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A Comparison of Radiant and Circulating Space Heaters in Farm Dwellings

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INTRODUCTION

Many types of space heaters are in use in farm dwellings at the present time. They are manufactured and sold with and without jackets. Those with jackets are assumed to heat by convection currents of air which are warmed by passing over the combustion drum. Heaters which are manufactured without jackets are called radiant heaters and are presumed to heat for the most part by radiation. Actually, however, heaters of both types heat by a combination of convection and radiation.

Space heaters commonly use several different types of fuel; oil-burning heaters only were used in this study.

The investigation reported in this bulletin was to compare the heating characteristics of a radiant heater with the heating characteristics of a circulating heater in a small unoccupied experimental farm house. The comparison was made on the basis of the fuel required by each to maintain a given thermostat setting, by comparing the distribution of warm air, and by studying the ability of each to circulate warm air to rooms other than that in which the heater was located.

LITERATURE

Senner[2] found that the cost of heating a house depends mainly upon (1) the average outside air temperature and the exposure of the house to wind, (2) degree of weather tightness of the house, (3) average temperature maintained inside the house, (4) efficiency with which the fuel is burned, and (5) unit cost of the fuel. It was implied in this work that the variables relating to the house were more important with respect to heating costs than the heating systems themselves.

[1]This bulletin is based on a thesis submitted by Mr. Phillips 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. This study was made as a part of the North Central Regional Project NC9 on Farm Housing Research, and was partially financed by funds authorized by Section 9BC Title 1 of the Research and Marketing Act of 1946.

[2]Arthur H. Senner, "Results of House Heating Studies," *Agricultural Engineering*, 16:450, November. 1935.

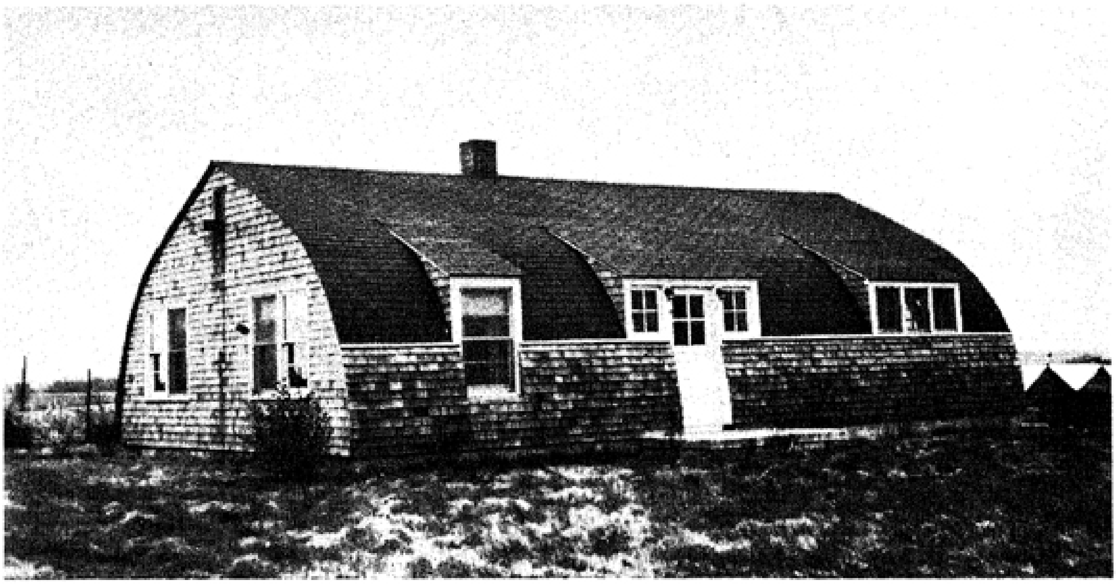


Fig. 1. Exterior view of the test house from the northwest corner.

Achenbach[3] of the National Bureau of Standards reported a detailed study of space heaters in 1949. He concluded that:

(1) A jacketed heater produced lower temperature differences between rooms than a radiant heater.

(2) A radiant heater produced slightly lower temperature differences between the levels of 2 and 60 inches above the floor.

(3) A radiant heater maintained a given temperature condition in the living zone with 15 to 20 per cent less heat output than a jacketed heater.

(4) The size of the heater within the range of sizes used had little bearing on temperature distribution.

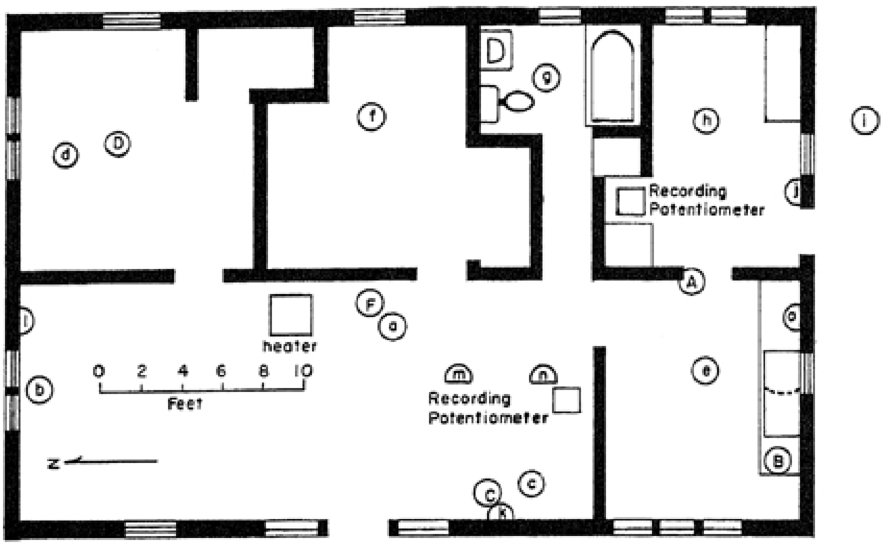
MATERIALS AND METHODS

House. The tests here reported were conducted in a five-room, one-story house constructed on a concrete slab, without a basement. The house, located on a farm near Columbia, Missouri, occupies a ridge with very few wind-breaks in the vicinity. (See Fig. 1.)

The house is of good construction, with walls and ceiling insulated by glass wool bats. The edges of the concrete floor slab are insulated by foam glass blocks. A floor plan of the house is shown in Fig. 2, which also indicates the locations of the instruments used.

Weather stripping was not used on the windows or doors. Infiltration of cold air into the house was considered rather excessive.

[3]Paul R. Achenbach, "Temperatures in a Test Bungalow With Some Radiant and Jacketed Space Heaters," Building Materials and Structures Report B.M.S. 114, (Washington, D. C.: United States Government Printing Office, 1949).



a,b,c,d,e and f thermocouples at 3", 30" and 93" above floor.
g and h thermocouples at 30" above floor.
i outside thermocouple shielded from radiation. (8' from wall)
j, k, and l surface thermocouples 30" above floor.
m surface thermocouple on ceiling.
n surface thermocouple on floor.
o surface thermocouple 45" above floor.
A hygrothermograph in attic.
B hygrothermograph 36" above floor.
C and D hygrothermographs on floor.
F fuel tank and water level recorder.

Fig. 2. Floor plan of the test house showing heater, thermocouple and recording instrument locations.

Heater. The heater used in these experiments is shown in Fig. 3. It was a Kenmore pot-type oil-burning circulating heater. This was a low-cost commercial space heater constructed of sheet iron. It was equipped with a commercial device for operation from a thermostat.

The manufacturer's rating of the heater was 49,000 Btu per hour maximum output.

For the circulating heater test, the heater was used as shown in Fig. 3. For the radiant heater test, the jacket was removed from that same heater. Refer to Fig. 4.

Fuel Measurement. The 5-gallon tank constructed with the heater was removed and an 11-gallon tank was connected to the valve assembly. The float of a Frieze water level recorder was placed inside the 11-gallon tank in such a manner that fluctuations in the level of fuel in the tank were recorded by the water level recorder. This arrangement is shown in Fig. 5. The fuel consumption of the heater was thus automatically recorded with an accuracy of about 0.01 gallons.

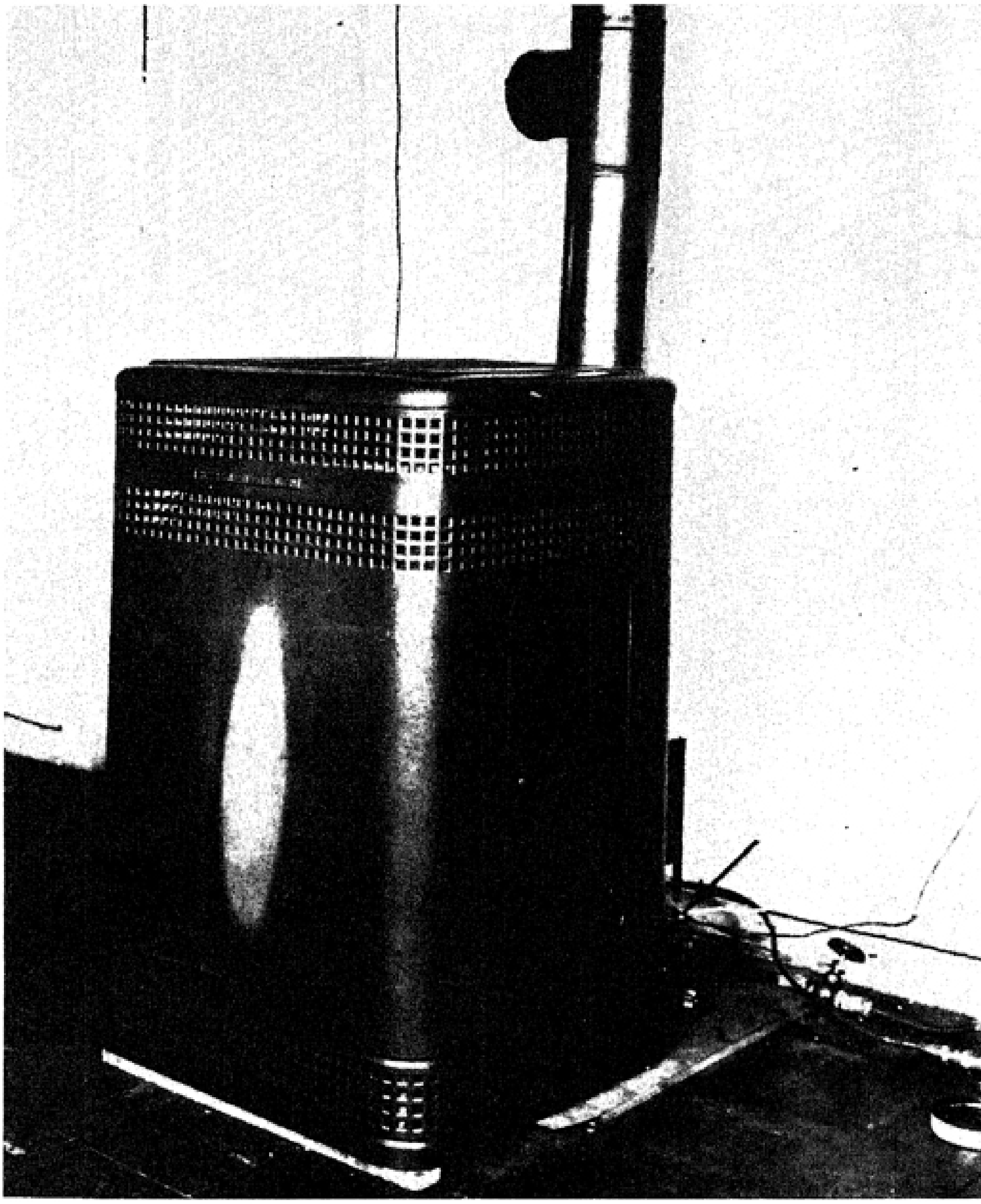


Fig. 3. The circulating heater used for the heating tests. Note that the heater is equipped with a commercial model automatic draft regulator.

Temperature Measurement. Copper - constantan thermocouples were used to measure the air temperatures at the various points selected throughout the house. See Fig. 2. The thermocouples were made from 20-gage duplex wire with soldered junctions.

Outside air temperature was measured with a 30-gage copper-constantan thermocouple shielded from solar radiation.

Surface temperatures of the floor and walls of the house were taken by means of 30-gage thermocouples attached to the surfaces and partially buried therein.

The electromotive force of the various thermocouples was recorded by two 16-record Brown Electronic Recording Potentiometers.

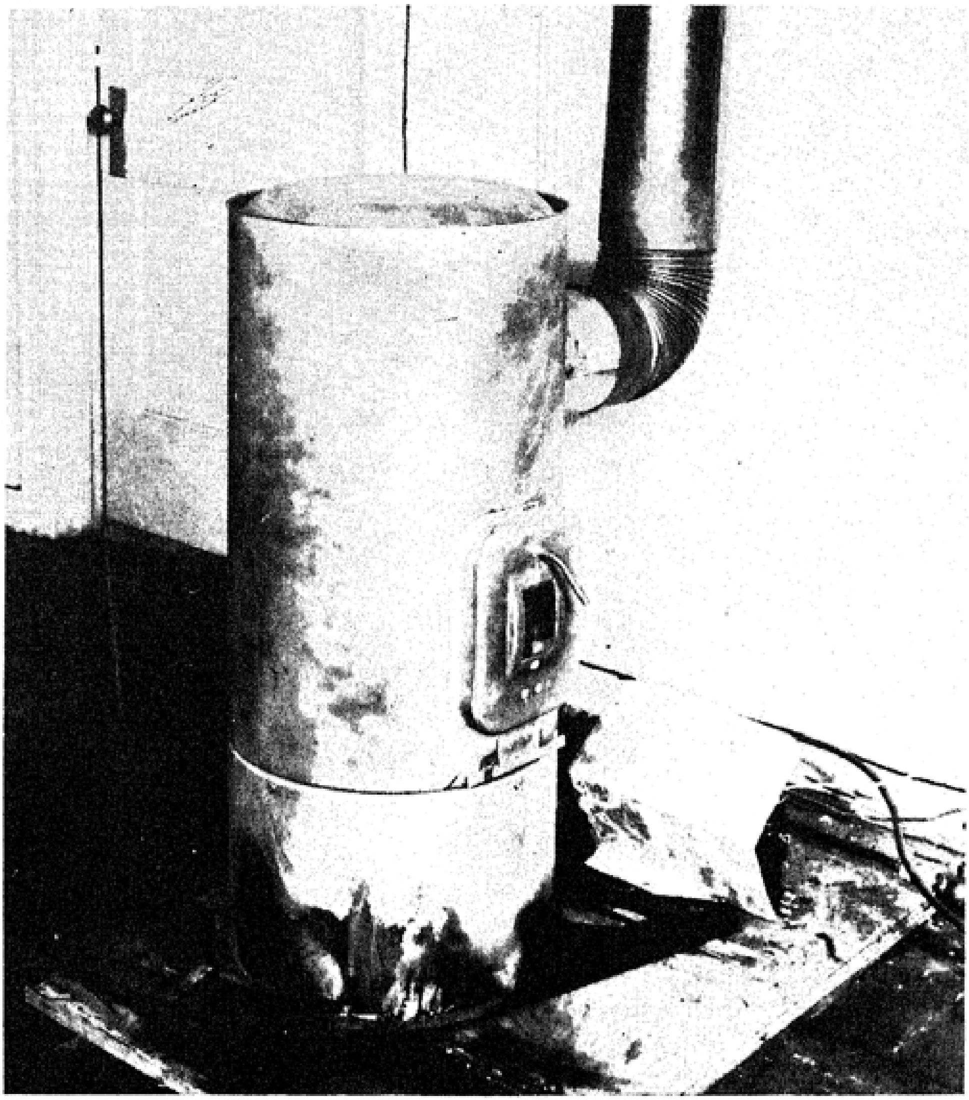


Fig. 4. The radiant heater used for the heating tests. This is the same heater shown in Fig. 3, with the jacket removed.

Strip charts calibrated in degrees Fahrenheit were used. Each instrument recorded a temperature reading every 30 seconds and required 8 minutes for a complete cycle. Frequent checks of potentiometer performance were made by use of a mercury thermometer.

Wind and Solar Radiation. These data were secured from the U. S. Department of Commerce Weather Bureau station located at the Columbia Municipal Airport. The station is located 6 miles northwest of the test house. Wind movements are measured by the Weather Bureau by a cup-type anemometer. Solar radiation is measured by use of an Eppley pyrheliometer.

Test Periods. The heating tests were commenced November 1, 1951 and completed by February 12, 1952. Alternate tests were run with the jacket off the heater and with the jacket on. No definite time was used for alternating the test. A tentative schedule was set

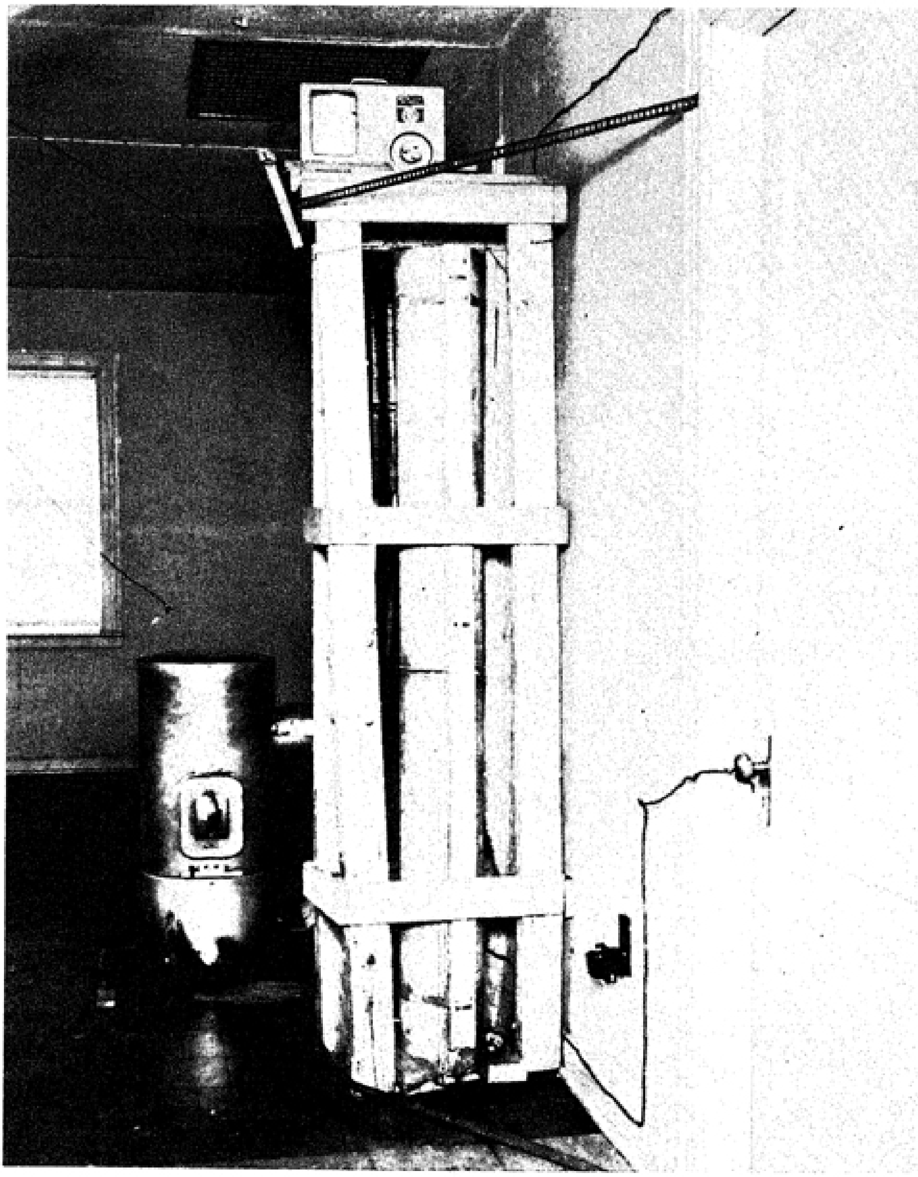


Fig. 5. The fuel tank and water level recorder used for measuring the fuel consumed, shown with radiant heater.

up to change the test every two weeks, but dependent on weather conditions.

The outside air temperatures ranged from 8° to 65°F. for both tests. Only the data for air temperatures from 10° to 50°F. were analyzed. The outside air temperature fluctuations were favorable; an approximately equal amount of data were secured for each test throughout the range of analyzed data.

Procedure. The thermostat setting was 70°F. during the entire test period. All inside doors in the house remained open. Window shades were completely drawn on all of the double-hung windows and on the south outside door.

For both tests air velocities were measured in the living room and in inside doorways of the house. These measurements were made to study the convection characteristics of the two different heaters.

Surface temperatures of the two heaters were measured at various times by use of thermocouples. These measurements were considered approximations only.

The daily wind movement at the test house was compared with the wind movement at the Weather Bureau station. The correlation between the measurements taken at the two places was not good. However, it was believed that the wind effect at the two locations was approximately equal and that the poor correlation was probably due to turbulence around the anemometer located at the test house. The wind velocity recorded each hour at the Weather Bureau station was used as part of the test data.

Relative humidity within the house was not under control during the testing periods.

DATA AND THEIR ANALYSIS

Comparative Fuel Consumption

Lag in the Rate of Fuel Burned With Respect to Outside Temperature Changes. Analysis of the data relating to fuel consumption and outside air temperature showed that the fuel burned per hour lagged about two hours with respect to the changes in hourly outside air temperature.

This two-hour lag of the rate of fuel burned with respect to outside air temperature was used throughout the experiment for the determination of the wind and solar radiation effects on fuel consumption and for the comparison of fuel consumed between the two test conditions.

Wind Effect on the Rate of Fuel Burned. The effect of wind on the rate of fuel consumed was assumed to have a two-hour lag, similar to a change in outside air temperature. Outside air temperatures of 20°, 30°, and 50°F. were selected as levels at which to make an analysis of the effect of wind velocity. The results of this analysis are shown in Figs. 6 and 7.

The correlation of these plotted values was low. The change of the rate of fuel burned due to wind velocity was greater at lower temperatures; however, the difference of the change was not significant for the outside air temperature range of 20° to 50°F. The average rate of change of fuel burned was 0.0051 gallons per hour for each mile per hour difference in wind velocity.

The average rate of change of fuel consumed by both heaters per degree F. change in outside air temperature was 0.0048 gallons per hour. This was approximately the same as the change in fuel con-

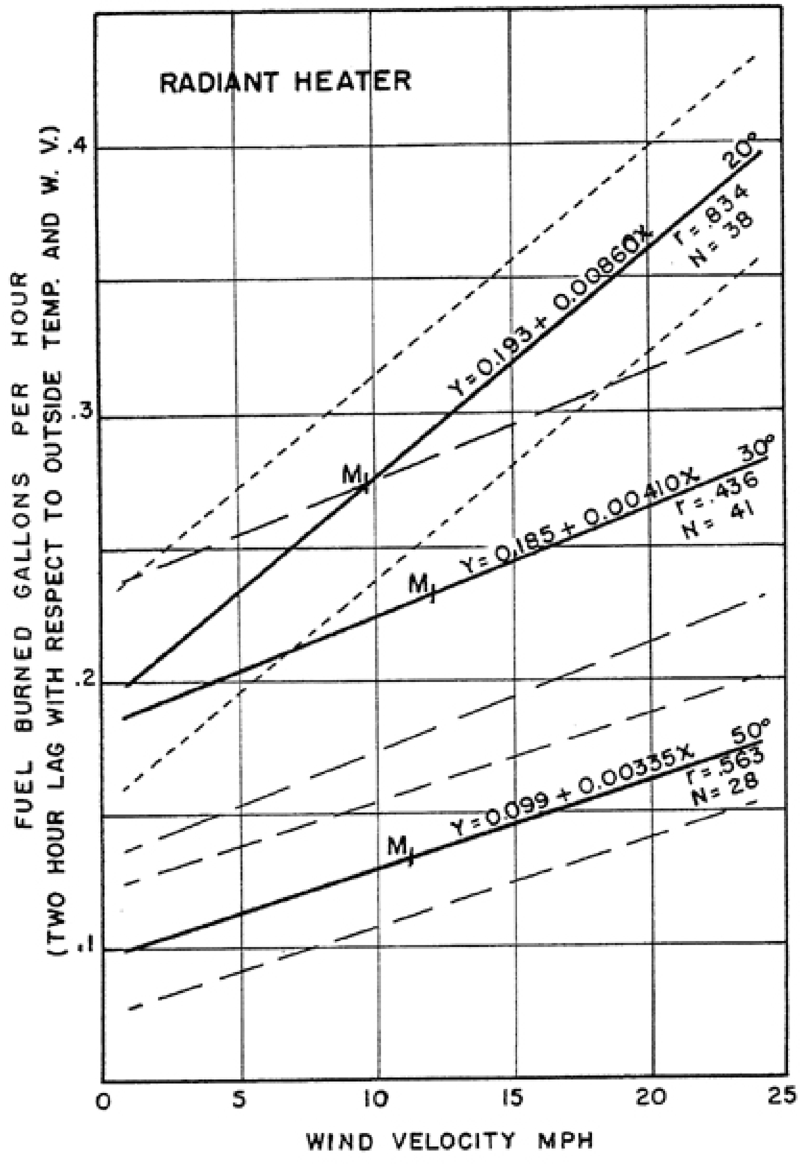


Fig. 6. The effect of wind velocity on the rate of fuel consumed by the radiant heater at 20°, 30° and 50°F. outside air temperature. Shown are the number of values in each sample, the mean (M) of these values, the coefficients of correlation and the standard error of estimate of each regression line.

sumed per mile per hour change in wind velocity. Thus the relation that a change of one mile per hour wind velocity was inversely proportional to a change of one degree F. in outside air temperature was used to correct outside air temperature for wind velocity.

It was found that by using the above-mentioned correction, the correlation between fuel consumed and outside air temperature was appreciably improved. It was also found that if the data were selected for wind velocity increments of 5 miles per hour, the correlation between fuel consumed and outside air temperature was improved as much as by using the above correction.

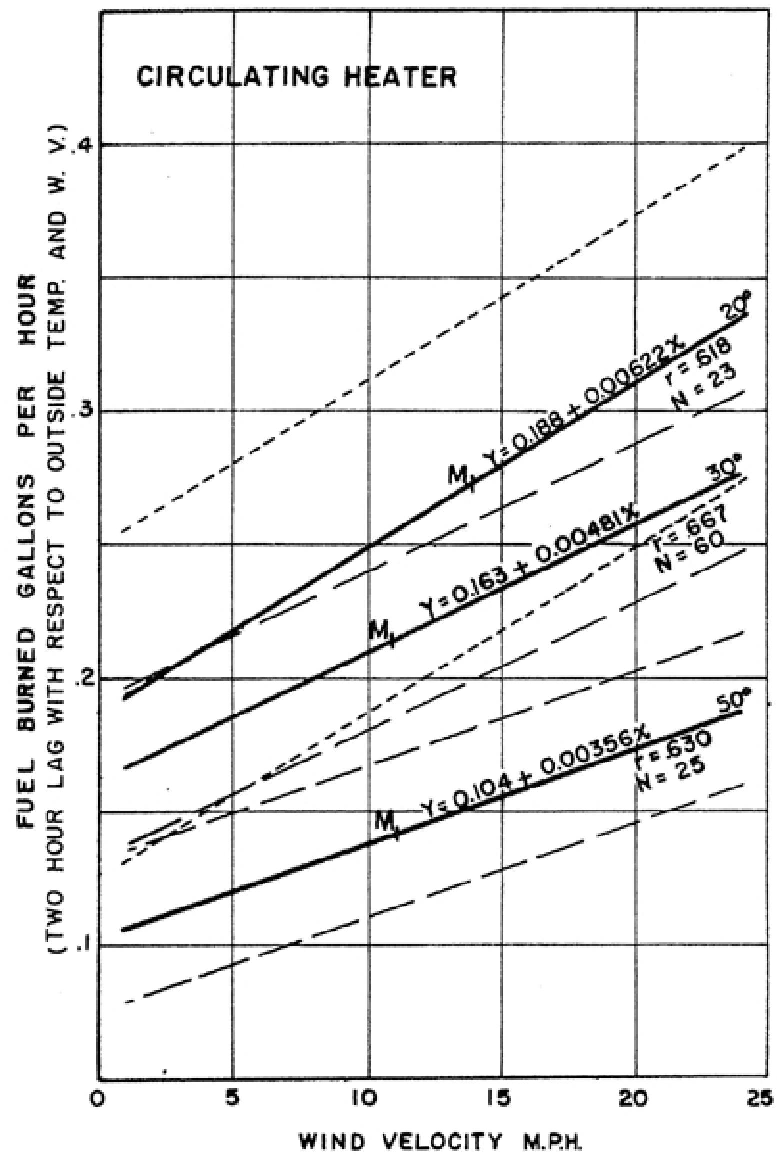


Fig. 7. The effect of wind velocity on the rate of fuel consumed by the circulating heater at 20°, 30°, and 50°F. outside air temperature. Shown are the number of values in each sample, the mean (M) of these values, the coefficients of correlation and the standard error of estimate of each regression line.

In order to reduce the effect of wind on the fuel consumption comparisons, the following procedure was employed. Fuel burned in gallons per hour corrected for the two-hour lag previously mentioned was plotted against hourly average outside air temperature. These plots were made for a series of wind velocity increments ranging from 0 to 5 miles per hour, 6 to 10 miles per hour, 11 to 15 miles per hour and 16 to 20 miles per hour for the period of November and December and the period of January and February. Examples of these plots are shown in Figs. 8 through 11.

These graphs indicate that the variations in the rate of fuel burned between the radiant heater and the circulating heater for cor-

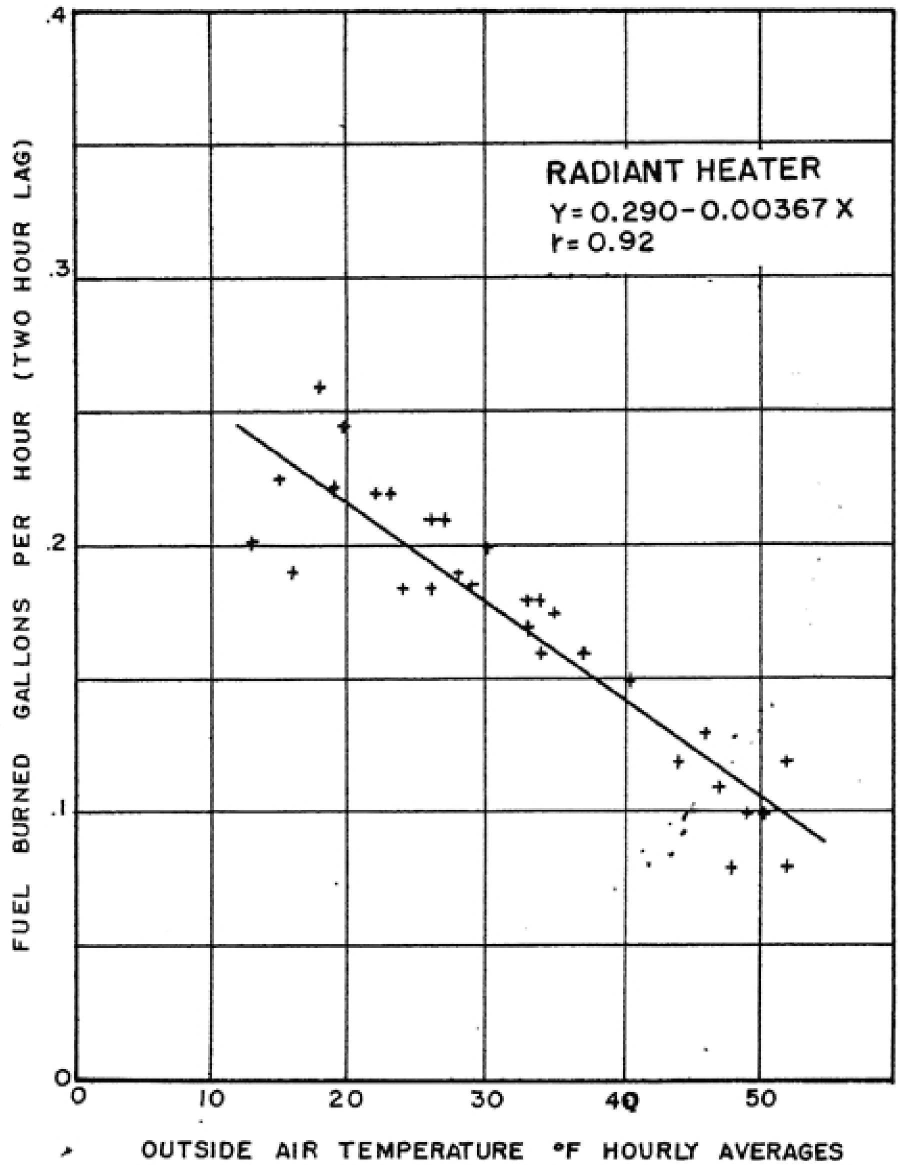


Fig. 8. Temperature-fuel curve for the radiant heater with a wind velocity of 6 to 10 miles per hour during November and December, 1951.

responding wind velocities were less than the variations in the rate of fuel burned between the radiant heater tests for different periods of time during the winter for the same increment of wind velocities. The variance between the plotted values for any given wind velocity increment with the circulating heater could happen as a result of chance more often than 5 per cent of the time. This also would apply to the radiant heater tests at wind velocities of 10 miles per hour or less. The increase of fuel burned per hour with a decrease in outside air temperature when using the radiant heater at wind velocities above 10 miles per hour was significantly greater during the tests of January and February than during the tests in November and December.

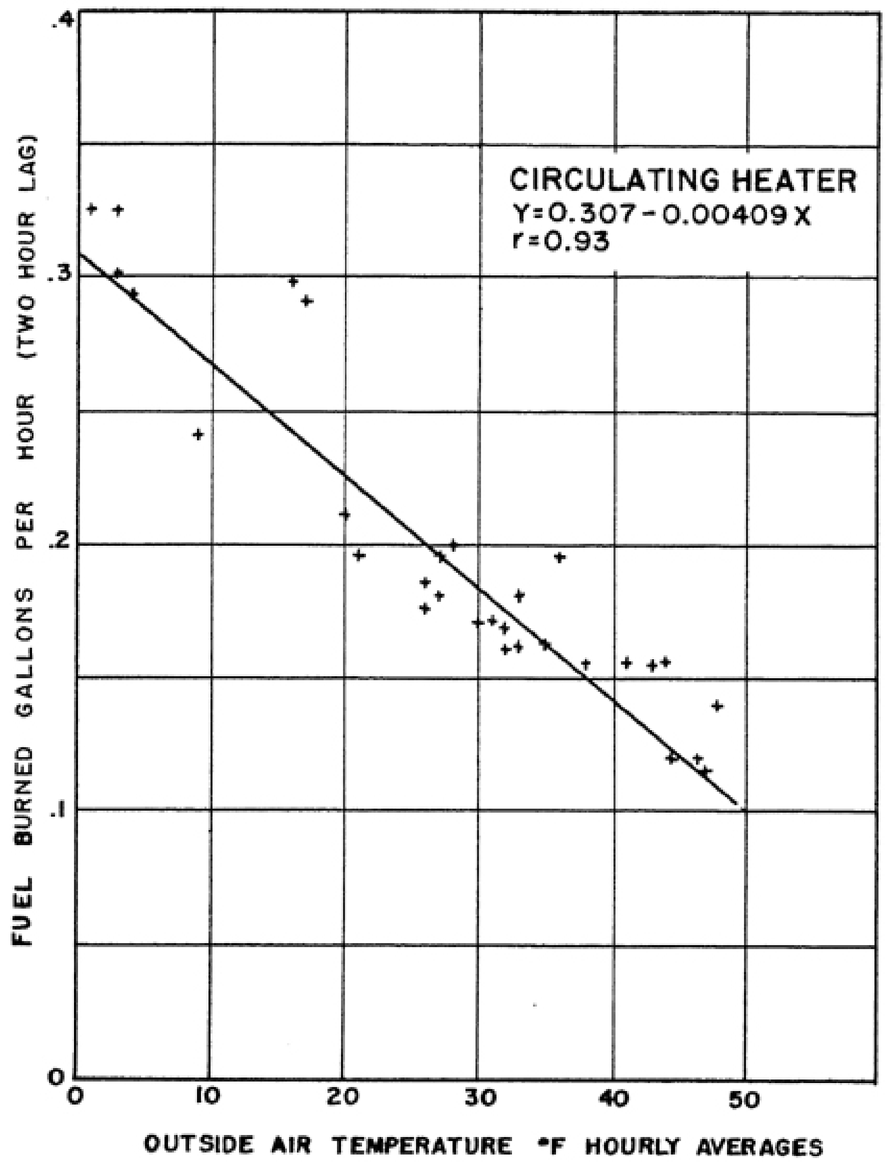


Fig. 9. Temperature-fuel curve for the circulating heater with a wind velocity of 6 to 10 miles per hour during November and December, 1951.

Under these conditions, it is shown that the tests gave no significant difference in the rate of fuel burned by the radiant heater when compared to the rate of fuel burned by the circulating heater. This statement is considered true for outside air temperatures of from 10° to 50°F.

Solar Radiation Effect on the Rate of Fuel Burned. The solar radiation effect was first analyzed on a daily basis. Fuel burned per day and daily averages of temperature and wind velocities were used to make the analysis. It was found that no significant difference existed in the average rate of fuel consumed per day that could be ascribed to the effect of solar radiation.

Solar radiation was analyzed further, on an hourly basis to de-

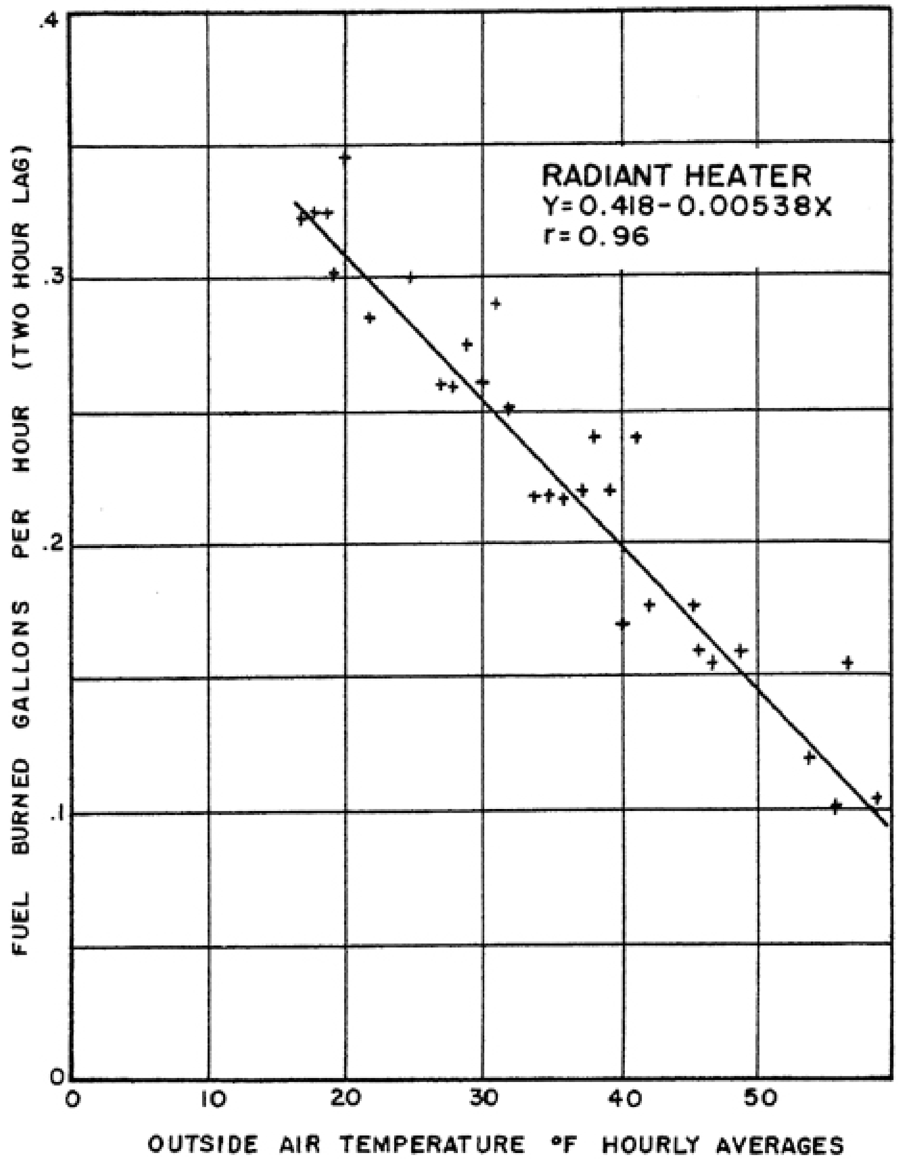


Fig. 10. Temperature-fuel curve for the radiant heater with a wind velocity of 11 to 15 miles per hour during January and February, 1952.

termine the difference between the daytime effect and the nighttime effect on the rate of fuel burned. Forty-four hours having relative high solar radiation (35 to 234 with an average of 149 Btu per square foot per hour, or 9.5 to 63.2 with an average of 40.3 calories per square centimeter per hour) were selected from *both* tests and compared with 44 hours at night as to the effect on the rate of fuel burned. The analysis of these data consisted in plotting the values of fuel burned per hour against outside air temperature corrected for wind velocity (one mile per hour wind velocity was used as inversely equivalent to one degree F. outside air temperature). The values during solar radiation were plotted in Fig. 12, and those for no solar

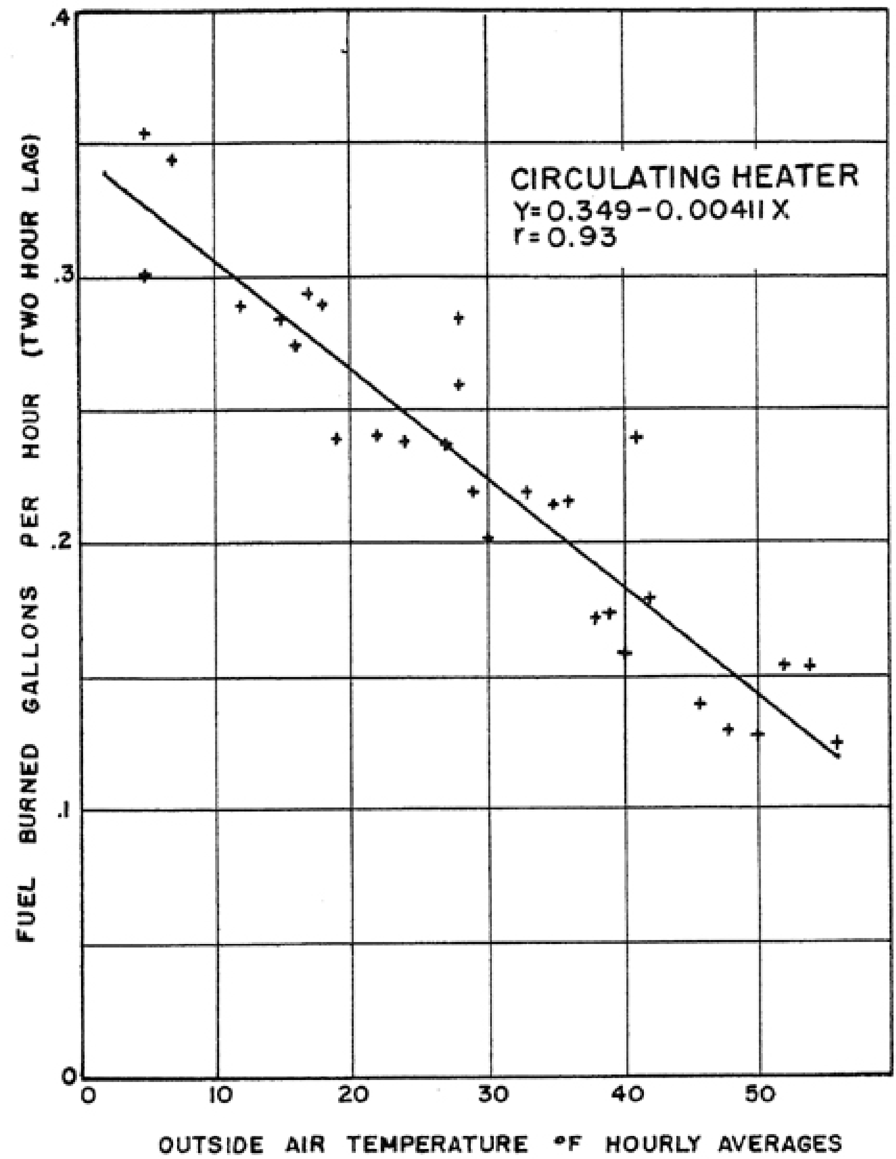


Fig. 11. Temperature-fuel curve for the circulating heater with a wind velocity of 11 to 15 miles per hour during January and February, 1952.

radiation in Fig. 13. The mean values of each of these plots were adjusted to the mean value of both plots along the slope of the least squares line of both plots. This showed that the difference in the rate of fuel consumed by both heaters at a wind-velocity-corrected temperature of 22°F. with solar radiation and without solar radiation was 0.036 gallons per hour. The analysis indicated that for each Btu per square foot per hour of solar radiation an expected reduction in fuel burned per hour of 0.00024 gallons would occur (0.00088 gallons per hour for each calorie per square centimeter per hour).

In consideration of the probable error operating in the above analysis the following factors must be considered. The film coeffi-

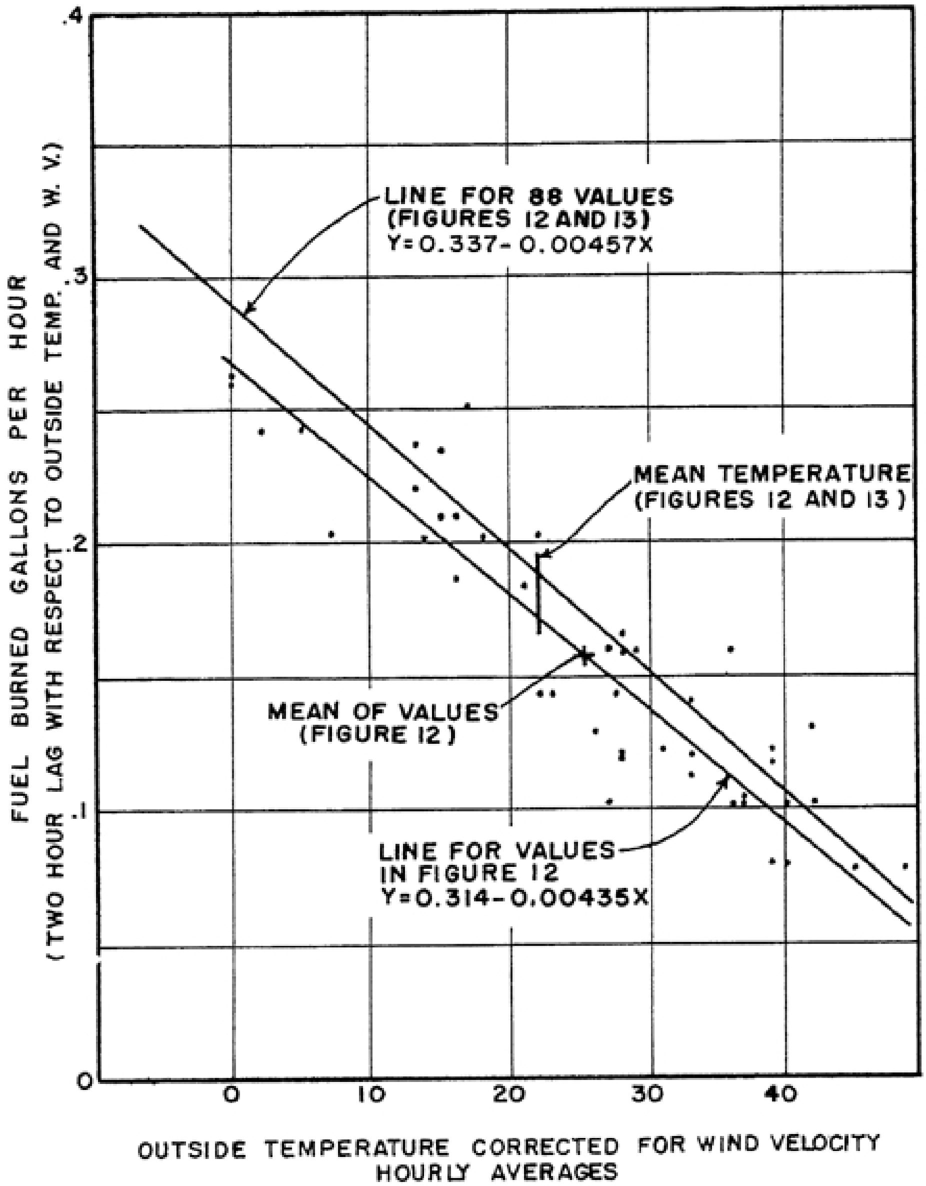


Fig. 12. Fuel consumed per hour by both heaters during hours with solar radiation (day time). The average radiation was 149 Btu per square foot per hour (40.3 calories per square centimeter per hour). Fuel plotted against outside air temperature, showing the least squares line for these values and the least squares line for the values of both Fig. 12 and Fig. 13.

cient of resistance of the outer surface of the house changes with changing wind velocity. The absorptivity or emissivity of the outer surfaces of the house may have changed during the test periods to an unknown degree. The changing angle of incidence of the solar radiation would possibly introduce errors in making the above comparison.

Since solar radiation of above 55 Btu per square foot per hour (15 calories per square centimeter per hour) occurred during less than 10 per cent of the test period, the data secured during higher

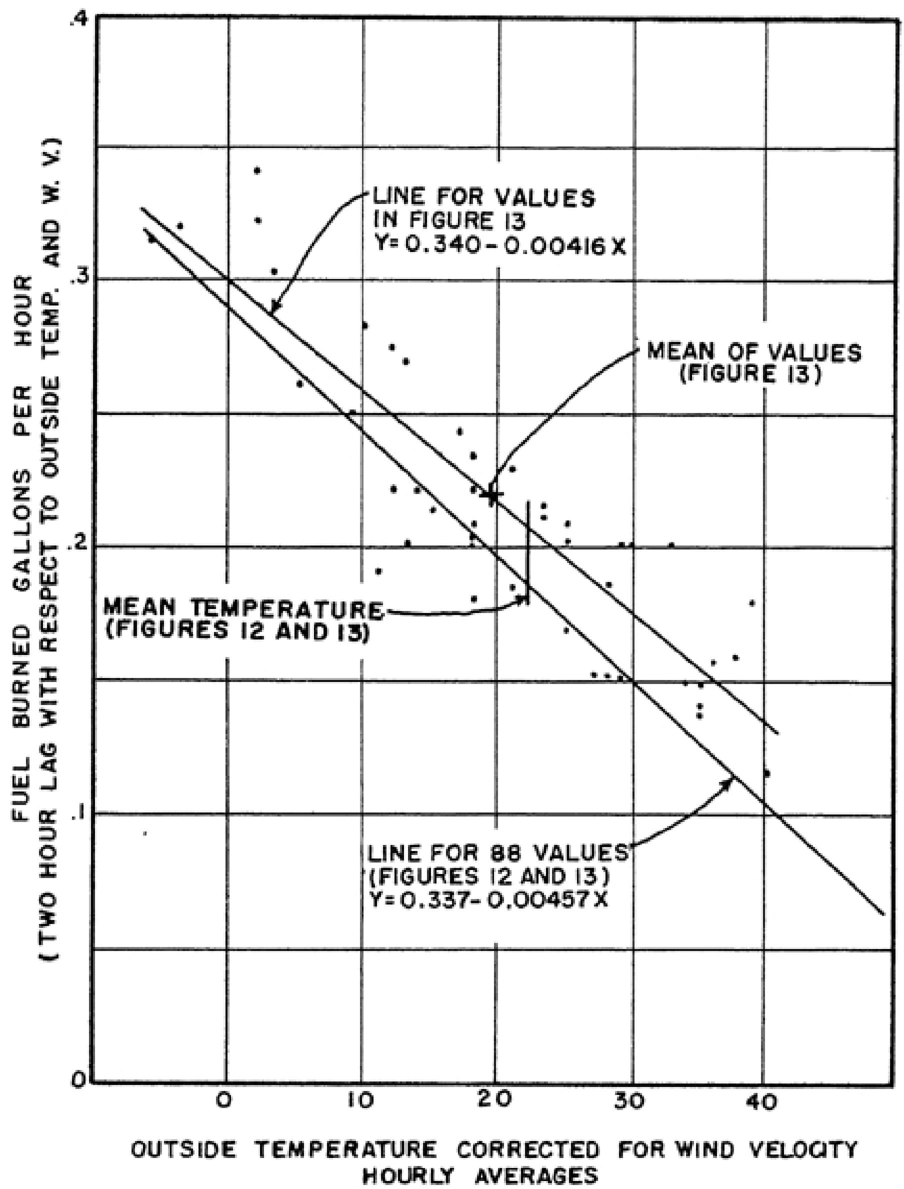


Fig. 13. Fuel consumed per hour by both heaters during hours with no solar radiation (night time) plotted against outside air temperatures, showing the least squares line for these values and the least squares line for the values of both Fig. 12 and Fig. 13.

solar radiation were not used in the previous comparisons of fuel consumed by each heater. See Figs. 8 through 11. This reduced the variable effects of solar radiation.

Temperature Distribution

Method of Analysis. Four one-hour periods were selected at four-hour to eight-hour intervals from each 24-hour day as a sample for study of the temperature distribution for both heater tests. The inside temperatures or combinations of these inside temperatures

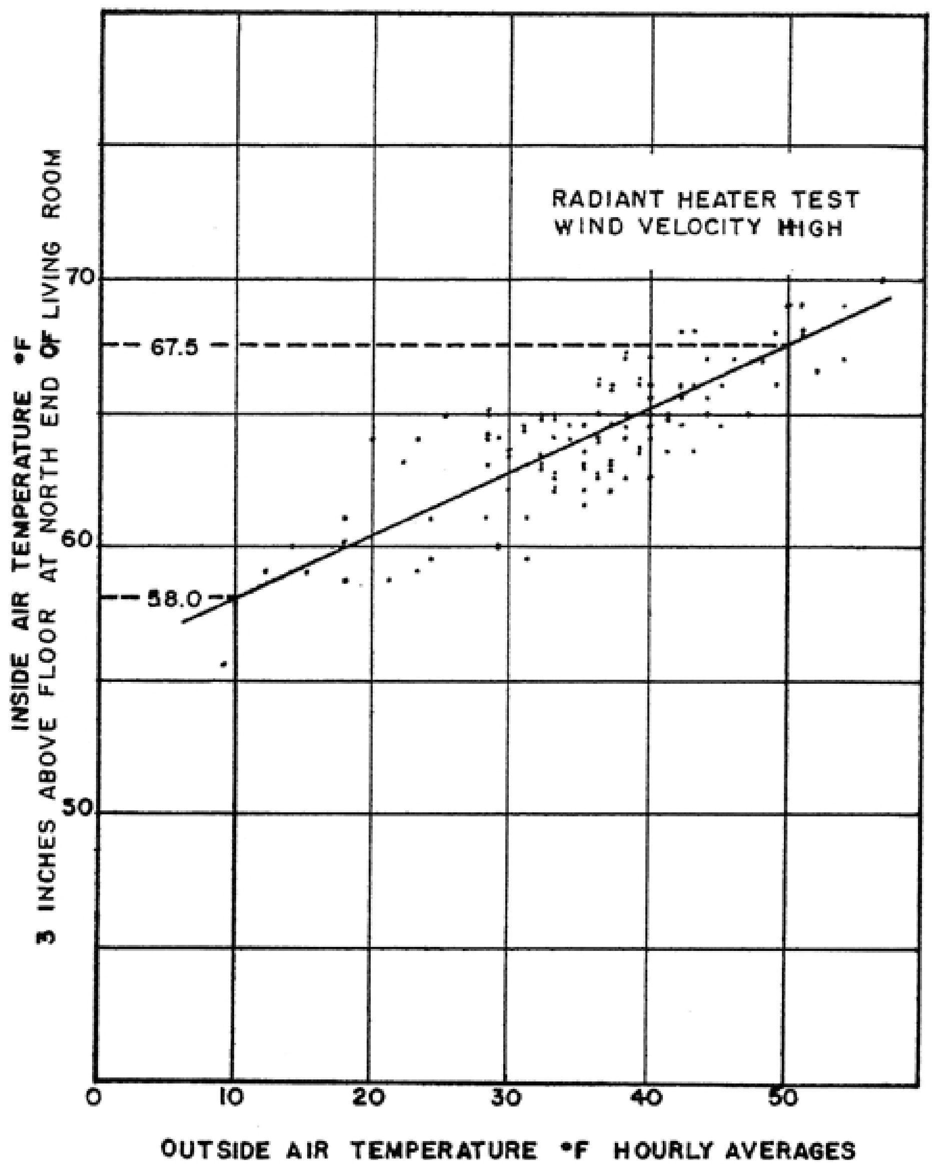


Fig. 14. Example of the method of determining the inside average temperatures at a given location or area with outside hourly average temperatures of 10° and 50°F. Detailed results of this method of analysis are shown in Tables 1, 2, 3, and 4.

maintained by the radiant heater tests were compared with those maintained by the circulating heater tests.

Two outside air temperatures were selected at which levels the inside temperature comparisons of the two heaters were made. The selected outside air temperatures were 10° and 50°F. The inside temperatures at the various locations under study, refer to Fig. 2, were plotted against outside air temperature. Hourly averages were used for each temperature plotted. A sample plot of this kind is shown in Fig. 14. As in the figure, the inside temperature values at the coordinates on this line corresponding to the outside air temperatures of 10° and 50°F. were used for the comparisons.

Comparisons were made at high and low wind velocities. Wind velocities above 10 miles per hour were considered as high and wind velocities of 10 miles per hour or less were considered as low.

Vertical Temperature Distribution. The main inside air temperatures at 3 inches above the floor, 30 inches above the floor, and 93 inches above the floor were determined as explained above for 10° and 50°F. outside air temperature. These determinations were made for each heater test.

It was found that the radiant heater maintained slightly higher air temperatures (0.5° to 3.5°F.) 30 inches above the floor than the circulating heater. The circulating heater maintained higher air temperatures (1.0° to 5.0°F.) at 93 inches above the floor (3 inches below the ceiling). When the outside air temperature was at 10 degrees, both heaters maintained higher inside air temperatures (1.0° to 1.5°F.) near the ceiling during high wind velocities than during low wind velocities. A summary of results of the vertical temperature distribution investigation is shown in Table 1.

Table 1. Mean Temperaturers at 3, 30 and 93 Inches Above the Floor*

	Radiant Heater			
Wind Velocities	High		Low	
Outside Air Temperatures	10	50	10	50
Inside Temperatures				
3 in. above floor	58.5	67.5	59.6	66.5
30 in. above floor	62.5	69.0	63.0	69.0
93 in. above floor	78.5	76.0	77.5	76.5
	Circulating Heater			
Wind Velocities	High		Low	
Outside Air Temperatures	10	50	10	50
Inside Temperatures				
3 in. above floor	58.0	66.0	60.5	66.5
30 in. above floor	59.0	68.0	62.5	68.5
93 in. above floor	83.0	77.5	82.5	77.5

*Values in all tables represent the Arithmetic mean of 100 or more readings.

Horizontal Temperature Distribution. The comparison of the horizontal distribution of outside air temperatures was made by determining the average air temperature at each thermocouple, see Fig. 2, for each heater test. The mean of the air temperatures measured at 3, 30, and 93 inches above the floor was found for each hour

Table 2. Mean Temperatures at Thermocouple Columns Located in Figure 2

	Radiant Heater			
Wind Velocities	High		Low	
Outside Air Temperature	10	50	10	50
Location of Column				
3.5 ft. south of heater	74.5	75.0	74.5	75.0
South end of living room	70.0	73.0	70.5	72.0
North end of living room	68.0	72.0	68.5	72.0
Kitchen	65.5	70.5	65.0	70.5
South bedroom	64.0	69.0	65.0	69.5
North bedroom	61.5	68.0	63.0	68.0
	Circulating Heater			
Wind Velocities	High		Low	
Outside Air Temperatures	10	50	10	50
Location of Column				
3.5 ft. south of heater	73.0	74.0	73.5	74.0
South end of living room	70.0	72.5	71.5	72.5
North end of living room	67.0	70.5	68.0	71.0
Kitchen	69.0	70.5	69.0	71.0
South bedroom	64.0	68.5	65.0	68.5
North bedroom	60.5	67.0	62.0	68.0

selected as explained previously. These average temperatures for study of horizontal temperature distribution are shown in Table 2.

The average temperature maintained 3.5 feet south of the heater was 1° to 1.5°F. higher for the radiant heater than for the circulating heater. At the north and south ends of the living room, there was little difference in the average air temperatures maintained by each heater.

There was no appreciable difference in the average air temperatures maintained in the outlying rooms when the outside air temperatures was 50°F. The average air temperature in the kitchen was 4.0° lower for the radiant heater than for the circulating heater when the outside air temperature was 10°F.

Table 3 contains the average air temperature values used during the test period at different locations, each measured by one thermocouple and determined by the graphical method previously described and illustrated in Fig. 14.

The thermocouples at the north end of the living room and at the south end of the living room were 14 feet from the heater. The radiant heater maintained higher average temperatures (1.5° to 3.0°F.) 3 inches above the floor at the north end than the circulating heater. The reversed condition was true at the south end of the living room.

The highest average temperatures measured were 3½ feet from

Table 3. Air Temperatures Measured at Various Locations Used to Supplement Average Temperatures in Tables 1 and 2

	Radiant Heater			
Wind Velocities	High		Low	
Outside Air Temperature	10	50	10	50
Inside Air Temperatures				
North end of living room 3 in. above floor	58.0	67.5	59.5	67.5
South end of living room 3 in. above floor	59.5	70.0	59.5	70.0
3.5 ft. south of heater 93 in. above floor	88.5	81.5	87.0	81.0
North bedroom 3 in. above floor	54.5	65.5	56.0	65.0
South bedroom 93 in. above floor	69.0	71.5	71.0	71.5
Utility room 30 in. above floor	59.0	67.0	59.5	67.0
Bathroom 30 in. above floor	61.0	68.0	62.0	68.5

Table 3 (Con't). Air Temperatures Measured at Various Locations Used to Supplement Average Temperatures in Tables 1 and 2

	Circulating Heater			
Wind Velocities	High		Low	
Outside Air Temperatures	10	50	10	50
Inside Air Temperatures				
North end of living room 3 in. above floor	56.0	64.5	58.0	66.0
South end of living room 3 in. above floor	62.0	67.5	62.0	67.5
3.5 ft. south of heater 93 in. above floor	94.0	82.5	92.5	82.5
North bedroom 3 in. above floor	52.0	65.0	55.0	64.0
South bedroom 93 in. above floor	71.0	71.5	72.5	72.5
Utility room 30 in. above floor	58.5	67.0	59.0	67.5
Bathroom 30 in. above floor	60.0	67.0	61.0	67.0

Table 4. Surface Temperatures in the House Measured at Locations Indicated in Figure 2

	Radiant Heater			
Wind Velocities	High		Low	
Outside Air Temperature	10	50	10	50
Location of Thermocouples				
North wall of living room	71.0	72.5	68.0	72.0
West wall of living room	60.0	69.0	58.0	68.0
Ceiling of living room	87.0	78.0	80.5	77.0
Floor of living room	65.5	68.5	64.0	68.0
South wall of kitchen	61.5	69.5	62.0	69.0
South wall of utility room	55.0	66.5	54.0	66.0
	Circulating Heater			
Wind Velocities	High		Low	
Outside Air Temperature	10	50	10	50
Location of Thermocouples				
North wall of living room	65.0	68.5	65.0	68.5
West wall of living room	60.0	67.5	58.0	68.5
Ceiling of living room	84.0	77.0	80.5	77.5
Floor of living room	66.5	68.5	66.5	69.0
South wall of kitchen	59.5	70.5	62.0	71.0
South wall of utility room	55.5	67.5	58.0	66.5

the heater and near the ceiling. The circulating heater maintained 5.5°F. higher average temperatures at this location than did the radiant heater when the outside air temperature was 10°. There was little difference in the average air temperature at 93 inches above the floor in the south bedroom for either of the two heating tests or for different outside air temperatures or wind velocities.

Temperatures at 30 inches above the floor in the utility room indicated very little difference in the temperatures maintained by the two heaters. The heat supply to the utility room could be transferred only by convection.

Surface Temperatures. The average surface temperatures measured at the locations shown in Fig. 2 are given in Table 4.

The wall temperature at the north end of the living room was maintained at a higher level (3.0° to 6.0°) by the radiant heater than by the circulating heater. The floor temperature in the living room was slightly higher (1.0° to 2.5°) at 10°F. outside temperatures with the circulating heater than with the radiant heater.

Examination of Table 4 reveals that it would be difficult to generalize that any marked difference in maintenance of surface temperatures could be ascribed to either heater.

Air Movement. Measurements of air velocity in the living room showed that there were large variations in the velocity. Readings varied from 5 to 35 feet per minute at various locations in the living room.

No significant difference in air velocities at any location was determined between the two heaters. Interior velocity measurements were made when the outside wind velocity was below 10 miles per hour and when the outside air temperature was between 25° and 40°F.

CONCLUSIONS

1. There is no significant difference in rate of fuel consumption between the radiant heater and the circulating heater. Under given wind, sun, and temperature conditions, a small increase in fuel consumed by both heaters was noted as the winter season advanced.
2. In the living zone, which ranged from the floor to 30 inches above, there was little difference in air temperatures maintained by each heater. Air temperatures near the ceiling were somewhat higher with the circulating heater.
3. Wall, ceiling, and floor surface temperatures showed very little difference between the radiant heater and the circulating heater.

ABSTRACT

Tests were performed in an unoccupied experimental house to compare the performance of an oil-burning radiant space heater with a similar type circulating space heater under Missouri winter conditions. It was found that the fuel consumption was essentially the same for both heaters. The temperature distribution in the living area was essentially the same for both heaters. Very little difference in interior wall, ceiling, and floor temperatures between the two heaters was observed. It was concluded that the heating characteristics of each type heater were approximately equivalent. The circulating heater was considered more desirable due to appearance and safety from burns.