	81.5	93.3	78.9	73.3	74.1	80.2	20.0
94	90.4	103.1	83.6	78.5	78.6	86.8	24.6
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	3.5	3.4	1.6	3.1	3.2	3.0	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	11.4	9.8	9.8	10.8	10.0	10.3	
2-94	28.5	36.6	21.2	19.4	17.7	24.6	

Average Basement Temperature	43.9°F
Average Attic Temperature	37.2°F
Average Ceiling Surface Temperature	79.2°F
Average Floor Surface Temperature	62.6°F

TABLE 9

Temperature Distribution with Royal Heater, Gravity Flow
Outdoor Temperature - 31.3°F 2 Supply Grilles

Height Above Floor	Average Room Temperature					Average of 5 Rooms	Maximum Horizontal Temperature Difference Between Rooms
	Kitchen	Living Room	Bath Room	North Bed Room	South Bed Room		
Inches	°F	°F	°F	°F	°F	°F	°F
2	64.1	67.5	64.1	61.5	62.8	64.0	6.0
30	67.1	70.0	67.0	66.1	67.3	67.5	3.9
60	72.3	74.8	71.4	69.6	70.6	71.7	5.2
78	78.0	86.7	76.0	71.8	72.4	77.0	14.9
94	85.0	94.8	79.3	75.7	75.3	82.0	19.5
MAXIMUM HORIZONTAL TEMPERATURE VARIATION WITHIN ROOMS							
30	2.0	2.6	1.2	2.3	2.3	2.1	
VERTICAL TEMPERATURE DIFFERENCE, ROOM AVERAGE							
2-60	8.2	7.3	7.3	8.1	7.8	7.7	
2-94	20.9	27.3	15.2	14.2	12.5	18.0	

Average Basement Temperature	47.6°F
Average Attic Temperature	45.2°F
Average Ceiling Surface Temperature	76.3°F
Average Floor Surface Temperature	62.6°F

Test No
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Air Temp.a

(a) An aux
(b) Based

TABLE 10

SUMMARY OF RESULTS

PERFORMANCE OF ROYAL JET HEATERS
MODELS FG-3-45, FF-3-45

Test No		1	2	3a	4	5	6	7	8	9
Method of Air Circulation		Gravity	Booster	Gravity	Gravity	Gravity	Booster	Booster	Gravity	Gravity
Number of Warm Air Outlets		2	2	2	3	3	3	2	2	2
Outside Temperature	°F	-15.2	-14.6	-13.2	-13.4	-4.9	-4.5	-5.0	15.7	31.3
Observed Gas Consumption	Cu Ft/hr	47.52	46.54	45.29	42.78	45.43	46.02	45.14	29.53	20.58
Correction Factor		1.00	0.99	0.98	0.97	0.98	0.97	0.97	0.98	0.98
Corrected Gas Consumption	Cu Ft/hr	47.52	46.07	44.38	41.50	44.52	44.64	43.79	28.94	20.17
Heating Value	Btu/cu ft	1,047	1,047	1,045	1,051	1,047	1,047	1,047	1,026	1,022
Heat Input to Furnace	Btu/hr	49,800	48,240	46,380	43,620	46,610	46,740	45,850	29,690	20,610
CO_2 in Flue Gases	%	6.5	6.7	6.5	6.5	6.5	6.7	6.7	6.5	6.5
Stack Temperature	°F	765	726	765	765	765	726	726	765	765
Indirect Efficiency	%	66	68	66	66	66	68	68	66	66
Heat Output of Furnace	Btu/hr	32,870	32,800	30,590	28,790	30,760	31,780	31,180	19,600	13,600
Electrical Heat Input	Btu/hr	1,990	1,640	2,350	1,540	1,780	1,890	1,750	2,740	2,670
Observed Heat Loss of House	Btu/hr	34,860	34,440	32,940	30,330	32,540	32,670	32,930	22,340	16,270
Ceiling Heat Loss	Btu/hr	1,640	1,640	1,400	1,600	1,710	1,670	1,770	1,120	830
Computed Heat Loss of House (b)	Btu/hr	34,900	35,880	37,420	36,360	33,050	34,550	35,020	22,570	16,010
Power Consumption of Blower	Watts	-	25	-	-	-	25	25	-	-
Average Temp. 30 in.Level	°F	63.7	66.5	71.4	68.8	69.8	73.6	74.2	66.7	67.5
Basement Air Temperature	°F	37.5	35.9	38.6	62.8	40.1	38.3	38.0	43.9	47.6
Attic Air Temperature	°F	16.8	19.6	15.7	25.5	24.1	27.4	27.1	36.5	45.2
Ceiling Surface Temp.	°F	84.5	85.5	77.6	88.1	89.9	93.1	92.6	79.2	76.3
Avg.Cold Wall Temp.30 to 60 in. above floor	°F	56.7	60.2	61.0	61.7	65.5	70.0	69.4	62.9	64.2
Floor Surface Temp.	°F	54.4	59.6	59.6	66.0	64.0	66.9	66.7	62.6	64.2
Air Temp.at Return Grilles	°F	62.0	64.2	78.9	69.3	67.4	69.3	70.7	68.8	66.8
Air Temp.at Supply Grilles	°F	191.5	173.0	190.7	192.7	201.3	176.0	181.3	187.9	151.5

(a) An auxiliary fan was mounted near the heater to direct warm air toward the bedroom doors.
(b) Based on the average indoor-outdoor temperature difference at the 30-inch level.

TABLE 11

Summary of Sound Level Measurements in Test Bungalow With Royal Jet Heater

Room	Height of Microphone Above Floor Inches	Weighting Net Work	Sound Level, Decibels			
			Back-ground	Burner on	Burner & Fan on	Pilot Only
Kitchen	60	flat	50	64	63	53
		70	34	51	50	39
		40	24-	36	42	24-
Kirchen	24	flat	50	56	56	53
		70	34	42	46	39
		40	24-	36	42	24-
Living Room	60	flat	46	50	52	-
		70	31	43	47	-
		40	24-	39	43	-
Living Room	24	flat	48	50	51	-
		70	31	44	47	-
		40	24-	40	43	-
South Bedroom	60	flat	50	53	55	-
		70	37	41	43	-
		40	24-	34	39	-
South Bedroom	24	flat	50	52	54	-
		70	37	42	44	-
		40	24-	35	38	-

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