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FUEL SAVINGS RESULTING FROM CLOSING OF ROOMS AND FROM USE OF A FIREPLACE

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COOPERATION WITH

THE NATIONAL WARM-AIR HEATING AND
AIR CONDITIONING ASSOCIATION

AND

THE INSTITUTE OF BOILER AND
RADIATOR MANUFACTURERS

BY

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AND

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ABSTRACT

1. Closing of Rooms

Studies were made of the fuel savings to be effected by closing of rooms in two insulated houses, in which the heating systems were automatically controlled. One house was heated by means of a gas-fired, forced-air system and the other by means of an oil-fired, forced-circulation, hot-water system. In both houses the windows, including those in bedrooms, remained closed at all times.

When the heat input from the burner greatly exceeded the heat loss from the house and two of the unheated rooms were located directly above the room in which the thermostat was located, no actual saving in fuel consumption was accomplished, even though more than one-third of the living quarters were closed off. On the other hand, when the heat input from the burner corresponded to the heat loss from the house and the unheated rooms were not adjacent to the room in which the thermostat was located, a small saving in fuel consumption was effected by the closing of about one-fourth of the living quarters.

In any case, the actual reduction in fuel consumption was materially less than anticipated reductions based on floor area, room volume, and heat loss, since in computing the anticipated savings no account could be taken, either of the orientation of the unheated rooms with respect to the heated portion of the house, or of the adverse changes that might take place in the operation of the plant as a result of shutting off registers or radiators. Hence, any broad generalization that closing of rooms will result in material reductions in fuel consumption must be regarded with some caution.

2. Use of Fireplace in Living Room

Tests were conducted with and without the use of the fireplace in the living room. When the room thermostat was located in the dining room the temperatures in all of the rooms, except the living room, were maintained at about 72 deg. F. Hence, the open fire in the living room served merely as an adjunct to the main heating plant. With this method of operation the gas consumption for the house was slightly greater than when the fireplace was not used.

When the room thermostat was located in the living room, the localized heating effect in the room by the open fire served to satisfy the demands of the room thermostat, with the result that the tempera-

tures in the remainder of the house dropped several degrees below 72 deg. F. Under these conditions, a substantial saving in gas consumption was effected by the fireplace fire. In order to obtain the maximum fuel conservation of the main heating plant with the least disturbance to comfort conditions in the house, the following method of operation is desirable:

(1) Use the fireplace fire in the living room and reduce temperature, either manually or automatically, in all other rooms in the house.

(2) Use the fireplace in mild weather in fall, early winter, and spring.

(3) Use the fireplace only on relatively calm days.

(4) Close the fireplace damper when the fireplace is not in use, or place a tightly-fitting cover over the front of the fireplace after the fire has died down.

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I. Introduction

1. *Previous Studies Related to Fuel Conservation.*—An extensive accumulation of data relating to heat losses from buildings and the utilization and conservation of fuels has been reported in publications issued during the past twenty-five years by the University of Illinois Engineering Experiment Station. A bibliography, given in Appendix A of this bulletin, indicates the subjects studied, as well as the publications in which the reports are available. A considerable amount of this work has been done in the Warm-Air Heating Research Residence, and in the past three years in the I=B=R Research Home, both of which are located in Urbana, Illinois. In both research buildings, the studies on heating plants have been made under conditions simulating field practice.

The tests reported in this bulletin are additional studies of fuel conservation that have been suggested by the Research Advisory Committee of the National Warm Air Heating and Air Conditioning Association and the Advisory Research Committee of the Institute of Boiler and Radiator Manufacturers. The first portion of this bulletin deals with tests made by closing and not heating parts of the houses. The second portion of this bulletin presents results of tests in which coal was burned in a fireplace grate, and the fireplace was used as an adjunct to the main heating plant.

In studies dealing with fuel utilization, the results are to a large extent dependent upon the specific arrangement of building, heating system, fuel-burning equipment, and control system. Hence, the results presented in this bulletin do not apply exactly, and in the same order of magnitude, to all types of buildings, heating systems, fuels, and controls. Nevertheless, the results do offer a reasonable basis for deciding whether the suggested measures have any merit in conserving fuel. They also offer some information in a field noticeably lacking in actual test data.

2. *Acknowledgments.*—The results presented in this bulletin were obtained in connection with two cooperative investigations at the University of Illinois, conducted by the Engineering Experiment Station. The investigation of warm-air furnace heating systems is sponsored by the National Warm Air Heating and Air Conditioning Association.

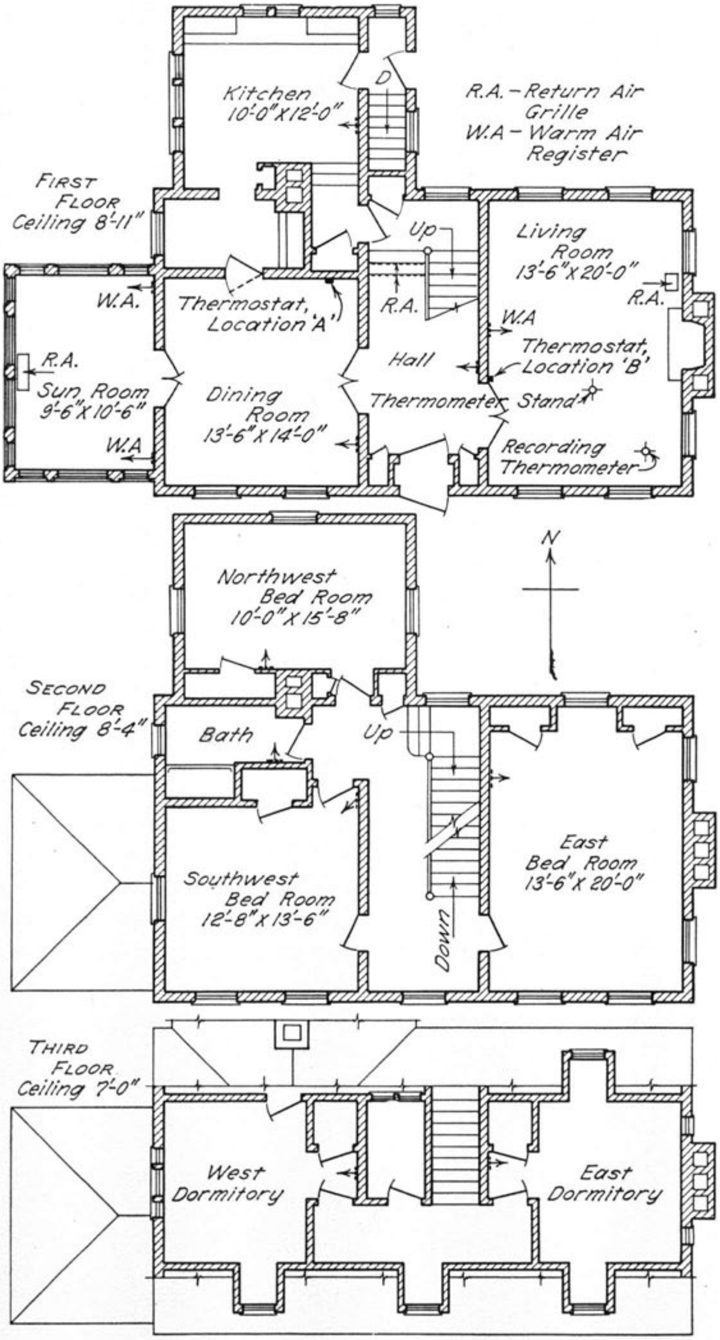


Fig. 1. Floor Plans of Residence A

The investigation of steam and hot-water heating systems is sponsored by the Institute of Boiler and Radiator Manufacturers. Both investigations are conducted under the general administrative direction of DEAN M. L. ENGER, Director of the Engineering Experiment Station, and of PROFESSOR O. A. LEUTWILER, Head of the Department of Mechanical Engineering. The study was supervised by PROFESSOR A. P. KRATZ, Research Professor of Mechanical Engineering.

II. DESCRIPTION OF RESIDENCES AND HEATING EQUIPMENT

3. *Residence A.*—Residence A is a three-story structure of standard frame construction with side walls and ceiling fully insulated with mineral wool insulation. The floor plans of Residence A are shown in Fig. 1. The total space heated, not including the basement, amounted to 17 790 cu. ft. All of the fifty windows in the three stories, with the exception of two small, quarter-round windows in the east dormitory, were provided with tightly-fitting storm sash. The calculated heat losses were approximately 51 140 B.t.u. per hr. at an indoor-outdoor temperature difference of 80 deg. F. The house is completely furnished, and during the heating season was occupied by three people.

The heating plant consisted of a steel, gas-fired, warm-air furnace used in connection with a forced-air heating system. The gas control valve was of the two-stage type, which permitted either of two rates of gas input to be maintained. The circulating fan, of the centrifugal type, was equipped with a two-speed motor, and either of two fan speeds could be used. The fuel used was natural gas from the Texas-Oklahoma Pipe Line, having a high heating value of 1000 B.t.u. per cu. ft.

In Fig. 2 is shown a line diagram of the duct system in the basement. The single trunk duct, carrying the warm air from the furnace, included a venturi air-measuring section. The weight of air flowing through the duct system was determined at the air-measuring section by means of a Pitot tube placed in the center of the 8 in. by 9 in. throat, and calibrated against a traverse of the duct. The resistance of the venturi section introduced a pressure loss of about 0.085 in. water gage for an air delivery of 1211 cu. ft. per min.

The heating system was controlled by means of a heat-anticipating type room thermostat operating to open and close the gas control valve. A fan switch, or bonnet thermostat, was used to start the fan when the bonnet air temperature reached a predetermined value, which occurred about 1½ minutes after the gas control valve was opened, and to stop the fan when the bonnet air temperature dropped to a

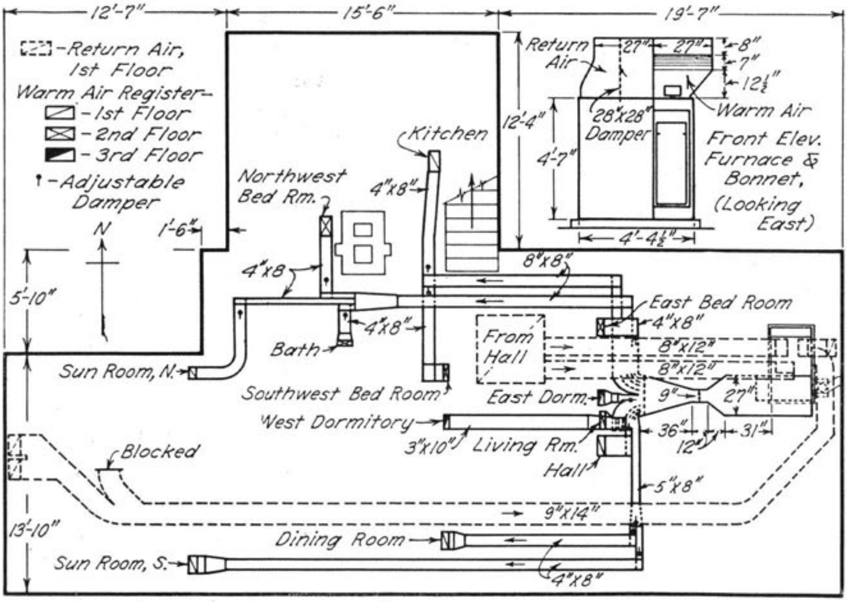


Fig. 2. Basement Duct System for Residence A

predetermined temperature. The operation of the heating plant was intermittent and was entirely automatic.

For the tests reported in this bulletin the twelve warm-air registers were located in the side wall approximately seven feet above the floor. The return air system included grilles in the living room, hall, and sun room.

4. *Residence B.*—Residence B is a two-story building typical of the small well-built American home. The construction is brick veneer on frame, and all of the outside walls and the second story ceiling are insulated with mineral wool bats 3⅝ in. thick. All windows and outside doors are weather stripped. No storm sash were used at the windows, but storm doors were used on the two outside doors. The calculated heat loss for the house is 43 370 B.t.u. per hr. at an indoor-outdoor temperature difference of 80 deg. F. The floor plans and details of the wall and radiator recess constructions are shown in Fig. 3. The house is completely furnished, and during the heating season it was occupied by two people.

The heating system consisted of a one-pipe, forced-circulation, hot-water system installed in connection with a three-section, cast-iron,

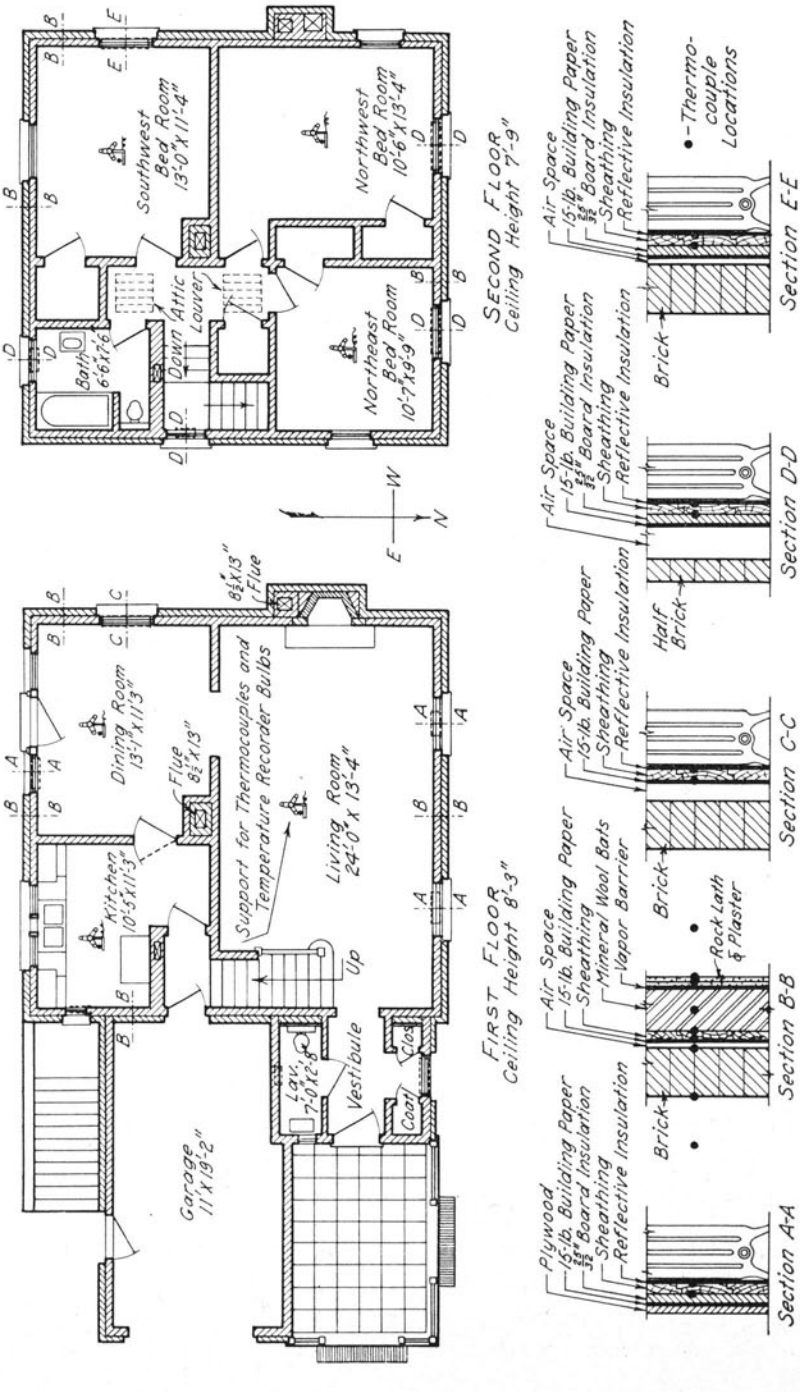


FIG. 3. FLOOR PLANS OF RESIDENCE B

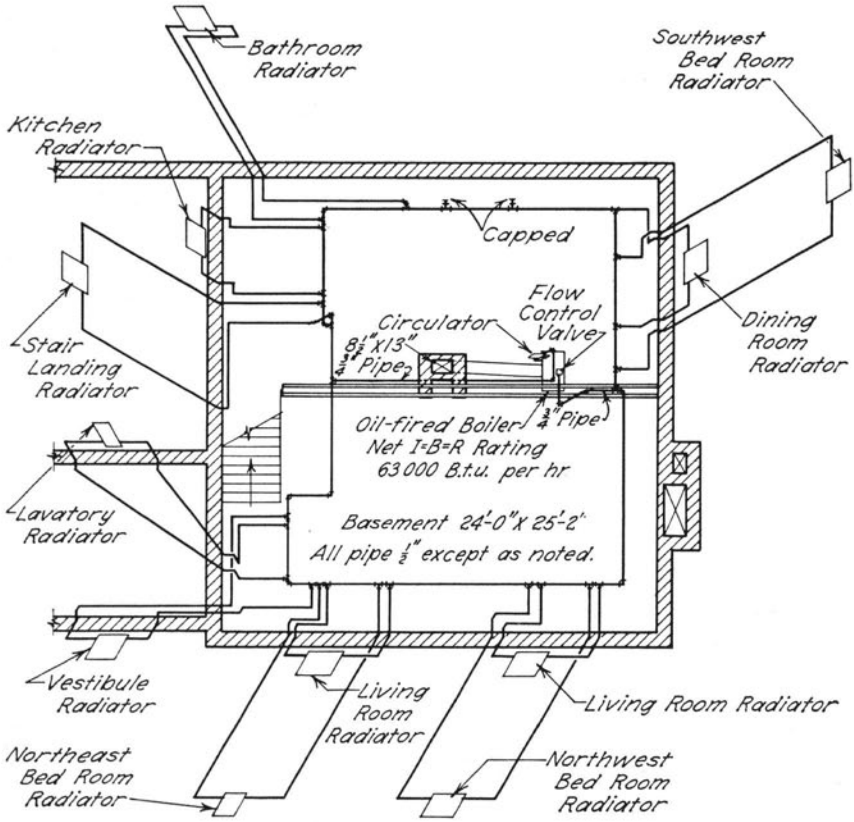


FIG. 4. BASEMENT PIPING SYSTEM FOR RESIDENCE B

oil-burning boiler having a net I=B=R rating of 63 000 B.t.u. per hr. A diagram of the arrangement of the heating system and piping layout is shown in Fig. 4. The oil burner was of the pressure-atomizing conversion type, and was fired at a rate of 7.5 lb. per hr. during the on-periods, with oil having a calorific value of 19 550 B.t.u. per lb.

Small-tube type, 19-in., 4-tube, cast-iron radiators were used in open recesses below the windows. The radiators were connected to two supply loops, as shown in Fig. 4. The locations of all radiators in each room of the house are shown by the broken-line rectangles in Fig. 3.

In all of the tests, the operation of the burner and circulator was controlled by a heat-anticipating thermostat located 30 in. above the floor in the living room. A high-limit aquastat located in the boiler stopped the burner, but not the circulator, whenever the temperature of the water in the boiler attained 205 deg. F. Neither a flow-control valve nor a low-limit aquastat was used in these tests. Water was circulated at the rate of 4.1 gal. per min. when the circulator was in operation. When the three bedroom radiators were turned off, the rate of water flow through the boiler was reduced by 0.2 per cent.

III. Fuel Savings Resulting From Closing of Rooms

5. *Method of Conducting Tests in Residence A.*—The average of the air temperatures in all of the rooms being heated was maintained at approximately 72 deg. F. at the 60-in. level both day and night. The windows, including those in bedrooms, remained closed at all times. Observations of weather, indoor room air temperatures, room relative humidities, and other incidental data were made daily at 7:00 a.m., 11:00 a.m., 4:00 p.m., and 10:00 p.m. Complete data were obtained for each 24-hr. test period on the gas consumption, the total integrated time of operation of the fan and of the gas valve, the total electrical input to the fan motor and the gas valve, and the total number of on-periods of both the circulating fan and the gas valve. Daily observations were made of the volume of air circulated and the fan speed. In addition, continuous records of temperatures, draft in chimney, and CO_2 in flue gas were obtained for each 24-hr. period. By means of the draft hood at the flue outlet of the furnace, basement air was admitted into the chimney, and the draft as measured over the gas flame was substantially zero in pressure at all times. For each series of tests, data were obtained over a wide range of outdoor weather conditions.

The operating conditions maintained in the three test series, in which portions of Residence A were closed off, were as follows:

Schedule of Tests in Residence A

Operating conditions common to all three test series:

Fan.—

Two speed; low speed at 358 r.p.m.; high speed* at 535 r.p.m.

Bonnet Thermostat Setting.—

Low speed cut-in at 90 deg. F.; cut-out at 80 deg. F.
High speed cut-in at 120 deg. F.; cut-out at 95 deg. F.

Gas Input.—

High-low flame; low input, 59 cu. ft. per hr.; high input,* 93 cu. ft. per hr.

*High flame and high speed were obtained only for outdoor temperatures colder than about 5 deg. F.

TABLE 1
FLOOR AREAS, ROOM VOLUMES, AND HEAT LOSSES FOR ROOMS NOT HEATED IN RESIDENCE A

Room	Floor Area* sq. ft.	Room Volume* cu. ft.	Calculated Heat Losses: Conventional, Room Heated B.t.u. per hr.	Adjusted, Room Not Heated B.t.u. per hr.	Reduction per cent
1	2	3	4	5	6
Sun room	145	1156	9 485	2405	74.6
E. bedroom	252	2144	5 905	3780	36.0
E. dormitory	140	868	3 650	1310	64.1
All 3 rooms	537	4168	19 045	7495	60.6

*Floor areas and volumes of closets not included.

Room Thermostat.—
Located in dining room at 60-in. level.

Series 1-42.—

All rooms in Residence heated day and night.
Air delivery, 810 c.f.m. at low speed of fan.
Energy input to fan motor, 177.3 watts.*

Series 3-42.—

Same as series 1-42, except that sun room was not heated.
Registers, return grilles, and doors to sun room closed.
Air delivery, 745 c.f.m. at low speed of fan.
Energy input to fan motor, 175.3 watts.*

Series 4-42.—

Same as series 1-42, except that sun room, east bedroom, and east dormitory were not heated.
Registers, grilles, and doors to all three rooms closed.
Air delivery, 730 c.f.m. at low speed of fan.
Energy input to fan motor, 175 watts.*

It may be observed that in series 1-42 all of the rooms in the house were heated; in series 3-42 the sun-room doors were closed and felt weatherstripping applied to the edges, the register valves in the two warm-air registers were closed, and the return-air grille in the room was covered with paper weighted down by a rug; in series 4-42 the sun room, east bedroom on the second story, and east dormitory on the third story were all closed and not heated. No adjustments were

*Energy input to fan motor includes that required to overcome resistance of venturi air-measuring section, which introduced a pressure loss of about 0.085 in. for an air delivery of 1211 c.f.m.

otherwise made in dampers or register valves in the remainder of the duct system, or in the control settings.

The floor areas, room volumes, and calculated heat losses for the rooms closed off and not heated are shown in Table 1. In column 4 are shown the heat loss calculations for the rooms, based on an indoor-outdoor temperature difference of 80 deg. F. These values have been designated as "conventional" heat loss. In column 5 are shown the calculated heat losses from the rooms closed off, basing the computations on the calculated equilibrium temperature in the unheated rooms. These values have been designated as "adjusted" heat loss. A detailed discussion of the adjusted heat losses is presented in Appendix B.

6. *Method of Conducting Tests in Residence B.*—During all tests made in Residence B the temperature of the air 30 in. above the floor in the heated portion of the house was maintained constant at approximately 72 deg. F., both day and night. The windows, including those in bedrooms, remained closed at all times. At 7:00 a.m., 11:00 a.m., 5:00 p.m., and 10:00 p.m. observations were recorded of the room-air temperatures 3 in., 30 in., and 60 in. above the floor, and 3 in. below the ceiling, of the air temperature in the basement and the attic, and of the relative humidity in the rooms. Complete daily records were also made of the operating time, the number of cycles, and the power consumption of the oil burner and circulator, and of the weight of oil consumed. Continuous records were made of the stack temperature, the CO_2 in the flue gas, the temperature of the water at the boiler outlet and return, and the outdoor air temperature. Other daily observations included the total amount of electricity and gas used in the house, the number of occupants, and general weather conditions.

Two series of tests were made which differed only in the number of rooms being heated. In series K all rooms in the house were heated day and night, and all room doors were left open. In series L the radiators in the three second-story bedrooms were turned off, and the bedroom doors were kept closed. As the bedroom doors fit rather tightly except for the ¾-in. crack along the bottom, no felt weather-strip was used. With the windows closed it was hardly possible that an appreciable interchange of air between the heated and unheated room could occur through the cracks around the door. Both the results of the test and computations based on probable pressure differences indicated that if anything such an interchange occurred from the heated to the unheated room rather than in the opposite direction.

The floor areas, room volumes, and heat losses for the rooms not

TABLE 2
FLOOR AREAS, ROOM VOLUMES, AND HEAT LOSSES FOR ROOMS NOT HEATED IN RESIDENCE B

Room	Floor Area* sq. ft.	Room Volume* cu. ft.	Calculated Heat Losses		
			Conventional, Room Heated B.t.u. per hr.	Adjusted, Room Not Heated B.t.u. per hr.	Reduction per cent
1	2	3	4	5	6
N.E. bedroom	1032	800	4 395	2180	50.4
N.W. bedroom	1481	1148	4 945	2410	51.3
S.W. bedroom	1430	1108	5 250	2965	43.5
All 3 rooms	3943	3056	14 590	7555	48.1

*Floor areas and volumes of closets not included.

heated in series L are given in Table 2. The methods used in computing the heat losses shown in this table were identical to those used in computing the values in Table 1.

7. *Results of Tests in Residences A and B.*—The fuel consumptions obtained with the three series of tests conducted in Residence A are shown in the lower part of Fig. 5. For a given outdoor temperature the fuel consumption for the case in which the sun room alone was closed, (series 3-42), was slightly less than that for the case in which the entire Residence was heated, (series 1-42); whereas the fuel consumption for the case in which the three rooms were closed, (series 4-42), was appreciably smaller than those for either of the other two cases. The reductions in fuel consumption, amounting to about 5 per cent and 15.5 per cent for series 3-42 and 4-42, respectively, are listed in Table 3, column 12.

Curves for fuel consumption for the tests conducted in Residence B are shown in Fig. 6 and the percentage reduction in fuel consumption is shown in Table 3, column 12. In this case, the closing of the three bedrooms on the second story, (series L), actually gave an increase in fuel consumption over that for the case in which the entire house was heated, (series K), for a wide range of outdoor temperatures. At an outdoor temperature of 38 deg. F., corresponding to the average winter temperature in Urbana, Illinois, the increase amounted to approximately 2.5 lb. of oil per day, or about 10 per cent. For an outdoor temperature of 25 deg. F. the fuel consumption for the two cases was about the same. At all outdoor temperatures below 25 deg. F. some

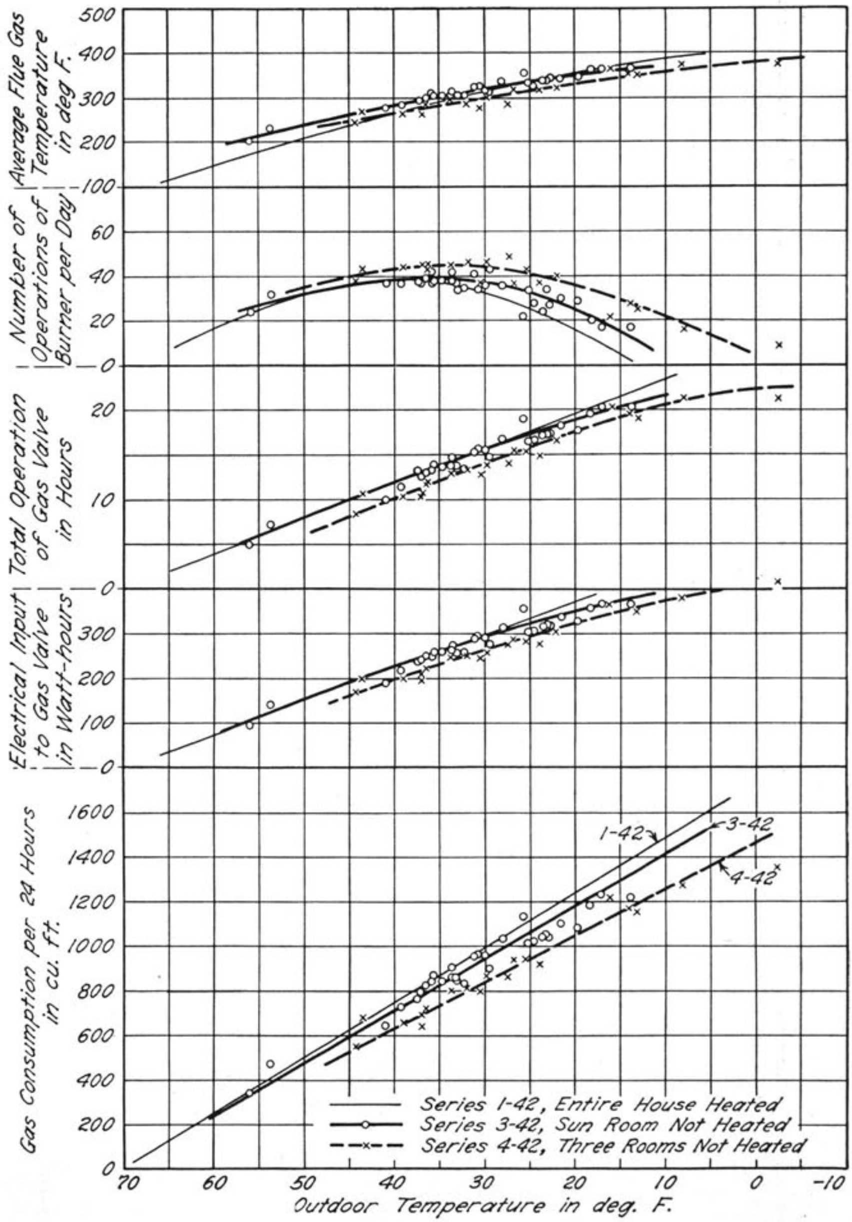


FIG. 5. FUEL CONSUMPTION IN RESIDENCE A AS AFFECTED BY CLOSING OF ROOMS

TABLE 3

SUMMARY OF HEAT LOSSES AND REDUCTIONS IN FLOOR AREAS, ROOM VOLUMES, AND HEAT LOSSES FOR RESIDENCES A AND B

Series No. and Rooms Heated	Ratio of Heat Input Rate to Calculated Heat Loss	Floor Area†	Room Volumes†	Calculated Heat Losses, B.t.u. per hr.			Reduction in Calculated Heat Loss From House, in per cent		Reductions, in per cent		
		sq. ft.	cu. ft.	Conventional, Room Heated	Conventional, Room Not Heated	Adjusted, Room Not Heated	Based on Conventional Heat Loss	Based on Adjusted Heat Loss	Floor Area	Room Volumes	Fuel Consumption by Test
1	2	3	4	5	6	7	8	9	10	11	12
Residence A											
1-42 All rooms heated	High flame 1.82 Low flame 1.15	2133	17 790	51 140							
3-42 Sun room not heated	High flame 2.11* Low flame 1.34*	1988	16 634		41 655	44 060	18.5	13.9	6.8	6.6	5.0‡
4-42 Three rooms not heated	High flame 2.35* Low flame 1.49*	1596	13 622		32 095	39 600	37.2	22.6	25.2	23.5	15.5‡
Residence B											
K All rooms heated	3.38	1123	8 998	43 370							
L Three rooms not heated	4.18*	728	5 942		28 780	35 815	33.5	17.2	35.1	33.9	−10.0‡ 0.0¶

*Based on values in column 7.
†Floor areas and volumes of closets not included.
‡Based on an outdoor temperature of 38 deg. F.
¶Based on an outdoor temperature of 25 deg. F.

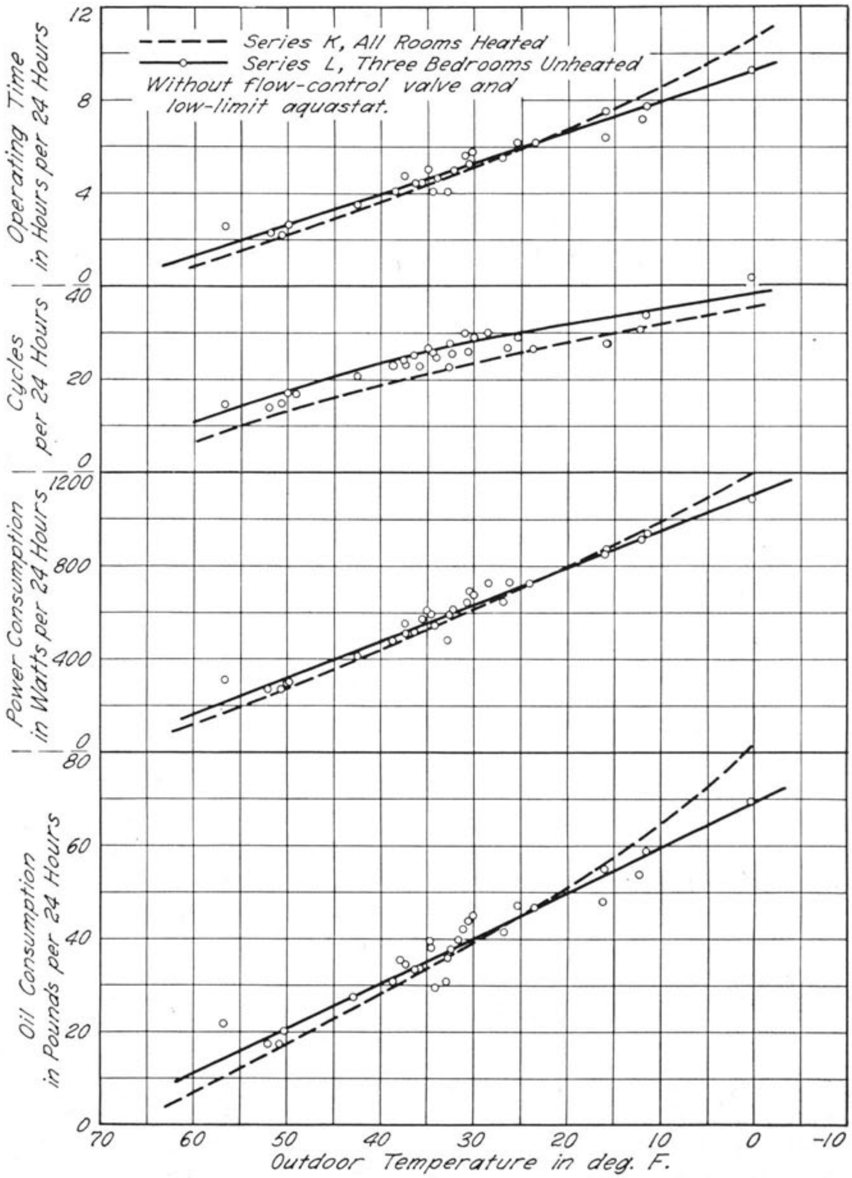


FIG. 6. FUEL CONSUMPTION IN RESIDENCE B AS AFFECTED BY CLOSING OF ROOMS

fuel savings were effected by operating with the bedrooms closed and unheated.

Three methods suggest themselves for determining the anticipated saving in fuel consumption effected by closing of rooms:

(1) To compute the reduction on the basis that the fuel consumption is proportional to the living space, as represented by floor area, (Table 3, column 10).

(2) To compute the reduction on the basis that the fuel consumption is proportional to the living space, as represented by room volume, (Table 3, column 11).

(3) To compute the reduction in calculated heat losses. In making the latter calculation two courses are open:

(a) To revert to the original heat loss calculations based on the design temperature difference, and merely subtract the heat loss for the individual rooms from the total calculated heat loss from the house. This has been designated as "conventional" and is shown in Table 3, column 8.

(b) To recalculate the heat loss from the rooms closed, basing the computations on the calculated equilibrium temperature in the unheated rooms, as explained in detail in Appendix B. This has been designated as "adjusted" and is shown in Table 3, column 9.

It may be noted that in practically every case the actual reduction in fuel consumption, (Table 3, column 12), was materially less than the anticipated reductions based on floor area, room volume, and heat loss. It should be emphasized strongly at this point that anticipated savings based on reduction in floor area, room volume, and heat losses take no account of corresponding adverse changes that may take place in the operation of the plant as a result of shutting off registers and radiators.

In Residence B no actual savings in fuel consumption was accomplished even though more than one-third of the living quarters were closed and not heated. Even before any rooms were closed, the burner and boiler were largely oversized for the house. When the rooms were closed this condition was aggravated since it was not practical to reduce the heat input to the burner. Furthermore, the heat loss from the living room, in which the room thermostat was located, was increased by an additional heat transfer through the ceiling to the unheated rooms. Thus, in order to maintain the living room at 72 deg. F. at any given outdoor temperature, it was necessary either that the

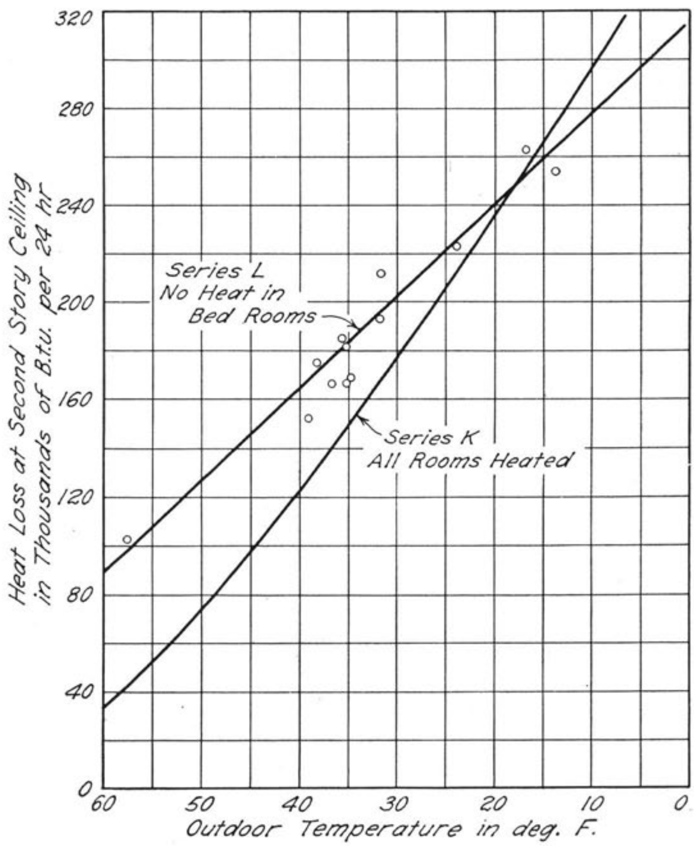


FIG. 7. DAILY HEAT LOSS FROM CHIMNEY GAS

radiators be supplied with water at a higher average temperature, or that the circulator operate longer in series L than in series K. The observed data indicated that, although the total circulator operating time remained unchanged, there was a definite increase in the average temperature of the water circulating in the system, together with an increase in the frequency of circulator operation. The increased heat loss from the living room, together with the probable decrease in operating efficiency resulting from the use of an oversized boiler and burner, effected an increase in the chimney losses,* as shown by the curves of Fig. 7. The increase in the chimney loss at an outdoor temperature of 38 deg. F. amounted to 40 000 B.t.u. per 24 hr., which

*For a detailed discussion of the method of computing chimney gas losses see appendix of "Performance of a Hot-Water Heating System in the I=B=R Research Home," Univ. of Ill. Eng. Exp. Sta. Bul. No. 349.

is equivalent to about 2 lb. of oil. This corresponded fairly well with the observed increase in fuel consumption at this same outdoor temperature.

In the case of Residence A, even the high-flame burner was not greatly oversized. Actually, during the tests the furnace operated practically all of the time on the low-flame burner, which was sized very closely proportionate to the heat loss from the house. In addition, the reduction of air volume was not very great, (section 5, Schedule of Tests), no change in temperature of the circulating air was obtained, and hence no material reduction in operating efficiency of the plant occurred. The actual reduction in air volume in any forced-air or gravity warm-air plant is largely dependent on the resistance characteristics of the duct system and the motive head causing flow. Under some conditions, the characteristics of the fan in the forced-air system may be such that closing of a few rooms will result in a large reduction in air volume and thus create an appreciable rise in both the bonnet air temperature and flue gas temperature. As an extreme case, if all register and grille openings, except one, were closed, a very marked reduction in air volume would occur, and the efficiency of heat transmission would decrease, possibly to such an extent as to overheat the furnace.

It should be emphasized strongly that the differences in savings shown in Residences A and B should not be interpreted as being attributable to the fact that one was heated by a forced circulation warm-air plant and the other by a forced circulation hot-water plant, since both types of plants, when properly designed, installed, and controlled, can be operated to give the same fuel consumption in the same building. The differences in savings should be attributed to differences in structural features of the two buildings, differences in location and character of the rooms closed as related to the rest of the house, and differences in the adverse effect of reducing the size or capacity of the heat distribution systems in the two particular plants under consideration.

It is true that in many cases a material saving might be effected by closing of rooms. In some cases, however, no reduction, or even an actual increase in fuel consumption might occur. Hence, any broad generalization that closing of rooms will result in material savings in fuel must be regarded with some caution.

IV. Fuel Savings Resulting From Use of a Fireplace

8. *Method of Conducting Tests.*—A first-story plan view of Residence A is shown in Fig. 1, giving the relative positions of the fireplace, the thermostat locations in the dining room and living room, the locations of shielded thermometers and recording thermometer, and the return-air grilles.

A line diagram of the fireplace and grate used to burn coal is shown in Fig. 8. The chimney attached to the fireplace was tile lined, 12 in. by 12 in. in cross section, 32 ft. high, and built on the east wall of the house. The coal used in the fireplace grate was a high-volatile, Eastern Kentucky lump coal, having the following proximate analysis:

Moisture	3.75 per cent
Fixed Carbon	55.30 per cent
Volatile Matter	36.75 per cent
Ash	4.20 per cent
Sulphur	0.70 per cent
Calorific Value	13 755 B.t.u. per lb

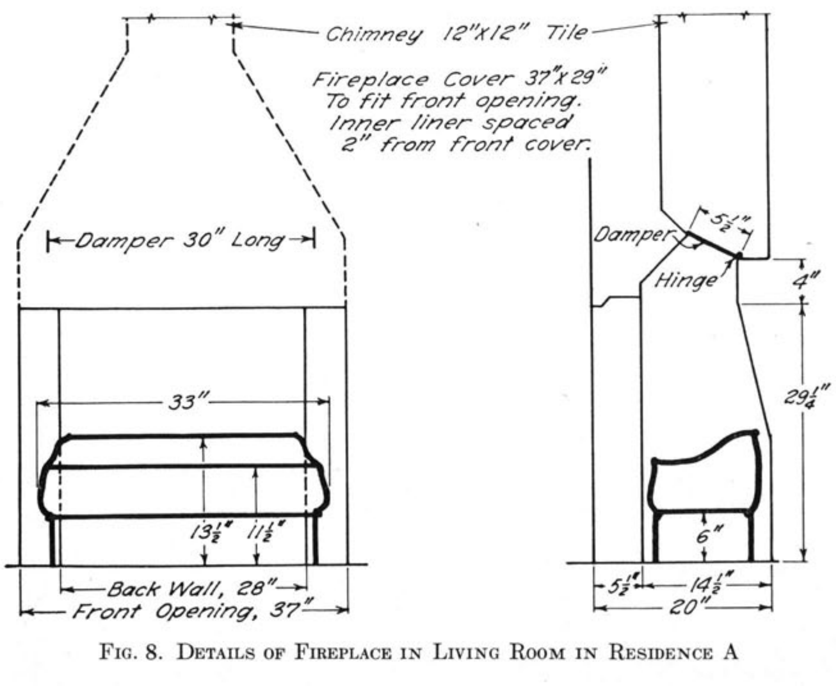


Fig. 8. Details of Fireplace in Living Room in Residence A

At 4:00 p.m. the fireplace damper was opened, the coals were ignited with paper and wood kindling, and a total charge of 35.0 lb. of fuel was added to the grate during the period from 4:00 p.m. to about 7:00 p.m. The coal ignited readily and burned with long yellow flames, extending as much as 24 in. above the fuel bed, and with a noticeable release of smoke and soot. The fire attained a maximum intensity at about 6:30 p.m. to 7:30 p.m., and by 10:00 p.m. consisted of a glowing bed of coke. The fire consisted of only a few glowing embers after about 11:00 p.m. In the morning the loose ashes were shaken down and collected for weighing, the unburned coke was weighed and replaced in the grate, and sufficient fresh coal was added to bring the total charge to 35.0 lb.

Three main series of tests were conducted in accordance with the following schedule, and were designated as series 2-42, 5-42, and 6-42. In addition, a few tests were made in which a sheet metal shield was placed in the fireplace opening to seal the opening completely during the period from 10:30 p.m. to 4:00 p.m. of the following day. These supplementary tests have been designated as series 5a-42 and 6a-42.

Schedule of Tests for Fireplace Studies in Residence A

Series 2-42.—

All rooms in house were heated; fireplace was not used; fireplace dampers were closed.

Room thermostat was located in dining room.

Gas Input: low flame 59 cu. ft. per hr., high flame 93 cu. ft. per hr.

Single speed fan operation at 535 r.p.m., 310 watts input.

Bonnet thermostat setting: fan cut-in 100 deg. F., fan cut-out at 75 deg. F.

Series 5-42.—

Same as series 2-42, except that fireplace was used; fireplace damper was opened at 4:00 p.m., and closed at 7:00 a.m.

Series 5a-42.—

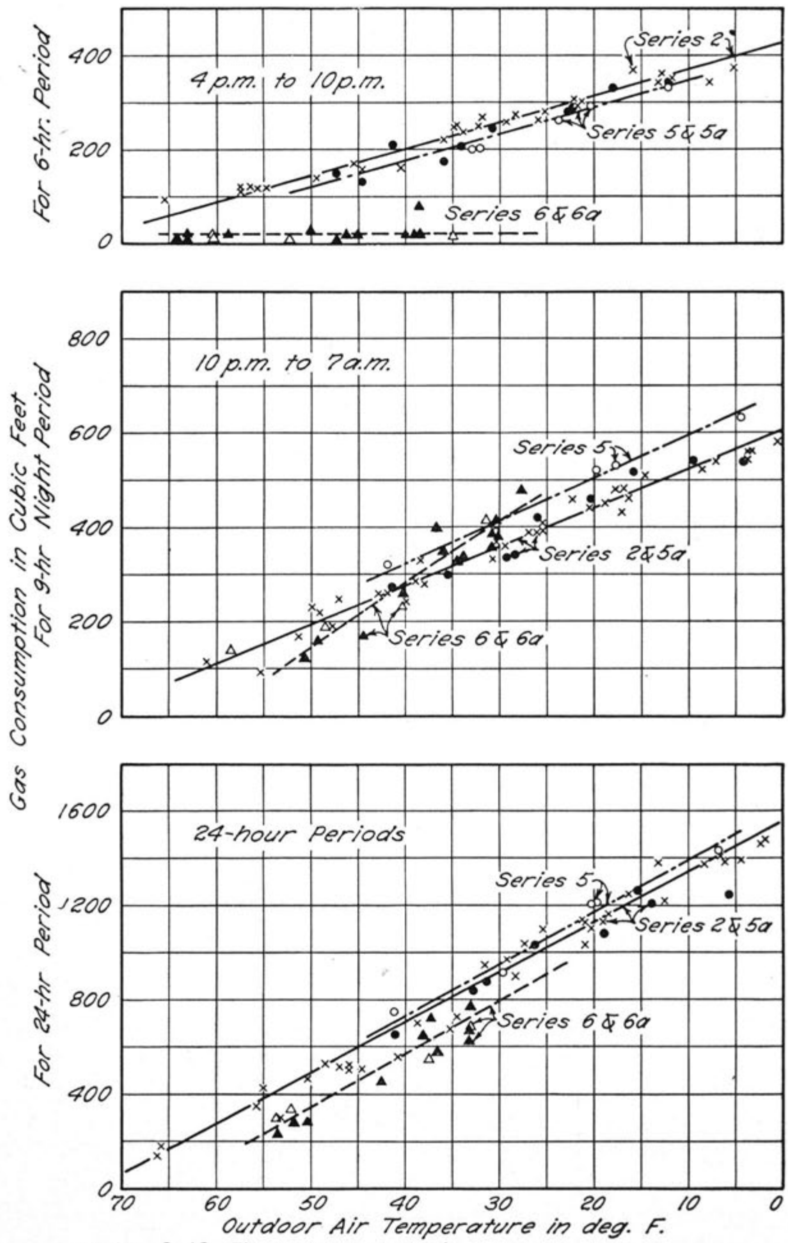
A modification of series 5-42 in which fireplace opening was sealed with a sheet metal cover at 10:30 p.m.; cover was removed at 4:00 p.m. the following day.

Series 6-42.—

Same as series 5-42, except that room thermostat was moved to living room location.

Series 6a-42.—

Same as series 5a-42, except that room thermostat was moved to living room location.



Series 2-42. Fireplace not used.
Series 5-42. Fireplace used Thermostat in dining room.
Series 5a-42. Same except fireplace sealed at 10:30 p.m.
Series 6-42. Fireplace used. Thermostat in living room.
Series 6a-42. Same except fireplace sealed at 10:30 p.m.

FIG. 9. FUEL CONSUMPTION IN RESIDENCE A AS AFFECTED BY USE OF FIREPLACE

For all test series, the gas input to the furnace was obtained, not only for the 24-hr. period beginning at 11:00 a.m., but also for the shorter interim periods; namely, for the 6-hr. period from 4:00 p.m. to 10:00 p.m., and for the 9-hr. period from 10:00 p.m. to 7:00 a.m. The gas consumption for these shorter periods, as well as for the 24-hr. period, were compared for the different test series.

9. *Results of Tests.*—The open fire in the living room increased the air temperature in the living room about 6 to 8 deg. F. above normal temperature at 8:00 p.m. These readings were obtained with a glass thermometer protected from radiation from the fireplace by a light wooden case, on the outside of which was placed a bright metal shield, with an air space between the two shields. The temperature readings observed with a blackened-bulb glass thermometer, placed 6½ ft. from the fire and 5 ft. above the floor, were from 2 to 3 deg. F. higher than the temperatures observed with the protected thermometer. The heating effect of the fireplace was largely confined to the living room, and did not extend to the dining room which was across the hall from the living room. Temperature readings of the air entering the return grille, located less than 2 ft. from the fireplace, indicated that when the fireplace was in use the return air temperature was increased at most only about 2 or 3 deg. The return air temperature in the hallway grille was not materially affected by the excessive temperatures in the adjacent living room.

The results obtained are shown in Fig. 9, in which gas consumptions for stated periods are plotted against the average outdoor temperature prevailing during the periods. In the top set of curves are shown the gas consumptions for the period from 4:00 p.m. to 10:00 p.m., when the fire in the fireplace was active. The gas consumptions during the period from 10:00 p.m. to 7:00 a.m., when the fire in the fireplace was not active, are shown in the middle set of curves. The consumptions during the period between 7:00 a.m. and 4:00 p.m. were the same for all tests, and are not shown. The total gas consumption for 24-hr. test periods are presented in the bottom set of curves, and in Table 4 for outdoor air temperatures of 50 deg. F. and 30 deg. F.

When the room thermostat was located in the dining room, the temperature in all of the rooms, except the living room, were maintained at about 72 deg. F. during the entire 24-hr. period. Hence, the open fire in the living room served merely as an adjunct to the main heating plant during the period from about 4:00 p.m. to 11:00 p.m. With this method of operation, (series 5-42), the gas con-

TABLE 4
FUEL CONSUMPTION FOR MAIN HEATING PLANT
WHEN FIREPLACE WAS IN USE

Method of Operation	Series No.	Cubic Feet of Gas Consumption of Main Heating Plant for 24-hr. Period, for Outdoor Temperatures of—	
		50 deg. F.	30 deg. F.
Normal operation No fireplace fire	2-42	500	925
Fireplace fire Thermostat in dining room	5-42	520	950
Fireplace fire Thermostat in living room	6-42	360	800

Note: With series 6-42, temperatures in all rooms except the living room dropped below 70 deg. F. during period from 4 p.m. to about midnight.

sumption for the house during the evening period was slightly less than that for the same period when the fireplace was not in use, (series 2-42). During the night period, however, the heated air in the house escaped through the open fireplace damper, with the result that a greater gas consumption was required when the fireplace was used than when the fireplace was not used and the damper was kept closed. The overall effect, as shown in Table 4, was that the total 24-hr. gas consumption for the house was somewhat greater when the fireplace was used. When the fireplace opening was closed at 10:30 p.m. with a tightly-fitting sheet metal cover, (series 5a-42), the total gas consumption was about the same as when the fireplace was not used. With either of these two methods of operation, (series 5 and 5a), no sacrifice in heating comfort was experienced in any portion of the house, the living room temperature was maintained warmer than normal, and the fuel consumed in the fireplace represented an excess over the normal fuel consumption of the main heating plant. Hence, the use of a fireplace in the living room under conditions in which the temperature of the remainder of the house is maintained at a normal value is not conducive towards fuel conservation.

When the room thermostat was located in the living room, (series 6-42), the localized heating resulting from the fire in the fireplace served to satisfy the demands of the thermostat. The gas furnace did not operate during the evening period, and the consumption of gas was only that required for the pilot light, as shown by the top set of curves in Fig. 9. By 10:00 p.m. the temperatures in all of the rooms, except the living room, dropped from 2 to 6 deg. F. below 72 deg. F., depending upon the exposure of the room and the outdoor temperature. Under these conditions, which approximate the operation with night setback in temperature, a substantial reduction in gas consumption was effected by the fireplace fire. Comfort conditions were not maintained in all of the rooms of the house, but the living room did provide a haven of warmth. The lower set of curves in Fig. 9 indicates that the reduction in gas consumption was proportionally much greater in mild weather than in cold weather. In fact, for outdoor air temperatures between about 70 to 60 deg. F. the main heating plant was seldom required to operate. In addition, the temperatures in the rooms apart from the living room did not drop much below 70 deg. F.

The fireplace chimney serves as a ventilation duct, and the amount of air drawn up the chimney depends to a large extent on the available draft. The magnitude of this draft is large on cold days, at times of large heat release in the fireplace, and on windy days. Although the fuel reductions obtained with the use of a tightly-fitting cover, placed over the front of the fireplace after the fire had died down, were not significantly large, the results indicated the desirability of keeping the fireplace vent closed tightly when the fireplace was not in use.

In general, it may be concluded that in order to obtain the maximum fuel conservation with the main heating plant with the least disturbance to comfort conditions in the house, the following method of operation of the fireplace is desirable:

(1) Use the fireplace in the living room and reduce temperatures, either manually or automatically, in all other rooms in the house.

(2) Use the fireplace in mild weather, namely, in fall, early winter, and spring.

(3) Use the fireplace on relatively calm days.

(4) Close the fireplace damper when the fireplace is not in use or place a tightly-fitting cover over the front of the fireplace after the fire has died down.

Appendix A

LIST OF PUBLICATIONS DEALING WITH FUEL UTILIZATION

In Table 5 is shown a list of publications dealing with fuel utilization and conservation written by members of the Department of Mechanical Engineering of the University of Illinois. The results of studies on these subjects have been reported in bulletins and circulars of the University of Illinois Engineering Experiment Station, in the Transactions and in the Journals of the American Society of Heating and Ventilating Engineers, and in two books entitled "Gravity Warm-Air Heating, A Digest of Research" and "Winter Air Conditioning—Forced Warm-Air Heating."

One important relationship has been observed that is common to most of the tests reported, and that is that the characteristics of the house, chimney, heating system, fuels, and controls are mutually dependent on each other, and that the performance of any single component should be considered in its relation to the other components of the entire heating system.

Appendix B

EQUILIBRIUM TEMPERATURES USED IN ADJUSTED HEAT LOSS CALCULATIONS

In calculating the heat loss from a room in the conventional manner, the assumption was made that the indoor air temperature was 72 deg. F. and the outdoor air temperature was −8 deg. F., giving an indoor-outdoor temperature difference of 80 deg. F. It was further assumed that all rooms were at 72 deg. F., and therefore no heat transfer occurred through interior partitions and doors.

However, when a room is not heated and is adjacent to heated rooms, a heat transfer is effected from the heated room to the unheated room through interior partitions and doors. At the same time a heat transfer occurs from the unheated room to the outdoors or to colder spaces. For any given outdoor temperature an equilibrium condition will be attained in which the heat transfer from the normally heated rooms to the unheated room is numerically equal to that from the unheated room to the outdoors. The air temperature of the unheated room for this equilibrium condition is designated as the equilibrium temperature.

TABLE 5

BIBLIOGRAPHY RELATING TO HEAT LOSSES, FUEL CONSERVATION, AND FUEL UTILIZATION

(From reports by staff of University of Illinois Engineering Experiment Station)

Item	G—Gravity Warm-Air F—Forced Warm-Air S—Steam W—Hot Water	A.S.H.V.E. Transactions (T), or Journal (J)	University of Illinois Bulletin or Circular	Book "Gravity Warm-Air Heating"	Book "Winter Air Conditioning"
Construction of House					
Insulation, effect on plant performance	F	(T) v. 47, p. 355			P. 169
Insulation, ceiling, 1 in. thick	G		Bul. 189, p. 110	P. 421	
Insulation, discussion			Circ. 37, p. 79		
Storm windows and doors	F	(T) v. 42, p. 87	Circ. 26, p. 100		P. 165
Storm windows and doors	S		Bul. 223, p. 62		
Curtains and shades at windows	S		Bul. 223, p. 68		
Furnaces and Distribution System					
Resistance of 6 types of return systems	G		{Bul. 189, p. 58 {Circ. 45, p. 22	P. 332	
Booster fan in gravity system	G		Bul. 246, p. 40	P. 166	
Volume and temperature of circulating air	F	(T) v. 48, p. 393			P. 199
Volume of circulating air	G-F		Bul. 246, p. 40	P. 171	
Two-speed and single-speed fan	F	(T) v. 44, p. 309	Bul. 318, p. 64		P. 245
Radiators and Enclosures					
Radiator enclosures and shields	S	(T) v. 35, p. 77	Bul. 192		
Radiator finishes	S	(T) v. 33, p. 41	Bul. 223, p. 55		
Radiator location and recess construction	W		Bul. 349		
Thermostatic Controls					
Single and dual controls	G		Bul. 189, p. 100	P. 424	
Types of control systems	F	(T) v. 40, p. 37	Bul. 266, p. 60		P. 224
Bonnet temperature control setting	F	(T) v. 48, p. 393			
Night set-back in room temperature (gas)	G		Bul. 246, p. 96	P. 398	P. 254
Night set-back in room temperature (oil)	F		Bul. 318, p. 49		P. 254
Night set-back in room temperature (oil)	W	(J) Dec. 1942, p. 743	Bul. 349		
Flow control valve and low limit aquastat (oil)	W	(T) v. 48, p. 163	Bul. 349		
Fuels and Combustion					
Six types of coals and coke tested	G	(T) v. 34, p. 385	Bul. 189, p. 84	P. 370	
Coal—slotted firepot construction	G		Bul. 141, p. 58	P. 362	
Coal—methods of firing			Circ. 46		
Coal—down-draft furnace		(J) Aug. 1943, p. 431	Circ. 43, p. 83		
Gas—conversion furnace	G		Bul. 246, p. 84	P. 384	

TABLE 5 (CONCLUDED)

BIBLIOGRAPHY RELATING TO HEAT LOSSES, FUEL CONSERVATION, AND FUEL UTILIZATION

(From reports by staff of University of Illinois Engineering Experiment Station)

Item	G—Gravity Warm-Air F—Forced Warm-Air S—Steam W—Hot Water	A.S.H.V.E. Transactions (T), or Journal (J)	University of Illinois Bulletin or Circular	Book "Gravity Warm-Air Heating"	Book "Winter Air Conditioning"
Oil Burning					
Conversion and designed furnace	F	(T) v. 43, p. 215	Bul. 318, p. 29		P. 451
Input rates	F	(T) v. 43, p. 215	Bul. 318, p. 29		P. 448
Draft regulating damper	F		Bul. 318, p. 45		
Stoker					
Stoker-firing and hand-firing	F	(T) v. 45, p. 297	Circ. 39		
Coal feed and burning rates	F	(T) v. 46, p. 125			
Combustion Efficiency					
Overall efficiency	G	(T) v. 35, p. 361	{Bul. 318, p. 39 {Bul. 189, p. 52		P. 458
Flue gas losses			Circ. 44		
Chimney losses	W		Bul. 349		
Miscellaneous					
Wind effects	G		{Bul. 246, p. 107 {Bul. 189, p. 78	P. 399 P. 407, 412	
Sun effects	G		{Bul. 246, p. 107 {Bul. 189, p. 78	P. 407, 412	
Snow effects	G		Circ. 15, p. 24	P. 420	
Degree—days		(J) Jan. 1943, p. 38			
General discussion on fuel savings			{Circ. 47 {Circ. 26, p. 100		

TABLE 6
TABULATION OF ADJUSTED HEAT LOSSES AND GAINS FOR UNHEATED ROOM
Residence B, northeast bedroom (assuming infiltration)

Item	Area sq. ft.	Coefficient, U, in B.t.u. per sq. ft. per hr. per deg. F.	Temperature Difference deg. F.	Heat Loss, or Gain, in B.t.u. per hr.
(1)	(2)	(3)	(4)	(5) = (2) × (3) × (4)
Adjusted heat losses				
Wall	132.5	0.074	$t+8$	$9.8t+78.4$
Ceiling	102.8	0.068	$t-10$	$7.0t-70.0$
Window	25.0	1.13	$t+8$	$28.3t+226.4$
Infiltration	432 cu. ft. per hr.	0.018*	$t+8$	$7.8t+62.4$
Total				$52.9t+297.2$
Adjusted heat gains				
Inside wall	75.6	0.34	$72-t$	$1850.4-25.7t$
Floor	102.8	0.24	$75-t$	$1852.5-24.7t$
Door	16.9	0.45	$72-t$	$547.2-7.6t$
Total				$4250.1-58.0t$

*B.t.u. per cu. ft. per deg. F. = 0.075 × 0.24 = 0.018.

In Table 6 is shown the calculations for the determination of the equilibrium temperature for the northeast bedroom in Residence B, based upon an indoor air temperature of 72 deg. F. in the heated rooms, and an outdoor air temperature of − 8 deg. F. The total adjusted heat losses, shown in Table 6, may be expressed by the equation

$$H_l = 52.9\,t + 297.2. \quad (1)$$

The total adjusted heat gains, shown in Table 6, may be expressed by the equation

$$H_g = 4250.1 - 58.0\,t \quad (2)$$

in which

H_l = total adjusted heat loss, in B.t.u. per hr.
H_g = total adjusted heat gain, in B.t.u. per hr.
t = equilibrium temperature, in deg. F.

When the equilibrium temperature is attained, the total adjusted heat losses from the room are equal to the total adjusted heat gains of the room. That is,

$$52.9\,t + 297.2 = 4250.1 - 58.0\,t \quad (3)$$

or,

$$t = 35.6 \text{ deg. F., say 36 deg. F.} \quad (4)$$

TABLE 7
CALCULATED AND ACTUAL EQUILIBRIUM TEMPERATURES FOR OUTDOOR TEMPERATURE OF −8 DEG. F.

Residence	Room	Equilibrium Temperature, deg. F.		
		Actual	Calculated	
			Assuming Infiltration	Assuming Exfiltration
1	2	3	4	5
A	Sun room	29	20	32
A	E. bedroom	55	40	45
A	E. dormitory	50	18	25
B	N.E. bedroom	47	36	41
B	N.W. bedroom	49	31	37
B	.W. bedroom	56	38	42

By substituting in Equation (1) the value of t from Equation (4), a value for the total adjusted heat loss of **2180** B.t.u. per hr. is obtained. Similar calculations were made for each of the unheated rooms in both residences. The equilibrium temperatures so obtained are shown in Table 7, column 4, and the adjusted heat losses for each room are shown in Table 1, column 5, and in Table 2, column 5.

In these calculations it was assumed that infiltration of outdoor air occurred through the cracks around the windows into the unheated rooms, resulting in a heat loss. Whenever air enters a closed space by infiltration an equal quantity of air must leave the space by exfiltration. Thus when one or more rooms of a house are unheated, it is possible that infiltration might occur in the heated rooms and exfiltration in the unheated rooms, resulting in an additional heat gain in the unheated rooms. In this case, using the example shown in Table 6, the item for the infiltration loss is replaced by an item for an exfiltration gain amounting to $432 \times 0.018 \times (72 - t)$. The equilibrium temperature based on this assumption is equal to 41 deg. F., and is shown in Table 7, column 5, together with those for each of the other rooms.

In Fig. 10 are shown the calculated equilibrium temperatures for the northeast bedroom in Residence B for varying outdoor temperatures. The plotted points, through which an average curve was drawn, represent the actual observed temperatures in the room obtained over a wide range of weather conditions. Both the actual and calculated equilibrium temperatures for an outdoor temperature of − 8 deg. F.

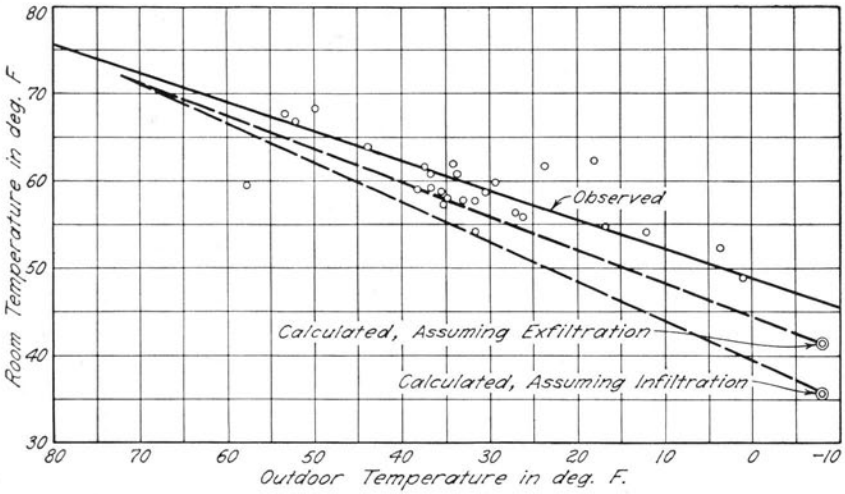


FIG. 10. EQUILIBRIUM TEMPERATURE IN NORTHEAST BEDROOM IN RESIDENCE B

are shown in Table 7 for each of the unheated rooms. By comparing the corresponding values in columns 3 and 4 it may be noted that the actual equilibrium temperature was in every case higher than the calculated values assuming infiltration. The discrepancy was large, and varied from + 9 to + 32 deg. F. The discrepancy between the actual temperature and the calculated temperature assuming exfiltration was somewhat less, and varied from − 3 to + 25 deg. F. The discrepancy between the actual and the calculated equilibrium temperatures can be attributed to uncertainties in the heat transmission calculations, and to unaccounted-for heat gains from chimney, solar effect, etc. Hence, it appears that calculated values of both equilibrium temperature and resultant calculated fuel savings should be accepted with caution.

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†Copies of the complete list of publications can be obtained without charge by addressing the Engineering Experiment Station, Urbana, Ill.

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**Bulletin No. 344.* Fatigue Tests of Commercial Butt Welds in Structural Steel Plates, by Wilbur M. Wilson, Walter H. Bruckner, Thomas H. McCrackin, Jr., and Howard C. Beede. 1943. *One dollar.*

**Bulletin No. 345.* Ultimate Strength of Reinforced Concrete Beams as Related to the Plasticity Ratio of Concrete, by Vernon P. Jensen. 1943. *Seventy cents.*

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**Bulletin No. 347.* Fracture and Ductility of Lead and Lead Alloys for Cable Sheathing, by Herbert F. Moore and Curtis W. Dollins. 1943. *Eighty cents.*

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