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J. H. LONGWELL, *Director*

SOME TESTS OF JACKETED SPACE HEATERS FOR HEATING SMALL FARM DWELLINGS

Carl A. Reaves and R. E. Stewart

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COLUMBIA, MISSOURI

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SOME TESTS OF JACKETED SPACE HEATERS[1]

FOR HEATING SMALL FARM DWELLINGS

CARL A. REAVES[2] AND R. E. STEWART

THE PROBLEM

Inquiries pertaining to heating problems have directed attention to the need for information on satisfactory and economical methods of heating farm dwellings. Many of these dwellings are old and were constructed without much attention to their heating characteristics. Looseness of construction, inadequate insulation and faulty arrangement of interior walls and openings prevent good heat distribution.

Heretofore these houses have been partially and uneconomically heated by a space heater in each room where heat was required. Ceilings are usually more than 8 feet above the floor, and are rarely insulated. Interior doorways comprise the only openings between rooms. Heat transfer by gravity circulation is dependent upon temperature differences, and this necessitates the accumulation of a bank of high temperature air from 3 to 5 feet down from the ceiling before outlying rooms can be heated by gravity circulation. Considerable heat is lost into the unheated attic in attempting to heat air in the living zone satisfactorily. This point is illustrated by the fact that ice and snow on roofs of these uninsulated houses melt even though the outdoor temperature is below freezing. Windows fit very loosely, permitting excessive infiltration of air. Insulated exterior walls are uncommon.

It is apparent that the heating loads and obstructions to heat distribution must be reduced before these houses can be heated satisfactorily with a single space heater. There are approximately 250,000 farm dwellings in Missouri, and it is assumed that from 85 to 90% of these are equipped with space heaters. The types most commonly used are wood stoves, coal stoves, oil heaters and fireplaces, with extensive use of gas heaters in recent years.

The advent of electricity on the farm has increased the heating prob-

[1]The term space heater applies to any heating system that heats the environment directly by radiation, and by convection currents. There are two distinct types with respect to their heat distribution characteristics. The radiant type consists essentially of a fire-pot, and it heats the environment mainly by radiation. The circulator is essentially a jacketed radiant heater, and it heats by convection currents.

[2]This bulletin is largely an abstract from a thesis submitted by Mr. Reaves to the graduate faculty of the University of Missouri in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Engineering.

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lem. The number of electrified farms in Missouri increased from 55% in 1945 to approximately 80% in 1950. This provides economical power for an automatic pressure water system, and a bathroom is usually built after a water system is installed. This creates another heating problem because it is desirable to maintain bathroom temperatures at a higher level than is possible with central space heaters and gravity circulation. Often the space available for the bathroom is at some distance from the heat source.

Coal and wood cook stoves serve a two-fold purpose by furnishing radiant heat while in use. On many electrified farms these stoves are replaced with an electric range which radiates very little heat. This necessitates a heater in the kitchen or some method of transferring heat from the room in which the heat source is located.

INDICES OF COMFORT

Dry-bulb temperature, relative humidity, air-movement and radiation all affect comfort. Each of these comfort factors has been studied and can be approximated, but a method of measuring a particular environment where all four are considered is yet to be devised. The American Society of Heating, Ventilating and Air Conditioning Engineers (2)* use the "effective temperature" (E.T.) index, which is defined as an "empirically determined index of the degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement". It is believed that under ordinary room conditions with still air, the dry-bulb temperature in itself is a better index of warmth than is E.T. or any other composite index (11). Where radiation sources are present, and air and wall temperatures differ significantly, the operative temperature is considered a better index.

Operative Temperature, as developed by Winslow, Herrington and Gagge (4), combines air temperature, reflected radiation, and air movement into a single value. It has the practical disadvantage that mean skin temperature of the human subject must be known in order to estimate operative temperature.

Mean skin temperature is a comfort index in the absence of perspiration. Various workers (5, 6) have shown that below the zone of evaporative cooling there is a relationship between comfort and mean skin temperature.

To sum up, no physical integrating instrument exists which is capable of combining the four environmental factors into a single value. Measurement of these factors can be made most satisfactorily by separate recordings.

LITERATURE

Thulman and Seely (10) reported that 35% of all urban homes and 63% of all rural homes in the nation in 1940 were heated by space heaters of one kind or another (wood, coal, oil, or gas). The advantages of space heaters are: (1) Low first cost; (2) high efficiency; (3) ease of installation; (4) low fuel consumption; (5) provision of a comfort zone by radiation near the heat source. The greatest disadvantages are: (1) They take up

*Numbered references are listed in back of this bulletin.

usable space in the living quarters; (2) they usually do not maintain temperatures satisfactorily uniform throughout the house.

Thulman and Seely (10) suggest that the operating cost will equal the first cost several times during the life of a heating system. Hence the operating cost is of greater importance. Consequently these investigators, in their paper, recommend allowable budget amounts for heat and 30 gallons of hot water per day for various annual incomes. The allowances are based on degree-days.*

The Heating, Ventilating and Air Conditioning Guide (3) gives the yearly total degree-days for major cities in Missouri.

Achenbach (1) conducted a study of temperatures in a test bungalow with some radiant and jacketed space heaters during 1949. Some of his conclusions were:

1. Space heaters are a satisfactory method of heating small homes in a mild climate.

2. The maximum temperature differences within the living zone† vary almost directly with the heat output.

3. The radius of the comfort zone varies directly with the outdoor temperature.

4. The heater should be located as nearly as possible in the center of the house, and it should have an equal chance of heating each room by radiation and natural convection currents.

5. Regardless of heater location, the jacketed heaters produced less horizontal temperature difference than did the radiant heaters.

6. Regardless of heater location, the radiant heaters produced less temperature difference in the living room zone than did the jacketed heaters.

7. The use of open transoms over interior doorways increased the heat delivered to colder rooms.

8. Use of a fan to blow the warmed air toward colder rooms increased temperatures in the living zone and decreased the horizontal temperature differences. It was found that the fan should be placed as near as practical to warm air as it rises from the heater, and its direction of discharge should be toward the colder parts of the house.

Simmons and Lanham (8) used oil-fired circulating heaters in a study of factors that affect temperatures in southern farm homes. Tests were conducted in two three-room and six one-room experimental houses. Among conclusions drawn were:

1. With a lapped weather-boarding exterior and beaded ceiling lumber interior on relatively new wood-frame construction, fuel consumption was reduced 30% by minimizing air infiltration through walls and around windows and doors.

2. An increase in wind velocity from 3.0 to 9.7 miles per hour caused an increase in fuel consumption of 56%, with wood-frame construction

*For any one day, when the mean temperature is less than 65° F., there exists as many degree-days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65° F.

†The term living zone as used in this report refers to the area from 2 to 60 inches above the floor.

three years old. This structure was made of lapped weather-boarding without paper or sheathing on the exterior and with beaded ceiling lumber on the interior.

3. At low wind velocities differences in fuel consumption as great as 38% can be expected in two houses of identical design and materials (same building material as in conclusion 1), due to differences in age of building, unequal tightness of construction, and other variables.

4. At low wind velocities fuel consumption was reduced approximately 25% when construction similar to that in conclusion 1 was insulated, walls and ceiling, with 3⅝ inches of cottonseed hulls.

5. In the one-room metal house, fuel consumption was reduced approximately 50% (with wind velocities from three to nine miles per hour) by use of cottonseed hulls for ceiling and wall insulation.

6. Reductions in fuel consumption of as much as 47.8% were produced in wind velocities up to 9.7 miles per hour by installing wind barriers in walls, around windows and doors, and curtain walls between foundation piers.

7. With the same fuel consumption, temperatures in these low-cost houses were made equivalent to those in relatively high-cost houses by use of inexpensive wind barriers in the walls and ceiling, tight foundations and cottonseed hulls for insulation in walls and ceiling.

8. Vertical temperature differences within test houses varied directly with fuel consumption.

9. Concrete-slab floors laid on a gravel fill will maintain higher and more uniform temperatures than wood floors on piers.

La Rock and Dodge (7) conducted a study of temperatures and related conditions in Wisconsin farmhouses. Among their conclusions were:

1. The average dry-bulb temperatures and effective temperatures maintained in all of these houses at the 60 inch level from 8 a. m. to 10 p. m. were higher than is usually considered comfortable. The average dry-bulb temperatures in the regularly heated rooms fell for the most part within the range of 75° to 80° F. with respective effective temperatures from 69° to 75° under all outside weather conditions.

2. In very cold weather conditions relative humidities fell below the desirable of from 30 to 50%, either with or without special humidifying devices. Observations indicated that outside temperatures had more effect on the relative humidity within a house than did any other factor and that retarding the flow of vapor to the outside would be a more effective means of maintaining higher humidities than attempts to introduce moisture into the air.

3. The most obvious source of discomfort in unimproved houses with a high rate of heat loss appeared to be due to large differences in the air temperature between floor and ceiling.

4. In the old houses the temperature of the air close to the floor rather than the rate of air movement was probably the principal cause of discomfort to the occupants.

Stewart (9) used an oil-fired jacketed heater in a study of the most effective method of use in heating a small one-story farm home. Some of his conclusions were:

1. Neither an under-floor* nor an above-ceiling duct system (when used individually) aided heat distribution over that of the heater without ducts.

2. A 40 or 50% decrease in vertical temperature differences occurred when the under-floor and above-ceiling duct system were used simultaneously and without forced circulation.

3. Operation of a blower installed in above-ceiling duct, with both duct systems open, decreased the vertical temperature difference beyond 50% but this improvement occurred near the ceiling (above the living zone).

PLAN FOR STUDY OF THE PROBLEM

Work was undertaken to determine the effectiveness and also the limitations of oil-fired circulating heaters in supplying and distributing winter heat in small homes; also, to determine the effectiveness of additional means for distributing the heat throughout the house.

An ideal heating system would maintain zero temperature differences throughout the house from floor to ceiling. Since an ideal system is never realized in practice, a record of temperature variation within the house can be used as a performance index for any particular system. Therefore, three houses were selected for study, and tests were designed to decrease high temperature differences (characteristic of space heaters) by providing more positive air circulation.

INSTRUMENTS

1. **Dry-bulb Temperature.** During the 1949-50 heating season dry-bulb temperatures were recorded intermittently with an electronic potentiometer (Figure 1). This instrument recorded dry-bulb temperatures on a strip chart at 16 remote locations. Sensing elements and lead wire used in this study were made of 20-gauge copper-constantan wire. Fifteen thermocouples were located throughout each test house at 3 and 30 inches above the floor and at 3 inches below the ceiling. The points three inches above the floor and 3 inches below the ceiling were selected to aid in determining a performance index for the system under test. Thirty inches above the floor was selected because this is approximately chest high for a person in sitting position, and the upper portion of a human body is perhaps more sensitive to environmental conditions. The 16th thermocouple was used to record outdoor temperatures.

It was realized that temperature measurements at 15 locations in the house were too few; therefore, during the 1950-51 heating season, two potentiometers were used in House No. 2. Dry-bulb temperatures were recorded at 31 locations throughout the house at 3, 30, 60, and 72 inches above the floor and at 3 inches below the ceiling.

2. **Thermocouple Shields.** Effects of radiation on thermocouples were

*Under-floor ducts refer to cold-air return passages radiating out to the house exterior walls from a central chamber. Heater is located on a grille over the central chamber.

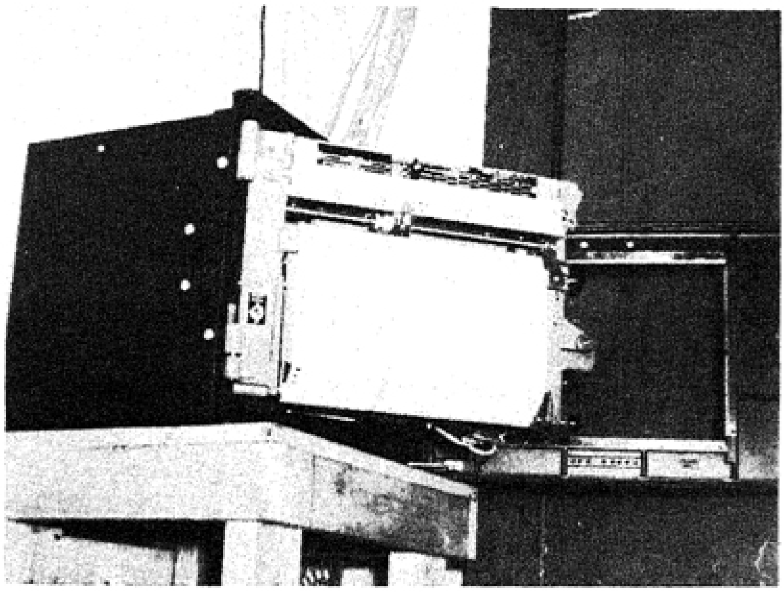

Figure 1. A view of the Electronic Potentiometer used in this study to record dry-bulb temperatures.

reduced by shields that were made of two concentric short lengths of conduit pipe (Figure 2).

Shields used on thermocouples located inside the house were 2 inches long with diameters of inner and outer tubes of ½ and 1 inch, respectively. Relative position of these tubes was fixed by set screws threaded through the outer tube and jammed against the inner one. All shields received two coats of aluminum paint.

The outdoor thermocouple shield was identical to those for the interior except in diameter and length. It was made 4 inches long with diameters of the inner and outer tubes of ¾ and 1½ inches, respectively.

3. Relative Humidity. Clock-faced type hygrothermographs were used to obtain continuous records of relative humidity within the house. Mechanically-wound seven-day clocks drove circular charts that were graduated to read percentage relative humidity and Fahrenheit dry-bulb temperature directly. The humidity sensing element was of the human-hair type. The dry-bulb temperature element was of the coiled-spring type. Humidity elements were calibrated every 48 hours with a hand-aspirated psychrometer.

4. Air Movement. An indicating velometer of the air-actuated pointer-vane type was used to measure interior air velocities in all tests. This instrument indicated instantaneous velocity reading in feet per minute. The scale ranged from 0 to 500 feet per minute. Readings were taken by holding the velometer directly in the air stream.

5. Fuel Measurement. Fuel consumption of oil-fired circulating heaters is low. When the flow is automatically controlled, it is extremely variable. An instrument that will record fuel flow continuously with accuracy under these circumstances is not commonly available.

An instrument was devised to record the movement of a heater fuel valve, but proved to be generally unsatisfactory.

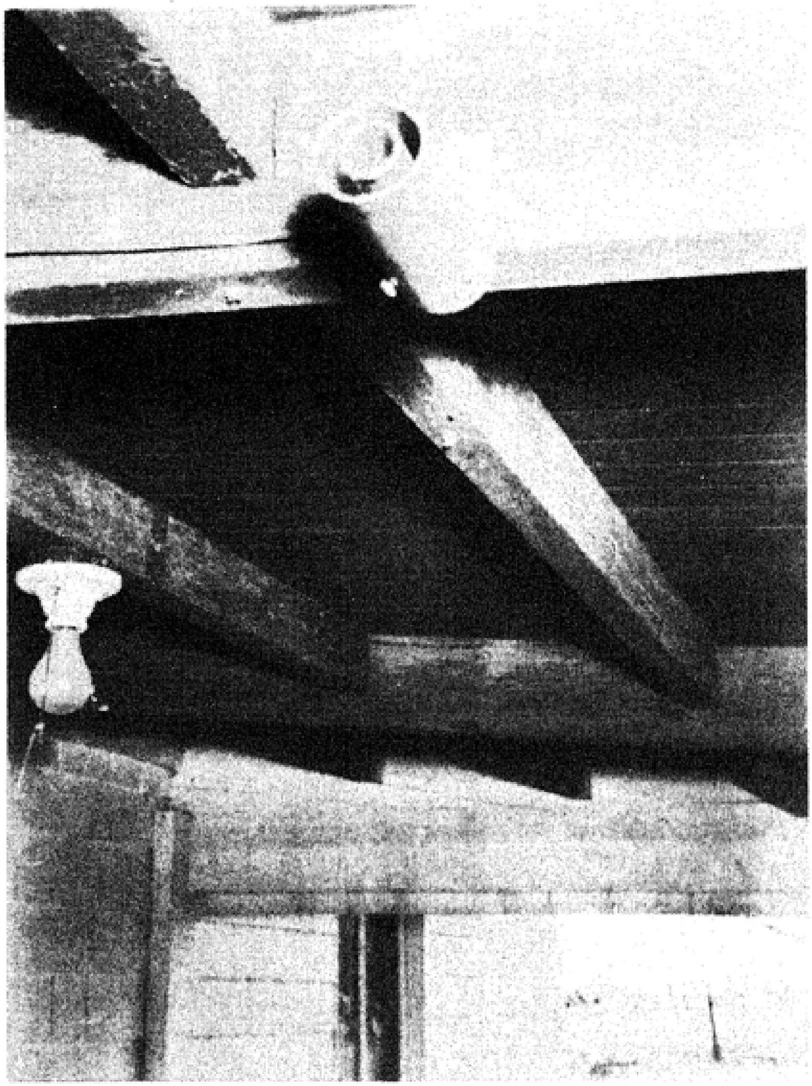

Figure 2. Radiation shield for the outdoor dry-bulb temperature thermocouple.

A more accurate measuring system was used during the 1950-51 heating season. A standard water-level recorder such as those employed in hydrological research was used in conjunction with a cylindrical fuel tank that was approximately 7 inches in diameter (Figure 3). The 11-gallon fuel tank was filled once each day. One gallon of fuel was represented by 2.44 inches of chart, and the chart could be read to 0.01 of an inch. The rate of chart travel was 1 inch per hour. This gave a very satisfactory record of fuel measurement, and the rate or the total consumption could be determined for any desired period of time.

6. Temperature Control. A thermostat located in the same room as the heat source controlled heat output automatically. It remained set at 78° F. throughout all tests in each house, and was regulated to maintain temperatures within plus or minus two degrees of the setting.

Fuel flow was controlled by a commercially-available automatic device fastened to the fuel carburetor. This device consisted of a fine wire coil on one side of a metal strip that was fixed at one end. The other end rested

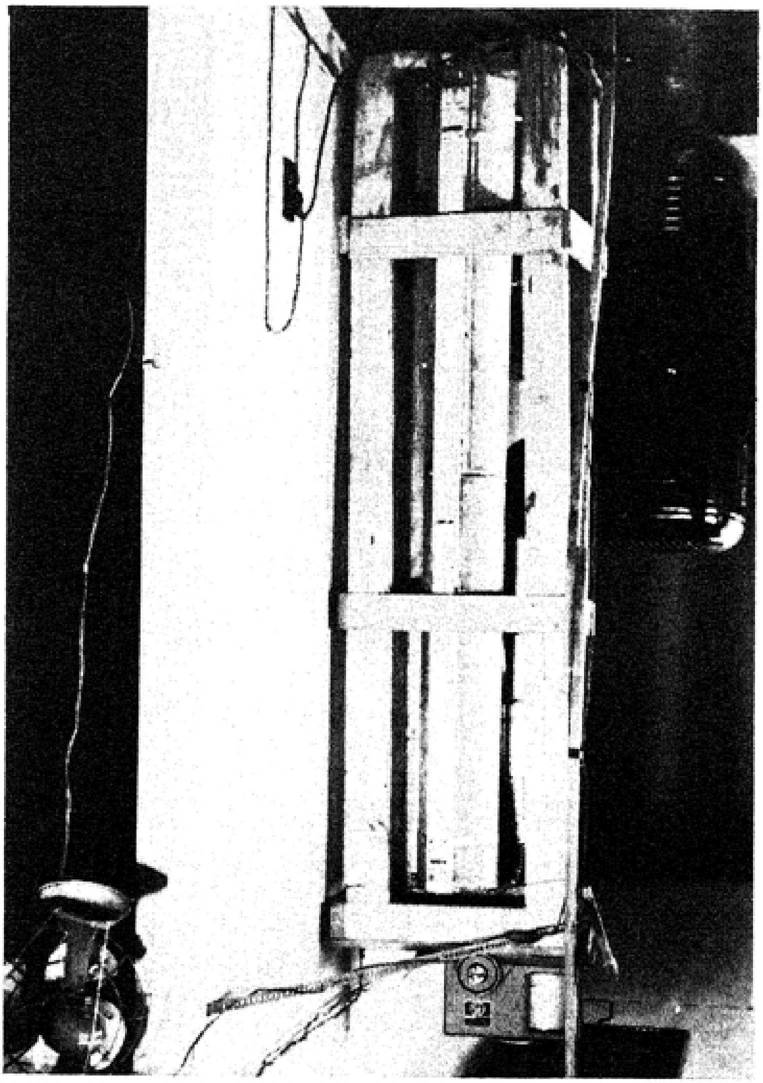

Figure 3. Fuel-rate measuring system as used in House No. 2 (1950-51). The oil-fired circulating heater is shown in background, and the 10-inch ventilation fan that circulated air into the south bedroom can be seen in the upper right hand corner.

on the fuel valve. This wire coil was connected in series with the thermostat and a source of electricity. When the thermostat closed (called for heat) the circuit was completed. Flow of electricity heated the wire coil to a high temperature. Heat was conducted to one side of the metal strip and caused that side to expand at a faster rate than the other. The loose end of this metal strip curved upward to release the spring loaded valve and permit fuel flow to the burners. When the thermostat opened (breaking the circuit) the strip cooled and straightened, closing the fuel valve to pilot flow.

DESCRIPTION OF TEST HOUSES AND TESTS

House No. 1. Test house No. 1 was built in 1940. It was a conventional type one-story basementless bungalow. Figures 4 and 5 are a photograph and floor plan, respectively.

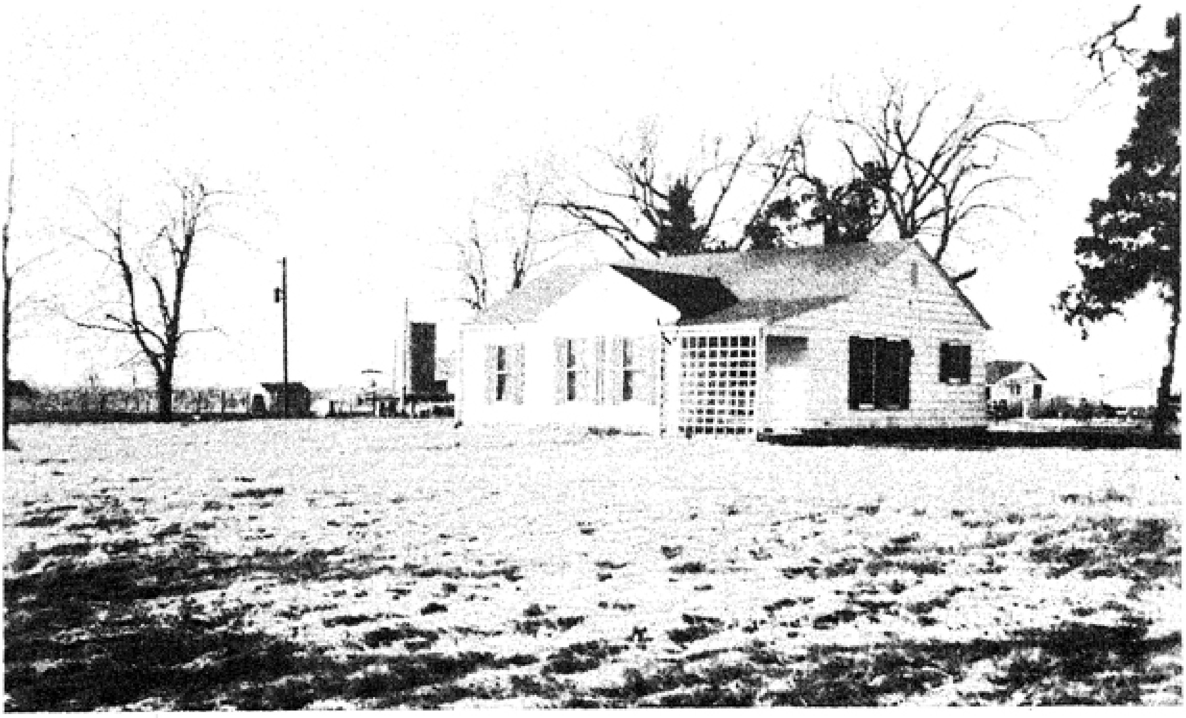

Figure 4. Test House No. 1 as seen from the southeast corner.

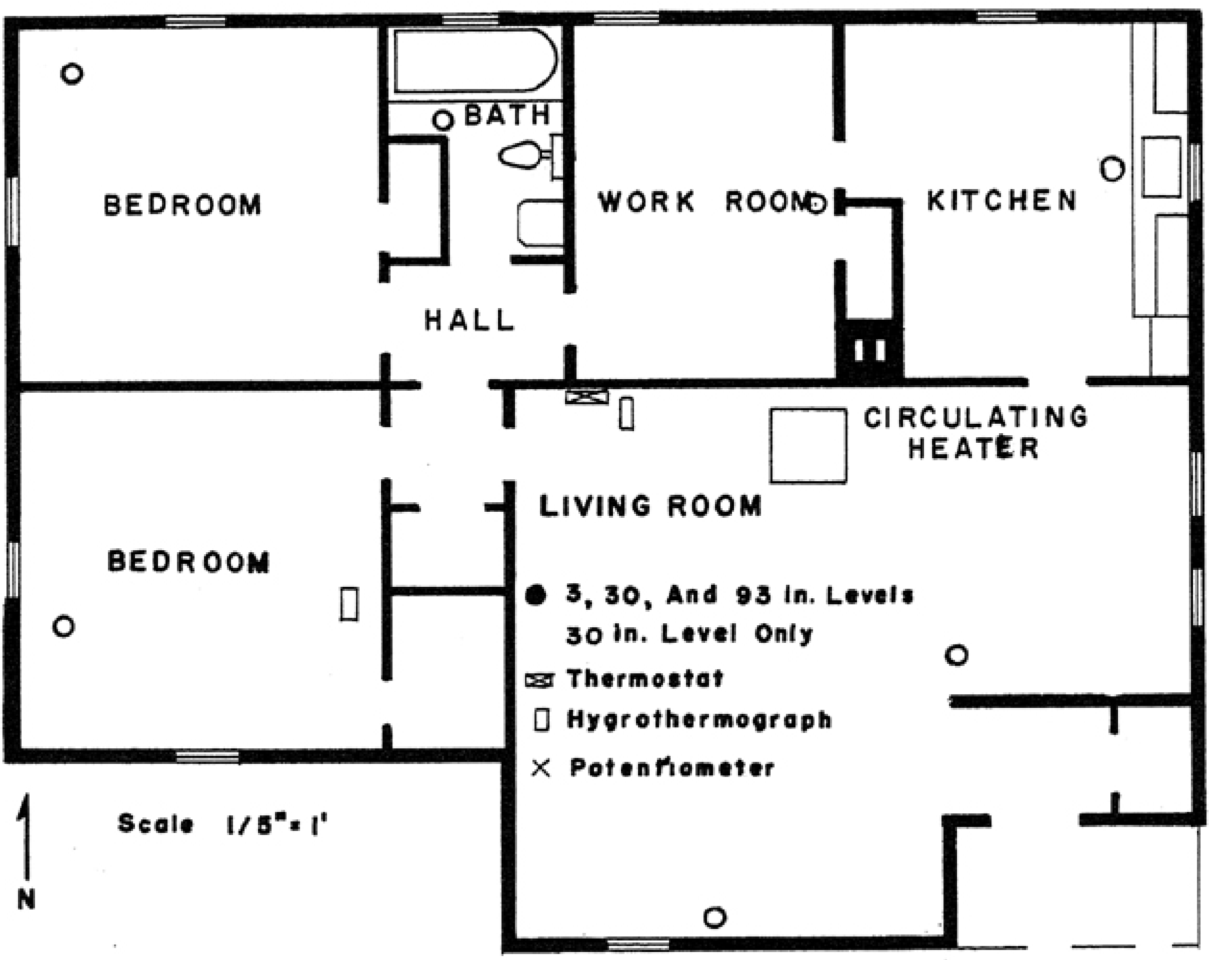

Figure 5. Floor plan of House No. 1 showing location of heater, thermocouples, and hygrothermographs.

a. Construction Details:

Floor—Concrete slab laid on a gravel fill.
Ceiling—One-half inch insulation board.
Exterior Walls—1-inch drop siding and building paper on the outside; ½ inch insulation on the inside; 2 x 4 inch studding.
Roof—American 3-tab asphalt shingles on 1-inch solid sheathing.
Insulation—Blanket-type rock wool placed between both exterior wall studs and ceiling joists.
Windows—Wood, double hung and weatherstripped. No storm sash.
Exterior Doors—Weatherstripped; glass paneled; no storm doors.
Floor Ducts—Under-floor concrete cold-air returns leading to a central chamber. Heater located over central chamber. When floor ducts were used the heater jacket was enclosed down to floor level thus forcing cold air to return through the ducts rather than over the floor.
Ceiling Height—8 feet.
Louvers—6 x 12 inch louvers above the west living room door, south bedroom door, north bedroom door, hall door, bathroom door, and utility room door.
Floor Area—1,031 square feet, including that under the walls.

b. Habits of the Occupants. This house was occupied by a family of two that were away during most of the tests. Both of the occupants were away from home during the day and exterior doors were used very little. An electric range was used for cooking. A small coal stove located in the utility room was used for heating water, and it was usually fired once in the morning and once in the evening.

c. Specifications of Circulator used in House No. 1. The manufacturer's specifications of this oil-fired circulating heater are as follows:

Burner pot size	10 inches
Fuel tank capacity	2 gallons
Minimum fuel flow	2.25 gallons per 24 hrs.
Maximum fuel flow	14.00 gallons per 24 hrs.
Approximate maximum heat output	49,000 Btu per hour.

d. Test Description:

Test A—Basic circulator.
Test B—Circulator with transoms above interior doors open.
Test C—Circulator with transoms above interior doors open and with a 10-inch fan located on the floor behind the heater.
Test D—Circulator with transoms above interior doors open, with floor ducts open.
Test E—Circulator with transoms above interior doors open, with floor ducts open, and with a 500 cfm. centrifugal fan located in the central floor duct chamber.

House No. 2. House No. 2 was built in 1946. It is an experimental round-roof, one-story and basementless bungalow. Figures 6 and 7 are a photograph and floor plan, respectively. This is the only house in which tests were conducted during the 1950-51 heating season.

a. Construction Details:

Floor—Concrete slab laid on a gravel fill.
Ceiling—One-half inch insulation board.
Exterior Walls and Roof—Exterior—Wood shingles on spaced sheathing on both vertical ends. Wood shingles on both sides from the foundation up to the window sills and American 3-tab asphalt shingles from there to

Figure 6. Test House No. 2 as seen from the northeast corner.

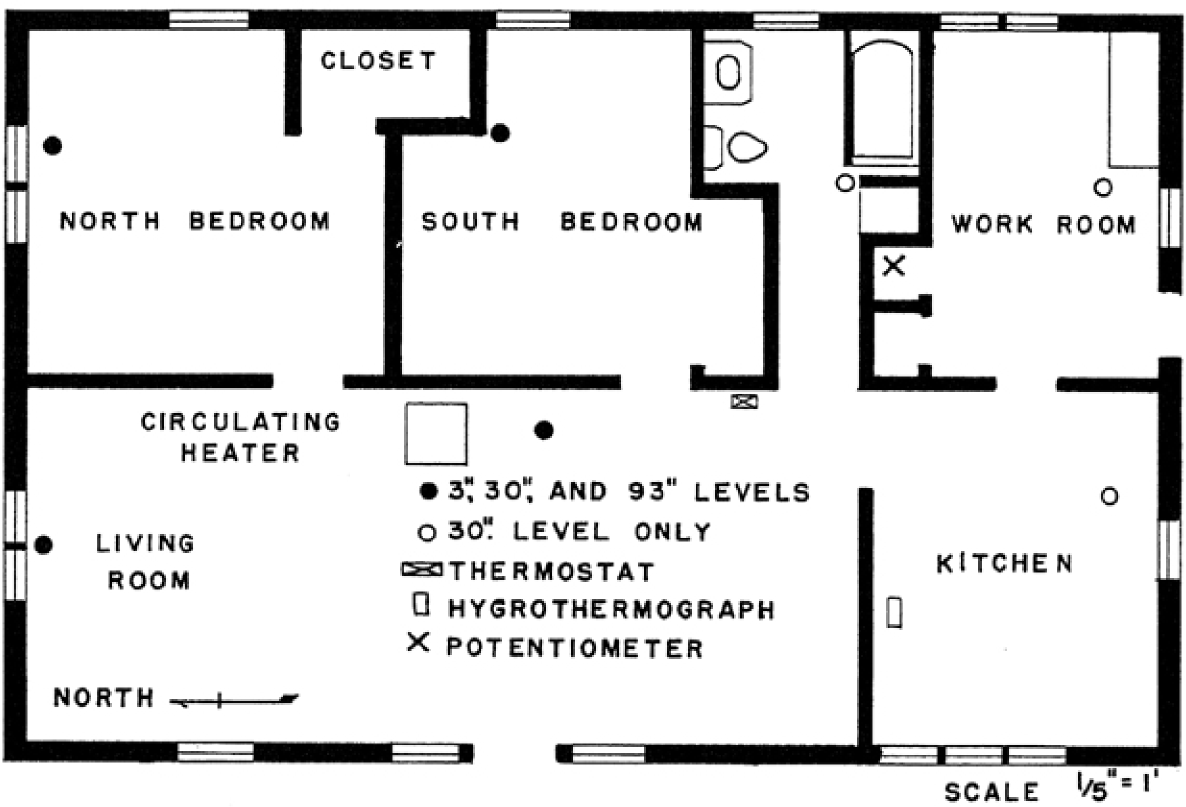

Figure 7. Floor plan of House No. 2 showing location of heater, thermocouples, and hygrothermographs.

the ridge. Interior—Plywood from floor to ceiling, and one-half inch insulation board on the ceiling. Laminated rafters (5¾ x 1.5 inch boards per rafter).

Insulation—Blanket type rock wool (2 inches thick) was placed between rafters from floor to ceiling and between the ceiling joists. Foam glass was placed between the floor and foundation walls.

Windows—Recessed in dormers; double hung; weather stripped; and no storm sash.

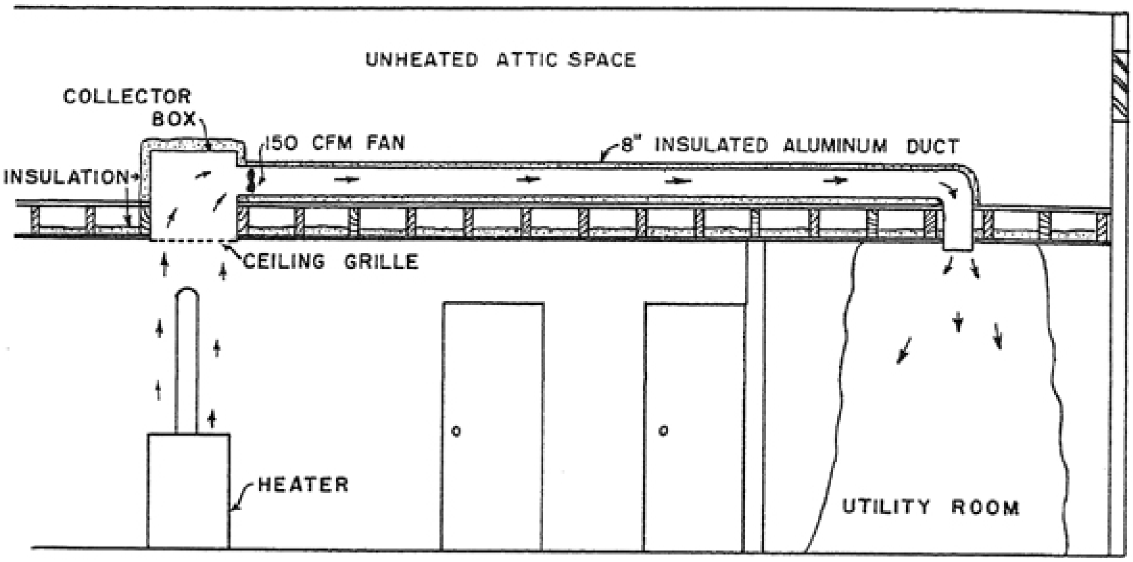

Figure 8. Diagrammatic sketch of overhead warm-air duct used in House No. 2 during both test seasons.

Exterior Doors—Recessed in dormers; weather stripped; glass paneled; no storm door.

Floor Ducts—Under floor concrete ducts leading to a central chamber.

Ceiling Duct—Eight inches round, insulated aluminum duct extending from hot-air collector box over heater through attic to utility room. A 150 cubic feet per minute fan was mounted in the duct. See Figure 8.

Ceiling Height—8 feet.

Floor Area—1,030 square feet, including that under the walls.

b. Habits of the Occupants. This house was occupied during the 1949-50 heating season by a family of two. An electric range was used for cooking, and considerable moisture was added to the air during preparation of meals. Water stood in under-floor ducts during rainy periods, and this perhaps affected relative humidities in tests where the ducts were used. Water was evaporated from a humidifier integral with the circulator. The north bedroom door was closed during periods that the occupants were asleep. During the 1950-51 heating season this house was unoccupied.

c. Specifications of Circulator. The manufacturer's specifications of the oil-fired circulating heater are as follows:

Fuel tank capacity	5 gallons
Minimum fuel flow	2 gallons per 24 hrs.
Maximum fuel flow	13.2 gallons per 24 hrs.
Approximate maximum heat output	55,000 Btu per hr.

This heating unit had a pot-type burner interconnected with a cylindrical hot-tube radiating jacket. A centrifugal fan pulled air down through this jacket (against gravity) and discharged it near the floor in front of the heater.

d. Test Description: (1949-50 heating season)

Test A—Basic circulator.
Test B—Circulator with integrally mounted fan.
Test C—Circulator with wall fan to bathroom.
Test D—Circulator with duct to utility room (gravity flow).
Test E—Circulator with duct and 150 cfm. fan to utility room.

e. Test Description: (1950-51 heating season)

Test A—Basic circulator.

Test B—Circulator with duct and 150 cfm. fan to utility room.

Test C—Circulator with integrally mounted fan.

Test D—Circulator with duct and 150 cfm. fan to utility room, with integrally mounted fan.

Test E—Circulator with floor ducts open.

Test F—Circulator with floor ducts open, with a 16-inch desk-type ventilating fan on low speed and located on the floor on the north side of the heater. Air discharge was up and across the heater jacket.

Test G—Circulator with north radiation door open, with 16-inch desk-type ventilating fan on low speed and located on the floor on the north side of the heater. Air discharge was up and across the heater firepot.

Test H—Circulator with integrally mounted fan, with duct and 150 cfm. fan to utility room, with 16-inch desk-type ventilating fan oscillating on low speed located 38 inches high and 9 feet out in front of the heater.

Test I—Circulator with integrally mounted fan, with duct and 150 cfm. fan to utility room, with a 150 cfm. wall fan located above the bathroom door, with a 10-inch desk-type ventilating fan located at the top of the door opening into each of the two bedrooms.

Test J—Circulator with floor ducts open with a 10-inch desk-type ventilating fan on low speed and located on the floor on the north side of the heater. Air discharge was up and across the heater jacket.

Test K—Circulator with integrally mounted fan, with floor ducts open.

House No. 3. Test house No. 3 is approximately 75 years old. It is a conventional frame one-story bungalow on a rock pillar foundation. Approximately 90% of the space between pillars was enclosed. Figures 9 and 10 are a photograph and floor plan, respectively.

a. Construction Details:

Floor—Double wood floor with a layer of building paper in between. No. 1 tongue-and-grooved yellow pine 1 inch thick.

Ceiling—Papered wood lath and plaster.

Exterior Walls—Wood shingles on one layer of building paper on 1 inch sheathing on 2 x 4 inch studs exterior. Papered wood lath and plaster interior.

Roof—Green asphalt shingles on old and partly decayed wood shingles on spaced 1 inch sheathing on 2 x 4 inch rafters.

Insulation—Loose rock wool 3 inches deep between ceiling joists.

Windows—Large, wood, and double hung. Glass storm sash on lower half and glass cloth on upper half.

Exterior Doors—Weatherstripped and glass paneled. Glass cloth on screen door.

Ceiling Height—9 feet 8 inches.

Duct—A duct 7.5 by 18 inches in size was constructed across the ceiling of the dining room. It extended from the living room into the northwest bedroom, Figure 11.

Floor Area—1,046 square feet.

b. Habits of the Occupants. This house was occupied by a family of four. Water was kept in the humidifier integral with the heater at all times. Considerable cooking was done on an electric range which added moisture to the air. No effort was made toward controlling habits of the occupants other than keeping interior doors open or closed as specified in each test.

c. Specifications of Circulator. The manufacturer's specifications of this oil-fired circulating heater are as follows:

Figure 9. Test House No. 3 as seen from the northwest corner.

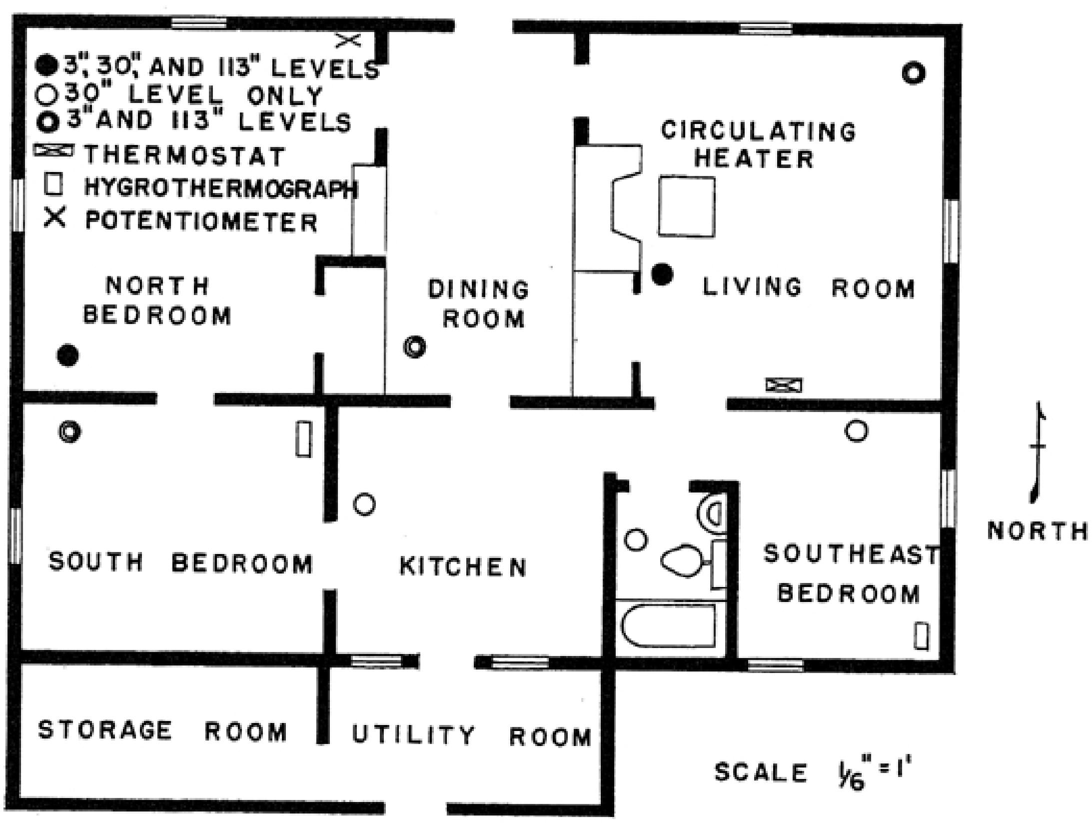

Figure 10. Floor plan of House No. 3 showing location of heater, thermocouples, and hygrothermographs.

Burner pot size .... twin, 10-inch.
Minimum fuel flow .... 2 gallons per 24 hrs.
Maximum fuel flow .... 12 gallons per 24 hrs.
Maximum heat output .... 80,000 Btu per hr.

d. Test Description:

Test A—Basic circulator.

Test B—Circulator, transom open, and all interior doors open.

Test C—Circulator with integrally mounted heater fan with transom opening, without duct, and with all interior doors open.

Test D—Circulator with twin 150 cfm. wall fans in transom opening, with all interior doors open.

Test E—Circulator with duct, with twin 150 cfm. wall fans blowing all air to northwest bedroom. Dining room-northwest bedroom door closed.

Test F—Circulator with duct and twin 150 cfm. wall fans, with air divided between dining room and northwest bedroom. Dining room-northwest bedroom door closed.

Test G—Circulator with duct and twin 150 cfm. wall fans blowing all air to dining room. Northwest and southwest bedrooms closed off from heat.

Test H—Circulator with duct and 500 cfm. fan blowing ¼ air to dining room and ¾ to northwest bedroom. Dining room-northwest bedroom door closed.

Because of the interior arrangement of this house, it was deemed necessary to provide some controlled method of transferring the heated living room air to outlying rooms. In an effort to attain a continuous and positive circulation of air from living room, to northwest bedroom, to southwest bedroom, to kitchen, to either southeast bedroom or dining room and back to the living room, a duct was located next to the dining room ceiling. It connected transom openings in the living room and northwest bedroom walls. To permit proportioning forced air to dining room or northwest bedroom as specified in certain tests, a door was hinged in one side of the duct. The door opened inside the duct, and its position was adjustable from closed to open at a 45-degree angle. Fans were mounted on the living room side of this duct in such a way that they were easily changeable. Figures 11 and 12 are photographs of the duct and fans.

TEST PROCEDURE

The scope of this study was limited to oil-fired circulating units. All tests in Houses No. 1 and No. 2 were run through a range in outdoor temperature of from 20° to 50° F. and House No. 3 through a range of from 15° to 50° F. The weather in Columbia is relatively mild and it was not feasible to operate each test, once it was started, to completion. As a result, most tests were made in several segments, but sufficient time was allowed between each segment, or test, for conditions within the house to attain a steady state.

Data were obtained on dry-bulb temperatures at various levels between floor and ceiling, outdoor air dry-bulb temperature, relative humidities in at least three locations in each house, air movement through doors and louvers, and fuel consumption.

Interior air thermocouples were checked periodically with dependable mercury thermometers, and in all cases temperatures were correct to within

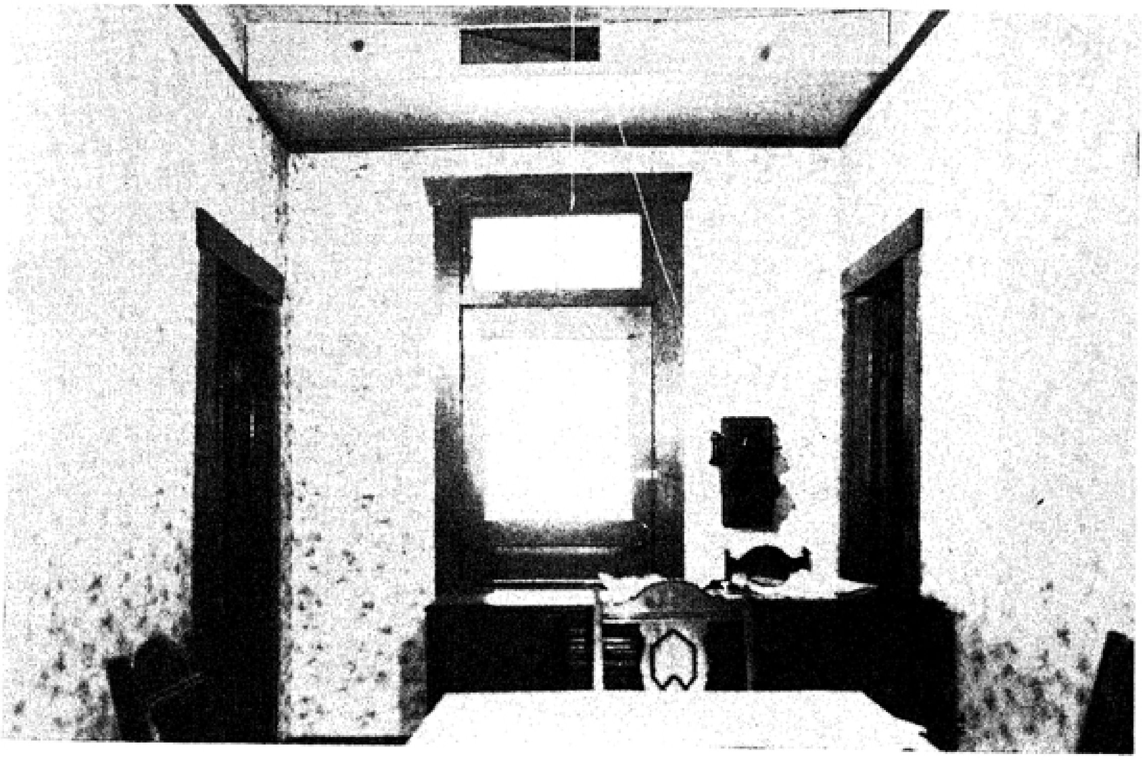

Figure 11. A view of duct across the dining room ceiling that connects the living room and northwest bedroom of House No. 3. Note adjustable door in center of duct to proportion air to dining room and northwest bedroom which is on the left.

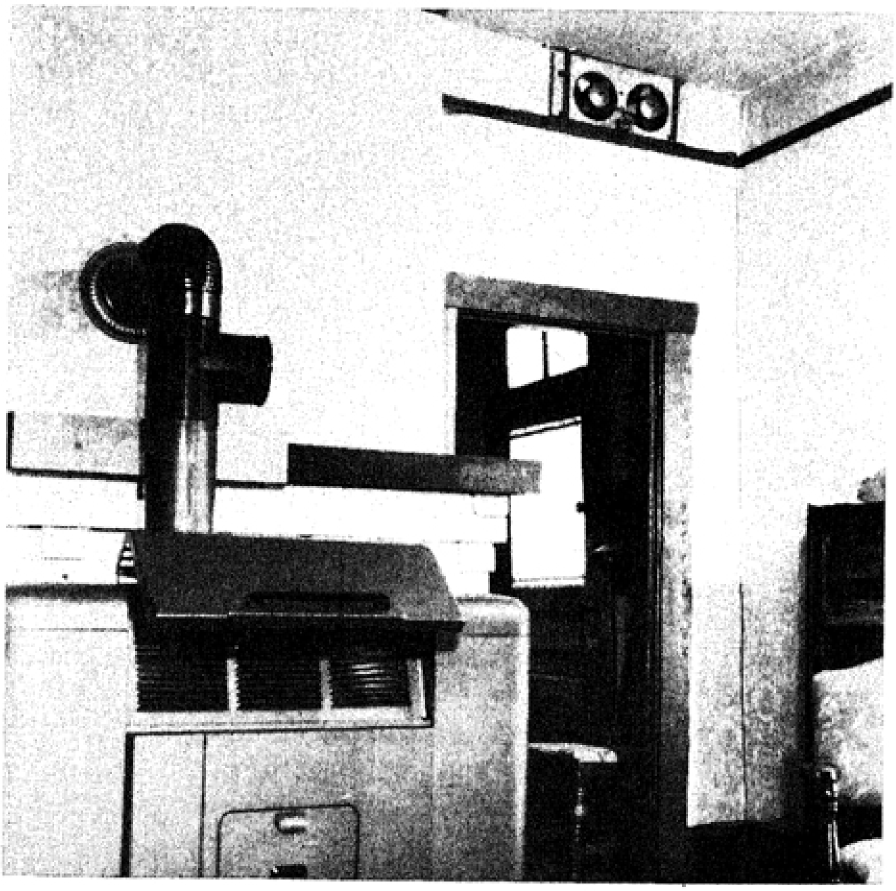

Figure 12. A view of the twin 150 cubic feet per minute wall fans placed in end of duct (upper right hand corner) of House No. 3. The fan thermostat is shown above the twin burner oil-fired circulating heater and to the left of fans.

1° F. The outdoor air thermocouple was checked periodically with the local weather bureau. Experimental temperatures varied from 1° to 1.5° F. higher than those of the weather bureau.

PRESENTATION AND DISCUSSION OF THE DATA

In general, data taken in all three houses indicate that small one-story dwellings in Missouri can be heated satisfactorily with a circulating type space heater, provided some auxiliary forced circulation is used. Records of tests in which the circulator was used without auxiliary devices for heat distribution show that during cold weather the thermal environment was less satisfactory. Almost any effort toward improvement of heat distribution improved conditions on the whole, and in some tests they approached those usually considered desirable.

Since the habits of occupants were not controlled, it was impossible to evaluate each test exactly with respect to its efficiency in heat distribution. Similarly, effects of solar radiation and outdoor wind velocity and direction were not measured. These factors affect the heat loss or gain of a structure measurably, which in turn affects the heat distribution in a structure. Conditions in each test were controlled to some degree by a room thermostat which operated the fuel valve automatically.

Tests were conducted through a range in outdoor temperature of 20° to 50° F. but in this report all discussion will pertain to the range 20° to 30° F. unless otherwise specified.

EFFECTS OF RATE OF FUEL CONSUMPTION ON TEMPERATURE DIFFERENCES FROM FLOOR TO CEILING

One method of heat distribution with space heaters is gravity flow, which is dependent upon temperature differences. Temperature differences from floor to ceiling are dependent largely on rate of fuel consumption. This temperature difference may be considered as a measure of the lag in producing a desirable thermal environment. For a given house any factor that tends to increase fuel consumption increases temperature differences both horizontally and vertically. Some of the factors that require an increase in the rate of fuel consumption are loosely fitting windows and doors that permit excessive air infiltration, insufficient insulation, high wind velocities, and large differences in air temperature indoors and out.

Fuel consumption data were obtained only in House No. 2. Figure 13 shows the relation of temperature differences between floor and ceiling* and heat output. These curves present temperatures measured in the living room only (location of heat source). The air stratification was greater in the living room than in other rooms. The curves illustrate the advan-

*For purposes of discussion, thermocouple height above the floor will hereafter in this report be referred to as follows:
Floor—Dry-bulb temperatures measured at 3 inches above floor.
Living area—Dry-bulb temperatures measured at 30 inches above floor.
Upper living area—Dry-bulb temperatures measured at 60 inches above floor.
Ceiling—Dry-bulb temperatures measured at 3 inches below ceiling.

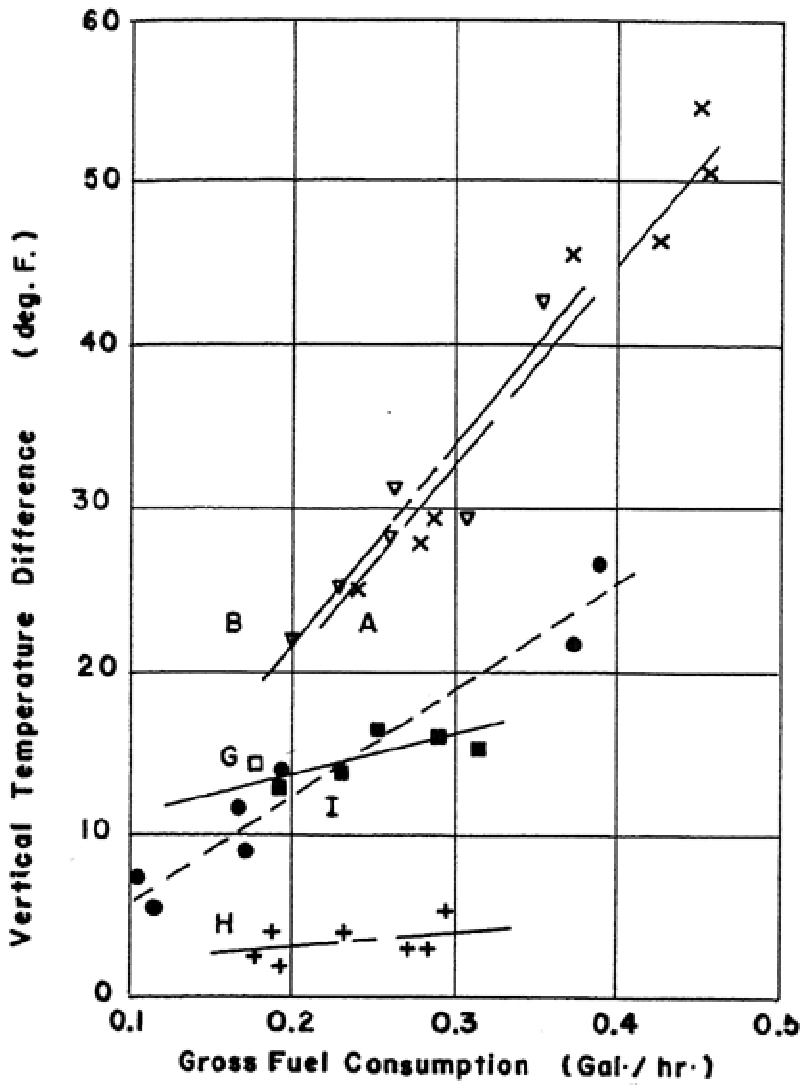

Figure 13. Relation of fuel consumption to temperature differences that occurred in the living room of House No. 2 from 3 inches above floor to 3 inches below ceiling (1950-1951). Curves are identified by their corresponding test description letters.

tage, with respect to reducing temperature stratification, of keeping the fuel-rate as low as possible.

Another factor of importance shown in these curves is the effect of auxiliary circulation. It is noted that with exception of Test B the slope of the curves decreases with an increase in air circulation.

EFFECTS OF OUTDOOR TEMPERATURE AND INDOOR HEAT DISTRIBUTION ON FUEL CONSUMPTION

Operating cost is one of the deciding factors that determine the efficiency of a heating system. Curves of outdoor temperatures plotted against fuel consumption for the tests conducted in House No. 2 during the 1950-51 heating season, are shown in Figure 14.

It can be seen from the curves in Figure 14 that any effort toward improvement of heat distribution decreased the average fuel consumption. Temperatures in all tests ran higher than are usually considered satisfac-

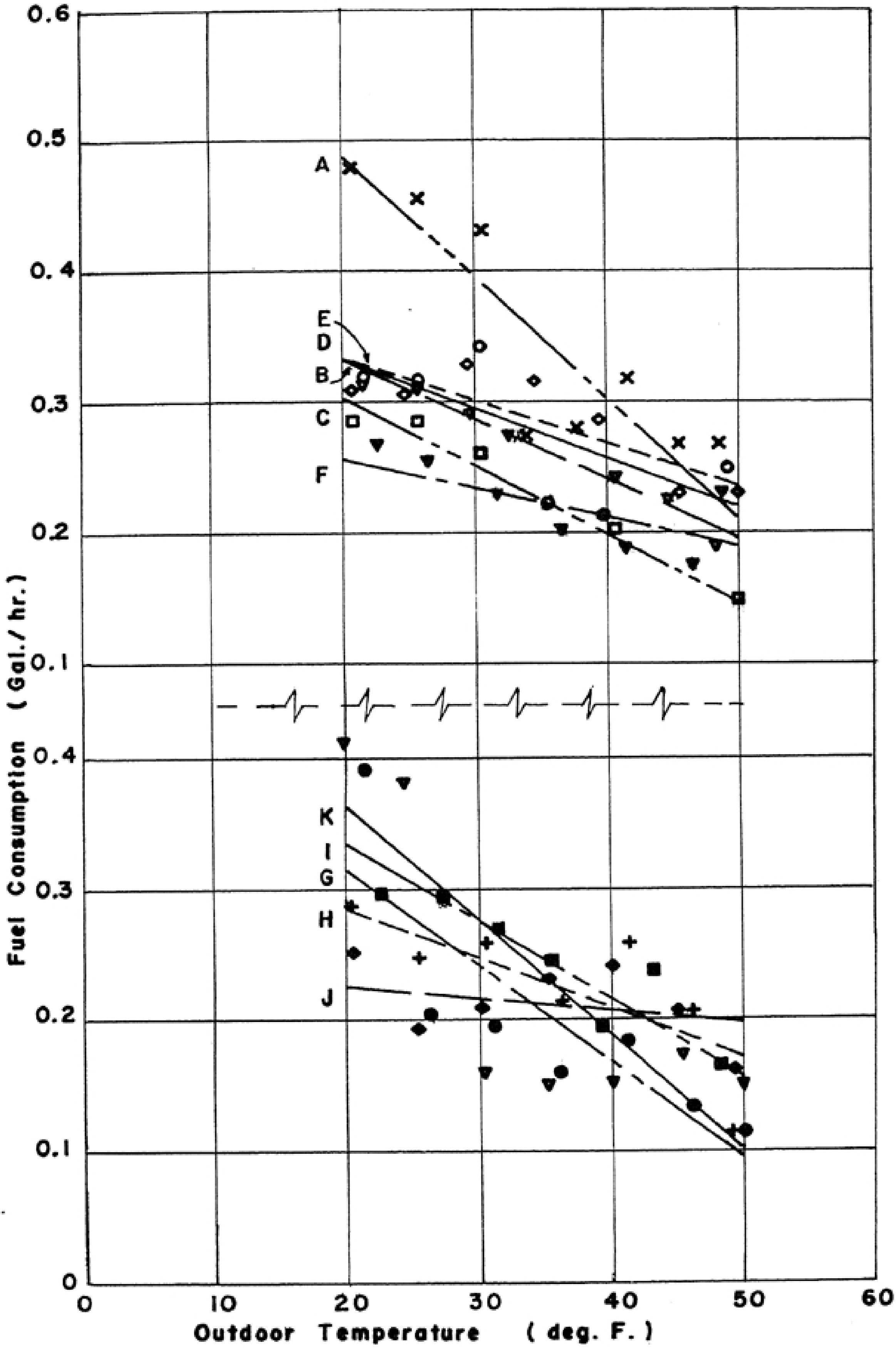

Figure 14. Relation of fuel consumption to outdoor temperature for each test conducted in House No. 2 (1950-51).

tory for a farm home. Thus it is seen that any effort toward a more uniform heat distribution can be profitable both from the comfort and operation cost standpoint.

At 35° F., the tests in House No. 2 ranked in descending order of fuel consumption as follows: Test G, J, C & F, H & K, I, B, D, E, and A. The fuel consumption rates were probably affected to some degree by variations in solar radiation, wind velocity and direction.

A study of the results of these tests in House No. 2 indicates considerable reduction in fuel consumption for various degrees of forced air circulation in the room. For example, at 35° F. outside air temperature, Test G (16-inch fan blowing air up and across heater fire pot) used only 4.61 gallons of fuel per 24 hours while Test A used 8.28 gallons, or a difference of 3.67 gallons per 24 hours. This gave a 44% decrease in fuel consumption. This is significant when it is realized the only difference between the two tests was that Test G utilized a 16-inch summer ventilation fan.

Test J differed from Test F only in size of fans used which were 10-inch and 16-inch, respectively. Test J used slightly less fuel but it also produced lower dry-bulb temperatures in the living zone and higher temperatures from the upper living zone to the ceiling. The difference in fuel consumption was less than one gallon per week, and the size of fan used in any given farmhouse would depend upon the size of fan available.

The fuel-rate in Test H at 35° F. was 2.85 gallons per day less than in Test A, but the more important factor in Test H was that the greatest difference in temperature from floor to ceiling was less than 8° F. This air temperature stratification compares favorably with that obtained from a more expensive central heating system.

Test I (with five fans running) burned 30% less fuel than did Test A (no fans), and it also maintained much more uniform temperatures. The maximum differences in temperature (11.2° F.) from floor to ceiling occurred in the utility room where the fan discharge was at the ceiling. Many persons would consider the five fans used in this test an excessive number, but the test is valuable since it proves a small well-constructed house can be heated satisfactorily with one space heater, and with less fuel than required by the circulator alone to heat the house less satisfactorily. These same fans may be utilized for summer ventilation, making the cost less prohibitive.

The fuel-rate of Test B at 35° F. was 25% less than that of Test A, Test D 20% less and Test C 36% less. The difference in the over-all average temperature maintained between any two of these tests was slightly greater than 1° F. This difference would not justify the use of fans but a further study of dry-bulb temperatures show that a better distribution of warm air occurred in certain tests. From the standpoint of cost of operation only, Test C (the stove with integral fan) appeared to be the best.

Test E differed from Test A in that the floor ducts were open in the former. The fuel-rate in Test E was 19% less while there was very little difference in average temperatures for the two tests. Test F differed from Test E in that the former utilized a 16-inch fan. Fuel consumption was

21% less in Test F, and also temperature differences were less than in Test E. From the standpoint of fuel consumption only, the installation of floor ducts, or cold-air returns, in new construction would be warranted if used with or without fans.

RELATIVE HUMIDITY

Figure 15 consists of curves of relative humidities with their respective outdoor dry-bulb temperatures for each house for a typical 24-hour period. As discussed in the section on test arrangements, House No. 1 was not occupied during parts of the test and water was not kept in the heater humidifier. Water was present in floor registers and central chamber of the duct system. House No. 2 was occupied only during the 1949-50 heating season and water was added in the heater humidifier continuously. House No. 3 was occupied by a family of four and water was kept in the heater humidifier at all times.

Preliminary tests in House No. 1 indicated that the amount of water evaporated from the heater humidifier was insufficient to significantly increase the room humidity. This statement can be further verified by noting the curves in Figure 16 for Houses No. 1 and No. 2. The construction of these two houses are fairly comparable with respect to calculated heat losses. Relative humidity in the more loosely constructed House No. 3 ran above 50% for the most part. One cause of higher humidity in House No. 3 is that the dry-bulb temperatures near the floor where humidity measurements were made were lower than in the other houses. As temperature decreases relative humidity increases, other factors remaining constant.

Another cause for higher humidity in House No. 3 was cooking, which added considerable moisture to the air. It was not uncommon for the humidity readings to increase from about 35% relative humidity to as much as 50% during the preparation of a meal.

It was concluded that with a normal amount of food preparation, relative humidity in most parts of a small house heated by a circulating heater would remain within the comfort range of 30 to 50%. It is true that under these conditions humidity will fluctuate.

EFFECT OF UNDER-FLOOR DUCTS ON HEAT DISTRIBUTION

Theoretically an underfloor duct system should eliminate cold drafts across the floor. Usually floor registers for the cold-air return system are placed beneath windows near the exterior walls. When the heat source is located near the center of the house this permits warmed air to gravitate from the heat source to floor registers and the cooler air to return through ducts beneath the floor back to the heat source.

The chimney effect of a heated house is always considerable in cold weather because the weight of a given volume of air depends upon its temperature. To increase chimney effect, the heaters were jacketed down to the floor with heavy paper when testing the effect of under-floor ducts. Ducts were made of concrete but it is possible that considerable air leaked around the heater.

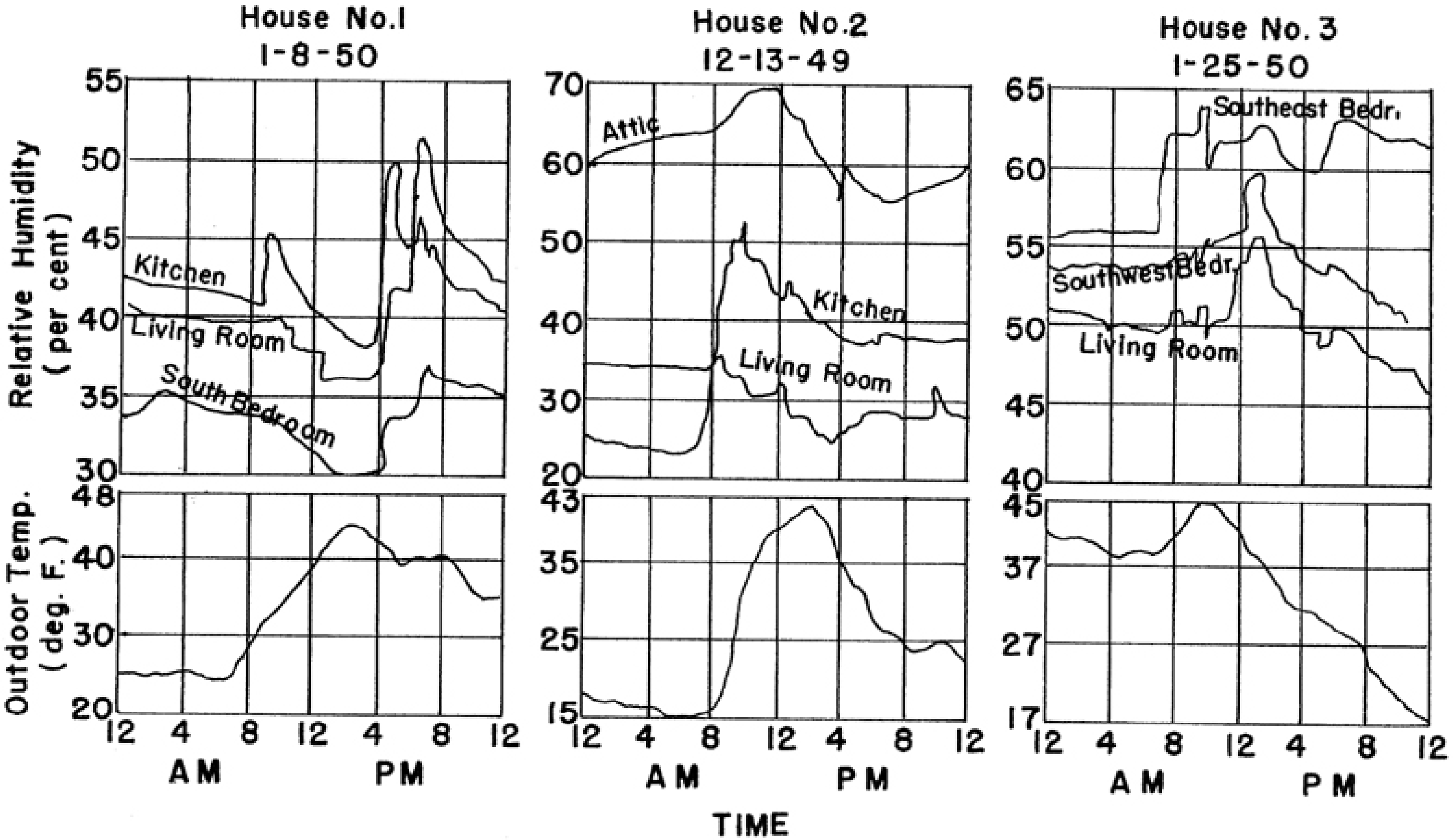

Figure 15. Changes in relative humidity and corresponding outdoor temperature for each test house during typical 24-hour periods (1949-50).

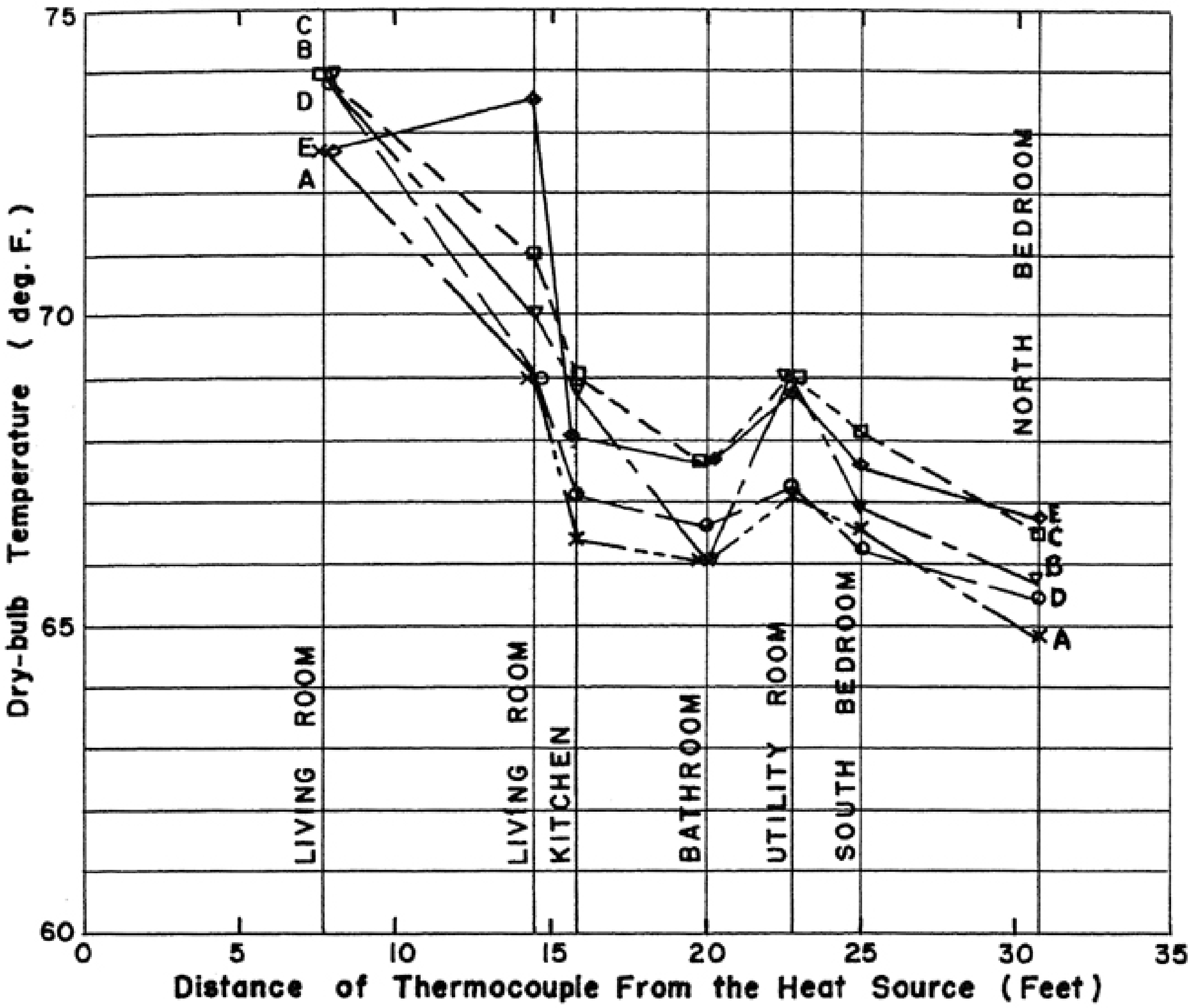

Figure 16. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 1 for a range in outdoor temperature of 20° to 30° F.

The use of under-floor ducts (without forced circulation) in House No. 1 had little effect on temperatures. This is seen by comparing results of Tests A and D, Table 1. The under-floor ducts did decrease temperatures near the ceiling slightly but this had no effect within the living zone. Test E (500 cfm. forced through the ducts in the direction of normal circulation) increased temperatures at the floor as much as 4.3° F. and decreased those at the ceiling as much as 22.9° F. Temperatures in the living area were increased in each room with a maximum of 4.4° F. occurring in the living room. While the floor ducts alone decreased vertical temperature differences slightly, the ducts with forced convection decreased the difference from floor to ceiling as much as 26.0° F., with an average of 12.8° F. Floor ducts alone decreased the maximum horizontal temperature difference 1.8°, 0.5°, and 1.9°, -2.4°, and 21.9° F. at the respective elevations.

Table 1. Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, and 93 Inches Above Floor Obtained in House No. 1 for a Range in Outdoor Temperature of 20° to 30° F. (1949-50).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F. Living Room	North Bedroom	South Bedroom	Bathroom	Kitchen	Utility Room	AVERAGE	Maximum Horizontal Temp. Difference
A	3	65.5	56.3	60.3	66.1	66.3	67.2	60.7	9.2
	30	69.2	64.8	66.4				66.7	4.4
	93	100.8	69.7	76.4				82.3	31.1
B	3	60.6	57.5	60.6	66.0	68.3	69.0	59.6	3.1
	30	70.0	65.7	66.9				67.6	4.3
	93	96.8	70.0	76.5				81.1	26.8
C	3	67.2	61.5	63.7	67.7	69.1	69.0	64.1	5.7
	30	71.0	66.5	68.1				68.6	4.5
	93	86.8	71.5	75.5				77.9	15.3
D	3	65.4	58.0	60.4	66.7	67.0	67.2	61.3	7.4
	30	69.3	65.4	66.2				67.0	3.9
	93	98.7	69.5	76.0				81.4	29.2
E	3	67.9	60.6	62.9	67.7	67.9	68.6	63.8	7.3
	30	73.6	66.8	67.5				68.7	6.8
	93	77.9	68.7	72.0				72.9	9.2
		Temperature Difference (° F.)							
A	3-30	3.7	8.5	6.1					
	3-93	35.8	13.4	15.9					
B	3-30	9.4	8.2	6.3					
	3-93	31.2	12.4	15.6					
C	3-30	3.8	5.0	4.4					
	3-93	19.5	9.8	11.5					
D	3-30	3.9	7.4	5.8					
	3-93	32.8	11.4	15.1					
E	3-30	5.7	6.2	4.6					
	3-93	9.8	8.0	8.9					

Likewise, the use of under-floor ducts alone (without forced convection) in House No. 2 proved ineffective both from the standpoint of increasing temperatures and decreasing differences in temperature vertically and horizontally. See Table 3, Test E. The central chamber of the floor duct system in House No. 2 was too small to allow the installation of a fan. A fan was therefore placed on the floor in such a way that it blew air up and across the heater jacket. Considerable air entered louvers, on the side of the heater jacket, and blew up and across the fire pot, and out of the jacket through the top grille. Sixteen-inch and ten-inch summer ventilation fans were used in conjunction with under-floor ducts in Tests F and J, respectively. Both fans increased temperatures at the floor and living area and decreased those at the ceiling. The 16-inch fan increased temperatures as much as 6.2° and 4.6° F. at the floor and living area with a decrease of 9.5° F. at the ceiling. Figures for the 10-inch fans were 2.6°, 1.6°, and 6.0° F. for the respective elevations. The 16-inch fan decreased vertical temperature difference from floor to ceiling as much as 15.7° while the 10-inch fan decreased the difference as much as 13.3° F. The maximum temperature difference between rooms was decreased as much as 3.0° and 6.5° F. by the 16-inch and 10-inch fans.

It was concluded that with new construction the installation of an underfloor duct system with some method of forced air circulation is warranted.

Table 2. Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, and 93 Inches Above Floor Obtained in House No. 2 for a Range in Outdoor Temperature of 20° to 30° F. (1949-50).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F. Living Room	North Bedroom	South Bedroom	Bathroom	Kitchen	Utility Room	AVERAGE	Maximum Horizontal Temp. Difference
A	3	65.9	62.1	69.4				65.8	7.3
	30	72.6	71.4	72.4	71.8	73.1	66.3	71.3	6.8
	93	97.6	76.1	81.7				85.1	21.5
B	3	67.0	61.6	68.5				65.7	6.9
	30	75.3	68.9	74.7	74.0	72.7	70.2	72.6	6.4
	93	87.0	72.2	77.1				78.8	14.8
C	3	65.3	62.2	67.5				65.0	5.3
	30	72.6	69.0	71.6	72.7	73.2	70.0	71.5	4.2
	93	102.4	79.6	82.5				88.2	22.8
D	3	64.7	59.2	65.9				63.3	6.7
	30	71.9	64.2	70.5	69.8	70.2	68.1	69.1	7.7
	93	106.9	71.2	82.3				86.8	35.7
E	3	65.0	60.7	66.1				63.9	5.4
	30	71.8	68.3	71.1	71.2	73.3	73.6	71.6	5.3
	93	95.6	75.9	78.5				83.3	19.7
		Temperature Difference (° F.)							
A	3-30	6.7	9.3	3.0					
	3-93	31.7	14.0	12.3					
B	3-30	8.3	7.3	6.2					
	3-93	20.0	10.6	8.6					
C	3-30	7.3	6.8	4.1					
	3-93	37.1	17.4	15.0					
D	3-30	7.2	5.0	4.6					
	3-93	42.2	12.0	16.4					
E	3-30	6.8	7.6	5.0					
	3-93	30.6	15.2	12.4					

Table 3. Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, 60, and 93 Inches Above Floor Obtained in House No. 2 for a Range in Outdoor Temperature of 20° to 30° F. (1950-51).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F. Living Room	North Bedroom	South Bedroom	Bathroom	Kitchen	Utility Room	AVERAGE	Maximum Horizontal Temp. Difference
A	3	67.6	63.7	68.3	66.6	67.6	64.7	66.4	4.6
	30	71.5	68.0	70.2	69.9	70.7	69.2	69.9	3.5
	60	78.4	72.9	75.6	75.5	75.8	74.3	75.4	5.5
	93	102.5	81.5	83.0	86.2	86.8	83.4	88.9	21.0
B	3	68.3	63.8	66.7	66.9	67.8	65.5	66.5	4.5
	30	70.9	67.8	69.3	69.1	69.8	68.3	69.2	3.1
	60	80.0	74.5	76.5	76.7	79.9	81.0	78.1	6.5
	93	97.5	77.9	79.5	82.8	90.9	88.8	86.2	19.6
C	3	74.6	64.9	68.6	69.0	68.5	65.7	68.6	9.7
	30	78.7	69.9	73.6	72.7	72.7	71.1	73.1	8.8
	60	80.2	73.2	75.5	76.7	76.7	75.1	76.2	7.0
	93	87.4	75.3	77.3	80.2	84.2	79.1	80.6	12.1
D	3	72.0	64.9	69.2	69.7	69.7	67.9	68.9	7.1
	30	74.8	69.3	72.7	72.3	72.0	73.3	72.4	5.5
	60	79.4	73.2	75.4	75.1	76.3	75.6	75.8	6.2
	93	84.7	73.8	76.2	78.3	83.0	78.3	79.1	10.9
		Temperature Differences (° F.)							
A	3-30	3.99	4.3	1.9	3.3	3.1	4.5		
	3-60	10.8	9.2	7.3	8.9	8.2	9.6		
	3-93	34.9	17.8	14.7	19.6	29.2	18.7		
B	3-30	2.6	4.0	2.6	2.2	2.0	2.8		
	3-60	11.7	10.7	9.8	9.8	12.1	15.5		
	3-93	29.2	14.1	12.8	15.9	23.1	23.3		
C	3-30	4.1	5.0	5.0	3.7	4.2	5.4		
	3-60	5.6	8.3	6.9	7.7	8.2	9.4		
	3-93	12.8	10.4	8.7	11.2	15.7	13.4		
D	3-30	2.8	4.4	3.5	2.6	2.3	5.4		
	3-60	7.4	8.3	6.2	5.4	6.6	7.7		
	3-93	12.7	8.9	7.0	8.6	13.3	10.4		

Table 3 (Cont'd.). Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, 60, and 93 Inches Above Floor Obtained in House No. 2 for a Range in Outdoor Temperature of 20° to 30° F. (1950-51).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F.							Maximum Horizontal Temp. Difference
		Living Room	North Bedroom	South Bedroom	Bathroom	Kitchen	Utility Room	AVERAGE	
E	3	70.0	64.5	68.0	67.7	68.5	65.6	67.4	5.5
	30	72.2	68.4	70.2	69.9	70.6	68.5	70.0	3.8
	60	79.2	73.8	76.5	76.1	76.8	74.8	76.2	5.4
	93	102.5	80.4	82.1	85.8	93.7	83.0	87.9	22.1
F	3	73.8	68.7	69.5	70.7	69.3	66.7	69.8	7.1
	30	75.3	72.6	73.0	73.5	73.5	71.3	73.2	4.0
	60	81.4	77.5	76.4	77.7	77.9	75.3	77.7	6.1
	93	93.0	77.4	75.0	81.6	86.8	78.5	82.1	18.0
G	3	69.2	64.8	70.3	68.9	69.0	67.6	68.3	5.5
	30	71.8	68.6	72.2	72.5	72.7	71.3	71.5	4.1
	60	76.2	71.1	73.9	74.9	77.9	74.2	74.7	6.8
	93	85.3	73.8	76.5	78.3	83.7	77.7	79.2	11.5
H	3	79.5	68.8	72.1	71.4	71.4	70.4	72.3	10.7
	30	80.6	73.1	75.0	73.4	73.8	72.2	74.7	8.4
	60	82.6	75.6	76.7	75.1	76.8	73.8	76.8	8.8
	93	82.6	76.2	76.8	76.5	79.3	75.0	77.7	7.6
		Temperature Differences (° F.)							
E	3-30	2.2	3.9	2.2	2.2	2.1	2.9		
	3-60	9.2	9.3	8.5	8.4	8.3	9.2		
	3-93	32.5	15.9	14.1	18.1	25.2	17.4		
F	3-30	1.5	3.9	3.5	2.8	4.2	4.6		
	3-60	7.6	8.8	6.9	7.0	8.6	8.6		
	3-93	19.2	8.7	5.5	10.9	17.5	11.8		
G	3-30	2.6	3.8	1.9	3.6	3.7	3.7		
	3-60	7.0	6.3	3.6	6.0	8.9	6.6		
	3-93	16.1	9.0	6.2	9.4	14.7	10.1		
H	3-30	1.1	4.3	2.9	2.0	2.4	1.8		
	3-60	3.1	6.8	4.6	3.7	5.4	3.4		
	3-93	3.1	7.4	4.7	5.1	7.9	4.6		

Table 3 (Cont'd.). Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, 60, and 93 Inches Above Floor Obtained in House No. 2 for a Range in Outdoor Temperature of 20° to 30° F. (1950-51).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F.							Maximum Horizontal Temp. Difference
		Living Room	North Bedroom	South Bedroom	Bathroom	Kitchen	Utility Room	AVERAGE	
I	3	76.2	73.2	75.9	76.1	70.4	68.0	73.3	5.8
	30	78.5	73.0	76.0	77.8	73.5	75.1	75.7	5.5
	60	82.0	73.3	77.9	78.8	76.2	77.5	77.6	8.7
	93	85.9	72.7	77.1	78.3	80.0	79.2	79.0	13.2
J	3	68.4	64.6	67.9	69.2	69.2	67.1	67.7	4.6
	30	71.5	69.0	71.2	71.5	71.5	70.3	70.8	2.5
	60	81.8	75.5	78.2	78.0	79.0	76.2	78.1	6.3
	93	90.0	75.5	78.6	82.9	87.2	81.6	82.6	14.5
K	3	74.3	65.4	71.5	69.8	69.5	67.6	69.7	8.9
	30	76.3	70.0	73.2	72.5	71.9	70.5	72.4	6.3
	60	79.5	73.1	75.5	74.8	75.4	73.1	75.2	6.4
	93	85.9	74.5	77.7	78.3	83.4	75.4	79.2	11.4
		Temperature Differences (° F.)							
I	3-30	2.3	-.2	0.1	1.7	3.1	7.1		
	3-60	5.8	0.1	2.0	2.7	5.8	9.5		
	3-93	9.7	-.5	1.2	3.2	9.6	11.2		
J	3-30	3.1	4.4	3.3	2.3	2.3	3.2		
	3-60	13.4	10.9	10.3	8.8	9.8	9.1		
	3-93	21.6	10.9	10.7	13.7	18.0	14.5		
K	3-30	2.0	4.6	1.7	2.7	2.4	2.9		
	3-60	5.2	7.7	4.0	5.0	5.9	5.5		
	3-93	11.6	9.1	6.2	8.5	13.9	7.8		

TRANSOMS OVER INTERIOR DOORWAYS

There were 6-inch by 12-inch transom openings above doors in House No. 1 between the living room and hall, hall and south bedroom, hall and north bedroom, and hall and bathroom. Test B was conducted to determine the effectiveness of these openings over that of the basic circulator alone (Table 1). They proved to be of little value for heat distribution either vertically or horizontally.

The ceiling in House No. 3 was over 9 feet high, and it was found in preliminary tests that air temperature was 125° F. or above at two feet below the ceiling. One opening 9 inches by 18 inches was cut in the living room-dining room wall directly beneath the ceiling. It was realized that this one opening was insufficient for good heat distribution, but because of wall and closet arrangement it was impossible to make more. It can be seen in Test B (Table 4) that most temperatures were increased from one to two degrees but this is too small to be considered significant.

Even though transom openings in this study had only negligible effect on heating, it is possible that considerable heat could be transferred by this method if the size and number of openings were larger. A disadvantage of openings is that they permit noise to travel from one room to another.

EFFECT OF FANS INTEGRAL WITH HEATER

The fan integral with heater used in House No. 2 during 1949-1950 and 1950-1951 seasons was of the centrifugal type and pulled air downward against gravity. Its discharge was near the floor in front of the heater. Conditions of Test B in Table 2 were the same as in Test C in Table 3 except the house was occupied during the 1949-1950 season shown in Table 2. In Test B, Table 2, temperatures were increased a maximum of 3.9° F. in the living zone and decreased a maximum of 10.6° F. at the ceiling by the use of the fan. Corresponding figures for Test C, Table 3, were 7.2° and 15.1° F. Temperature differences from floor to ceiling were decreased as much as 11.7° F. in Test B and 22.1° F. in Test C. The maximum temperature difference between rooms was decreased 6.7° F. in Test B and 8.9° F. in Test C.

The fan integral with heater in House No. 3 was a centrifugal type mounted above and behind the burners. Its discharge was slightly downward and across the fire pots. It can be seen from Test C. in Table 4 that temperatures at the living area were increased from 1.6° to 5.1° F., by the use of the fan, while those near the living room ceiling were lowered 10.4° F. The temperature difference from floor to ceiling was decreased a maximum of 9.0° F., and the maximum difference between rooms was decreased 11.8° F.

In all three of the above tests, comfort conditions in the living room were improved greatly, but the warm air circulation did not extend to outlying rooms as much as desirable. With a fan pulling air against gravity and forcing it outward and downward in front of the heater, the floor in front of the heater is kept much warmer. Also, there is much less stratification of air near the heater. With less stratification, however, there is less heat transferred to adjacent rooms.

Table 4. Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, and 113 Inches Above Floor Obtained in House No. 3 for a Range in Outdoor Temperature of 20° to 30° F. (1949-50).

Test	Elevation Above Floor Inches	Average dry-bulb temperatures (° F.) for a range in outdoor temperature of 20° to 30° F.								Maximum Horizontal Temp. Difference
		Living Room	North west Bedroom	South west Bedroom	Dining Room	Kitchen	Bath-room	South east Bedroom	AV-ERAGE	
A	3	55.3	47.3	46.7	55.1				51.1	8.6
	30	66.2	56.9			59.3	58.7	60.0	60.2	9.3
	113	100.7	66.3	62.3	84.5				78.5	38.4
B	3	56.8	49.8	48.7	56.8				53.0	8.1
	30	67.3	59.4			61.5	60.7	61.4	62.1	7.9
	113	102.1	78.3	64.0	86.9				82.8	38.1
C	3	53.9	48.6	48.9	54.5				51.5	5.9
	30	71.3	60.5			61.2	60.4	61.6	63.0	10.9
	113	90.3	70.9	63.7	78.6				75.9	26.6
D	3	55.9	47.6	46.5	54.7				51.2	9.4
	30	68.0	58.6			59.2	59.0	61.2	61.2	9.4
	113	102.3	80.2	65.7	91.8				85.0	36.6
Temperature Differences (° F.)										
A	3-30	10.9	9.6							
	3-113	45.4	19.0	15.6	29.4					
B	3-30	10.5	9.6							
	3-113	45.3	28.5	15.3	30.1					
C	3-30	17.4	11.9							
	3-113	36.4	22.3	14.8	24.1					
D	3-30	12.1	11.0							
	3-113	46.4	32.6	19.2	37.1					

Table 4 (Cont'd.). Average Dry Bulb Temperatures and Temperature Differences For Each Test at 3, 30, and 113 Inches Above Floor Obtained in House No. 3 for a Range in Outdoor Temperature of 20° to 30° F. (1949-50).

Test	Elevation Above Floor Inches	Average dry bulb temperatures (° F.) for a range in outdoor temperatures of 20° to 30° F.								Maximum Horizontal Temp. Difference
		Living Room	North west Bedroom	South west Bedroom	Dining Room	Kitchen	Bath-room	South east Bedroom	AV-ERAGE	
E	3	57.2	48.1	46.9	55.8				52.0	10.3
	30	69.1	59.0			61.0	60.5	63.0	62.5	10.1
	113	101.5	83.5	67.6	86.2				84.7	33.9
F	3	63.9	53.3	54.9	62.7				58.7	10.6
	30	72.0	61.3			68.7	64.6	64.3	66.2	10.7
	113	100.7	78.7	65.5	89.3				83.6	35.2
G	3	56.4	47.9	47.0	55.8				51.8	9.4
	30	67.2	55.5			61.7	60.4	61.5	61.3	11.7
	113	99.5	68.5	61.4	91.7				80.3	38.1
H	3	56.7	49.6	48.5	55.9				52.7	8.2
	30	68.8	59.6			60.9	60.4	63.9	62.7	9.2
	113	104.4	84.3	67.8	92.3				87.2	36.6
Temperature Differences (° F.)										
E	3-30	11.9	10.9							
	3-113	44.3	35.4	20.7	30.4					
F	3-30	8.1	8.0							
	3-113	36.8	25.4	10.6	26.6					
G	3-30	10.8	7.6							
	3-113	43.1	20.6	14.4	35.9					
H	3-30	12.1	10.0							
	3-113	47.7	34.7	19.3	36.4					

EFFECT OF FANS

A 150 cfm. (cubic feet per minute) wall fan was installed above the living room-bathroom door in House No. 2, with its discharge into the latter. This fan was located approximately 13 feet horizontally from the heat source and was ineffective. The bathroom temperature was increased only 0.9° F. at the living area and the occupants complained of a cold draft (Test C of Table 2).

To determine if the size of heater in House No. 2 was sufficient to heat the entire house satisfactorily, five fans were used in Test I of Table 3. The duct with 150 cfm. fan was used in the utility room; a 150 cfm. fan was installed above the bathroom door; a 10-inch summer ventilation fan was placed in top of the door opening to each bedroom (discharging toward bedroom), and the fan integral with stove was used. Only one temperature measurement fell below 70.4° F. and this occurred at the floor in the utility room (68.0° F.). The greatest temperature difference from floor to ceiling was 11.2° F., and the maximum difference between rooms was 13.2° F. at the ceiling. The maximum vertical temperature difference was decreased 22.7° F. over that of the basic circulator alone, and the maximum difference between rooms was decreased 7.8° F. It should be noted that all of these temperatures were higher than common for design purposes. Use of five fans simultaneously is perhaps impractical; however, this test indicates the possibility of using a small fan to heat a given room when desirable. For example, bedrooms need be heated only a short time before going to bed and before getting up. A time-switch could easily be installed to control the fan automatically or it could be controlled by hand. This reasoning also applies to the kitchen, utility room and possibly the bathroom. Another important fact was observed in this test: with all the fans in operation the heating was not only greatly improved, but the fuel consumption was also lowered at the same time. (See Figure 13.)

Two 150 cfm. fans were installed above the living room-dining room door of House No. 3 with discharge into the dining room. Results of this test are given in Test D of Table 4. The fans increased the temperatures very little over those produced by the basic circulator, within the living zone, but increased temperatures at the ceiling as much as 13.9° F. Temperatures at the living area were increased a maximum of 2.2° F. Much of the ineffectiveness of the fans used in Test D of House No. 3 can be attributed to the fact that the living room-dining room door remained open during the test. Since the fans were located so high, much of the air evidently circulated back through the living room door. It is possible that the fans might have been more effective had the door been closed.

EFFECT OF SMALL DUCTS AND FANS

One main purpose of this study was to determine the feasibility of utilizing high temperature air directly above the heat source to heat small outlying rooms. Examples of new heating problems are the installation of a bathroom which requires higher temperatures, and kitchens where wood or coal cook stoves have been replaced by electric ranges.

A 150 cfm. wall fan was installed in an 8-inch round aluminum duct in House No. 2. Intake of the fan and duct was from an insulated collection box (Figure 8) located directly above the heat source and extended into attic. The collector box could be shut off from the heater at will. This duct was covered with two inches of insulation material, and it extended through the attic to an opening in center of the utility room ceiling. Length of the duct was 23 feet. Results of using this fan and duct are given in Test E of Table 2 and Test B of Table 3. In Test E (Table 2) temperatures in the utility room were increased 7.3° F. at the living area by the use of the fan and duct over the temperature obtained with the basic circulator alone (Test A, Table 3). The use of this fan and duct, however, decreased living zone temperatures in other rooms as much as 3.1° F. The utility room temperature was 73.6° F. which is sufficiently high to be satisfactory for any room including the bathroom. In the second test of this system, Test B, utility room temperatures were increased 5.4° F. at the ceiling and 0.8° F. at the floor by use of the fan and duct. Temperatures in the living room were decreased 5.0° F. at the ceiling while those at the floor and living area were little affected.

Preliminary tests in House No. 3 indicated that the interior arrangement of walls was unsatisfactory for heat distribution. It was impossible to get sufficient heat to pass through the dining room into the northwest bedroom. A 9-inch by 18-inch plywood duct (Figures 11 and 12) was installed in the dining room with ends opening into living room and northwest bedroom. It was constructed in such a way that the air coming from the living room could be discharged entirely into the dining room or the northwest bedroom, or part to both rooms. Tests E, F, G, and H of Table 4 utilized this duct. Test E with 300 cfm. discharge into the northwest bedroom increased all temperatures slightly. Greatest increases occurred near the ceiling in the two west bedrooms. The amount of air circulated was evidently insufficient with such a high ceiling (9'5").

It was realized that House No. 3 would be difficult to heat with only one circulator. In Test F (Table 4) one-half of the air was discharged into the dining room in an attempt to improve temperature conditions in the most used rooms. Temperatures were increased at the living zone as much as 5.8° F. in the living room, 9.4° F. in the kitchen, 5.9° F. in the bathroom, and 4.3° F. in the southeast bedroom. Those at the floor were increased from 6.0° to 8.6° F., but this was accompanied with an increase at the ceiling. Since temperatures were still lower than desired, the two west bedrooms were closed off to decrease the size of heat load. In Test G air was discharged into the dining room at 300 cfm. by the interconnecting duct. Temperatures in the heated portion of the house were increased from 1.0° to 2.4° F. at the living area but those in unheated rooms ran almost as high as they did when heated by the basic circulator alone. This indicates that very little heated air was transferred to the west bedrooms by gravity. An explanation for such high temperatures in this unheated portion is that the doors may not have been closed at all times, and, too, the doors fitted very loosely which permitted considerable heat infiltration.

Test H in House No. 3 was conducted with a 500 cfm. fan moving air through the duct from the living room. About three-quarters of this air was discharged into the northwest bedroom and about one-quarter into the dining room. All temperatures throughout the house were increased but those near the ceiling were increased most.

It was concluded that before House No. 3 could be heated satisfactorily with one space heater, one or more of the following changes should be made: The ceiling should be lowered; the heat source should be placed more nearly in the center of the house; more openings should be made between the living room and adjacent rooms, and more fans utilized.

EFFECT OF VENTILATION FANS

Realizing that it is impractical to put above-ceiling or under-floor ducts in many houses, tests were performed to learn if heat distribution could be improved with the use of ordinary summer ventilation fans.

In Test C (Table 1 of House No. 1) one 10-inch fan was placed on the floor and behind the heater. Its discharge was up and across the outside of the heater jacket. Temperatures at all locations were increased at the floor and living area. Temperature differences from floor to ceiling were decreased a maximum of 16.3° F., and the maximum difference between rooms at the 30-inch level was decreased 15.8° F. The temperature was increased from 1.7° to 5.2° F. at the floor and from 1.6° to 2.8° F. at the living zone.

In another test a 16-inch ventilation fan was placed in an open radiation door of the heater jacket (Test G, Table 3) in House No. 2. The fan blew air up and across the heater fire pot inside the jacket and out the top grille. Temperatures were increased at the floor and living zone and decreased at the ceiling in each room. Temperature differences were decreased as much as 1.3° F. from floor to 3-inch level, 3.8° F. from floor to 60-inch level, and 18.8° F. from floor to ceiling. The maximum horizontal difference between rooms was decreased 9.5° F. Even though this fan was set on low speed, air velocities near it were rather high. Since all temperatures were higher than those usually considered satisfactory, it appears that a smaller fan would have been sufficient.

RELATION OF ROOM TEMPERATURES AT THE LIVING ZONE TO DISTANCE FROM THE HEAT SOURCE

Gravity heat distribution with a jacketed space heater is dependent upon temperature differences. As the distance from the heat source is increased, the temperature for a given height above the floor will decrease. As the temperature decreases the relative humidity increases; therefore, an exact area where conditions are, or are not, desirable is difficult to define. This is assuming neither forced circulation nor obstructions to heat flow.

Figure 16 shows relation of temperature at the living zone to distance from the heat source as obtained in House No. 1 for a range in outdoor temperature of 20° to 30° F. It can be seen from these curves that in each test (except E) the temperature decreased as the distance increased within the living room where there were no obstructions to heat flow. Due to obstruction of walls, temperatures decreased sharply with respect to distance, even with forced circulation, as air moved from the living room to those adjacent. In Test E a 500 cfm. fan was circulating air through the floor duct system (forced convection). Temperatures were higher in the utility room than in the bathroom, even though the distance was greater from the heater, because warm air flowed to the utility room through two doors.

There is less than 3° F. difference shown in Figure 16 between any two tests at any location (except Test E at one point in the living room), but it should be remembered that forced circulation affected temperatures at the living zone less than at any other elevation. For example, forced circulation gave the greatest effect in decreasing temperatures near the ceiling and increasing those near the floor. All of these temperatures were sufficiently high for comfort except those in the bathroom, which should have been from 2° to 5° F. higher.

It can be seen in Figures 17, 18a and 18b (Tests of House No. 2) that

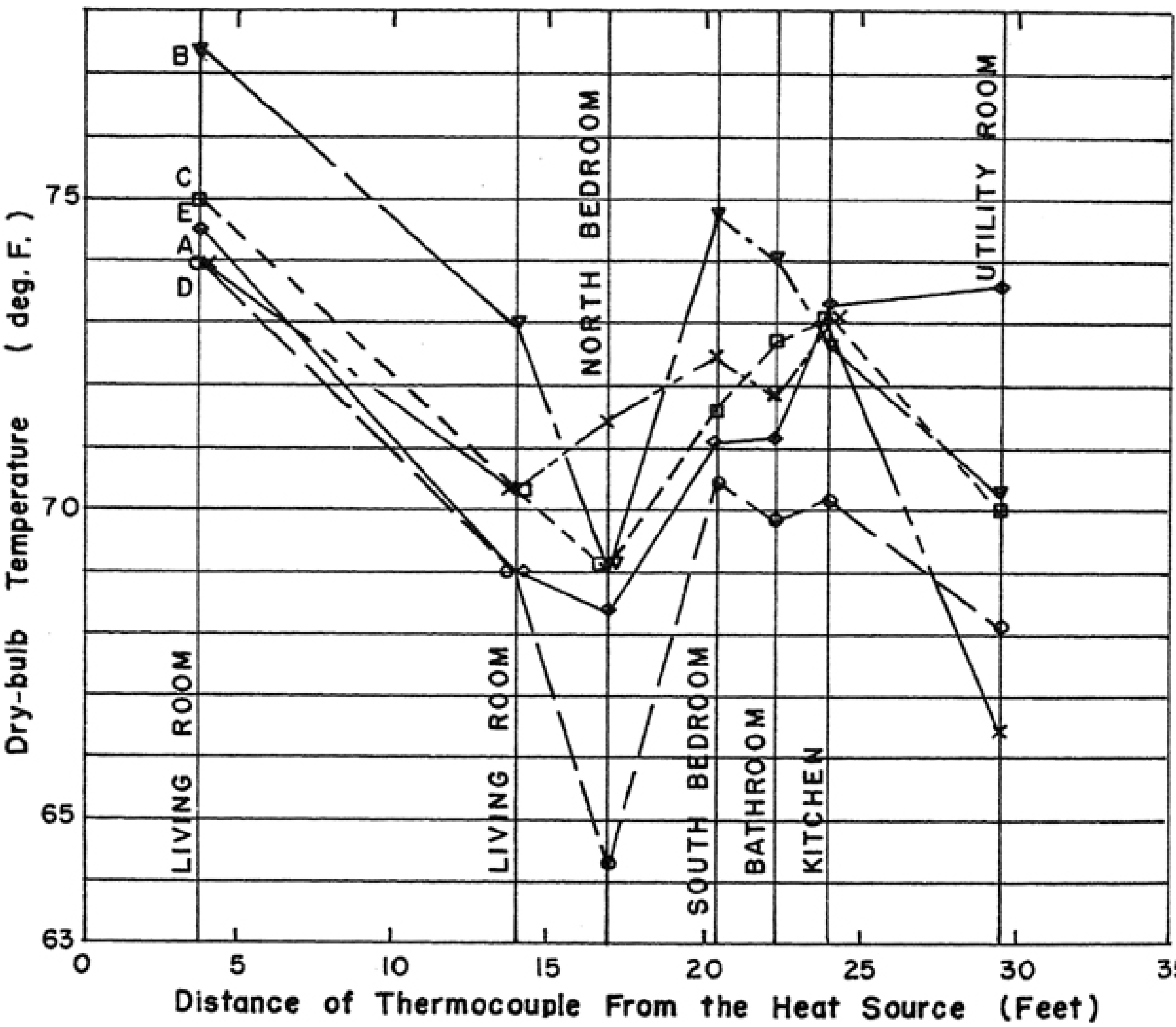

Figure 17. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 2 for a range in outdoor temperature of 20° to 30° F. (1949-50).

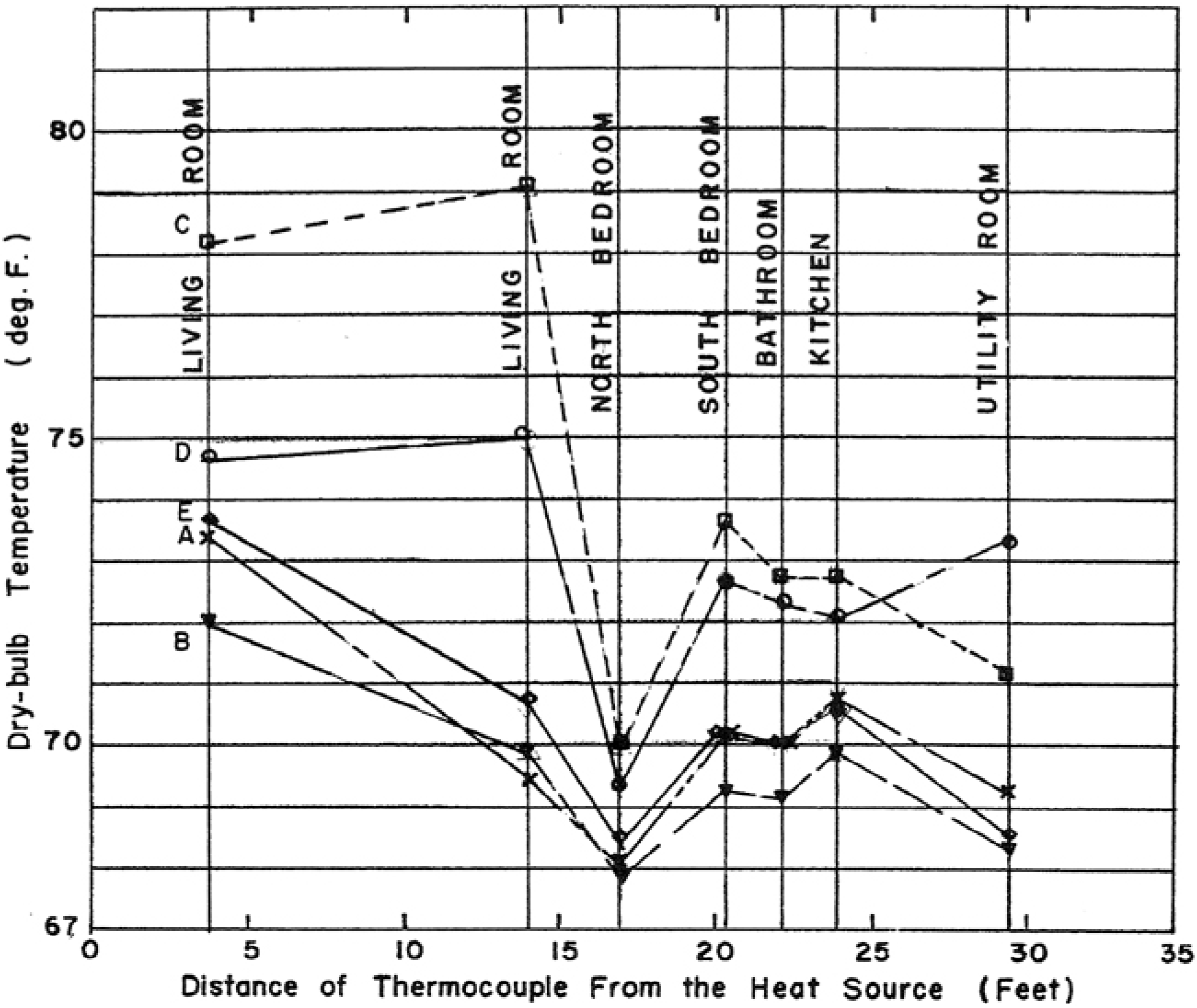

Figure 18a. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 2 for a range in outdoor temperature of 20° to 30° F. (1950-51).

most all tests maintained temperatures higher than actually desirable in each particular room. All tests maintained temperatures in the south bedroom too high for comfort. One reason temperatures ran lower in the north bedroom than those at greater distances, is because there were three windows in it that fitted loosely and permitted a high rate of cold-air infiltration. Again it is indicated in Test C of Figure 18a and Test H of Figure 18b that as the temperature is increased or the heat output is increased, temperature differences between rooms increase.

In Figures 19a and 19b (Tests of House No. 3) the effects of a high ceiling are illustrated. Temperatures in the living zone dropped from 7° to 10° F. from living room to bathroom (14 feet). The only opening for warm air flow to the bathroom was one door approximately 7 feet high. This necessitated a bank of high temperature air 2 feet 5 inches in depth near the living room ceiling before temperatures in the bathroom could be affected.

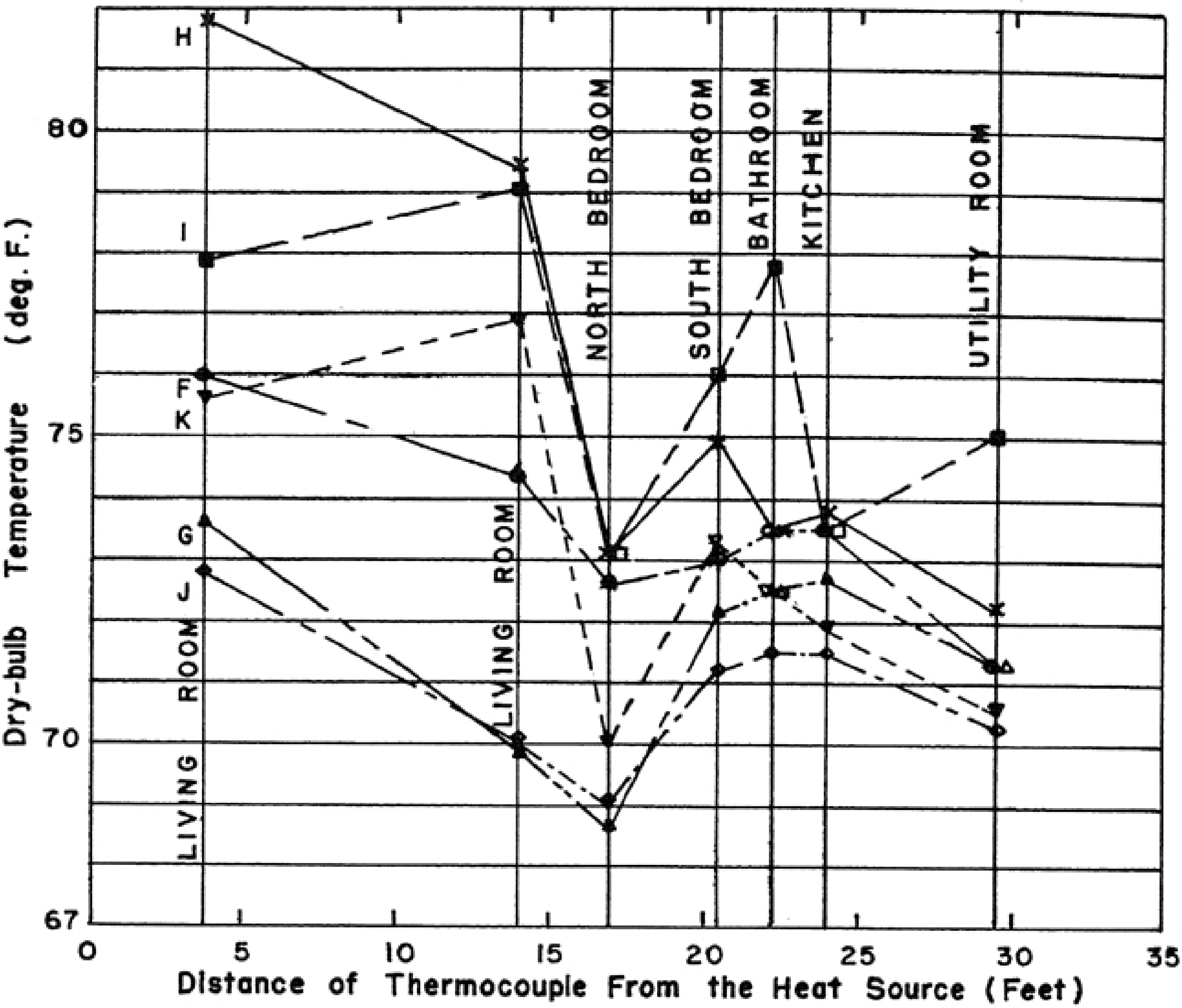

Figure 18b. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 2 for a range in outdoor temperature of 20° to 30° F. (1950-51).

Temperatures in all rooms other than the living room in House No. 3 ran slightly lower than desirable, but it should be remembered that relative humidity percentages were comparatively high, which increased the degree of comfort. It was concluded that before this house could be heated by a single circulating heater within the desirable limitations set by the United States Bureau of Standards (1), the ceiling should be lowered, or more openings provided for transferring heat to outlying rooms, or both. Also, the capacity of the heating unit should be increased or rate of heat loss from the house should be decreased.

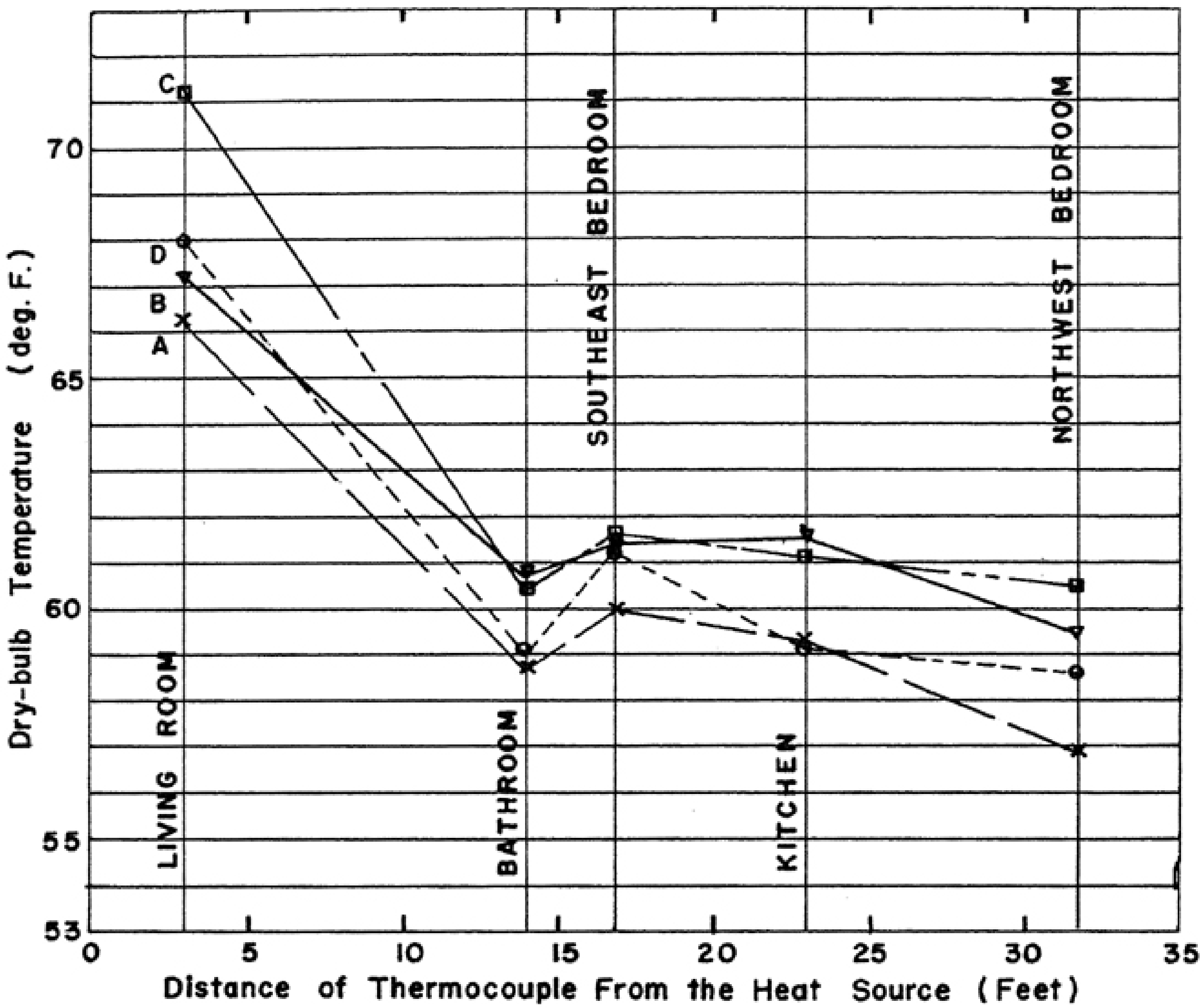

Figure 19a. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 3 for a range in outdoor temperature of 20° to 30° F.

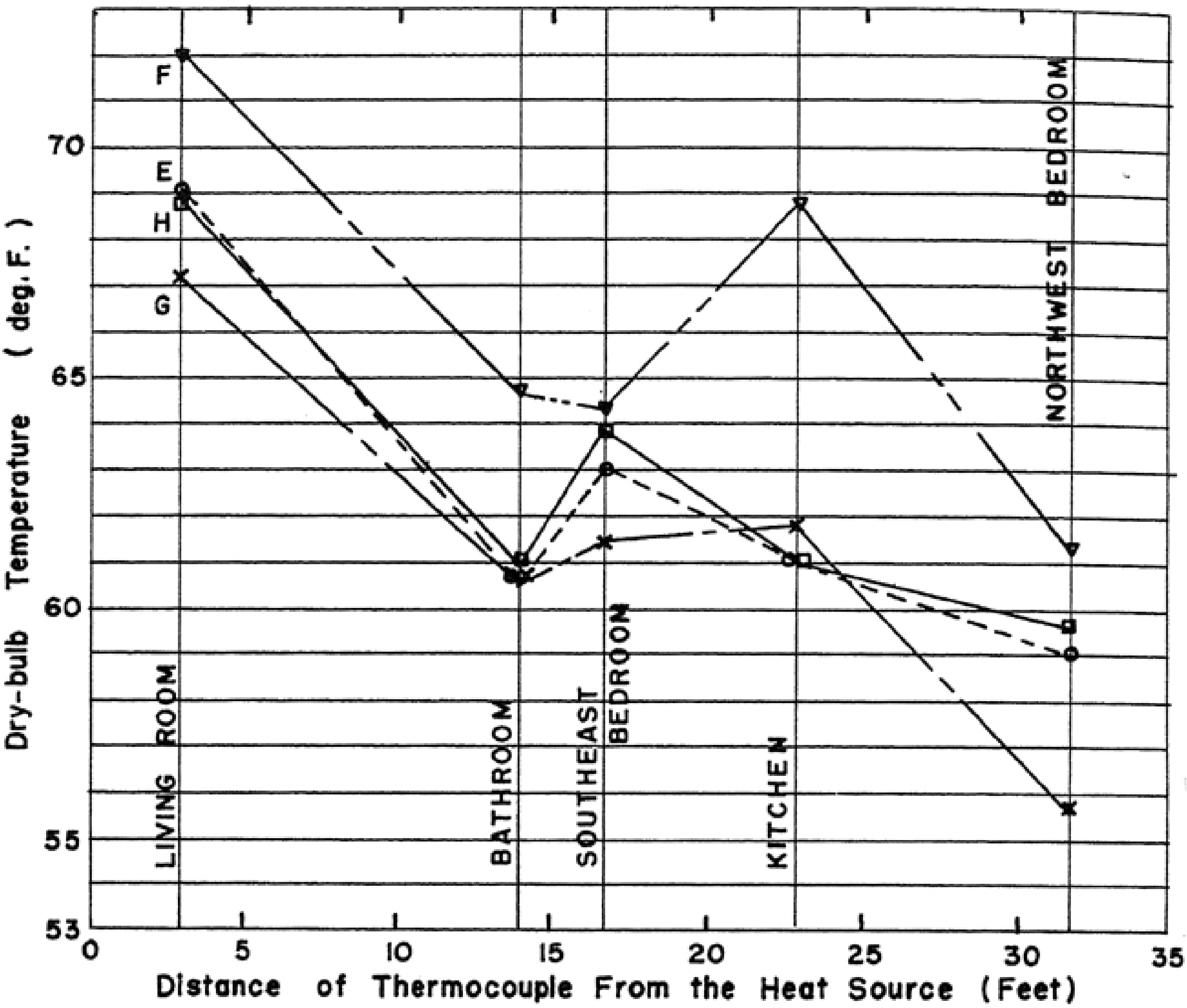

Figure 19b. Relation of dry-bulb temperatures at 30 inches above floor to distance of thermocouple from the heat source in House No. 3 for a range in outdoor temperature of 20° to 30° F.

SUMMARY AND CONCLUSIONS

The objective of this study was to determine the effectiveness and also the limitations of oil-fired circulating heaters in supplying and distributing winter heat in three small farm homes. Another objective was to determine the effectiveness of additional means for distributing heat throughout the house. Various sizes of fans from 150 to 500 cfm. (cubic feet per minute discharge) were tested under different conditions. Under-floor duct systems were tested with and without forced circulation in two houses. The effectiveness of transom openings above interior doors was investigated. Small low-cost overhead ducts were used in two cases to transfer heat to outlying rooms.

Three houses were studied during the 1949-50 heating season and the investigation was continued in one house during the 1950-51 season. An oil-fired jacketed circulating heater was used in each house. The fuel combustion was controlled automatically by a room thermostat set at 78° F. throughout all tests. House No. 1 was occupied intermittently during the tests; House No. 2 was occupied during the 1949-50 season but unoccupied during 1950-51 season; House No. 3 was occupied during all tests.

Data obtained include dry-bulb temperatures at specified elevations in each room, relative humidity in at least three locations in each house, and outdoor dry-bulb temperature. Accurate fuel consumption measurements were secured only in House No. 2 during 1950-51 season. Wind movement and solar radiation were not correlated with the observed data.

The following conclusions are made:

1. In general, small one-story dwellings can be heated satisfactorily with a single space heater and ventilation fans if the weather is not too severe, the heat loss is not too great, and the arrangement of interior walls and openings are such that they do not greatly obstruct heat distribution.
2. Temperature differences from floor to ceiling vary almost directly with fuel consumption. Hence, heat loss from the structure should be minimized to keep the fuel consumption low. This illustrates the value of insulation.
3. Fuel consumption varies inversely with the outdoor temperature and also inversely with forced circulation. Fuel consumption can be decreased by the use of fans to promote circulation.
4. Under-floor duct systems alone are of little value for heat distribution, but with forced convective circulation through the ducts temperature differences from floor to ceiling show marked decrease. Temperatures in the living zone can thus be improved.
5. Transom openings above interior doors are of little value to heat transfer, but those used in this study were small and if the openings were large enough and sufficient in number it is possible that considerable warm air could be transferred to outlying rooms in this manner.
6. Fans integral with heater can improve living zone temperatures to a marked degree throughout a small house.
7. Fans improve warm air distribution in proportion to their distance from the heater. Close location to the heater is more desirable. Good improvement can be gained by placing a fan directly behind the heater, blowing air up and across the heater. This accords with Achenbach's (1) conclusions.
8. Overhead or above-ceiling air ducts are effective in heating an outlying room directly. Efficiency is increased by mounting a fan in such ducts to promote forced convection (Figure 8). This device is less effective in houses having ceiling heights greater than 9 feet.

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