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TEMPERATURES AND RELATED CONDITIONS IN WISCONSIN FARMHOUSES

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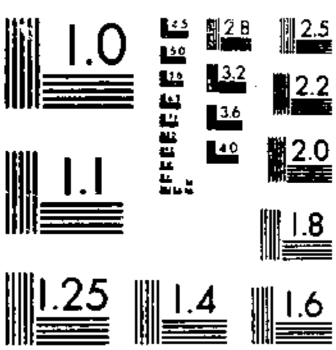

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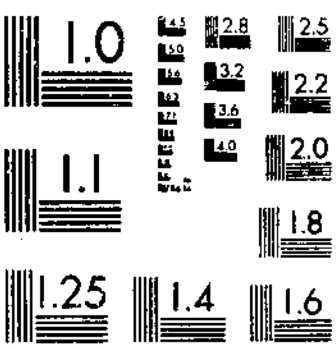
NATIONAL BUREAU OF STANDARDS-1963-A



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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Temperatures and Related Conditions in Wisconsin Farmhouses[1]

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INTRODUCTION

That proper housing has an important effect on the well-being of the family is generally accepted today. As a rule, farm families are more fortunate in many respects than those living in crowded urban areas.

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[2] Acknowledgment is made of advice and assistance given by F. W. Duffee, chairman, and S. A. Witzel, professor, Department of Agricultural Engineering, College of Agriculture, University of Wisconsin; and to E. C. Meyer, formerly of the Department of Agricultural Engineering, College of Agriculture, University of Wisconsin, O. E. Brunkow, formerly associate architect, and O. S. Shivers, formerly agent, Division of Farm Buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering, for their assistance in conducting the investigations.

There is usually opportunity for an abundance of fresh air, sunshine, and exercise, and children have ample space to play safely outdoors. On the other hand the dwelling plays a more important part in the life of the farm family than in that of most urban families. In the colder sections of the country particularly, the life of the family is centered in the home during the long winter months.

It is evident, therefore, that if the farm home is to function satisfactorily the physical charateristics and particularly the thermal environment are of considerable importance.

In 1935 the Bureau of Plant Industry, Soils, and Agricultural Engineering[3] undertook a study of temperature and related factors that might affect the comfort and livability of farmhouses. This study was to determine if possible the chief sources of discomfort, their causes, and the methods of correcting them so that farm families could improve their living conditions.

Two projects were started, one at Madison, Wis., in cooperation with the Wisconsin Agricultural Experiment Station, which is reported in this publication, and the other at Athens, Ga., in cooperation with the University of Georgia.[4]

Wisconsin was selected as representative of a large section of the United States in which winters are long enough and severe enough to constitute a major factor in farmhouse design and construction and in the selection of equipment.

To obtain information on as many as possible of the factors affecting the comfort and livability of farmhouses, plans were made to carry on investigations in occupied houses. Farmers who wished to remodel or otherwise substantially improve their homes or who planned to build new houses were selected as cooperators in order that both existing conditions and the value of various improvements might be studied.

In the years 1936–40 and during the winter of 1941, more or less complete studies were made in nine houses, which as a group were fairly representative of the houses of the region. After the studies had been completed five of these were completely remodeled, one was replaced by a new house, and two were insulated. Studies were then repeated in the improved houses in order to determine the effect of the changes.

In each of the old houses there were various features that caused dissatisfaction, but one problem—discomfort in cold weather—was found in all of them. The studies made of thermal conditions during the winter in the existing houses and the effect of the improvements made to the houses on air temperature, relative humidity, temperature distribution, and surface temperatures are discussed in this publication.

FACTORS RELATING TO COMFORT

As a result of tests the American Society of Heating and Ventilating Engineers has developed the "effective temperature" (E. T.) scale or index,[5] which is defined as "an empirically determined index of the

[3] Then the Bureau of Agricultural Engineering.

[4] SIMONS, J. W., and LANHAM, F. B. FACTORS AFFECTING TEMPERATURES IN SOUTHERN FARMHOUSES. U. S. Dept. Agr. Tech. Bul. 822, 77 pp., illus. 1942.

[5] AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS. HEATING, VENTILATING, AND AIR CONDITIONING GUIDE 1947 (v. 25) Ed. 25, illus. New York. 1947. (See p. 214.)

degree of warmth perceived on exposure to different combinations of temperature, humidity, and air movement."

It was found in the tests by the American Society of Heating and Ventilating Engineers that in general most of the persons studied were comfortable in winter between the limits of 63° and 71° effective temperature (E. T.) with an air movement of between 15 and 25 feet per minute. The optimum was 66° E. T.

The effective temperature index applies to rooms heated by central systems of the convection type. It does not apply to rooms heated by such radiant methods as fireplaces or heating stoves without jackets. It is based on relative humidities and dry-bulb temperatures taken at a height of 60 inches above the floor and on air motion measured 36 inches above the floor. The effect of surface temperatures is not taken into consideration, except that it is pointed out (p. 218 of reference given in footnote 5) that "Radiation between the occupant of an enclosure and the surfaces of the room itself and objects within the room, including windows, heating and cooling equipment, and other occupants, has an important bearing on the feeling of warmth and may alter to some measurable degree the optimum conditions for comfort previously indicated."

While the effective temperature is of great importance in evaluating the effects of various conditions on comfort, Petersen[6] states (p. 82) that "from the point of view of physiological adaptation, the importance of the thermic environment lies frequently less in the actual temperature level than in the instability of temperature—the frequent repetition of fluctuations and the amplitude of the fluctuations . . . The possibilites of stimulation or fatigue are greatly enhanced under such conditions."

PROCEDURE

With these factors in mind, work was undertaken to determine the thermal conditions existing in these houses under normal, everyday use, which had a definite bearing on the comfort of the occupants. As a result no attempt was made to control or regulate the frequency with which the heating equipment was fired, the amount of fuel used, nor the daily routine of the family.

The following data were obtained in each of the important rooms in the test houses:

1. Air temperature at or as near the 60-inch level as possible.
2. Relative humidity at the same level as the dry-bulb temperature.
3. Inside surface temperatures of walls, floors, and ceilings.
4. Temperatures at various levels between floor and ceiling.

In additoin to these data some information was obtained at selected points on air movement in rooms, temperatures and air movements in the wall, floor, and ceiling construction (stud and joist spaces), and infiltration through windows.

Instruments

Air temperatures and relative humidities were recorded continuously in the various houses by means of hygrothermographs, which

[6] Petersen, W. F. The patient and the weather. v. 1, pt. 2. Ann Arbor, Mich. 1936.

were placed in as representative locations as possible in the rooms being studied.

In the unimproved houses instruments were placed on pieces of furniture where they would be least likely to be disturbed. The disadvantage of this method was that the instruments were not always at the same height and were anywhere from 28 to 60 inches above the

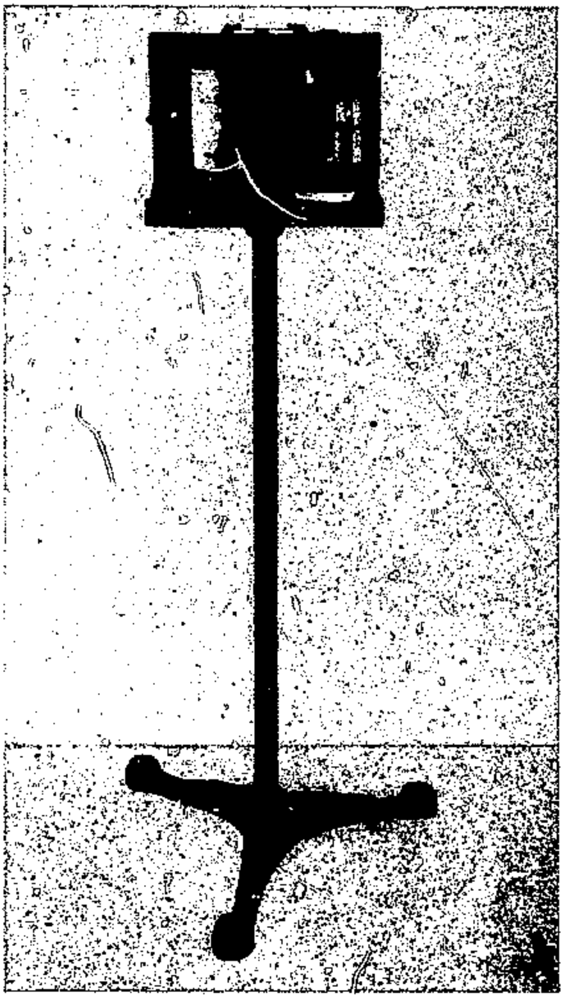

FIGURE 1.—Hygrothermograph on specially built stand.

floor. Later hygrothermograph stands were constructed that placed the instruments 60 inches above the floor (fig. 1). This height was selected, since it is the height used in determining effective temperature. It is also a common height for mounting thermometers and thermostats, as it is approximately the breathing level of a person standing erect.

For purposes of comparison the temperatures recorded by hygrothermographs placed at heights other than 60 inches were corrected for height, using thermocouple readings taken at various heights above the floor as a basis.

Hygrothermographs were checked at the beginning of each week's run by means of a psychrometer. Ordinarily the instruments were checked at a time when temperature and humidity were relatively stable, as both the thermal and humidity elements are somewhat slow in responding to sudden changes in temperature and humidity. As a rule no adjustments were made in pen arms of hygrothermographs; instead, discrepancies were marked on the charts and corresponding corrections made in reading them.

In the majority of the unimproved houses, surface temperatures and air temperatures in stud and joist spaces and in other inaccessible locations such as attics and storage spaces were recorded by means of thermocouples fixed in place. Copper-constantan thermocouples were used. Reference junctions were kept at 32° F. by immersion in a vacuum bottle filled with crushed ice and water.

Electromotive forces (e. m. f.) developed by the thermocouples were read by means of a semiprecision type, portable potentiometer and readings were taken to the nearest whole degree.

Whenever practicable, thermocouples for recording surface temperatures, with as much of the adjacent lead wires as possible, were embedded in the surface. When this could not be done the thermocouples were held in place with drafting tape.

Thermocouples used in measuring air temperatures were shielded from radiation by means of cardboard cylinders covered on the outside with aluminum foil and placed around the thermocouples with the axis of the cylinders in a vertical position. The ends of the cylinders were open to permit circulation of air around the thermocouples and several inches of the lead wires adjacent to the thermocouples were coiled within the cylinder to minimize the effect of radiation to or from the wires close to the thermocouple, thus affecting the accuracy of the readings.

Lead wires from the fixed thermocouples were carried to a terminal board, often located in the basement. Through this central terminal board connection of the lead wire of any desired thermocouple could be made to the potentiometer by means of spring or clip-type clothespins with copper-lined jaws connected to the free ends of lead wires extending to the potentiometer.

In addition to the fixed thermocouples, thermocouples mounted on a portable stand (fig. 2) were used to obtain wall, floor, and ceiling surface temperatures and air temperatures at various levels above the floor. The use of fixed thermocouples for recording surface and air temperatures was abandoned in the remodeled houses in favor of the portable stand. With this instrument the air and surface temperatures in a room could be taken more rapidly and the necessity for an elaborate wiring system was eliminated.

As in the case of the fixed thermocouples, those used to measure air temperatures were shielded with cylinders covered with aluminum foil. Thermocouples for measuring surface temperatures were secured to the surfaces with drafting tape. Before readings were taken these were allowed to remain in place long enough to assume the temperature of the surface. It is likely that in some instances the temperature recorded was not the exact surface temperature, as the air temperature adjacent to the tape probably affected it slightly. Care was taken in

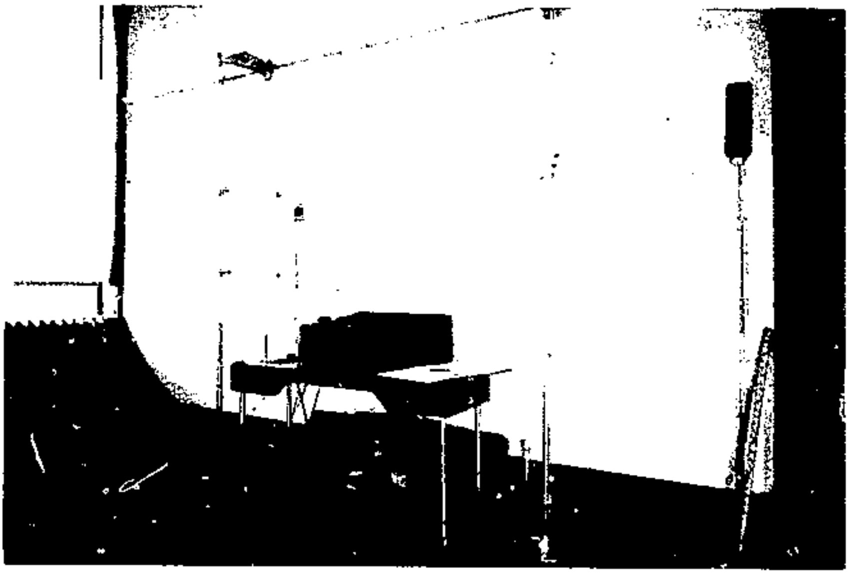

FIGURE 2.—Equipment for measuring the air temperatures at various heights above the floor and the wall, floor, and ceiling surface temperatures. Potentiometers are on the folding table, portable stands to the right and left, and reels of installation wire in the carrying case beneath the table.

analyzing data so that readings did not include those that were obviously affected by direct sunlight.

Lead wires from the thermocouples on the stand ran to a switchboard located on a potentiometer table. Brass plugs and jacks were used for connections. The introduction of brass and hard copper into thermocouple circuits resulted in additional thermal junctions that might introduce additional electromotive force into the circuit. For this reason care was taken to avoid differences in temperature of these junctions. The table was so located that the switch and switchboard were shielded from sunlight or direct radiation from heating equipment. Thermocouples to obtain air temperatures were at first mounted on the stand at heights of 1½, 3, and 60 inches above the floor and at 3 inches and ½ inch below the ceiling. The upper section of the stand telescoped so that it was adjustable to various ceiling heights.

Shortly after the work was started the heights of the thermocouples were changed to 3, 36, and 60 inches above the floor, which were more representative of the air temperatures to which the occupants of the rooms were exposed, and to 1 inch below the ceiling. Wall surface temperatures were taken at heights of 36 to 60 inches above the floor adjacent to the thermocouples recording air temperatures at these heights. Ceiling and floor surface temperatures at the stand location were obtained at the same time.

At first only one stand was used, but inasmuch as the time involved in changing the location and waiting for the thermocouples to come to equilibrium slowed up the rate of taking readings, a second stand was constructed. This made it possible for the readings of the thermocouples on one stand to be taken while the second stand was being relocated. As it took about a minute to obtain readings of all thermocouples on a stand in one location, there was usually enough time both to move the second stand and allow the thermocouples to come to equilibrium while the thermocouples on the first stand were being read.

Locations in the room where readings were to be taken were decided on in advance, and the strips of tape fastened to the wall, floor, and ceiling surfaces in the proper places and left in position during the day. This not only made for rapid locating of the stands but also avoided the necessity of waiting for the tape to assume the temperature of the surface to which it was attached.

In the early studies portable stand readings were taken only at what seemed to be the more important locations in each room. Several readings might be taken along the outside walls of the room and one or two in the center. In small rooms readings were sometimes taken only in the center. Later when two stands were used these readings were taken in groups 1, 18, and 36 inches from the wall. The number of groups depended on the size of the room. Floor and ceiling surface temperatures were taken at each stand location, and wall surface temperatures at two points on the wall at each location when the stand was 1 inch from the wall.

A few measurements of infiltration around doors and windows were attempted. A boxlike enclosure, or "mask," covering the entire opening, was used. This mask was fitted with a single tubular outlet to the room in which was mounted an anemometer. The mask was intended to receive all air entering at all points around the edges of the door or window and guide it to the outlet where it could be measured. Two types of anemometers were used, the windmill and the Hukill hot-wire thermocouple anemometer. Because of the time involved in making these measurements and because opening and closing of doors by the family in other parts of the house affected the reliability of the readings, these studies were discontinued and data will not be presented in this bulletin.

Air movements in the stud and joist spaces were measured with the Hukill thermocouple anemometer. With this instrument velocities as low as 6 feet per minute can be measured. It is particularly suited to the measurements of air currents in confined spaces.

This instrument, mounted on a board, was also used in measuring air currents and drafts in the rooms. Smoke puffs, using ammonium chloride and cigarette smoke, were used in tracing air currents.

Another instrument, the velometer, was also used in obtaining readings of air movements, both in the joist and stud spaces and in the rooms.

DESCRIPTION OF TEST HOUSES AND HABITS OF THE OCCUPANTS

The nine original houses in which studies were made ranged in size from 4 to 12 rooms; the condition varied from poor to good. Five of the houses were heated by gravity warm-air systems—one by a pipeless furnace, one by a one-pipe steam system, one by stoves, one by a circulator heater, and one by both a stove and a circulator heater. All of the houses were of wood-frame construction with wood siding except one that was stucco on wood frame and one that was built of split logs.

The changes made in the five houses that were remodeled consisted of adding or rearranging rooms, tightening construction, insulating, and in some cases replacing or remodeling the old heating equipment. The one new house that was built to replace the original structure was of stone instead of frame, as the old house had been. The changes made in two other houses consisted entirely of adding insulation. No changes were made in the remaining two houses.

Descriptions of the structure and heating equipment of each of the houses studied, before and after improvements were made, are given on pages 8 to 47.

In order to appreciate fully the conditions found in these houses, reference to the habits of the families, the regularity with which they fired their heating equipment, and the use they made of the various rooms is essential. A discussion of these habits is given along with the description of each of the houses.

In general, it may be stated that most of the families made a reasonable effort to fire their heating equipment with some regularity. Those in houses Nos. 1 and 6 did not. There was some tendency, however, for all of them to wait until the houses began to feel cold or too warm before firing or checking the dampers, especially during the day when the men were not in the house and the women were busy in the kitchen.

In houses where there were young children who were at home during the day there was a good deal of running in and out of the house, sometimes with outside doors left open for considerable periods of time. This was especially true in houses Nos. 1, 4, and 6.

In some houses the inability to heat all the rooms comfortably, either because there was no provision for heating them directly or because of an inadequate heating system, led to closing off some of the rooms during the winter and not using them at all. In other houses rooms were shut off principally to save fuel. In all cases family activities during the day and evening were largely confined to the kitchen with one other room,[7] usually the dining room or the living room, used to some extent in the evening.

In all of the houses except house No. 1, second story bedrooms were shut off during the day and not heated. In fact only in houses Nos. 1, 2, 7, and 9 were any bedrooms heated during the day. In most houses bedrooms were "warmed up" in the evening. In two of the houses, Nos. 2 and 4, the inability to heat more than one bedroom resulted in actual overcrowding, despite the fact that there were more than enough bedrooms in the house.

After remodeling, greater use was made of more of the rooms, although the practice of shutting off the second story during the day still persisted in most cases.

In presenting the data, the discussion of conditions will be confined largely to those found in the kitchen and the most frequently used rooms other than the kitchen, where an attempt to heat was made. Data on bedroom temperatures, however, are given in tables 4, 6, and 8, Appendix.

Description of House No. 1

House No. 1, shown in figure 3, was built in 1920. It was of the story-and-a-half type, with a full basement, and contained 10 rooms

[7] In the following discussion this room is referred to as the "most used room."

FIGURE 3.—House No. 4, from the southeast.

and a bath. Because the plate line was below the second-story ceiling, not all of the second floor area was usable. This resulted in unheated spaces adjacent to the bedrooms. Stud and joist spaces were open into these areas. First- and second-floor plans are shown in figures 4 and 5.

CONSTRUCTION DETAILS

Basement walls.—Concrete, 12 inches thick. Condition good.

Exterior walls.—Stucco on wood lath, ½-inch fiber insulation board and 1-inch wood sheathing on the outside, 2- by 4-inch studs. Wood lath and plaster on the inside. Condition, fair. (Stucco cracked and loose in places.)

Floors.—Double wood floors. Condition, good.

Ceilings.—Wood lath and plaster. Condition, good.

Roof.—Wood shingles on spaced shingle lath. Condition, good.

Insulation.—Exterior walls only. Condition, good.

Windows.—Wood, double hung. Fit, fair to good except in Nos. 6 and 7 in second story, which was poor. Windows with storm sash: Nos. 1 to 6 in first story and 1 to 4 in second story. Weatherstripping, none.

Exterior doors.—Wood-paneled, glazed. Fit of doors, poor. Storm doors, none.

Ceiling heights.—First floor, 8 feet 6 inches. (Washroom, 7 feet 10 inches.) Second floor, 7 feet 6 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

The gravity warm-air system had a furnace with a 24-inch fire pot with water pan for humidification. Wood was normally burned, but coal was used during these tests. There were warm air registers in all rooms. The system was well designed, except that the leader serving the kitchen also served the washroom and bedroom No. 2. While the leader was adequate for any one of the three rooms, it was not large enough to supply all. A wood burning kitchen range was used for cooking.

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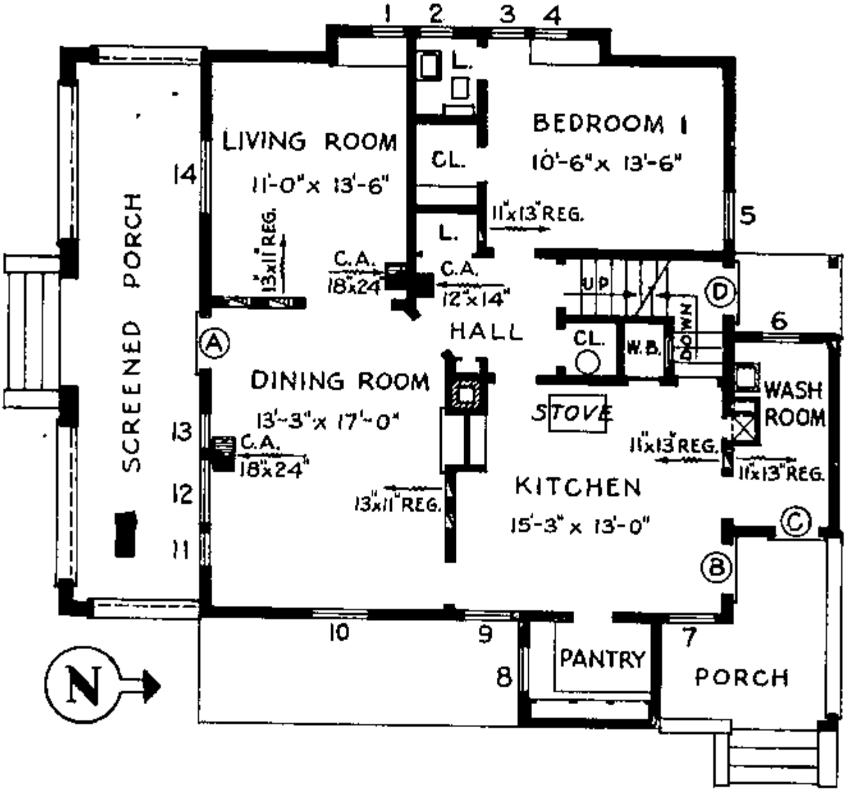

FIGURE 4.—First-floor plan of house No. 1, showing the location of warm-air registers and cold-air returns.

USE AND HEATING OF ROOMS

The family occupying this house consisted of the owner, his wife, a daughter aged 5, and a boarder. During the day the house was occupied less than most of the other houses studied. Both the owner and his wife were outdoors much of the time. The daughter also played outdoors a great deal, except in very bad weather.

All first-floor rooms were heated regularly during the day, although the kitchen was the only room used to any extent. All meals were eaten there. All laundry was done in the basement laundry room, which was located under the living room, and it was equipped with a wood-burning range for heating water. The dining room was used occasionally during the day, as the office desk and files were located there. It was also used in the evening by the family. The living room was used only for entertaining. In very bad weather bedroom No. 2 was used as a playroom for the little girl.

As a rule, the second floor was shut off during the day by means of the door at the foot of the stairs. Bedroom No. 3, the only used bedroom on the second floor aside from bedroom No. 2, was heated only in the evenings.

In general the family did not fire very regularly and sometimes the fire was very nearly allowed to go out. This was because they were in the house so infrequently and for such short periods of time

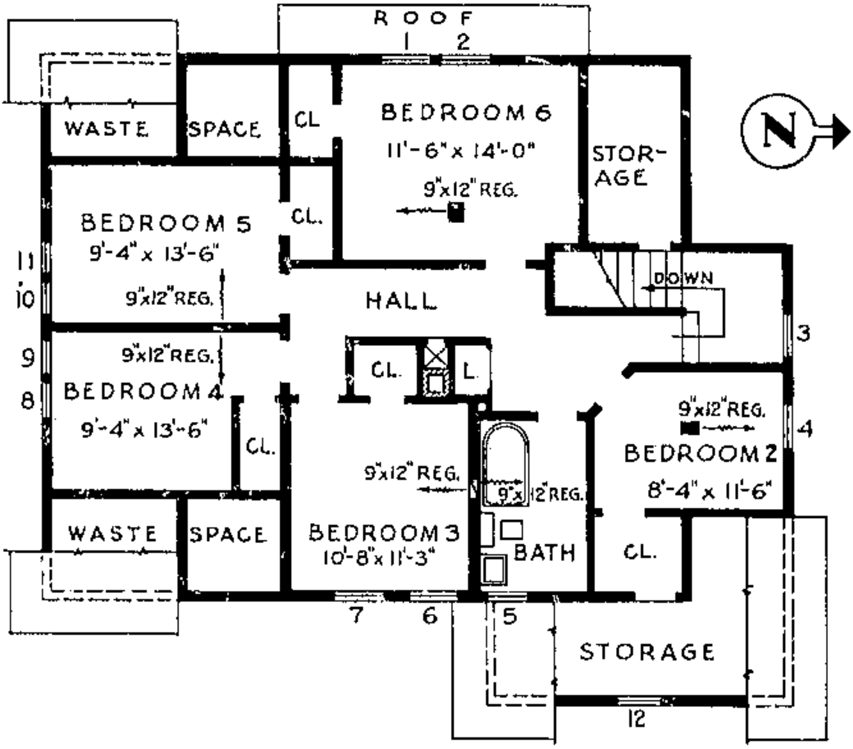

FIGURE 5.—Second-floor plan of house No. 1, showing location of warm-air registers and cold-air returns.

during the day. When the wife was in the house she was usually busy with cooking or some other task, and the fact that the house was not warm did not appear to bother her. Another factor that affected the temperature was the fact that the family went in and out of the house a good deal and frequently left outside doors standing open, sometimes for fairly long periods of time.

DESCRIPTION OF HOUSE NO. 1-R

The changes made in house No. 1 were not extensive. Those that would be expected to have some effect on temperature and humidity included repairing and insulating the walls and ceiling with 3⅝ inches of mineral wool, replacing the old stucco and insulation board covering the outside of the house with wood shingles, and rearranging the kitchen so that the exterior door did not open directly into it (fig. 6). Storm sash were installed on the windows of the kitchen, office, and washroom. No alterations were made to the second floor.

The result of these changes was to reduce the calculated heat loss[8] from 95,400 British thermal units (B. t. u.) per hour to 58,600 B. t. u.

[8] In calculating heat losses for all houses except when otherwise indicated, an inside temperature of 70° F. (at the 60-inch level) and an outside temperature of −15° F. were assumed. Only those rooms that were actually heated regularly or occasionally were included in the calculations.

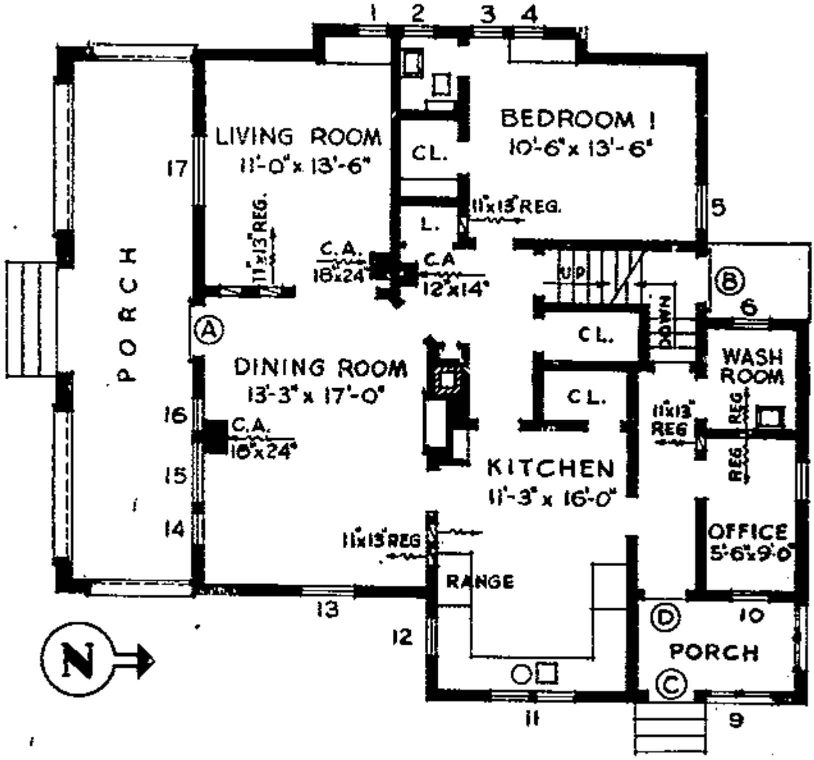

FIGURE 6.—First-floor plan of house No. 1-R, showing changes.

per hour, despite the fact that bedroom No. 6 was heated in the remodeled house. This amounted to a reduction in heat loss of 3.20 B. t. u. per hour per cubic foot of heated space.

No change was made in the heating system except that a register with a separate leader was provided for the kitchen and new registers in the new office (fig. 6) and washroom, served by a single leader, were installed.

USE AND HEATING OF ROOMS

Little change was made in the use of rooms in the remodeled house. As separate office space was provided, however, the dining room was probably used less during the day than before. As a result the kitchen was less of a passageway between the rear entrance door and the dining room. In addition to the rooms previously heated, bedroom No. 6 was being heated at the time readings were taken.

DESCRIPTION OF HOUSE NO. 2

House No. 2, an exterior view of which is shown in figure 7, was also a story-and-a-half house, with one bedroom and an unfinished attic on the second floor. It had a full basement, except for an unexcavated area under bedroom No. 2 and the bathroom. The plan of the first floor is shown in figure 8.

FIGURE 7.—House No. 2 from the west.

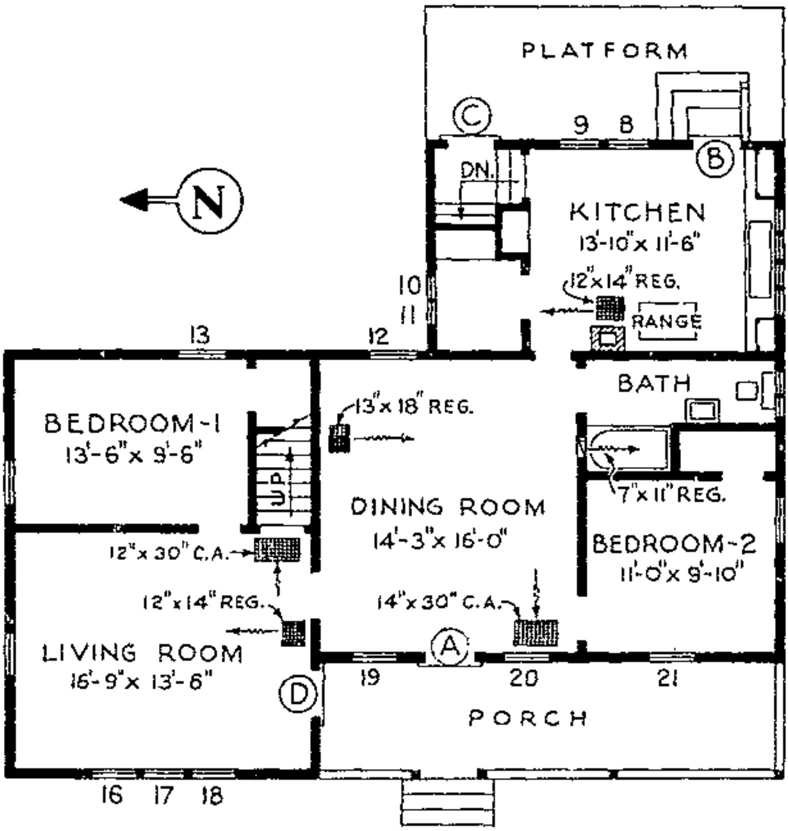

FIGURE 8.—First floor plan of house No. 2, showing location of warm-air registers and cold-air returns.

CONSTRUCTION DETAILS

Basement and foundation walls.—Stone and concrete. Condition, good.

Exterior walls.—Main part, bevel siding on exterior, 2- by 4-inch studs, wood lath and plaster on inside. Condition of walls, main part, poor. Kitchen wing, good.

Floors.—Single wood floors in dining room, bathroom, bedroom No. 2. Linoleum laid over wood floor in bathroom. Double floors in bedroom No. 1, living room, and kitchen. Linoleum laid over double wood floor in kitchen.

Ceilings.—Wood lath and plaster. Condition, good.

Roof.—Main part, asphalt shingles over wood shingles on spaced shingle lath on north and east slopes of roof, wood shingles only on south and west slopes; kitchen wing, asphalt shingles over tight sheathing. Condition, good.

Insulation.—None.

Windows.—Double-hung wood windows, Nos. 1, 8, 9, 12, 13, 14, 15, 16, and 18. Wood casements (hinged at side to swing in), Nos. 2, 3, 4, 5, 6, 7, 10, and 11. Fixed sash, No. 17. Fit of windows: First floor, good, Nos. 4, 5, 6, 7, 9, 10, 11, 16, 17; fair, Nos. 2, 3, 8, 12, 13, 19, 20; poor, Nos 1, 14, 15, 18, 21. Second floor, all poor. Weatherstripping, none. Storm sash, none.

Exterior doors.—Wood, paneled, upper part glazed. Fit of doors: Fair, A, B, and C; poor, D. Weatherstripping, none. Storm doors, A and D.

Ceiling heights.—First floor, 7 feet 10 inches; second floor, 7 feet 4 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

A gravity warm-air system was used. The following data were supplied by the manufacturers:

Efficiency at bonnet	69 to 65 percent.
Combustion rate	8 pounds per hour per square foot of grate area.
Ratio of heating surface to grate area	22 to 1.
Register temperature	135° to 145° F.
Diameter of grate	20 inches.
Leader pipe capacity	575 square inches.

The furnace was equipped with a water pan. There were warm-air registers only in the living room, dining room, kitchen, and bathroom. However, the grate area was sufficient to warrant additional ducts to the remaining first-floor rooms. This assumption is based on calculated heat losses, using an inside temperature of 70° F. at the 60-inch level and an outside temperature of −15°.

On the other hand, all of the leaders except that supplying the bathroom appeared to be undersized for the register temperature claimed. In a number of respects this system did not conform to the Standard Gravity Code (which is a generally accepted standard for the installation of gravity warm-air heating systems) in that it was designed for much lower register temperature (135° to 145° F. as against 175°) but did not have sufficient leader capacity.

Wood was the fuel used almost entirely for heating, as it was readily available on the farm. The gasoline range used for cooking the year around supplied little additional heat to the kitchen.

USE AND HEATING OF ROOMS

Before remodeling, the dining room and the kitchen were the two most used rooms. The living room and bedroom No. 1 were shut off entirely in winter because they could not be satisfactorily heated. The result was rather crowded sleeping facilities, as the owner, his wife, and their two children all occupied bedroom No. 2.

The important problem was to heat comfortably at least one more bedroom and if possible the living room, in order to provide a satisfactory place for the children to play indoors in bad weather and to have a room in which the family could entertain. It was also necessary to accomplish this at minimum cost.

It was decided to insulate the house thoroughly rather than change the heating system, as it was thought that a decided reduction in heat loss would probably make the entire first floor habitable. Later, when the family needed the second floor a new heating system could be installed or changes in the existing system could be made to provide registers in the rooms not served at the time.

Description of House No. 2–I

During the summer of 1937 the side walls of house No. 2 and the rafter spaces of the main part of the house were filled with mineral wool insulation. The ceiling of the kitchen was similarly insulated. The insulation was blown in, and as a result no sheathing was added to the walls of the main part of the house and no vapor barrier was provided in the walls.

In addition to the insulation the three windows in the west wall of the living room were replaced with a bank of three new windows. This was done because of the poor condition of the original sash and to improve the appearance of the house. Two dormer windows were located on the second-floor room, which at the time was used for storage but which the family later wished to finish off for an additional bedroom. All windows were provided with storm sash.

The wood shingles on the north, south, and west slopes of the roof over the main part of the house were covered with composition shingles to give a more uniform appearance. No change was made in the heating system.

The result of these improvements was to reduce the calculated heat loss of the entire first floor from 90,900 B. t. u. per hour to 45,000 B. t. u. per hour, or a reduction of about 50 percent.

USE AND HEATING OF ROOMS

After the changes were made the living room was regularly heated and used to some extent during the day. Bedroom No. 1 was occupied by the parents and the younger child. It was closed off during the day but opened in the evening to allow it to warm up before the family retired. The older child slept in bedroom No. 2.

Description of House No. 3

House No. 3 (fig. 9) was approximately 50 years old at the time studies were made. It was a two-story house, with six rooms on the first floor (fig. 10) and four bedrooms and a bathroom on the second floor (fig. 11).

There was a basement only under the dining room and bedroom No. 1.

FIGURE 9. House No. 3 from the southeast.

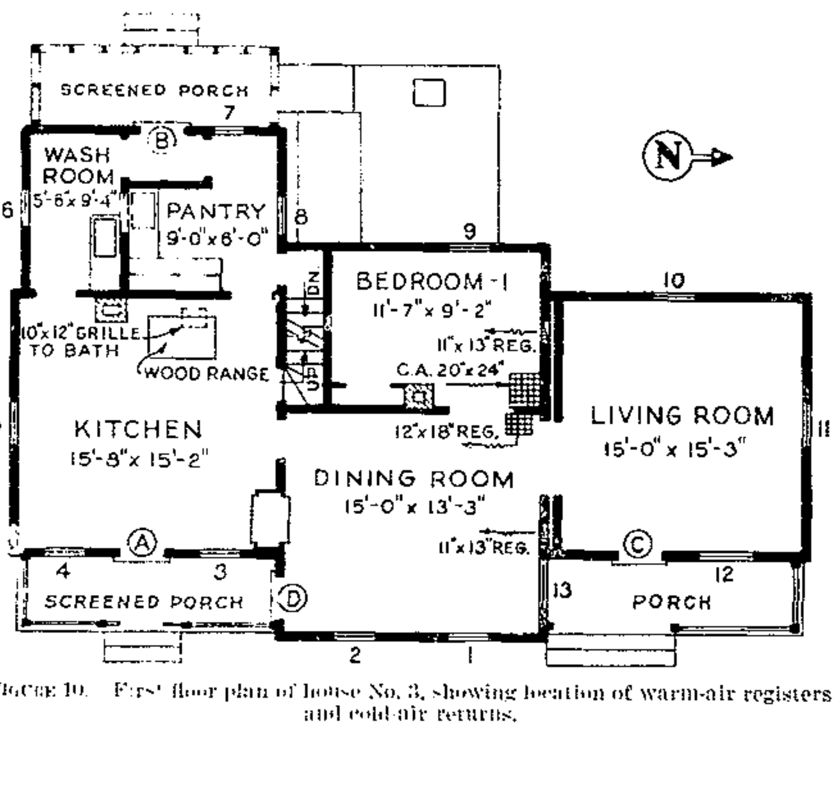

FIGURE 10. First floor plan of house No. 3, showing location of warm-air registers and cold-air returns.

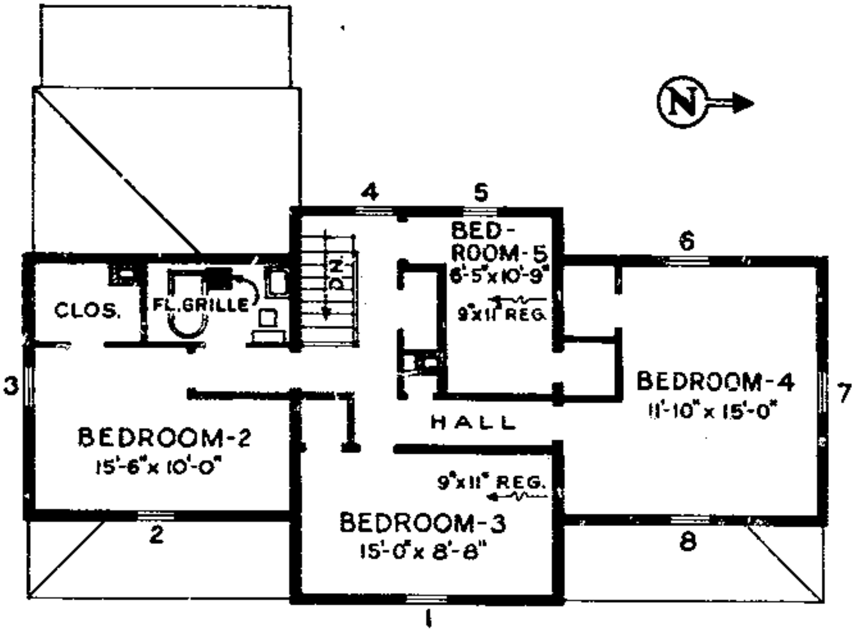

FIGURE 11.—Second-floor plan of house No. 3, showing location of warm-air registers and cold-air returns.

The calculated heat loss, assuming only used rooms to be heated, was 64,335 B. t. u. per hour, or 7.69 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Basement and foundation walls.—Stone, 18 inches thick. Condition, fair.

Exterior walls.—Wood siding, building paper, and sheathing on the exterior; 2- by 4-inch studs, wood lath, and plaster on the inside. Thirty-inch-high wood wainscot in kitchen. Condition, fair.

Floors.—Double wood floors in kitchen, pantry, and washroom, linoleum in kitchen. Single wood floors in other rooms. Condition, fair.

Ceilings.—Wood lath and plaster. Condition, fair.

Insulation.—None.

Windows.—Double-hung, wood windows, except Nos. 12 and 13, which are fixed sash. The fit of sash is as follows: First floor: Good, Nos. 7, 12, 13; fair, Nos. 1, 2, 4, 5, 6, 8; poor, Nos. 3, 9, 10, 11. Storm sash, windows 7, 8, and 9. Second floor: All fair, except Nos. 6 and 7, which were poor. Storm sash, windows 6 and 7.

Exterior doors.—Wood, paneled. Doors A and D glazed. Fit, all poor. Storm doors, none.

Ceiling heights—8 feet.

HEATING SYSTEM AND COOKING EQUIPMENT

The heating system was a gravity warm-air type. The furnace had a 24-inch fire pot and a capacity of 622 square inches of pipe area. The total cross section area of the leaders was 346 square inches. The cross section area of the recirculating duct was 314 square inches. Humidity was provided by means of an evaporating

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pan, located below the feed door, in which the water supply was maintained automatically.

There were warm-air registers only in the dining room and bedroom No. 1 on the first floor. The kitchen was heated by overflow heat from the dining room, supplemented by heat from the wood-burning kitchen range.

The leaders and stacks that supplied bedrooms Nos. 3 and 4 also served registers in the dining room and bedroom No. 1 on the first floor. As the only cold-air return was located in the northeast corner of bedroom No. 1, it is probable that most of the heat intended for these two second-floor rooms went into the dining room and bedroom No. 1.

The bathroom received heat from the kitchen range through a grille in the floor.

Calculations indicated that the furnace was more than adequate to heat those rooms with registers but not quite large enough to heat the entire house unless steps were taken to reduce the heat loss. The leaders and stacks supplying the dining room and bedroom No. 1 were larger than necessary for these rooms but not large enough to deliver sufficient heat to balance the heat loss for the entire first floor. The leader and stack that supplied bedroom No. 3, while adequate for the room, also connected to the second register in the dining room; and that which supplied bedroom No. 5 was adequate for that room but also supplied bedroom No. 1 on the first floor.

USE AND HEATING OF ROOMS

With the exception of the dining room, which was the most used room except for the kitchen, and bedroom No. 1, this house was difficult to heat comfortably, even in mild weather. Even these two rooms were uncomfortable in cold weather. The living room could not be satisfactorily heated at all, as there was no register in the room, and consequently it was not used in winter. This was also true of bedroom No. 4. The rest of the second floor was hard to heat without forcing the furnace, but as the space was needed to accommodate the family, which consisted of the owner, his wife, and two children (a boy and a girl), these rooms were used. The bedrooms, however, took so long to heat up in the mornings that the bathroom, which received some heat, was used as a dressing room.

Except in very cold weather, the entire second floor was usually shut off during the day by means of the door at the foot of the stairs. This door was opened to take the chill off the second floor a short time before the family retired.

The kitchen received most of its heat from the kitchen range supplemented by overflow heat from the dining room. In mild weather this room was not too uncomfortable, but in severe weather the owner's wife used to stop her housework occasionally and warm her feet in the oven. She also wore overshoes to help keep her feet warm on such occasions. The pantry was usually cold, as the only heat came from the kitchen. Nevertheless, it was used when preparing meals and washing dishes.

This family made an effort to keep the occupied part of the house comfortable in cold weather, but it was a difficult task.

Description of House No. 4

House No. 4 was 83 years old (fig. 12). It also was a story-and-a-half house with five rooms, a front and rear stair hall, and a woodshed on the first floor (fig. 13), and four bedrooms and a storage room on the second floor (fig. 14). There was a basement under all of the house except the woodshed.

Figure 12.—House No. 4 from the northwest.

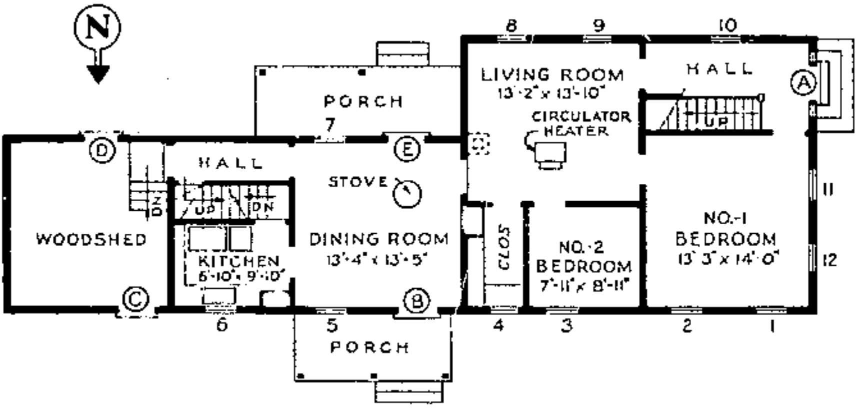

Figure 13. First-floor plan of house No. 4, showing location of heating equipment.

There was little attic space over the second-floor rooms, owing to the low eaves. There were a number of closets and storage areas under the eaves.

The structure was in fair condition. The lack of subflooring, particularly with the unheated basement, undoubtedly contributed to discomfort.

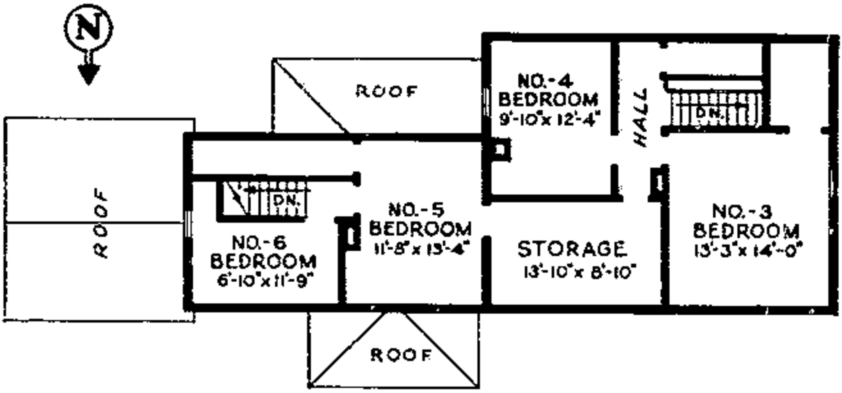

FIGURE 14.—Second-floor plan of house No. 4.

The calculated heat loss, assuming only used rooms heated, amounted to 35,968 B. t. u. per hour, or 4.94 B. t. u. per cubic foot of heated space per hour.

CONSTRUCTION DETAILS

Basement walls.—Stone, 18 inches thick. Condition, fair.

Exterior walls.—Bevel siding, building paper, square-edge sheathing on outside, 2- by 4-inch studs, wood lath, and plaster on inside. Condition, fair.

Floors.—Wood, single thickness except in kitchen, which had double flooring and was covered with linoleum. Condition, fair.

Ceiling.—Plaster on wood lath. Condition, fair.

Roof.—Wood shingles on spaced shingle lath. Condition, poor.

Insulation.—None.

Windows.—Wood, double hung. Condition, poor. Fit: First floor, fair except in window No. 6 in kitchen, which was poor; second floor, poor. Storm sash: Windows 5, 6, 7, 8, and 9 on first floor.

Exterior doors.—Wood, paneled. Condition, fair. Storm doors, B and E.

Ceiling heights.—Main part, first floor, 8 feet 2 inches; second floor, 7 feet 11 inches. East wing, first floor, 8 feet; second floor, 7 feet 6 inches.

HEATING AND COOKING EQUIPMENT

Heat was supplied in the living room by a manually regulated oil-burning, circulator heater, which was 3 years old. It was in good condition, and the manufacturers claimed it to be adequate in size to heat between 5,000 and 7,000 cubic feet of space. The coal- and wood-burning stove that heated the dining room had an 18-inch diameter grate and, although older than the circulator heater, was also in good condition. Cooking was done on an electric range.

This equipment appeared to be adequate to heat the entire first floor, as the space to be heated was only 7,287 cubic feet.

USE AND HEATING OF ROOMS

The family occupying this house consisted of the owner, his wife, and their 6-year-old son. Prior to remodeling, the only rooms used in winter were the living room, dining room, kitchen, and bedroom No. 2. The second floor was shut off entirely, as there was no provision for heating it. Bedroom No. 2 was occupied by all three members of the family, as it was the only room that received any appreciable amount of overflow heat.

Both the living room and the dining room were used a great deal by the family, and fewer activities were carried on in the kitchen than was the case in most of the houses studied.

The family made a real effort to keep the used rooms warm, but in spite of this they were uncomfortable in cold weather. Inability to heat the second floor resulted in crowded sleeping accommodations. The use of the dining room as the main entry was also undesirable because of the cold air admitted whenever anyone entered or left the house. The small son frequently left the door open as he ran in and out when at play.

FIGURE 15.—House No. 4-R from the northeast.

DESCRIPTION OF HOUSE NO. 4-R

Changes made in house No. 4 included, among other things, rearrangement of the first- and second-floor plans to provide more livable rooms, insulating walls and ceilings, installing new weather-stripped windows, laying a double floor in the living room, covering the old floors in the kitchen and office with linoleum, and installing a new heating system. An exterior view of the remodeled house is shown in figure 15 and the revised floor plans in figures 16 and 17.

CONSTRUCTION DETAILS

Basement walls.—Stone, 18 inches thick. Condition, good.

Exterior walls.—Wood siding, wood sheathing, building paper, 3⅝ inches of mineral wool, vaporproof paper, gypsum lath, and plaster (except in bedrooms No. 1 and No. 2 and stair hall, where there is no insulation and the interior finish is plaster on wood lath). Condition, good.

Floors.—Double wood floors in living room. Wood subfloor covered with linoleum in kitchen and office. Single floors in bedroom No. 1, stair hall, and second story. Condition, good.

Ceilings.—Second floor, plaster on gypsum lath, 3⅝ inches of mineral wool insulation (except over bedroom No. 2 and stair hall, which was uninsulated and finished with wood lath and plaster).

Insulation.—See walls and ceilings.

Roof.—New wood shingles on special shingle lath.

Windows.—Wood, double hung. Fit, all good. Weatherstripping: Nos. 9, 10, 11, 18, 19, 20, and 21. Storm sash: All windows.

Doors.—Wood, paneled. Doors B and C glazed. Fit, good. Storm doors: All.

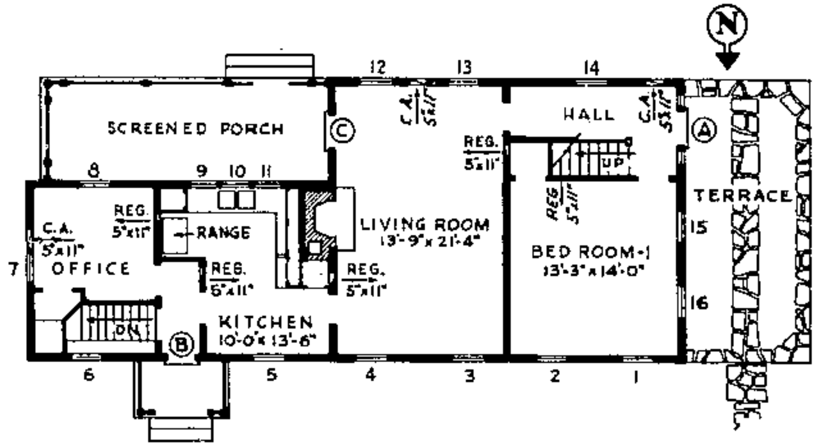

FIGURE 16.—First-floor plan of house No. 4-R, showing changes in room arrangement and location of warm-air registers and cold-air returns.

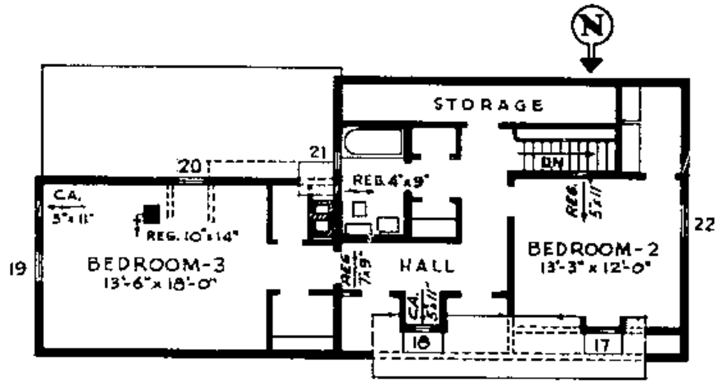

FIGURE 17.—Second-floor plan of house No. 4-R, showing changes in room arrangement and locations of warm-air registers and cold-air returns.

HEATING SYSTEM AND COOKING EQUIPMENT

The new heating system was a forced-warm-air type with an oil-burning furnace. The furnace, according to the manufacturers, had a capacity of 100,000 B. t. u. per hour and delivered between 1,000 and 1,200 cubic feet of air per minute. It was controlled by a thermostat located in the living room. The installation was good, the leaders, stacks, and registers all appeared to be properly sized, and there were registers in all rooms. All of the warm-air registers were located just above the baseboard, except one in the living room and those in the kitchen and office, which were 72 inches above the floor. The register in bedroom No. 3 was a floor register. Cooking was done on the electric range.

After remodeling there were 7,317 cubic feet to be heated on the first floor and 4,082 cubic feet on the second floor. The total calculated heat loss amounted to 44,800 B. t. u. per hour, or an average of 3.93 B. t. u. per hour per cubic foot of heated space.

USE AND HEATING OF ROOMS

These changes in room arrangement and the installation of the new heating system resulted in some changes in room use. Most important was the improvement in sleeping accommodations. Laundry facilities were provided in the basement, so that this operation was

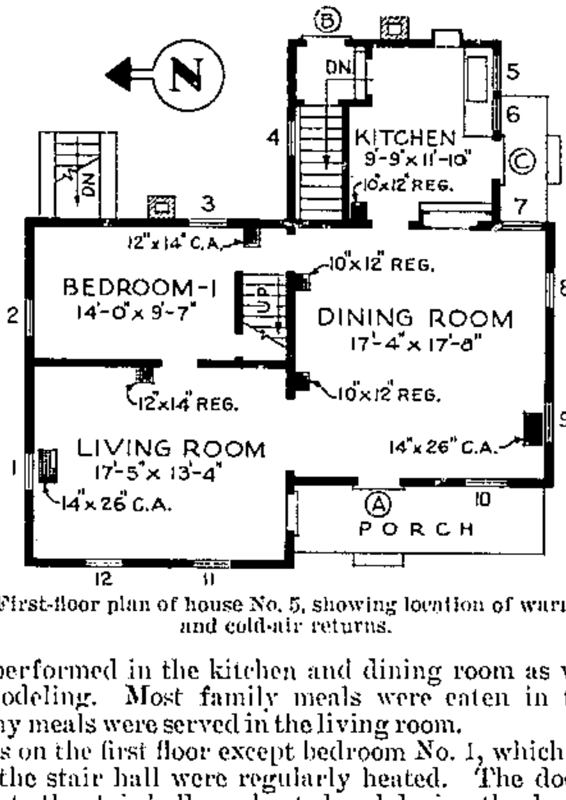

FIGURE 18.—First-floor plan of house No. 5, showing location of warm-air registers and cold-air returns.

no longer performed in the kitchen and dining room as was the case before remodeling. Most family meals were eaten in the kitchen, and company meals were served in the living room.

All rooms on the first floor except bedroom No. 1, which was a guest room, and the stair hall were regularly heated. The door from the living room to the stair hall was kept closed during the day. Only the bathroom on the second floor was heated at all times. The registers in the bedrooms were shut off during the day and opened a short time before retiring, while the registers in the hall were partly closed at all times. The doors to the bedrooms were always kept closed.

DESCRIPTION OF HOUSE NO. 5

The original part of house No. 5, built in 1865, consisted of the living room, bedroom No. 1 on the first floor, with the basement underneath, and bedrooms Nos. 2, 3, and 4 on the second floor (figs. 18 and 19).

Later the dining room with the storage space above it, the kitchen, and the summer kitchen were added. The furnace was installed in 1933. The house had a full basement, and there was an unfinished attic over all of the second story except the unheated storage space.

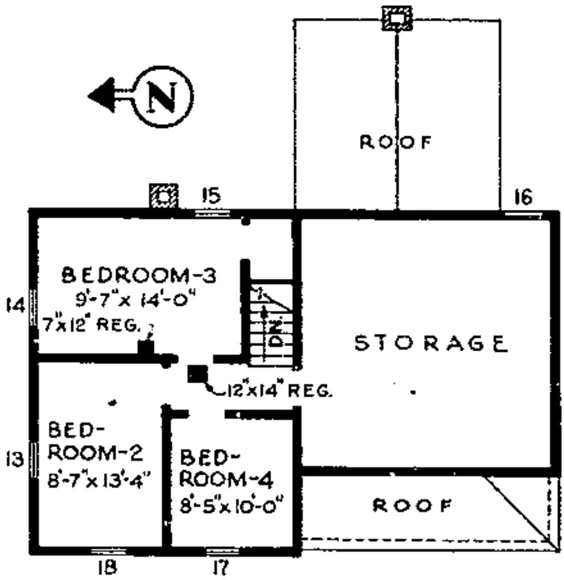

FIGURE 19.—Second-floor plan of house No. 5, showing location of warm-air registers.

FIGURE 20.—House No. 5 from the southwest.

Shortly before studies were started the basement under the dining room and kitchen was excavated. The summer kitchen was detached and moved a short distance away, and the basement stairs in the kitchen were built. A photograph of the house is shown in figure 20.

CONSTRUCTION DETAILS

Basement walls.—Stone and concrete.

Exterior walls.—Bevel siding, building paper, and square-edge sheathing on outside; 2- by 4-inch studs, wood lath, and plaster on inside. Condition of walls, poor.

Floors.—Double wood floors. Condition, poor.

Ceiling.—Wood lath and plaster. Condition, poor.

Roof.—Wood shingles on spaced shingle lath; north, south, and west slopes covered with asphalt shingles. Condition, poor.

Insulation.—None.

Windows.—Wood, double hung, except Nos. 2 and 3, which were sliding sash. Fit, poor. Weatherstripping, none. Storm sash, all except No. 7.

Exterior doors.—Wood paneled and glazed. Fit, poor. Weatherstripping, none. Storm doors, all.

Ceiling heights.—First floor: Main part, 8 feet 2 inches; south wing, 8 feet 5 inches. Kitchen and second floor: 7 feet 6 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

The gravity warm-air heating system was in good condition, but the furnace did not appear to be adequate to heat the entire structure. The capacity of the furnace was only 85,000 B. t. u. at the registers and the calculated loss 87,100 B. t. u., which was probably a very conservative estimate of the loss in view of the actual condition of the structure. The heat loss per hour per cubic foot of heated space was 4.43 B. t. u.

The furnace was hand-fired and the damper manually regulated. The fire pot was 24 inches in diameter. According to the manufacturer the combustion rate was 6 pounds of coal per square foot of grate per hour. The efficiency at the bonnet was 75 percent. The ratio of heating surface to grate area was 17.25 to 1, and the register temperature 175° F. The humidifier was of the pan type, with the water supply controlled by float. Semibituminous coal and some wood were the principal fuels. A wood-burning range was used for cooking.

USE AND HEATING OF ROOMS

The family occupying this house consisted of the owner and his wife, and a daughter who was at home only over week ends.

The two most used rooms during the winter months were the kitchen and dining room, although the living room was used when the family entertained, which they did quite frequently.

All regular meals were eaten in the dining room, and it was also used as the farm office and as a sitting room both during the day and in the evenings. This room was used more during the day than was the case in most of the other houses studied.

The most frequently used entrance was the east entrance to the kitchen, where the landing served as a vestibule. As there were no small children in the family the amount of traffic through the door was less than in some of the other houses. The front entrance was never used to any extent.

The bedrooms were not regularly heated during the day except in very cold weather. Usually the door at the foot of the stairs was opened and heat allowed to rise to the second floor in the evening before the family retired.

In general, this family made a reasonable effort to keep the house comfortable during the day, as both the owner and his wife spent more

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time in the house than most of the cooperators. However, the furnace was often fired only when the house began to feel cool.

Despite all of their efforts the family stated that they could not maintain comfortable conditions in cold weather, although in mild weather heating was no problem.

Description of House No. 5–R

During the summer of 1936, house No. 5 was remodeled. The house was enlarged somewhat, and the rooms rearranged. Figures 21 and 22 show the new arrangement of rooms and their sizes, and figure 23 shows an exterior view of the house.

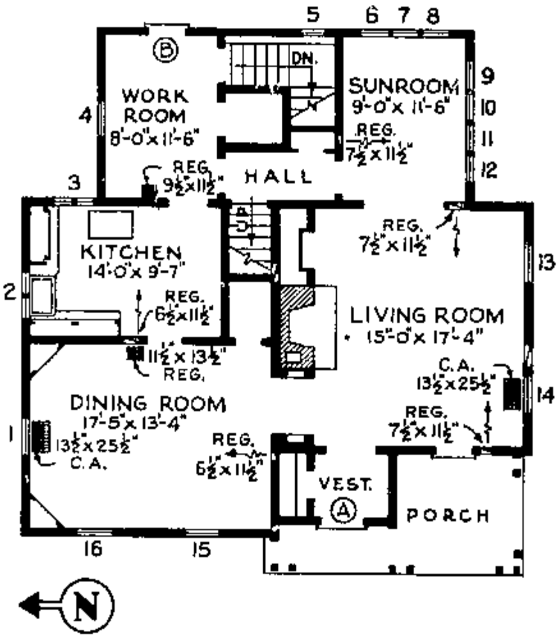

FIGURE 21.—First-floor plan of house 5–R, showing location of warm-air registers and cold-air returns.

The house was insulated, new weatherstripped windows installed, all exterior siding, building paper, and sheathing replaced, most of the roof reshingled, and the heating system remodeled. The changes in the structure resulted in a reduction in heat loss to 67,300 B. t. u. per hour. Since the heated space was increased the rate of loss was only 2.96 B. t. u. per hour per cubic foot.

CONSTRUCTION DETAILS

Exterior walls.—First story: Bevel siding, building paper, and 1-inch square-edged sheathing on the outside; 2- by 4-inch studs, gypsum lath, and plaster on the inside, 3⅝ inches of mineral wool insulation in stud spaces. Second story: bevel siding, building paper, and 1-inch square edge sheathing on the outside, 2- by 4-inch studs, ½-inch fiber-insulating plaster base, and gypsum plaster on inside.

Floors.—Living room, new wood floor laid over the old double wood floor. Kitchen and washroom floors, linoleum over 1-inch plywood subfloor laid over old floor. Dining room, sunroom, and second story rooms, double wood floors.

Ceilings.—First story, gypsum lath and plaster. Ceilings over sunroom and washroom insulated with 3 inches of mineral wool. Second story, ½-inch fiber-insulating plaster base and plaster.

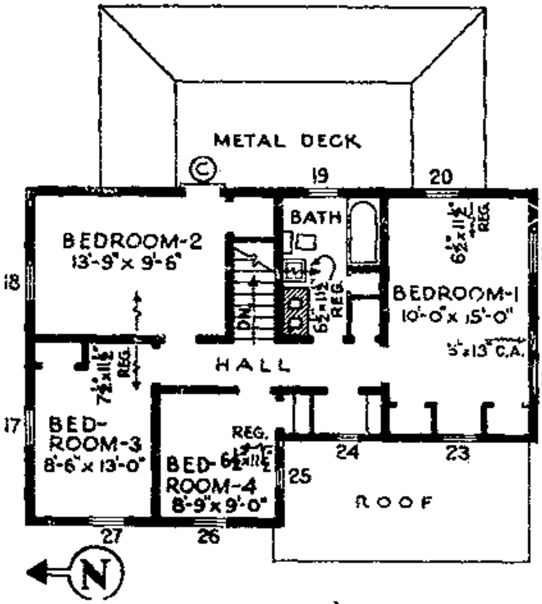

FIGURE 22.—Second-floor plan of house 5-R, showing location of warm-air registers and cold-air returns.

FIGURE 23.—House No. 5-R from the southwest.

Roof.—Wood shingles and metal decking on 1-inch wood sheathing over sunroom and washroom. Wood shingles on spaced shingle lath on main roof, with the north slope covered with asphalt shingles.

Insulation.—See walls and ceilings.

Windows.—Wood, double hung, except Nos. 2 and 3. Fit, good. Weatherstripping, all windows. Storm sash, all windows.

Exterior doors.—Wood, paneled. Door B upper panels glazed. Fit, good. Weatherstripping, none. Storm doors, doors A and B.

Ceiling heights.—Same as before remodeling, see page 25.

HEATING SYSTEM AND COOKING EQUIPMENT

The original furnace was retained and a booster fan installed in the bonnet, which increased the efficiency by about 10 percent, according to the manufacturer. This fan was controlled by a thermostat located in the bonnet. Thermostatic control for the dampers was also added and the thermostat located on the east wall of the dining room. The system was extended to supply heat to all rooms in the house.

Semibituminous coal and wood were still used as fuel in the furnace, but the wood-burning kitchen range was discarded and a new electric range substituted.

USE AND HEATING OF ROOMS

After remodeling, all downstairs rooms were used regularly during the winter. The living room was used for all leisure activities. Evening meals were usually eaten in the dining room, and breakfast and lunch in the kitchen. Only the sunroom was not used a great deal in cold weather and was frequently shut off. As before remodeling, the second floor bedrooms were not regularly heated during the day except in very cold weather. However, they were usually heated up in the evening. The bathroom was heated at all times. The new floor plan resulted in protection of occupied rooms from drafts when the rear door was opened. This was still the only entrance used to any extent. It also made it possible to close off the second floor without interfering with traffic between rooms on the first floor.

Description of House No. 6

House No. 6 was about 100 years old, the oldest of the houses studied. There were four rooms on the first floor and four on the second floor. There was no basement under the house except for a small excavated area reached by a trap door, under the hall and bedroom No. 1. There was an attic over the second floor and over the kitchen wing, which was only one-story high. Plans of the first and second floor are shown in figures 24 and 25. An exterior view of the house is shown in figure 26.

This house was in the poorest condition of any of those studied. The calculated heat loss from the structure, assuming all rooms heated, was about 134,700 B. t. u. per hour, or 13.11 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Foundations.—Stone. Condition, poor.

Exterior walls.—Main part: Two layers of lapped siding with building paper between on the outside; 2- by 4-inch studs, wood lath, and plaster on the inside, with ⅜-inch beaded ceiling wainscot 3 feet high in the din-

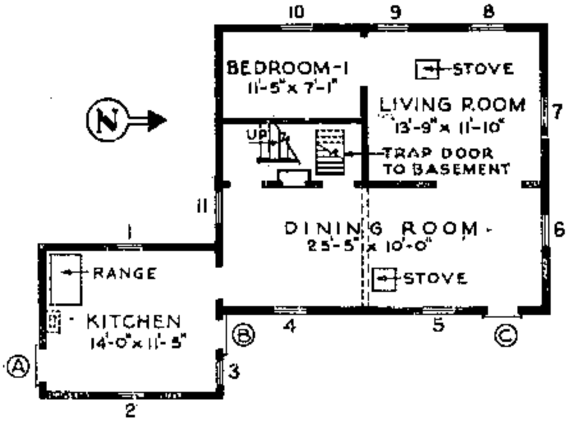

FIGURE 24.—First-floor plan of house No. 6, showing location of heating and cooking equipment.

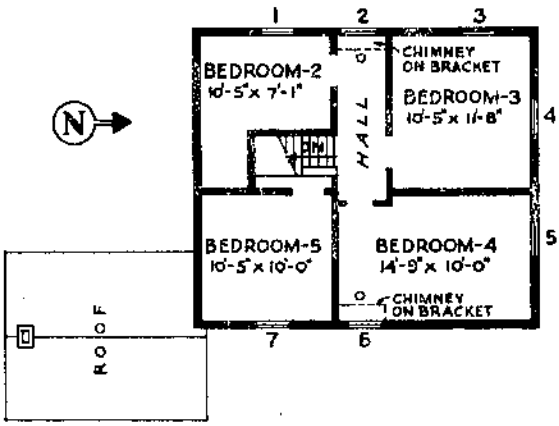

FIGURE 25.—Second-floor plan of house No. 6.

ing room. Kitchen wing: Lapped siding, building paper, square-edge sheathing on the outside; 2- by 4-inch studs, wood wainscot (⅝-inch beaded ceiling boards) 3 feet high, wood lath, and plaster above on the inside. Condition of walls: Poor, siding badly cracked, open joints around windows and doorframes.

Floors.—First story, double floors, no paper between. Second story, single floors. Condition of floors: Poor, floors sagged and cracked.

Ceilings.—Wood lath and plaster. Condition: Poor, plaster cracked.

Roof.—Wood shingles on spaced sheathing. Condition, poor.

Insulation.—None.

Windows.—Double-hung wood windows. Fit, poor. Weatherstripping, none.

Storm sash.—None.

Doors.—Wood, paneled. Fit of doors, poor. Weatherstripping, none. Storm doors, B and C (screen doors covered with tar paper).

Ceiling heights.—First story, 7 feet 8 inches. Kitchen wing, 8 feet 9 inches. Second story, 8 feet.

HEATING AND COOKING EQUIPMENT

The heating equipment consisted of old-fashioned cast-iron stoves located in the living room and dining room and a wood-burning range

FIGURE 26.—House No. 6 from the northeast.

in the kitchen. Had the structure been in first-class condition, the downstairs could probably have been heated reasonably well. As it was, it was impossible to heat the house satisfactorily. In addition, the type of fuel burned probably contributed to the heating difficulties, as wood of poor quality, corncobs, stumps, papers, trash, and anything that would burn was used.

USE AND HEATING OF ROOMS

The family consisted of the owner, his wife, and six children. The wife's mother visited them frequently and remained for several weeks at a time.

All rooms in the house were used, although the second floor was heated only by overflow heat.

In addition to meal preparation all laundry was done in the kitchen, and as there was a large family to wash for there was a good deal of laundry work. In bad weather the laundry was hung in the dining room and kitchen to dry.

The dining room was the most frequently used room aside from the kitchen and all meals were served there. The living room and dining room were used during the evening for leisure activities and during the day for children's play when the children could not be outdoors.

Two entrances to the house led into the kitchen, and the only other door, that opening into the dining room, was closed off during the winter. Because of the large family and especially the young children, these doors to the kitchen were opened a great deal. Also, there was no water supply in the house and water had to be carried from outdoors, which tended to increase the number of times the doors were opened.

Description of House No. 6-N

Owing to the poor structural condition of the old house it was decided not to attempt to remodel it but to build a new one.

The new house was larger than the old one and contained 14,098 cubic feet of living space exclusive of the basement, as against 10,270 cubic feet in the old house. There was a basement under the entire house and an attic. Plans of the first and second floors are shown in figures 27 and 28 and an exterior view of the house in figure 29.

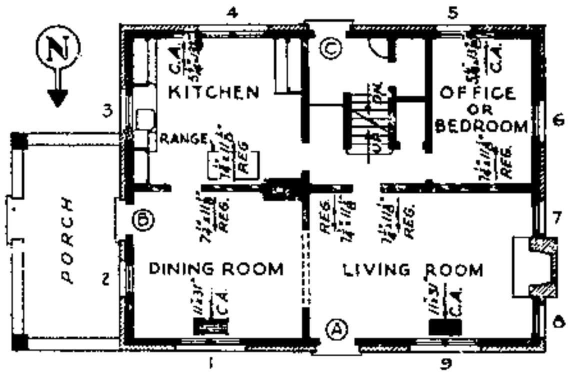

FIGURE 27.—First-floor plan of house No. 6–N, showing the location of warm-air registers and cold-air returns.

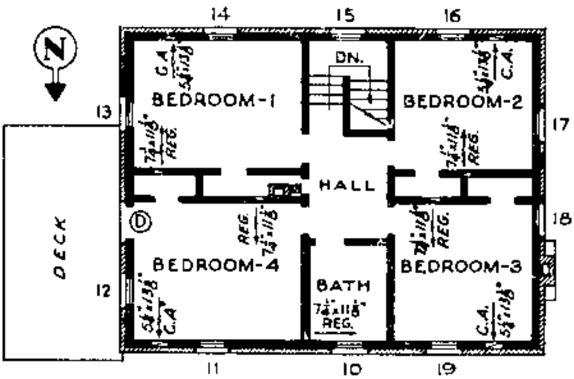

FIGURE 28.—Second-floor plan of house No. 6–N, showing location of warm-air registers and cold-air returns.

On the whole the new house was very satisfactory, except for the poor fit of two of the doors and the omission of insulation in the ceiling of the second floor. The calculated heat loss was 83,200 B. t. u. per hour, or 5.8 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Basement walls.—Concrete, 12 inches thick. Condition, good.

Exterior walls.—Five-inch stone veneer, 1-inch air space, wood sheathing on the outside, 2- by 4-inch studs, gypsum lath, and plaster on the inside. Two-inch blanket-type mineral wool insulation in stud spaces. Condition, good.

Floors.—Double floors throughout.

FIGURE 29.—House No. 6 N from the northeast.

Ceilings.—Gypsum lath and plaster.
Roof.—Wood shingles on spaced shingle lath.
Insulation.—Exterior walls only.
Windows.—Wood, double hung windows. Fit, fair. Weatherstripping, none. Storm sash, none.
Exterior doors.—Wood paneled and glazed. Fit: C, good; A, B, and D, poor. Weatherstripping, none. Storm doors, D only.
Ceiling heights.—First story, 8 feet 3 inches. Second story, 7 feet 9 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

The new house was equipped with a hand-fired gravity hot-air system. Hot-air registers and cold-air returns were located in all rooms except the bathroom, which had no cold-air return. On the whole the registers appeared to be properly located. A mistake was made in installing the duct work; the stack to the office was located so that it passed through a cold-air return. The stack was not insulated and it is likely that it interfered somewhat with the circulation.

The furnace had a capacity of 88,000 B. t. u. per hour and a leader capacity of 650 square inches.

USE AND HEATING OF ROOMS

All first-floor rooms in the new house except the kitchen were used during the evenings, while the kitchen was most frequently used during the day. Although the laundering was now done in the basement instead of the kitchen, the water for laundry work was still heated on the kitchen range.

Most traffic was still through the rear door, which opened into an entry rather than into the kitchen.

All of the first-floor rooms were heated regularly, both during the day and in the evening. Those on the second floor were not regularly heated except by overflow heat from the first floor. In very cold weather the registers in the bedrooms were opened in the evening before the family retired.

On the whole, the family were well satisfied with the house and considered it very comfortable even in very cold weather.

Description of House No. 7

House No. 7 was about 20 years old. It was a large house, with four rooms and an entry on the first floor and three bedrooms and an unfinished storage space on the second floor.

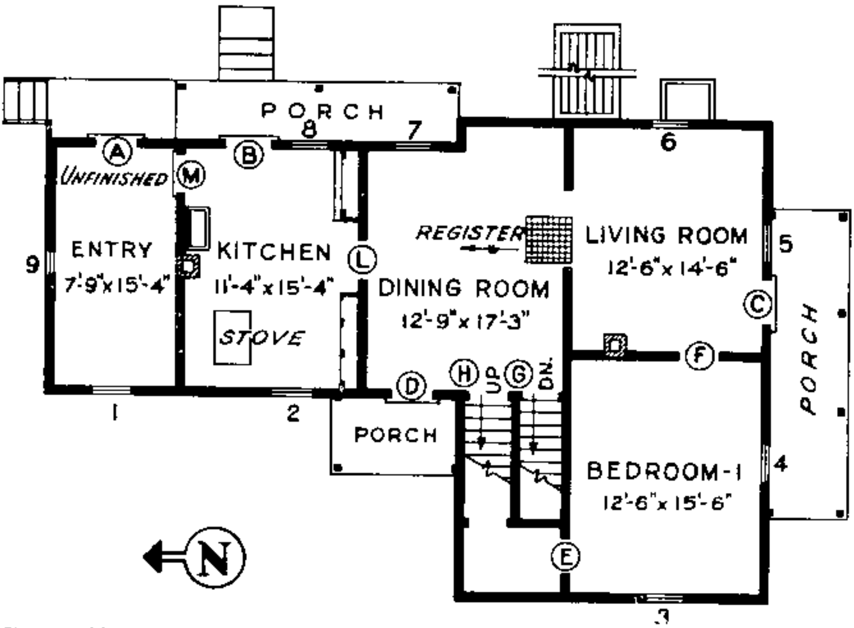

FIGURE 30.—First-floor plan of house No. 7, showing location of equipment.

There was a basement only under the main part of the house. This was unusually damp and frequently had water standing in it. Figures 30 and 31 show plans of the first and second floors. An exterior view of the house is shown in figure 32.

The framing for this house was of the balloon type. There was no fire stopping or other means of blocking off the circulation of air through the stud and joist spaces.

The calculated heat loss, assuming all finished rooms to be heated, amounted to 80,400 B. t. u. per hour, or 5.67 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Foundation walls.—Stone. Condition, poor.

Exterior walls.—Main part: Bevel siding, building paper, T & G sheathing on the outside; 2- by 4-inch studs, wood lath, and plaster on the inside. North wing: Bevel siding, T & G sheathing on the outside; no interior finish. Condition of walls, good.

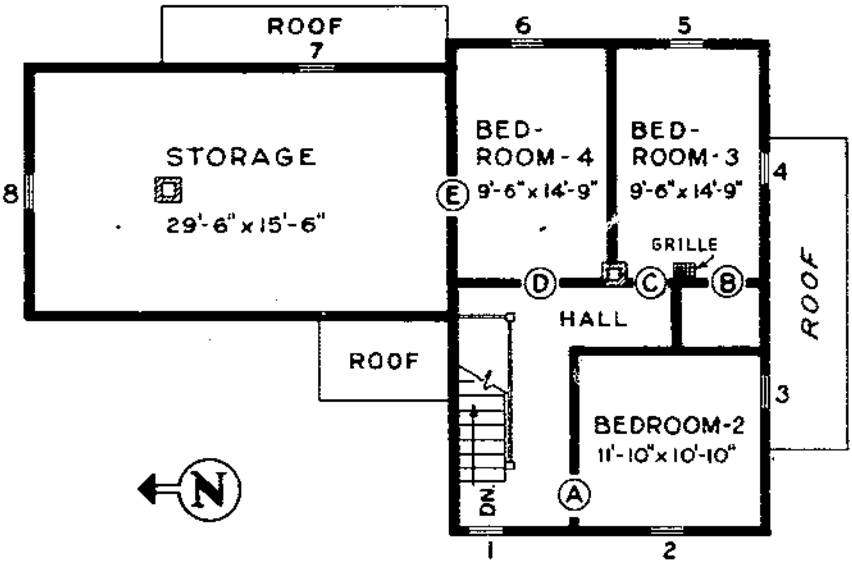

FIGURE 31.—Second-floor plan of house No. 7.

FIGURE 32.—House No. 7 from the southwest.

Floors.—First story, double floors except in entry. Second story, single floors throughout.

Ceilings.—Wood lath and plaster. Condition, good.

Roof.—Wood shingles on spaced shingle lath. Condition, good.

Insulation.—None.

Windows.—Wood, double hung. Fit, fair. Storm sash, all but Nos. 1 and 8. Weatherstripping, none.

Doors.—Wood-paneled. Fit: Poor, A, B, and D; fair, C.

Ceiling heights.—First story, 9 feet. Second story, 7 feet 9 inches.

HEATING AND COOKING EQUIPMENT

The house was heated by a pipeless furnace, with the register located in the dining room at the open arch to the living room. It had a 24-inch fire pot and should have been adequate, as it was supplemented by two kitchen ranges.

The furnace was hand-fired, and soft coal was ordinarily used for fuel although it was supplemented by wood. Soft coal and wood were also burned in the two kitchen ranges.

USE AND HEATING OF ROOMS

Part of the time while readings were being taken the house was occupied by two tenant families. The family occupying the first floor consisted of man and wife and four children. The couple living on the second floor had no children.

All of the finished rooms in the house were used. On the first floor the living room, which was the most used room aside from the kitchen, was used for leisure activities during the day and in the evening and as a bedroom for the parents and the youngest child at night. The dining room was used for the evening meal and also as a place for the children to read and study in the evening. Breakfast and lunch were eaten in the kitchen. The kitchen was also used for ironing and laundry work in very cold weather, although the laundry was usually done in the entry, which was an unfinished room. The children also played in the kitchen a great deal in bad weather. Bedroom No. 1 was occupied by the remaining three children in this family.

On the second floor bedroom No. 3 served as a living room, while bedroom No. 4 was used as the kitchen and contained a wood-burning range. This was the room used for all cooking, eating, laundry, ironing, and most leisure activities. The family slept in bedroom No. 2.

In general, the house was difficult to heat satisfactorily. The dining room on the first floor was usually too hot. Although the living room was fairly comfortable in mild weather it was cold in severe weather. The second floor with the exception of the kitchen (bedroom No. 4) was uncomfortable.

DESCRIPTION OF HOUSE No. 7-R

Remodeling was started on house No. 7 during the summer of 1937. The revised plans are shown in figures 33 and 34, and an exterior view in figure 35. It can be seen from these plans that the remodeling was quite extensive and that the house was enlarged considerably. In addition to the structural changes, which included insulating, a new heating plant was installed. However, at the time readings were taken the work had not been entirely completed and while the frames for the windows were installed none of the regular sash were in place except for three wood casement sash in the second story. Instead the well-fitted storm sash were being used.

On the whole the structure was better from the point of view of heating than it was before remodeling, even though infiltration around the windows may have been greater at times because of the lack of conventional double-hung sash.

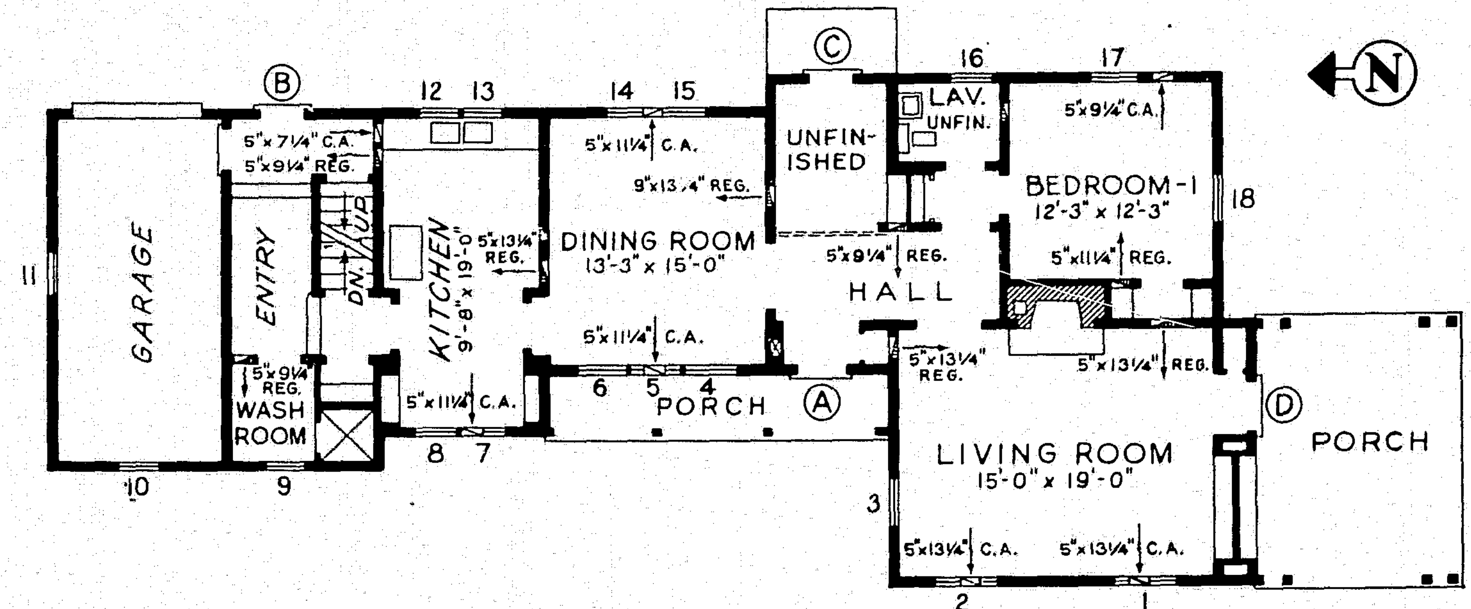

FIGURE 33.—First-floor plan of house No. 7–R, showing location of warm-air registers and cold-air returns.

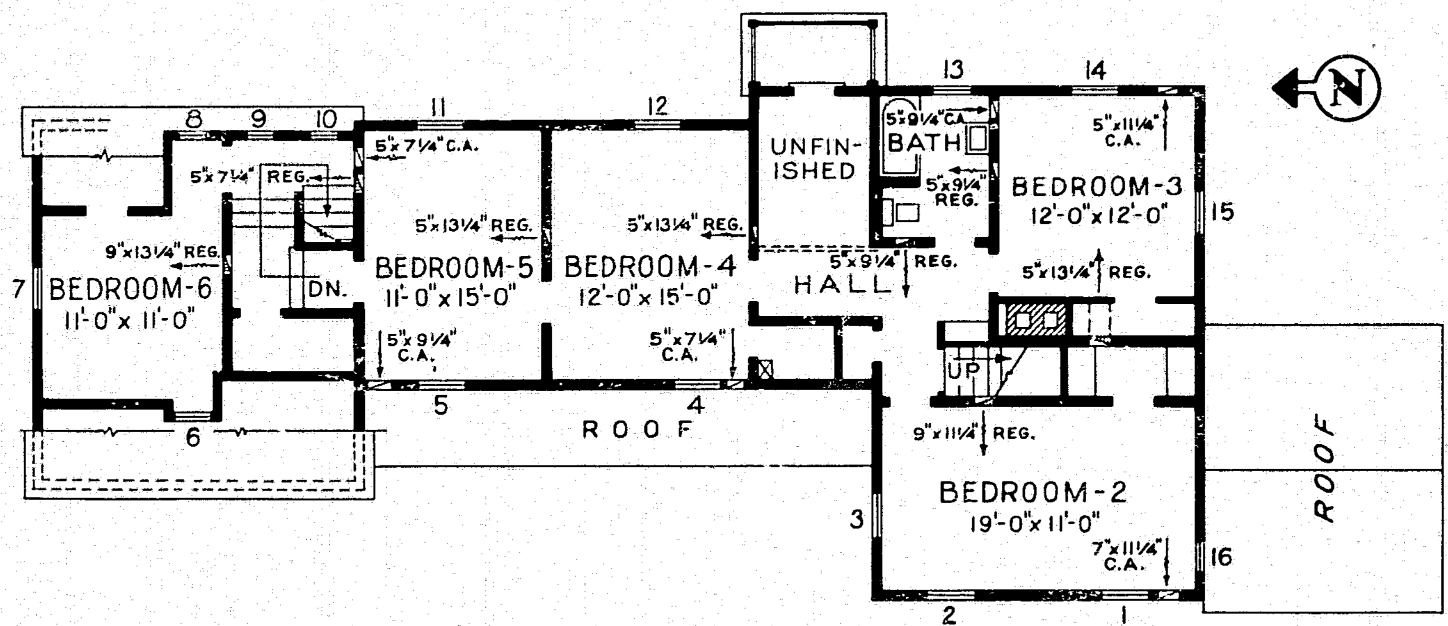

FIGURE 34.—Second-floor plan of house No. 7-R, showing location of warm-air registers and cold-air returns.

FIGURE 35.—House No. 7-R from the southwest.

The calculated heat loss for the remodeled house, assuming all used rooms to be heated, amounted to 96,000 B. t. u. per hour, or 4.78 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Basement walls.—Concrete. Condition, good.

Exterior walls.—Bevel siding, T & G sheathing on the outside, 2- by 4-inch stud space filled with 3⅝ inches of wood fiber insulation. (West wall of kitchen not insulated because of an oversight.) Vapor-proof paper, gypsum lath, and plaster on the inside. Condition, good.

Floors.—Double floors, building paper between. Condition, good.

Ceilings.—Second story: Gypsum lath and plaster, 4 inches of wood-fiber insulation.

Roof.—Wood shingles on spaced shingle lath. Condition, fair.

Insulation.—See exterior walls and ceilings.

Windows.—At time readings were taken frames were in place but sash had not been installed except in windows 8, 9, and 10, in the second story. These were wood casements. Storm sash were being used in all other windows. Fit, good except for wood casement windows 8, 9, and 10 in the second story.

Doors.—Wood, paneled and glazed. Condition, good. Storms doors, all.

Ceiling heights.—First story, 9 feet; second story, 7 feet 9 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

The forced warm-air heating system appeared to be adequate and well installed. The location of registers is shown on the plans. In general, the registers appear to have been well located. Since the system was designed for fairly high velocities the hot-air registers were placed over 6 feet above the floor in all important rooms. In the halls, bathroom, toilet, and washrooms the hot-air registers were located near the floor. The following data were obtained from the manufacturers of the furnace. Furnace rating 165,000 B. t. u. when delivering 2,225 c. f. m. It was equipped with gun-type oil burner. There were three spun-glass filters, with total area of 1,280 square inches. The automatic humidifier was controlled by humidistat.

USE AND HEATING OF ROOMS

Since the owner was carrying on the work of remodeling over a period of time it was not possible to wait until the house had been entirely completed to conduct studies.

The occupants were the owner, his wife, and four children. This was not a typical farm family, and as a result their habits were somewhat different than those of the other cooperators. The owner was in the milk business, and his working hours were those of a businessman rather than a farmer. His wife was very active in club work and other community activities, and the house was used for entertaining to a greater extent than the others.

The living room was used for most leisure activities and for entertaining. The children frequently read and studied in the dining room. The dining room was used for dinner in the evening, while breakfast and lunch were usually eaten in the dining end of the kitchen. Bedroom No. 1 was not completed and was not used nor heated at the time these studies were made. The front stairs to the second floor were also unfinished and the back stairs leading from the entry were regularly used by the family. Bedrooms Nos. 2, 3, 4, and 5 were occupied by members of the family and were regularly heated. Bedroom No. 6 was not finished and not heated and was used only for storage.

Description of House No. 8

House No. 8 was a large rambling structure built in 1872. Plans are shown in figures 36 and 37, and a view of the exterior in figure 38. The 2-story main part was practically square, with four rooms on the first floor and two bedrooms and two unfinished rooms on the second story. A rear story-and-a-half wing contained a dining room, kitchen,

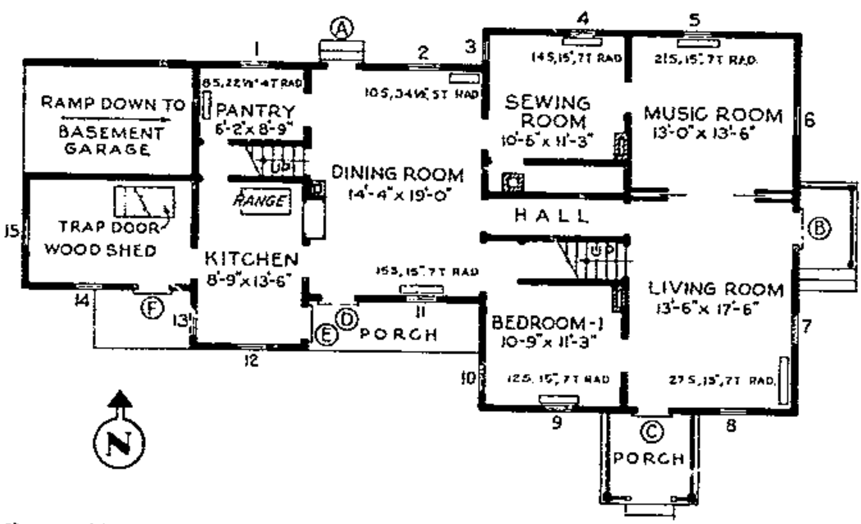

FIGURE 36.—First-floor plan of house No. 8, showing the location of radiators.

and pantry on the first floor and one large bedroom and storage room on the second floor. Attached to the rear wing was a woodshed. There was a basement under the entire house with the exception of the woodshed and the front part of the main section. The garage was located in the basement under the rear wing and reached by a ramp.

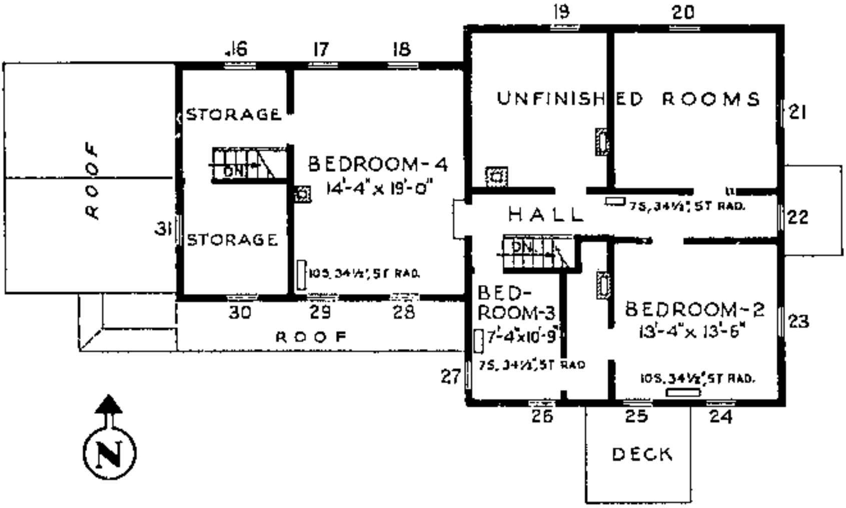

FIGURE 37.—Second-floor plan of house No. 8, showing the location of radiators.

FIGURE 38.—House No. 8 from the southwest.

The windows were larger than in the other houses and there were six entrance doors to the house, one of which (door E) was not used.

The calculated heat loss, assuming all rooms that had radiators were heated, was 145,378 B. t. u. per hour, or 8.04 B. t. u. per hour per cubic foot of heated space.

CONSTRUCTION DETAILS

Basement and foundation walls.—Stone and concrete. Condition, good.

Exterior walls.—Main part: Bevel siding, building paper, and square-edge sheathing on the outside; 2- by 4-inch studs, wood lath, and plaster on the inside. Rear wing: Bevel siding on 2- by 4-inch studs, sheathing on inside, furred with 1- by 2-inch strips, and finished with wood-beaded ceiling in the kitchen and wood lath and plaster in the pantry and dining room. Condition, fair.

Floors.—Single wood floors, those in kitchen and pantry covered with linoleum.

Ceiling.—Wood lath and plaster. Condition, fair.

Roof.—Main part composition shingles over wood shingles. Condition, good. Rear wing, wood shingles on spaced shingle lath. Condition, poor.

Insulation.—None.

Windows.—First story: Double-hung wood windows except No. 13, which was a one-leaf wood casement. Fit of sash was as follows: Good, No. 3; poor, Nos. 4, 12, 13, and 14; rest, fair. The following were fitted with storm sash: Nos. 1, 2, 3, 4, 9, 10, and 12.

Second story: Double-hung wood windows except Nos. 16, 17, 18, 28, 29, and 30, which were single sash fitted to slide between the studs, and No. 31, which was a single sash hinged at the top to swing out. Fit, all fair except Nos. 4, 12, 13, 14, [illegible], [illegible], [illegible], 21, and [illegible], which were poor.

Exterior doors.—Wood-paneled, except A, which was glazed. Glazed transoms over doors B and C. Fit, poor. Storm doors, none. Weather-stripping, none.

Ceiling heights.—Main part, first story, 10 feet 6 inches; second story, 9 feet 2 inches. Rear wing, first story, 8 feet 10 inches; second story, 7 feet.

HEATING SYSTEM AND COOKING EQUIPMENT

The house was heated by a one-pipe steam system that was 5 years old. Cooking was done on a coal range, and coal was used in the boiler.

Calculations showed that all of the rooms with radiators with the exception of the second floor bedrooms had adequate amounts of radiation to maintain inside temperatures of 70° F. with an outside temperature of −15° F. and that the boiler was adequate to take care not only of the rooms with radiators but also those without. The downstairs rooms, aside from the kitchen, required a total of 256 square feet of radiation and had an actual total of 297 square feet. The total radiation required for bedrooms Nos. 2, 3, and 4 amounted to 213 square feet, but actually only 133 square feet were provided. The boiler had a capacity of 650 square feet of equivalent direct radiation.

The dining room, which the family thought to be the most comfortable, had more radiation than calculations indicated was necessary. However, as this room was used as an entry, an excess of radiation was probably necessary. The majority of the radiators on the first floor were 7-tube radiators while those on the second floor were 5-tube.

USE AND HEATING OF ROOMS

The family occupying this house consisted of the owner, his wife, their young son, and a relative who acted as housekeeper. The wife taught music in the local school and gave music lessons at home in the evenings.

In general more use was made of the first-floor rooms than was the case in many of the houses studied. All rooms in which there were

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radiators (fig. 36) except the second-floor bedrooms were regularly heated. However, as most of the first-floor rooms were difficult to heat comfortably in cold weather, the dining room was used more by the family than the other rooms except the kitchen.

During the day the housekeeper was often alone in the house and since she was active she usually preferred moderate temperatures. In the evening, on the other hand, the family wanted the rooms they occupied to be warm.

Description of House No. 8-R

The changes in house No. 8 were quite extensive, and the usable space in the house was increased considerably. The rear wing was wrecked and a new wing constructed. Rooms in the main part of the house were also rearranged (figs. 39 and 40), and the entire structure was tightened and put in first-class condition. Exterior walls and ceilings were insulated, and ceiling heights were reduced in the first story of the main part by furring down. A photograph of the house is shown in figure 41.

As a result of these changes the calculated heat loss was reduced to 65,400 B. t. u. per hour, or 3.03 B. t. u. per hour per cubic foot of heated space, a reduction of 62 percent.

CONSTRUCTION DETAILS

Basement walls.—Stone and poured concrete. Condition, good.

Exterior walls.—Bevel siding, T & G and shiplap sheathing on the outside; 2- by 4-inch stud space filled with 3⅝ inches of mineral wool, vaporproof paper, gypsum lath, and plaster on the inside. Condition, good.

Floors.—Double wood floors throughout, linoleum in kitchen, dinette, washroom, and bathroom. Condition, good.

Ceiling.—Gypsum lath and plaster; 3⅝ inches of mineral wool insulation in second-floor ceiling. Condition, good.

Roof.—Wood shingles on spaced shingle lath. Condition, good.

Insulation.—See walls and ceilings.

Windows.—Wood, double-hung. Fit, good. Weatherstripping, all windows. Storm sash, all windows.

Doors.—Wood, paneled and glazed. Fit, good. Weatherstripping, none. Storm doors, all doors.

Ceiling heights.—First story, main part, 8 feet 8 inches; rear wing, 8 feet 4 inches. Second story, main part, 9 feet 2 inches; rear wing, 7 feet 6 inches.

HEATING SYSTEM AND COOKING EQUIPMENT

The remodeled house was heated by a new forced warm-air system, although it is probable that the old system would have performed the task satisfactorily after the improvements were made to the structure. Cooking was done on a new electric range.

The furnace had a capacity, according to the manufacturers, of 178,500 B. t. u. per hour at the registers, with a blower capacity of from 2,700 to 3,125 cubic feet per minute. The air was filtered by four filters, with a total area of 2,400 square inches. These were filter pads of the replaceable type. Humidification was supplied by a pan-type humidifier, with the supply of water maintained automatically.

The fan operation was controlled thermostatically by the temperature of the air in the plenum chamber.

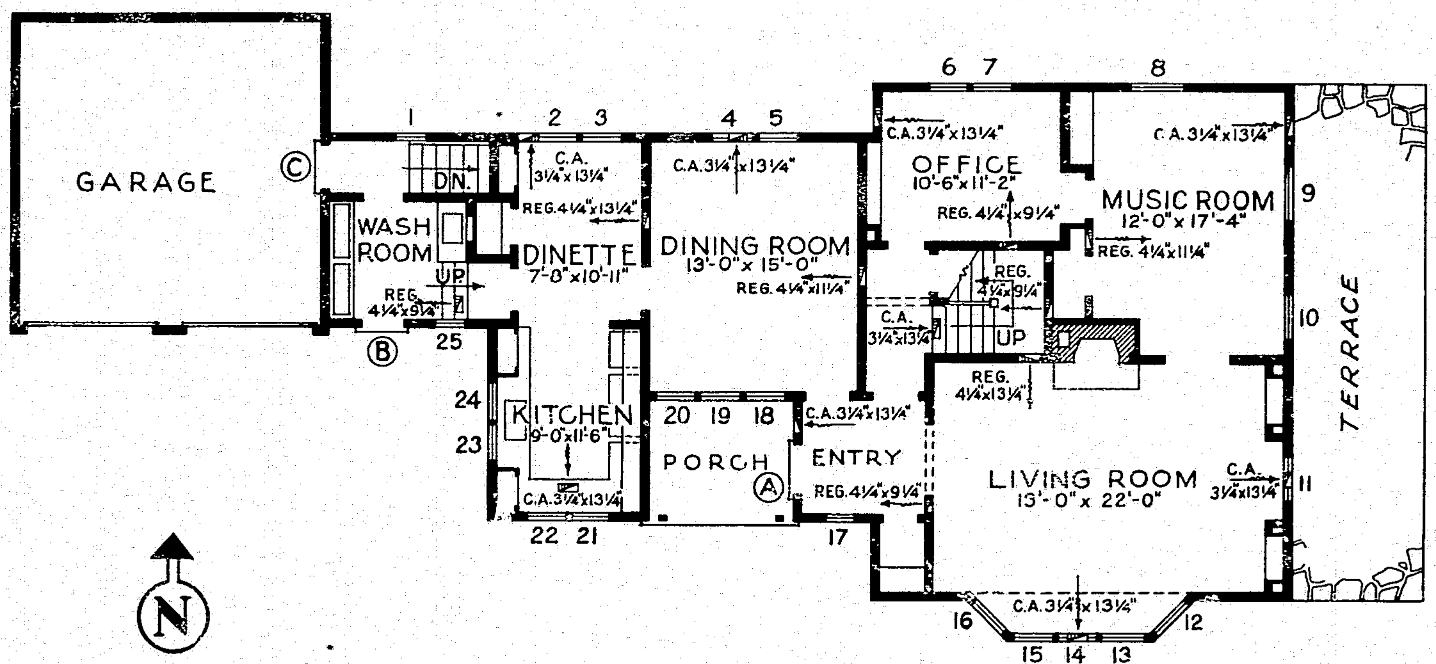

FIGURE 39.—First-floor plan of house No. 8–R, showing the location of warm-air registers and cold-air returns.

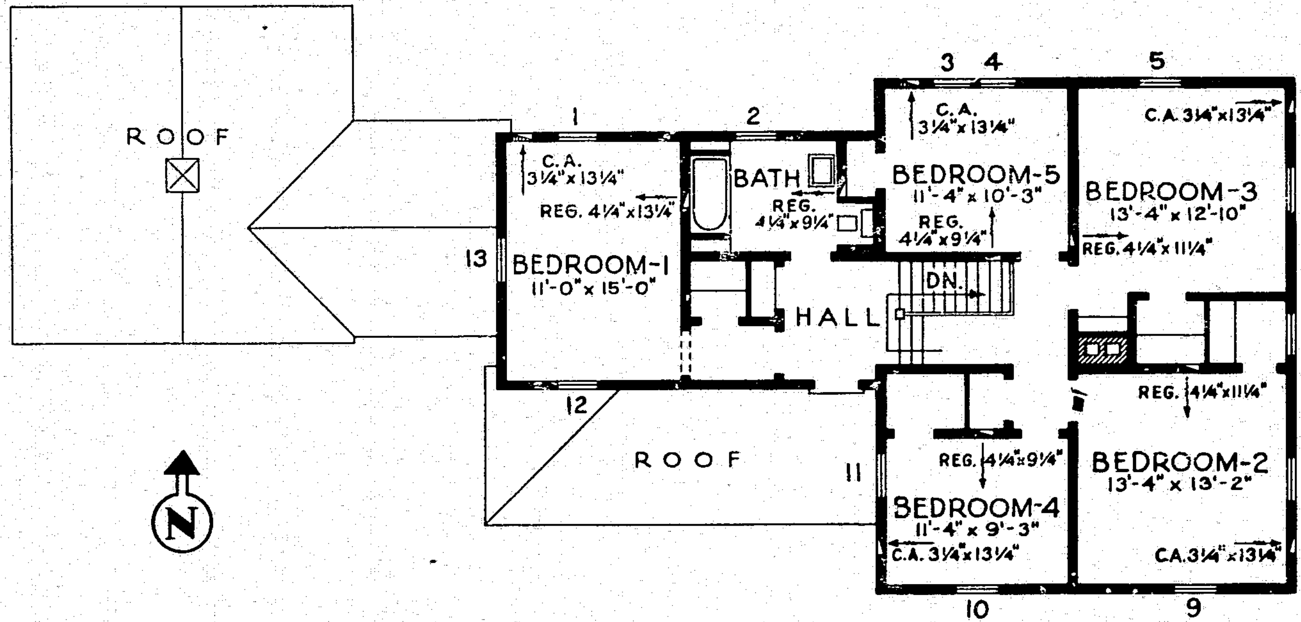

FIGURE 40.—Second-floor plan of house No. 8–R, showing the location of warm-air registers and cold-air returns.

The furnace was oil-fired, and the firing controlled by a thermostat located on the west wall of the living room.

According to calculations the furnace was more than adequate for the house, although the system as a whole did not appear to have been particularly well installed. The warm-air registers in all rooms except the living room and the study were located about 15 inches above the floor. The kitchen was difficult to heat, because the duct serving it was undersized and because the one hot-air register was located at one end of the long narrow room. According to the owner, the kitchen was uncomfortably cold at times.

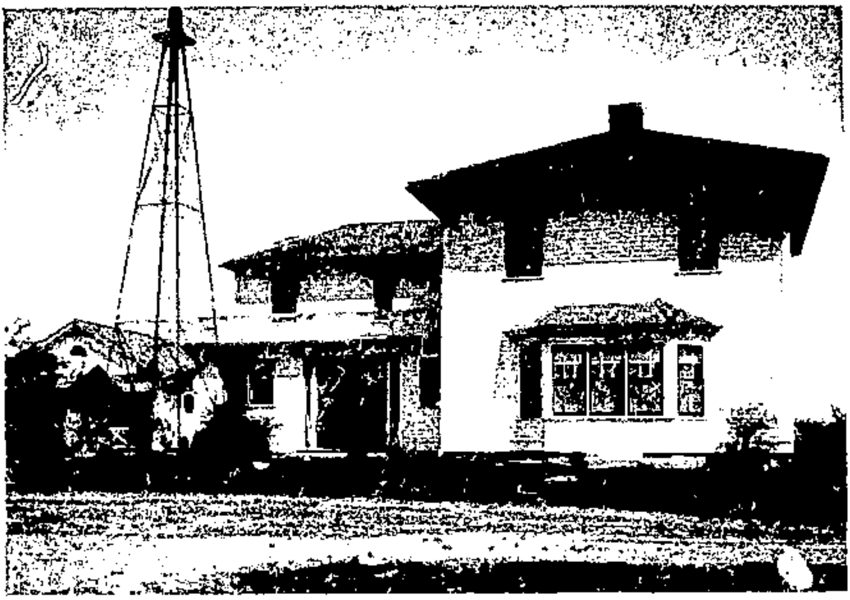

FIGURE 41.—House No. 8-R from the south.

USE AND HEATING OF ROOMS

After the house was remodeled more use was made of all the rooms, as they were now comfortable with the exception of the kitchen. The living room was used for most leisure activities in the evenings and for entertaining. The music room was also used in the evenings, but in cold weather it was sometimes closed off during the day. The study was used both by the owner as a farm office and by his wife when marking papers for her school work. The dining room was used for evening meals, while the dinette end of the kitchen was used at breakfast and lunch time.

The rearrangement of the rooms was of some advantage in heating since the number of entrances to the house was reduced from six to two, neither of which opened directly into an occupied room.

DESCRIPTION OF HOUSE No. 9

House No. 9 was built in 1934. It was a one-story house of split-log construction, with a cellar only under bedroom No. 2. There was an attic space only over the living room and the owner's bedroom. A plan of the house is shown in figure 42 and an exterior view in figure 43.

The calculated heat loss, assuming all rooms to be heated, was 64,994 B. t. u. per hour, or 12.17 B. t. u. per hour per cubic foot of heated space.

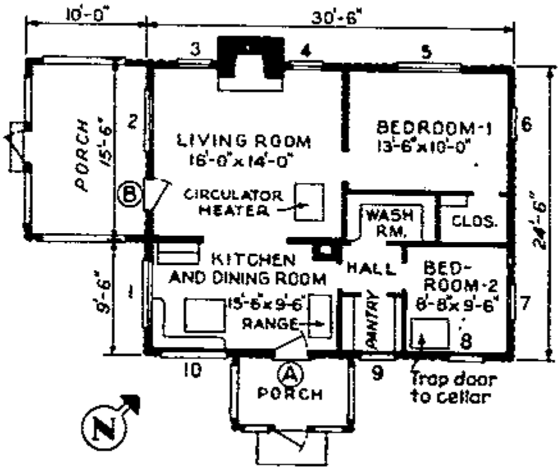

FIGURE 42.—Floor plan of house No. 9, showing location of heating and cooking equipment.

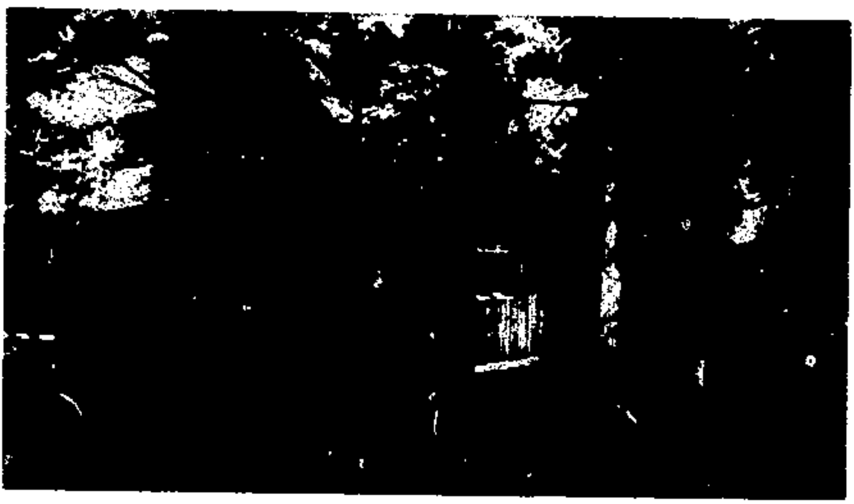

FIGURE 43.—House No. 9 from the north.

CONSTRUCTION DETAILS

Foundations.—Concrete. Condition, good.

Exterior walls.—Split logs (4 inches to 6 inches thick); two thicknesses of prepared roofing, 1- by 2-inch furring strips finished with ¼-inch box board, papered. Condition, good.

Floors.—Single wood floors covered with linoleum. Condition, good.

Ceiling.—¼-inch box board. Condition, good.

Roof.—Prepared roofing on wood sheathing.
Insulation.—None.
Windows.—Nos. 1, 2, 5, and 10 made up of two six-light barn sash; one sash slid horizontally, the other sash was fixed. Nos. 3, 4, 6, 7, 8, and 9 consisted of six-light barn sash hinged to swing in. All frames made of split logs. Fit of sash, poor. Weatherstripping, none. Storm sash, none.
Exterior doors.—Wood, paneled. Door (B) glazed. Fit, poor. Weatherstripping, none. Storm doors, none.
Ceiling heights.—Living room and bedroom No. 1, 7 feet 11 inches; kitchen and bedroom No. 2, sloping, 7 feet 7 inches to 6 feet 4 inches.

HEATING AND COOKING EQUIPMENT

The house was heated by a circulator heater supplemented by a kitchen range and a fireplace, that was not used while readings were being taken. The heater was centrally located for good heat distribution. Wood was burned in both heater and range.

USE AND HEATING OF ROOMS

The kitchen and the living room were the two rooms used during the day. All meals were eaten in the kitchen dining area, while the living room was used for most leisure activities.

All rooms in this house, including the bedrooms, were regularly heated during the day, and the family felt that their house was very comfortable.

OBSERVATIONS

The records taken in the nine houses before remodeling indicate that on the whole, in cold weather, the thermal environment left much to be desired. After improvements were made to the houses, thermal conditions more nearly approached those usually considered desirable.

However, as no attempt was made to impose any controls on the habits of the occupants or the operation of the heating system or the type of fuel burned, it is impossible to attribute definitely the conditions found to any particular feature of the house or its equipment. Similarly, it is difficult to say just which of the individual improvements made to these houses contributed most to the more desirable thermal conditions in the remodeled houses. In order to make definite determinations it would be necessary to have control over all conditions and to have some basis for comparing the effect of individual features. On the other hand, people do not live under controlled conditions and these studies are important because they show what may be expected in the way of thermal environment in typical farmhouses under normal everyday use.

In addition, although definite conclusions cannot be drawn, there are some assumptions that can reasonably be made, based both on the data and on the reactions of the occupants to the environment.

Conditions from which discomfort might result, observed in some or all of the houses before remodeling, included:

1. Fluctuations in air temperatures throughout the day.
2. Inability to heat all rooms uniformly or, in fact, to heat some rooms at all satisfactorily without overheating other rooms.
3. Fairly wide differences between the air temperature and the temperature of the exterior wall and ceiling surfaces.

4. Large vertical temperature differentials between the air near the floor, at the 60-inch level, and at the ceiling.

Of these factors the large vertical temperature differentials, or more particularly the low air temperatures near the floor, were common to all the unimproved houses. Also these large differentials were factors over which the occupants had no control.

After the houses had been remodeled or insulated, there were as a rule less pronounced fluctuations in air temperatures, less difference between the air temperatures in heated rooms, higher surface temperatures, and less differences between the temperatures of the air near the floor, at the 60-inch level, and at the ceiling.

Dry-Bulb Temperatures at the 60-Inch Level

One of the purposes of this investigation was to determine if possible the air temperatures occupants of these houses were able to maintain or seemed to prefer. It also seemed desirable to find out how nearly the "effective temperatures" recorded in these houses corresponded to those which the majority of subjects found to be comfortable in the course of the tests made by the American Society of Heating and Ventilating Engineers (A. S. H. V. E.).

In this particular discussion the temperatures referred to are always the dry-bulb temperatures 60 inches above the floor, unless otherwise indicated, and are those recorded during the day.

The day was assumed to be from 8 a. m. to 10 p. m. and was arbitrarily selected as a basis for comparing conditions in the various houses. Although all of the families arose much earlier, usually about 6 a. m., and fired their heating equipment at that time, this schedule was chosen because it was thought that during the earlier morning hours with all of the activity connected with preparing breakfast and getting the children off to school, less attention would be paid by the family to the temperature of the house than after the early morning rush was over and the household had settled down to the routine duties of the day. It was also thought that by 8 a. m. the temperature should have reached a reasonable level in all of the houses.

The average temperatures recorded in the most used rooms, the kitchen, and one bedroom of each house during periods of cold, moderately cold, and mild outside temperatures are given in tables 2, 3, and 4, Appendix. Average relative humidities and effective temperatures are also shown. In order to make them comparable, temperatures recorded by hygrothermographs located at heights other than 60 inches above the floor have been corrected by using the gradients recorded by portable stand readings. The temperatures shown in these tables represent averages of temperatures recorded during periods of from 1 day to 5 weeks, and it may be assumed that the temperature in the most used rooms, at least during periods of moderately cold and mild weather when excessive firing was not necessary, represent approximately the temperature levels the families wanted. Kitchen temperatures on the other hand may have been higher at times than the family wanted because of cooking, laundry, or other household tasks requiring heavy firing of the kitchen range. In bedrooms, as was pointed out earlier, there was rarely any attempt made to maintain a comfortable temperature level, at least during the day.

As can be seen from tables 2 and 3, the average temperatures maintained at the 60-inch level in the most used rooms and kitchens of these houses were much higher than is normally assumed for the purposes of heating-plant design. They were also above the level at which the greatest majority of individuals who were subjects at the American Society of Heating and Ventilating Engineers' research laboratories were comfortable during tests to determine effective temperatures. In moderately cold weather,[9] average temperatures in the most used rooms of all of the unimproved houses but No. 1 and No. 8 were between 75° and 81° F., and in mild weather only the average temperature in the dining room of house No. 1 was below 75°. No records were taken in a number of the houses during periods of cold weather; however, average temperatures in the most used rooms of the unimproved houses in which records were obtained ranged between 61° and 80°, with all but the average dining room temperatures in houses Nos. 1 and 2 within the range between 70° and 80°.

The heating system in house No. 2 was not adequate, based on the calculated heat loss from the structure, and required heavy firing to maintain high temperatures in cold weather. The family in house No. 1 paid less attention to the temperature of the rooms than those in most of the other houses, and the investigators found by actual experience that high temperatures could be maintained even in the most severe weather with very little extra attention to the furnace.

The temperatures in the kitchens of some of the unimproved houses were not quite so high as in the most used rooms, while in other houses they were higher (table 3, Appendix). In periods of mild weather average temperatures in the kitchens of all the houses but Nos. 1, 4, and 5 were between 76° and 85° F. In these three the average temperatures were 70° or more.

In the improved houses the tendency seemed to be toward slightly lower temperatures except in cold weather. In the most used rooms in three of the houses average temperatures were between 70° and 74° F. in mild weather, and in the remaining three were between 75° and 77°. In cold weather, on the other hand, average temperatures in three of the four houses in which temperatures were recorded were higher than they had been in the unimproved houses. In the kitchens of the improved houses average temperatures during periods of mild weather ranged from a low of 66° in house No. 8–R to a high of 80° in house No. 5 R. In houses Nos. 1–R, 4–R, and 5–R average temperatures in the kitchens were slightly higher than they had been before remodeling. In moderately cold weather kitchen temperatures were higher in houses Nos. 1–R, 4–R, and 6–N, and in cold weather they were higher in houses Nos. 2–I and 6–N.

Only in the kitchen of house No. 8–R were average temperatures below 70° F. This was apparently caused by the undersized duct supplying this room.

Average temperatures in the bedrooms of the unimproved houses during periods of mild weather ranged from a low of 54° F. in house

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[9] For purposes of discussion, outside temperatures have been arbitrarily grouped as follows:

Cold weather = outside dry-bulb temperatures below 11° F.

Moderately cold weather = outside dry-bulb temperatures 11° to 30° F.

Mild weather = outside dry-bulb temperatures above 30° F.

No. 4 to a high of 78° in house No. 9 (table 4, Appendix). In moderately cold weather the lowest average temperature was 53° in house No. 3, and the highest was 81° in house No. 7. In only four of the seven unimproved houses in which bedroom records were obtained were temperatures above 70° in mild weather and in only two during moderately cold periods. The average temperatures were below 70° in the bedrooms of all of the four houses in which records were obtained in cold weather.

In the improved houses, bedroom temperatures were below 70° F. in three of the five houses in which readings were taken in mild weather. On the other hand none were below 63°. In moderately cold weather readings were taken in seven improved houses. The average temperatures ranged from 61° to 76°, with bedroom No. 2 in house No. 2–I the only one above 70°. Readings were taken in only four improved houses in cold weather, and the average temperatures were below 70° in three. They ranged from a low of 60° in house No. 8–R to a high of 76° in house No. 2–I.

The only conclusions that can be reached from an analysis of the data and the habits of the occupants was that the temperature at the 60-inch level in any one directly heated room at any one time was largely the result of the attention given the fire by the occupants of the house. In other words, relatively high temperatures could be maintained at the 60-inch level in these houses.

Relative Humidity

The relative humidities recorded in the unimproved houses were not so low as might be expected, in view of the types of heating systems and the high dry-bulb temperature maintained.

Average relative humidities in the most used rooms of the unimproved houses were for the most part within the range of 30 to 50 percent in mild weather (table 2.) Only in house No. 3 was the average below 30 percent. However, in moderately cold weather average relative humidities were below 30 percent in four of the eight houses in which records were kept and below 30 percent in all of the five houses for which there are records when outside temperatures were below 11° F. The lowest relative humidities were recorded in the dining room of house No. 3, where the average was 21 percent in mild and moderately cold weather and 17 percent in cold weather.

In the kitchens of the unimproved houses (table 3, Appendix) average relative humidities were higher than in the most used rooms in four of the nine houses, slightly lower in three, and the same in one. In house No. 4 they were lower in moderately cold weather and higher in mild weather.

In mild weather the range within which the average relative humidities of the kitchens of the unimproved houses fell was between 30 and 68 percent (table 3). As in the case of the most used rooms they were lower in moderately cold and cold weather.

In the bedrooms of four of the six unimproved houses in which records were obtained humidities were higher than in either the most used rooms or the kitchens (table 4, Appendix). In one house (No. 2) they were lower than in the kitchen but higher than in the most used room, while in house No. 6 they were higher than in either, except that in cold weather they were lower than in the kitchen.

In the most used rooms of five of the seven improved houses average relative humidities were as high or higher in all weather than they had been before improvements were made, and ranged from a low of 26 percent in house No. 6–N during a period when outside temperatures were below 11° F. to a high of 51 percent in house No. 5–R during a period of mild weather. In the kitchens, on the other hand, average relative humidities were higher in all weather in three of the houses and lower in one. In the other three they were higher in some cases and lower in others.

In the bedrooms of the improved houses average relative humidities were not greatly different from those before remodeling in the houses where comparable records were available. They decreased slightly in house No. 1–R, and increased in house No. 7–R. In house No. 6–N they were higher in cold weather and the same in moderately cold weather. In house No. 2–I they increased in cold weather, decreased in moderately cold weather, and were the same in mild weather.

The three factors that appeared to affect the relative humidity in these houses were first, the inside-outside temperature difference; second, tightness of construction; and third, moisture introduced as a result of cooking and laundry.

If the humidifying devices in the heating systems had any appreciable effect on humidities it was not evident from these studies.

Effective Temperatures

Like dry-bulb temperatures, effective temperatures were relatively high. Studies made in the American Society of Heating and Ventilating Engineers' research laboratory indicated that 97 percent of the subjects felt comfortable at 66° E. T. In the most used rooms of unimproved houses the effective temperature was above this level in all houses during mild weather except No. 1, where the effective temperature was 64° (table 2, Appendix). In the rest the range was from 69° in houses Nos. 7 and 8 to 75° in house No. 9.

In cold weather effective temperatures were below 66° in the most used rooms of three of the six houses for which data are available. The range was from 58° E. T. in the dining room of house No. 1 to 70° in the dining room of house No. 3.

Effective temperatures were higher in the kitchens than in the most used rooms in the majority of cases. As might be expected they were generally lower in the bedrooms (table 4) than in the most used rooms.

In the most used rooms of the improved houses, during mild weather effective temperatures were lower in three cases than they had been in old houses and higher in two; while in cold weather they were higher in all cases except house No. 6, where they were the same.

In mild weather they ranged from a low of 66° E. T. in houses 7–R and 8–R to a high of 71° E. T. in house No. 2–I. In cold weather the range was from 65° E. T. in house No. 5–R to a high of 71° in house No. 2–I. As in the unimproved houses, effective temperatures in the kitchens were the same or higher than in the most used rooms in a majority of cases, while they were lower in the bedrooms.

Variability of Temperatures

The fact that high average dry-bulb and effective temperatures could be and often were maintained at the 60 inch level in all of the unimproved houses even in cold weather does not mean that the occupants were comfortable. Temperatures were variable, and occupants of most of these houses were exposed to a fairly wide range of temperatures during the day.

In general the lowest temperatures of the day were recorded between 8 and 9 o'clock in the morning, for although heating equipment was fired in most of the houses at about 6 a. m., the houses were very slow to heat up. After temperatures had leveled off, the variability in temperature depended largely on the attention given the fire by the family. As might be expected rooms in the houses in which coal or a combination of coal and wood was used were generally somewhat more uniform in temperature than in those in which wood alone or wood and corncobs were burned. Among the unimproved houses the most extreme ranges in temperatures were found in house No. 6, where differences between maximum and minimum temperatures amounted to as much as 40° F. in the kitchen and 30° in the living room. The house was heated by stoves in which wood and cobs were burned, and at the same time it was in the poorest condition of any of the houses.

The least range in temperature in the unimproved houses was found in the living room of house No. 4, which was heated by a circulator heater burning oil. This house was in fairly good condition.

As a group, temperatures in the insulated houses were less variable than in the uninsulated houses where the same type of fuel was used.

Here again there were exceptions that must be attributed largely to the attention families gave their heating systems. Figure 44 shows graphs of the ranges in temperatures recorded in regularly heated rooms in some of the houses for a selected week before and after improvements were made.

As can be seen from figure 44, *A* and *B*, ranges in temperature for these selected weeks were more extreme on some days in the insulated house (No. 2–I) than in the old house (No. 2). This indicates rather clearly that regularity of firing is the most important consideration. There was no change in the heating system in the insulated house and wood was burned both before and after insulating. Mean outside temperatures fell within the range of 20° to 40° F. for both weeks.

Figure 44, *C*, shows the relatively uniform temperature recorded in the living room of house No. 4. Here heat was supplied by an oil-burning circulator heater. Although it was not thermostatically controlled, at least there was a steady flow of heat. After the house was remodeled and the central, oil-fired, thermostatically controlled forced warm-air system was installed and the house insulated, there was considerably less variation in temperature throughout the day. The average range between maximum and minimum temperatures amounted to 4.7° F. (fig. 44, *D*) as compared to 8.8° before remodeling.

E and *F* of figure 44 show conditions in houses Nos. 5 and 5–R. Here temperatures were considerably less variable in the remodeled house than in the old house. The average daily range between maximum and minimum temperatures for the selected week amounted to only 5.8° F. in the living room of the remodeled house, with average outside temperatures between 21° and 28°, compared with a daily average range of 9.1° in the same room before remodeling when average outside temperatures were between 21° and 32°. A combination of wood and coal was burned both before and after remodeling. When

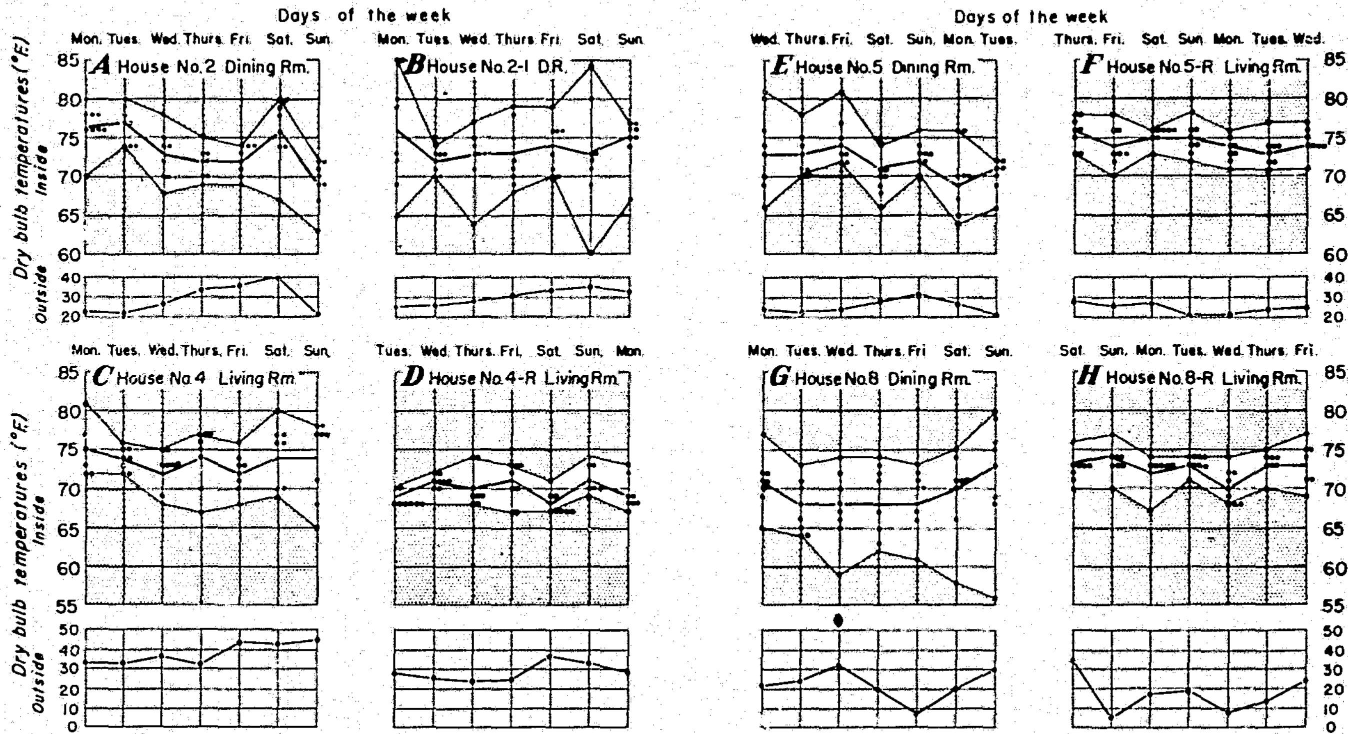

FIGURE 44.—Ranges between maximum and minimum dry-bulb temperatures recorded between 8 a. m. and 10 p. m. on each day of a selected week before and after improvements were made. The dots represent temperatures recorded at 2-hour intervals during each day. The black line connects the average daily temperatures, and the white area indicates the range in temperatures for each day.

the house was remodeled, however, a booster fan was installed in the bonnet of the gravity warm-air furnace and thermostatic controls for the dampers and fan were added. The furnace was still hand-fired. Even before remodeling temperatures were less variable in this house than in most of the others, largely because the furnace was fired regularly.

The comparison between an uninsulated house heated by a hand-fired, one-pipe steam system, with coal the principal fuel, and an insulated house heated by a thermostatically controlled oil-fired forced warm-air system is shown in figure 44, *G* and *H*. The variation in temperature in house No. 8–R was partly because the family usually kept the temperature down during the day and turned the thermostat up later in the afternoon.

Temperature Differences Between Heated Rooms

In the old houses there were frequently marked differences in temperature among the regularly heated rooms at the same hour. There was little that the family could do about this condition in houses heated by central systems, as these differences apparently resulted from the fact that the rate of heat loss from these rooms differed considerably and the heating systems were not designed to compensate for this uneven loss of heat. In addition, the temperatures in the kitchen were affected at times by the firing of the kitchen range for purposes other than heating.

In stove-heated houses, however, it was possible to maintain comparable temperatures in the different rooms, but this obviously required too much attention to fires to be very practical.

Typical examples of conditions found in four of the houses before and after remodeling are shown in figure 45.

In all these cases there was less difference between temperatures in the various heated rooms after improvements were made than before. This also held true in the other houses. The effect of insulation alone on these temperature differences is best shown by figure 45, *A* and *B*, which shows temperatures on typical days before and after remodeling in house No. 2 and 2–R. In this case no change was made in the heating system nor in the kind of fuel burned.

The advantage of an oil-fired circulator heater over a wood-burning stove is shown by figure 45, *C*. Temperatures in the living room were relatively even and high, while they were very irregular in the stove-heated dining room. Kitchen temperatures were understandably lower, as the kitchen was heated only by overflow heat from the dining room plus what little heat was given off by the electric range. In figure 45, *D*, the small temperature differences between rooms and the almost negligible fluctuation in temperature clearly illustrated the desirability of a thermostatically controlled heating system and a well-insulated house.

The most marked improvement was that shown by house No. 6–N over house No. 6 (fig. 45, *G* and *H*). This represented a change from a very poor house heated by stoves to a well-insulated house heated by a central gravity warm-air system. It is very apparent that the stoves in this old house were fired rather irregularly, as compared with that in house No. 4 (fig. 45, *C*), and this accounts very largely for the wide temperature differences. Even in the new house, with only the furnace to tend, this family made less attempt to maintain uniform temperatures than did most of the other families.

The more uniform temperatures throughout house No. 5–R as compared with those in house No. 5 (figs. 45, *E* and *F*) are probably due to

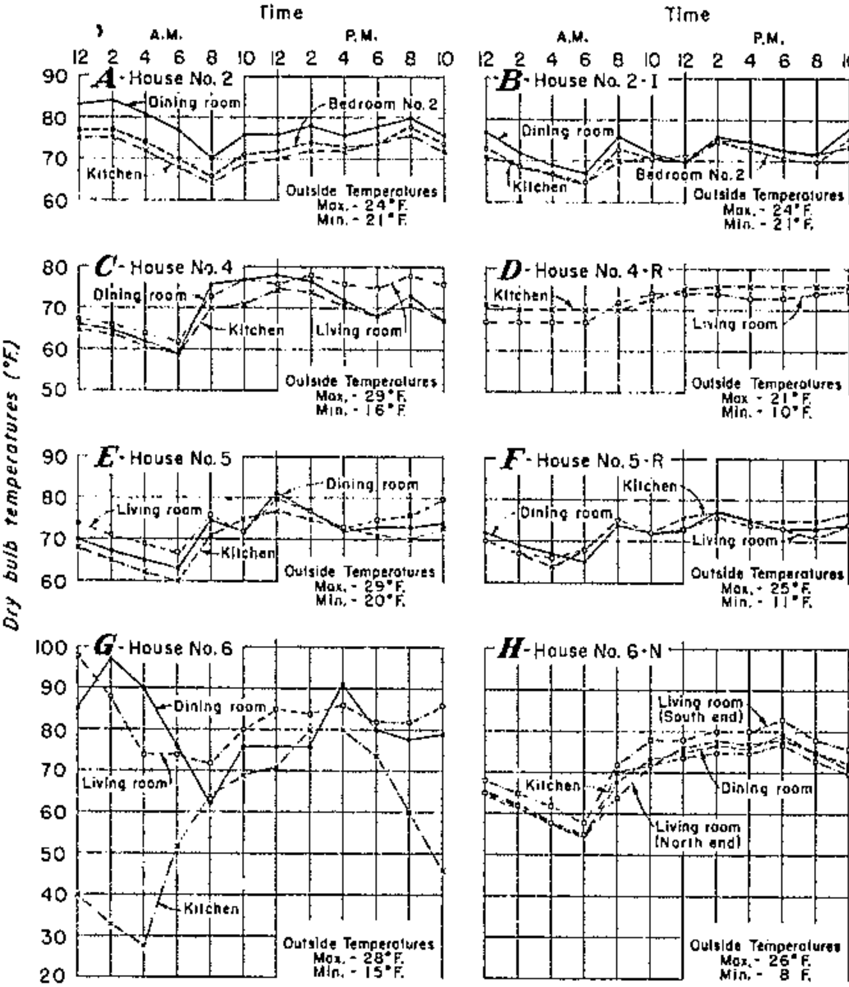

FIGURE 45.—Comparison between dry-bulb temperatures at the 60-inch level for a typical day in regularly heated rooms before and after improvements were made.

the insulation and the rearrangement of rooms as well as to the changes made in the heating system. In the remodeled house the kitchen was less exposed than it was before, even though it was on the north side of the house. In addition the back door opened into the workroom rather than directly into the kitchen. As a result, the temperatures, which were lower in the kitchen than in the living and dining rooms before remodeling, were now very close to those in these other rooms and in fact frequently a little higher. In every case where rooms were in exposed positions, as the kitchens were in houses Nos. 2, 5, and 6, temperatures were generally lower than in the more protected rooms. This was true even when heat was supplied both by a central system and by a wood- or coal-burning range.

Vertical Temperature Gradients

As was pointed out earlier vertical temperature gradients were the most obvious source of discomfort in the unimproved houses. In fact one of the major complaints of the occupants of many of these houses was that of cold feet during periods of severe weather. In the improved houses, on the other hand, these differentials were reduced considerably and according to the owners these houses are comfortable even in very cold weather.

Temperature gradients in the unimproved houses were extremely high in some cases. In the kitchen of house No. 6, for example, differences of as much as 60° F. between the air 3 inches above the floor and 1 inch below the ceiling were observed. The minimum differential recorded was 21°. The average difference between the temperatures at these levels for the entire winter test period was 35°, while the average differences between the temperature of the air 1 inch above the floor and 60 inches above the floor was 31°. The kitchen was exposed on three sides and partly exposed on the fourth. There was no basement under it and it had an unheated attic above. The heat was supplied largely by the kitchen range in which wood and cobs were burned, supplemented by overflow heat from the dining room. It represented the worst conditions found. Temperature differentials in the other rooms in the house, however, were nearly as bad. In the living room the minimum differential was 14°, the maximum, 35°, and the average, 26°, while in the dining room the minimum differential was 23°, the maximum, 47°, and the average, 34°.

The lowest average temperature gradients in the unimproved houses were found in the dining room of house No. 2 and the living room of house No. 1. These were 12° and 13° F., respectively. Temperature differentials recorded in the dining room of house No. 2 at single locations ranged from 1° to 29°, while in house No. 1 they varied from 7° to 23°. Figure 46 illustrates the temperature gradients recorded in the most used rooms of the unimproved houses on typical days. As readings could not always be taken in the various houses on days with the same or similar outside temperatures, they are not very comparable. They do show, however, the range in temperature to which the occupants of the old houses were exposed.

Figure 47 shows the gradients recorded in the most used rooms of the improved houses. In addition, maximum, minimum, and average temperatures recorded at the various levels and the differential between floor and ceiling for all rooms in which readings were taken in both the old and remodeled houses are given in tables 5 to 8, Appendix.

From a casual review of the data it appeared that the magnitude of the temperature differentials between floor and ceiling was influenced chiefly by the rate of heat loss from the structure and the type of heating system.

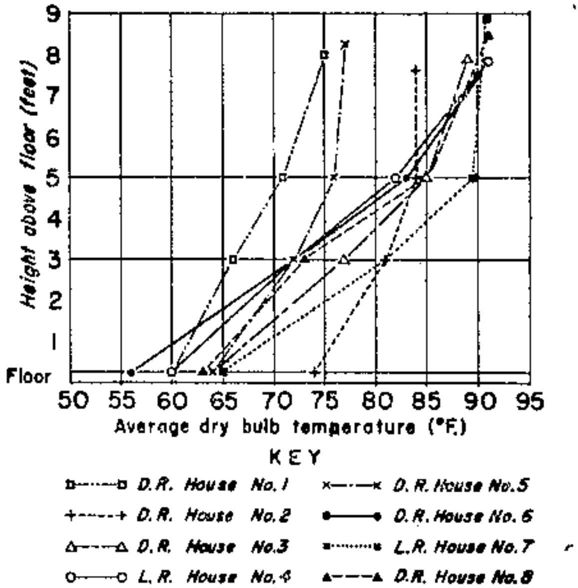

FIGURE 46.—Average temperature gradients between air 3 inches above the floor and 1 inch below the ceiling in the most used room of each of the unimproved houses. Each dot represents the average of all readings taken in the room at the same time at the level indicated.

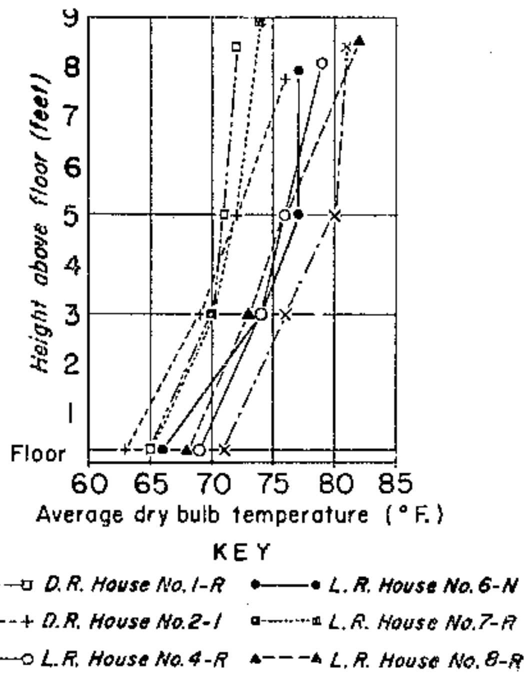

FIGURE 47.—Average temperature gradients between air 3 inches above the floor and 1 inch below the ceiling in the most used rooms of each of the improved houses. Each dot represents the average of all readings taken in the room at approximately the same time at the level indicated.

Since no good basis of comparison was possible the only means of arriving at any conclusion was through an analysis of the data that would separate as much as possible the influences of the two factors.

As the first step in this analysis the temperature gradients expressed in degrees per foot of height in the regularly heated rooms of both the unimproved and improved houses were plotted against differences in temperatures between the inside and outside air. The resulting curves indicated that in individual rooms the temperature differentials generally increased or decreased with the increase or decrease in the inside-outside temperature difference. Typical curves for houses Nos. 5 and 7 before and after remodeling are shown in figure 48. These were selected for illustration because there was a sufficient range in outside temperatures during the periods when readings were taken to give a clear-cut picture of the effect of inside-outside temperature differences on temperature gradients.

Similar curves were made to ascertain the effect of wind velocity. Its influence was also apparent, particularly in the rooms of unimproved houses, although less pronounced than that of inside-outside temperature difference. This was because its effect on a particular room varied not only with the velocity but also with the direction, both of which might change rapidly within a short period of time.

In the rooms of improved houses where windows were weather-stripped and fitted with storm sash the effect of wind velocity was much less apparent.

From this preliminary analysis it appeared that the rate of heat loss, of which inside-outside temperature difference and wind velocity are but components, was the most obvious factor affecting vertical temperature gradients. In an effort to separate the effect of heat loss from that of other variables the Bean Method of Graphic Correlation [10] was used. Temperature gradients in all rooms that were regularly used and heated during the occupied period of the day in each of the unimproved houses are shown in table 1. In addition, data that might affect these gradients are shown, including calculated heat loss expressed in British thermal units per hour (using actual inside and outside temperatures), wind velocity, and type of heating equipment. In addition to the known factors, there were unknown variables that probably affected the gradients, such as drafts caused by opening of doors or sudden increases in infiltration resulting from gusts of wind and the like, which cannot be compensated for. Therefore the results obtained by this method of analysis can be considered only as indicative of a trend.

Figure 49 shows the average temperature differentials in degrees per foot of height listed in table 1, plotted against the computed heat loss in British thermal units per hour. The curve represents the relation between the temperature gradients and this factor. The deviations of any of the observations from this curve may be assumed to be due to other factors. For example the position (well above the line) of items Nos. 4, 7, 8, 13, 16, and 17 may be explained by the fact that each of these rooms was adjacent to a room heated only by overflow heat from the room in question or to one heated only by a kitchen range. This source of heat loss is not taken into account in the heat-

[10] BEAN, L. H. A SIMPLIFIED METHOD OF GRAPHIC CURVILINEAR CORRELATION. Amer. Statis. Assoc. Jour. (N. S.) 24: 386-397, illus. 1929.

loss calculations. Another of these is the recorded wind velocity (a uniform velocity was assumed in heat-loss computations). However, as was pointed out previously, the effect of wind velocity is not the same in all cases. Rooms with few windows and no exterior doors, or, as in the case of a number of improved houses, with windows weather-stripped and fitted with storm sash, would not be affected by an increase or decrease in wind velocity to the same extent as rooms with more or larger windows or exterior doors and with the windows not weatherstripped or fitted with storm sash.

TABLE 1.—*Relations between temperature differentials between air 3 inches above the floor and 1 inch below the ceiling, heat loss, wind velocity, and heating equipment.*

Item No.	House No.	Type of room	Vertical temperature differentials per foot of height	Heat loss per hour [1]	Wind velocity	Type of heating	Condition of house
			° F.	*B. t. u.*	*M. p. h.*		
1	1	L. R	1.6	6,984	8	Gravity hot air	Unimproved.
2	1	D. R	1.8	13,474	6	do	Do.
3	2	D. R	1.6	9,209	11	do	Do.
4	3	D. R	3.0	9,431	7	do	Do.
5	5	L. R	2.1	7,609	12	do	Do.
6	5	D. R	2.1	10,638	12	do	Do.
7	4	L. R.	3.2	10,465	14	Circulator heater (oil)	Do.
8	9	L. R.	3.2	9,070	......	Circulator heater (wood)	Do.
9	8	L. R.	1.5	10,846	7	Steam	Do.
10	8	D. R	2.9	11,703	8	do	Do.
11	8	Music room	1.6	9,850	9	do	Do.
12	8	Sewing room	1.8	5,997	8	do	Do.
13	4	D. R	3.3	9,746	13	Stove (coal)	Do.
14	6	L. R	3.6	13,907	11	Stove (wood)	Do.
15	6	D. R	4.6	20,943	11	do	Do.
16	7	L. R	2.2	6,780	8	Pipeless furnace	Do.
17	7	D. R	3.2	6,180	8	do	Do.
18	1-R	L. R	.74	3,653	8	Gravity warm air	Improved.
19	1-R	D. R	.86	8,036	7	do	Do.
20	2-R	L. R	1.6	4,784	10	do	Do.
21	2-R	D. R	1.9	6,136	11	do	Do.
22	6-N	L. R	1.3	7,776	11	do	Do.
23	6-N	D. R	1.3	5,720	11	do	Do.
24	5-R	L. R	1.1	5,355	9	Gravity warm air with booster fan.	Do.
25	5-R	D. R	.9	2,040	9	do	Do.
26	4-R	L. R	.9	3,288	15	Forced warm air	Do.
27	4-R	Office	1.2	1,978	13	do	Do.
28	7-R	L. R	1.1	5,812	15	do	Do.
29	7-R	D. R	.9	5,535	14	do	Do.
30	8-R	L. R	1.1	4,440	10	do	Do.
31	8-R	D. R	.6	3,190	11	do	Do.
32	8-R	Music room	.6	2,250	10	do	Do.

[1] In calculating heat loss, actual inside dry-bulb temperatures and actual outside dry-bulb temperatures were used.

An examination of the plans and descriptions of the various structures will show that rooms listed in table 1 as items Nos. 2, 5, 7, 8, 9, 11, 13, 14, 15, 19, and 22 would all be likely to be definitely affected by an increase or decrease in wind velocity. Deviations from *A* for these rooms are therefore plotted against wind velocity (fig. 49, *B*). The effect of wind velocity is apparent from this figure, although the curve may be distorted because of the positions of items 7 and 13. These items represent two of the rooms that furnished overflow heat to other rooms and are therefore considerably above the line in *A*. It appears that in these particular rooms higher or lower temperature gradients than would normally be expected may be largely accounted for by

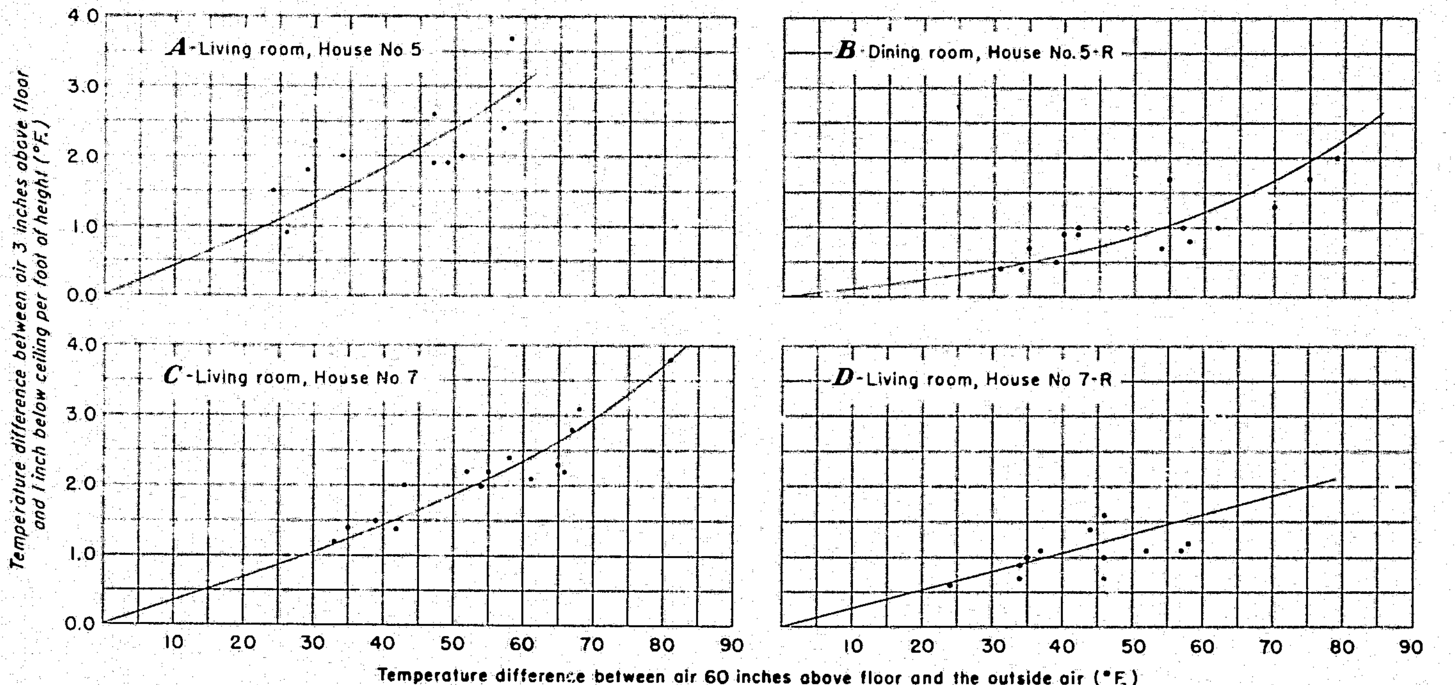

FIGURE 48.—The effect of inside-outside temperature differences on vertical temperature gradients in the most used rooms in houses Nos. 5 and 7 before and after improvements were made. Each dot represents temperature differences between the air 3 inches above the floor and 1 inch below the ceiling in degrees per foot of height plotted against the difference in temperature between the inside air 60 inches above the floor and the outside air.

the effect of wind. Deviations from *B* are then replotted against curve *A* (fig. 49, *C*) and a second approximation drawn in view of the changed position of the items that have been corrected for wind effect. Item No. 8 could not be corrected, as the wind velocity was not known. As can be seen from the corrected curve, all items with the exception

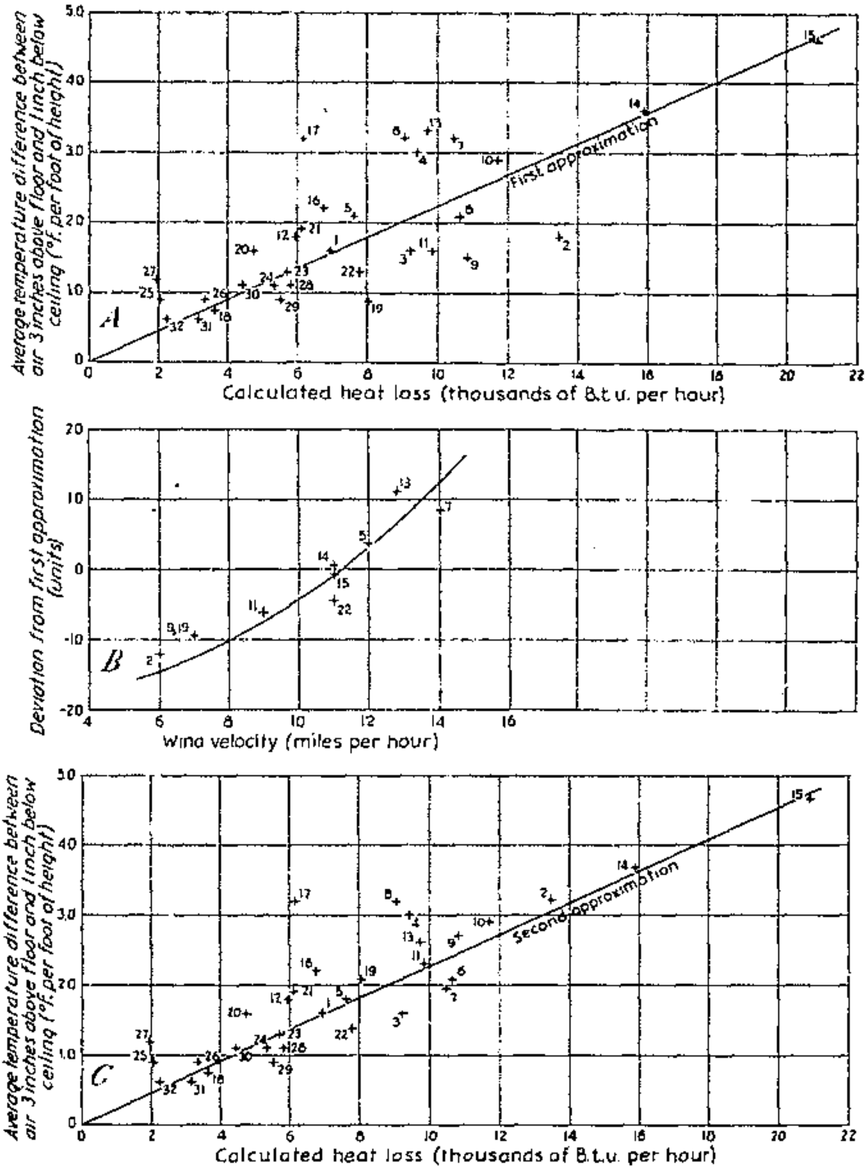

FIGURE 49.—Correlation of factors affecting vertical temperature gradients in regularly heated rooms other than kitchens in unimproved and improved houses: *A*, Relation of gradients to heat loss (first approximation); *B*, relation of deviations from curve *A* to wind velocity; *C*, relation of gradients to heat loss corrected for effect of wind velocity (second approximation).

of Nos. 8 and 17 are now reasonably close to the line representing the effect of heat loss.

The deviations that still exist are the result of factors that cannot be reasonably accounted for. An examination of this curve in connection with table 1 shows that they cannot be accounted for by types of heating, inasmuch as items representing the same type of heating system are scattered above and below line A, and any attempt to draw any conclusions in this connection would not be justified, as the unknown factors previously mentioned are as likely to be responsible for a given deviation as is type of heating.

In these curves the effect of the insulation, storm sash, and general improvement of the structure in the remodeled or new houses is very noticeable in the reduced vertical temperature differentials, and the conclusion reached was that any change in either the structure or arrangement of rooms that reduces heat loss tends to reduce these vertical differentials.

Surface Temperatures

The surface temperatures of walls, floors, and ceilings observed in these houses may or may not have had an important effect on the feeling of comfort of the occupants. At present there is no available information on optimum surface temperatures with which to compare those observed in these houses. It is generally believed, however, that surface temperatures reasonably close to the temperature of the air in the room are desirable in houses heated by convection systems. Effective temperature, for example, is based on the assumption that surface temperatures of the occupied room will be within a few degrees of the dry-bulb temperature at the 60-inch level.

Average surface temperatures recorded in the unimproved houses were nearly as variable as the air temperatures, and in general the relation between the room temperatures and the surface temperatures was more apparent than between the surface temperatures and the outside air temperature or the surface temperatures and the temperature differences between the air in the room and the outside air. As would be expected, however, the difference between the temperature of inside surfaces of exterior walls and the temperature of the air adjacent to the walls tended to be greater when the difference between inside and outside air temperatures increased. This tendency is not very apparent from the averages, as there was a considerable lag between changes in inside air temperature and the corresponding change in the temperature of the surfaces. This lag was even greater with relation to changes in the temperature of the outside air. Therefore, the surface temperature did not necessarily reflect the temperature of the air in the room or the temperature of the outside air at the time the reading was taken. However, when continuous readings were taken this trend was observed.

Thermal characteristics of the exterior walls in the unimproved houses did not differ greatly, except in house No. 2, where sheathing was omitted, and in house No. 1, which had 1 inch of insulation for sheathing, and these differences did not appear to be reflected in the temperatures of the inside surfaces of the exterior walls. This may have been due to the fact that heat loss through the entire wall between inside air and outside air was modified by convection currents within the stud spaces, which carried off heat into the attic because in most of the houses stud spaces were not blocked off from the attic spaces. In the improved houses, on the other hand, where stud spaces were filled with insulation, differences between average air and surface temperatures were much less. A discussion of air movements in the construction is given later.

In tables 9 and 10, Appendix, the average temperatures of the wall, floor, and ceiling surfaces and the adjacent air are given for the regularly heated rooms in each house during the day.

A comparison of the data in these two tables indicates quite clearly the effect of insulation on wall and ceiling surface temperature. Before insulating average surface temperatures of exterior walls ranged from 5° to 18° F. below that of the adjacent air. After remodeling, average surface temperatures ranged from 2° to 8° lower than the average temperature of the adjacent air, except in the living room of house No. 6–N, in which an average difference of 12° was recorded for some unknown reason.

Ceiling surface temperatures in the majority of the old houses averaged from 6° to 14° F. lower than the temperature of the air 1 inch below the ceiling, except for two extremes: The kitchen of house No. 9 where the average difference was only 3° and the dining room of house No. 6 where the average difference was 19°. In the insulated houses the average differences were largely between 0° and 6°. In the kitchen of house No. 1, however, the average temperature of the ceiling was 3° higher than the average temperature of the air 1 inch below.

Average surface temperatures of the floors in the unimproved houses were in most cases lower than those of the walls and ceilings. Floors ranged from a low of 45° F. in the living and dining rooms of house No. 1 to a high of 73° F. in the kitchen of house No. 5. In the improved houses the range was from 58° in the living room of house No. 2–I to 74° in the kitchen of house No. 6–N.

Before remodeling, average floor temperatures were below 50° F. in 2 of the 26 rooms for which there are data, between 50° and 60° in 7, between 60° and 70° in 14, and above 70° in 3. After remodeling, average floor temperatures were never below 50°, and only in 1 room were they below 60°. In 19 rooms the temperatures were between 60° and 70° and in 2 more they were above 70°.

In both the old and improved houses the temperatures of floor surfaces adjacent to outside walls were usually below those near the center of the room and indicated in some cases appreciable heat loss at the edges of the floor and ends of the joist spaces. For example, in the living room of house No. 6, during a period of cold weather, average floor surface temperatures 1 inch from the outside walls were 13° F. lower than those 36 inches from the outside walls, and in the kitchen were 10° lower. In the rest of the unimproved houses average temperature differences of from 4° to 6° were recorded in cold weather. In moderately cold weather average floor surface temperatures 1 inch from the outside walls were from 1° to 8° lower and in mild weather from 2° higher to 5° lower than those 36 inches from the walls.

In the improved houses average differences in temperature between the floor surfaces 36 inches or more from the exterior walls and those adjacent to the walls were about the same or slightly greater than in the old houses. In cold weather differences ranged from 2° to 14° F., in moderately cold weather from 2° to 7°, and in mild weather from 2° to 5°.

Although average floor surface temperatures were generally low in the unimproved houses, they were from 0° to 11° higher than the average air temperature 3 inches above the floor in all but 3 of the houses. In these (house No. 3, the living room and dining room of No. 1, and the dining room and kitchen of No. 4), the floors were from 1° to 8° colder than the air 3 inches above the floor. In the improved houses floor surface temperatures were from 2° below to 3° F. above that of the air 3 inches above the floor except in the living room of house No. 1-R where floors were 7° colder on the average than the adjacent air.

It can also be seen from these tables that average surface temperatures in those rooms in the unimproved houses that were heated by stoves tended to be somewhat higher in comparison with air temperatures than did average surface temperatures in rooms heated by purely convection systems. This was the result of radiant heat from the stoves; while all surfaces were not warmed equally, because of the varying distances from the heat source, the higher temperatures of the walls close to the stoves tended to bring the average up.

It is apparent from the data that the important factors affecting surface temperatures were the thermal characteristic of the walls, floors, and ceilings and the presence or absence of sources of radiant heat within the rooms. In the case of floors the presence or absence of a basement containing heating equipment also was a factor.

Air Movements in the Construction

In most of the old houses balloon framing was used, with the result that convection currents could be set up, as the air was free to circulate through the stud spaces into the joist spaces and, in the story-and-a-half houses, into the unheated spaces under the eaves. A typical wall section of house No. 1 is shown in figure 50, *A*, illustrating this condition. It is apparent that with construction such as this the insulation lath on the exterior of the wall was not so effective as it might have been had the ends of the stud spaces been blocked off. In the insulated houses this condition no longer existed, as these spaces were effectively blocked off.

Anemometer readings in the stud and joist spaces of some of the old houses indicate that there were convection currents of sufficient velocity to increase heat loss.

Anemometer readings taken in house No. 1 in the joist spaces over the kitchen and living room and in the attic showed air velocities of from 5 to 29 feet per minute. Air movements in the joist space over the kitchen averaged 7 feet per minute over a period of 4 days, and a thermocouple mounted in the space with the anemometer showed an average air temperature of 41° F. for the same period. At the same time the average temperature of the air 1 inch below the ceiling was 72°, and the ceiling surface, 63°. The average outside wind velocity was 6.3 miles per hour and the outside temperature −5°.

During this same period the velocity of the air movement in the joist space over the living room averaged 16.4 feet per minute and

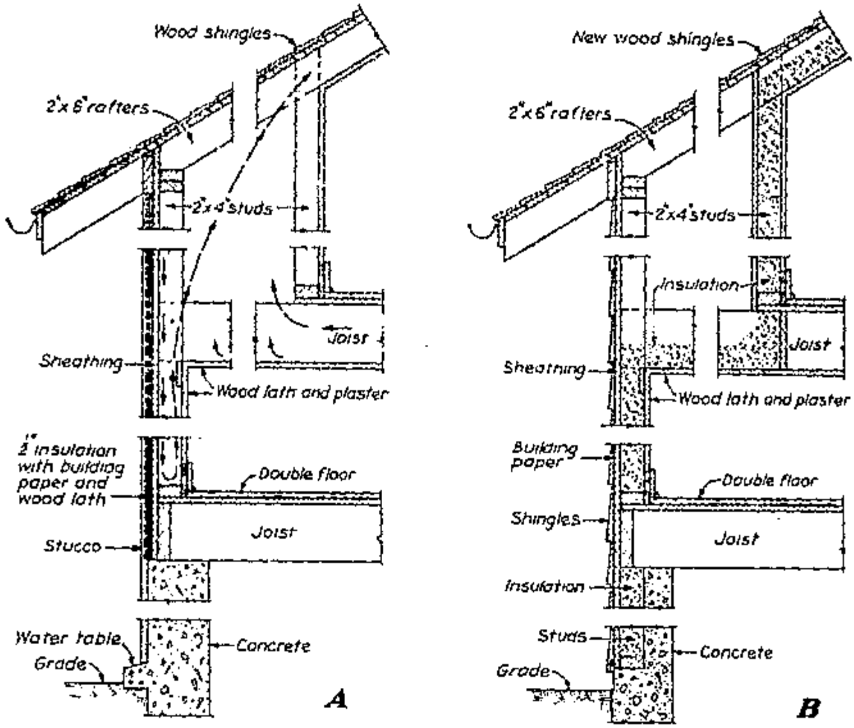

FIGURE 50.—*A*, Wall section of house No. 1, showing how air is free to circulate within the construction. This condition was typical for most of the old houses. *B*, Wall section of house No. 1-R, showing how insulation prevents convection currents within the construction.

the temperature in the space averaged 40° F. The average temperature of the air 1 inch below the ceiling was 64° and the average temperature of the ceiling 56°.

The air movements recorded in the attic space had an average velocity of 14.3 feet per minute and the air temperature was 36° F. The temperature of the ceiling below was 43°. The outside conditions were the same during all these readings.

In house No. 3 readings were obtained of air velocities in the attic space over bedroom No. 3. These were taken at 2-hour intervals for a period of 5 days and showed an average velocity of 12 feet per minute, with a maximum of 26 and a minimum of 7 feet per minute. At the same time the velocity of the air movements in a joist space under the kitchen floor varied between 7 and 8 feet per minute. Also during this same period air velocity in the second floor joist space over the kitchen averaged 9 feet per minute, with a high of 14 and a low of 7 feet per minute. During this period outside wind velocity varied between 9 and 3 miles per hour and averaged 7.

AIR MOVEMENTS WITHIN ROOMS

The records obtained showed that air movements within rooms were for the most part of short duration, usually lasting only a few seconds. They were, however, fairly high in velocity on occasion, particularly when doors in other parts of the house were open. They were most noticeable in such places as doorways and open archways between rooms and in the vicinity of cold-air registers. Fairly high velocities were also observed close to poorly fitted windows and outside doors and near doors leading into unheated rooms. These movements appeared to die out within a few feet, however, and could hardly be classified as drafts except within a very limited area. In the remodeled or new houses, on the other hand, air movements were so low as to be unmeasurable. Such gusts as were observed in the unimproved houses could not be discovered except close to windows that had been left unlocked or close to poorly fitted doors.

In house No. 1 readings with the exploration anemometer were taken on 2 days with average outside wind velocities of 7 and 9 miles per hour. On the first day these air movements varied from a high of 60 feet per minute on the floor in the rear entry opposite the outside door to a low of 9 feet per minute on the floor in the center of bedroom No. 1. The average velocity of all movements recorded in the living room on this day was 17 feet per minute, with a high of 27 and a low of 10, all close to the floor. At the same time the movements in the dining room averaged 14 feet per minute, with a high of 19 and a low of 12. In the kitchen the average was 21 feet per minute, with a high of 25 and a low of 18.

On the second day 45 readings were taken in various parts of the house, showing velocities of from 92 feet per minute at the sill of window No. 11 in the dining room to a low of 7 feet per minute in the southeast corner of the dining room 36 inches from each wall and 18 inches above the floor. The direction of most of these movements seemed to be from the interior of the rooms toward the cold outside walls, down these walls, and if there was no cold-air register along the outside walls, back across the floor toward a cold-air register.

Exploration anemometer readings in house No. 3 showed that air movements in this house were not excessive. A total of nine readings taken within an hour in various parts of the kitchen showed an average velocity of 16 feet per minute, with a high of 23 feet per minute on the floor at the center of the doorway to the dining room and a low of 10 in the center of the room and in the southeast corner of the room. In the dining room velocities were higher, and on the same day and at approximately the same time a total of seven readings in various parts of the room showed an average of 33 feet per minute, with a maximum velocity of 39 on the floor 12 inches from the center of the sliding door to the living room and a low of 29 feet per minute in the northwest corner of the room. Two readings in bedroom No. 1 averaged 12 feet per minute, and one in the pantry showed 20 feet per minute. During the time these readings were taken there was an outside wind velocity of 8 miles per hour from the north.

SUMMARY AND CONCLUSIONS

Since these studies were carried out under everyday living conditions and no attempt was made to control them, exact reasons for some of the conditions observed were not always apparent. These studies did show that frequently conditions were not what might be expected. However, the averages of a great many readings show trends that are clear enough to warrant certain conclusions. These may be summed up as follows.

(1) The average dry-bulb temperatures and effective temperatures maintained in all of these houses at the 60-inch level during the occupied period of the day (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., and the average effective temperatures within the range of 69° to 75° under all outside weather conditions. As this held true in the houses where any reasonable temperatures could be maintained simply by setting a thermostat as well as in those with manually fired systems, it must be concluded that these were the temperatures at which the occupants were most comfortable.

(2) In general the average relative humidities maintained in these houses, both improved and unimproved, during periods of moderately cold and mild weather were within the range generally believed to be desirable (30 to 50 percent). In very cold weather, however, the average relative humidities in the majority of the houses fell below this range. This was true of those with humidifying devices in connection with the heating systems as well as those without. Observations indicated that outside temperatures had more effect on the relative humidity of 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) In all the unimproved houses and some of the remodeled houses fluctuations in dry-bulb temperatures were relatively large and in some cases quite rapid. It appears that irregular firing, along with the type of fuel burned, was largely responsible for wide ranges in temperatures. In addition, the rate of heat loss from the structure was probably a contributing factor. In any event temperature fluctuation was a condition over which the occupants had some control even in the houses with the highest rate of heat loss and the poorest heating equipment.

(4) In the unimproved houses temperature distribution throughout the house was relatively poor and marked differences in temperature between heated rooms were the rule, as were temperature differences in various parts of the same room. This was a condition over which the occupants had little control, especially in the houses with improperly designed or installed central heating systems. Uneven rates of heat loss from different rooms and ducts or radiators not properly sized to take these discrepancies into account appeared to be the contributing factors.

(5) The most obvious source of discomfort in the unimproved houses appeared to lie in the very large differences in the air temperature between floor and ceiling. This too was a condition over which the occupants had no control. In general, large vertical temperature differentials were most pronounced in the more poorly constructed houses and tended to decrease or increase with the decrease and increase in the difference between inside and outside temperatures. This leads to the conclusion that these differentials were definitely affected by the rate of heat loss from the structure and that any

change in the structure that would reduce heat loss would result in lower temperature differentials between floor and ceiling. It was believed that the type of heating equipment would also have a marked effect on temperature gradients, but analysis of the data failed to indicate that this was the case with the types of systems observed.

(6) Surface temperatures in the regularly heated rooms of the unimproved houses, while not so low in some cases as might be expected from the condition of the structure, were probably low enough to cause some discomfort in many instances. In the improved houses surface temperatures were generally appreciably higher. Records of air movements within the joist and attic spaces of these houses indicate that in all probability not only the thermal properties of the wall, floor, and ceiling materials but also the type of construction were factors in determining surface temperatures. In other words it appears that framing that permits convection currents and encourages the movement of air within the construction spaces should be avoided and that where balloon framing is used, fire stopping, solid blocking, or filling stud spaces with insulation is desirable.

(7) Air movements within the rooms of the old houses, while of short duration and not clearly defined, were probably severe enough to cause considerable discomfort close to sources of air leakage, such as poorly fitted doors and windows. On the other hand such drafts were not measurable in the improved houses and do not appear to be a source of discomfort in tightly built houses. Even 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.

On the whole these studies point to the desirability of reducing heat loss from the structures by insulating, installing storm sash, storm doors, and weatherstripping, and by locating important rooms so as to take advantage of the sun and avoid prevailing winter winds. The advantage of having exterior doors open into entries, halls, or workrooms rather than into regularly occupied rooms was also apparent.

The importance of a properly designed heating system was also evident, although lower heat loss due to improvements in the structure appeared to compensate to a considerable extent for otherwise inadequate heating equipment. On the other hand the value of thermostatic control for heating equipment and of fuels requiring a minimum of attention in maintaining even temperatures was clearly demonstrated.

TABLE 2.—*Average dry-bulb temperatures, relative humidities, and effective temperatures maintained during the day at the 60-inch level in the most used rooms of the unimproved and improved houses*

House	Room	Method of heating	Type of fuel used	Average temperature of air when outside temperatures (° F.) were—			Average relative humidity when outside temperatures (° F.) were—			Average effective temperature when outside temperatures (° F.) were—		
				Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°
				° F.	*° F.*	*° F.*	*Percent*	*Percent*	*Percent*	*° E. T.*	*° E. T.*	*° E. T.*
1	Dining room	Gravity warm air [1]	Wood	61	71	69	26	37	34	58	66	64
1-R	do	do [1]	do	72	72	75	35	38	41	66	67	69
2	do	do [2]	do	69	78	77	26	27	32	64	70	70
2-I	do	do [2]	do	79	79	77	31	39	49	71	72	71
3	do	do [1]	do	80	78	81	17	21	21	70	69	71
4	Living room	Circulator heater [1]	Oil		77	78		44	47		71	72
4-R	do	Forced warm air [1 3]	do		74	72		40	43		68	67
5	Dining room	Gravity warm air [1]	Coal and wood		76			35			69	
5-R	Living room	Gravity warm air, booster fan [1 3]	do	70	70	72	30	40	51	65	65	68
6	Dining room	Stove [4]	Wood	76	80	80	23	28	40	68	72	73
6-N	Living room	Gravity warm air [2]	do	75	74		26	28		68	67	
7	do	Pipeless furnace [4]	do		81	76		28	33		72	69
7-R	do	Forced warm air [3 5]	Oil		72	70		35	44		66	66
8	Dining room	One-pipe steam [4]	Coal	75	74	75	27	31	40	68	68	69
8-R	Living room	Forced warm air [1 3]	Oil	77	76	75	29	33	35	69	69	66
9	do	Circulator heater [2]	Wood			85			30			75

[1] Water pan for humidification; water level controlled by float.
[2] Water pan for humidification; filled manually.
[3] Thermostatic control of furnace.
[4] No humidifying device.
[5] Equipped with humidistat.

TABLE 3.—*Average dry-bulb temperatures, relative humidities, and effective temperatures maintained during the day at the 60-inch level in the kitchens of the unimproved and improved houses*

House	Method of heating [1]	Type of fuel for range	Average temperature of air when outside temperatures (° F.) were—			Average relative humidity when outside temperatures (° F.) were—			Average effective temperature when outside temperatures (° F.) were—		
			Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°
			° F.	*° F.*	*° F.*	*Percent*	*Percent*	*Percent*	*° E. T.*	*° E. T.*	*° E. T.*
1	Gravity warm air [2]	Coal and wood		73	70		30	30		68	65
1-R	do. [2]	Electricity	77	76	77	25	30	34	69	69	70
2	do. [3]	Gasoline	73	77	76	36	56	68	67	70	70
2-I	do. [3]	do	77	76	74	39	46	59	70	70	70
3	do. [2, 4]	Wood	83	79	82	28	23	30	73	71	73
4	Stove and circulator heater [3]	Electric		71	72		43	50		66	68
4-R	Forced warm air [2, 5]	do		75	73		36	42		69	68
5	Gravity warm air [2]	Coal and wood		74	70		33	41		68	65
5-R	Gravity warm air, booster fan [2, 5]	do	75	74	80	36	37	42	69	68	73
6	Stoves [6]	Wood and cobs	63	71	76	41	41	48	60	66	71
6-N	Gravity warm air [3]	do	77	75		40	42		71	69	66
7	Pipeless furnace	Coal and wood		88	85		23	31		76	75
7-R	Forced warm air [5, 7]	Electricity		73	70		46	52		68	66
8	One-pipe steam [6]	Coal and wood	78	78	75	40	41	51	70	70	71
8-R	Forced warm air [2, 5]	Electricity	70	69	66	43	47	40	66	65	62
9	Circulator heater [3]	Coal and wood			87			30			76

[1] For principal type of fuel used, see table 1.
[2] Water pan for humidification; water level controlled by float.
[3] Water pan for humidification; filled manually.
[4] No register in room.
[5] Thermostatic control of furnace.
[6] No humidifying device.
[7] Equipped with humidistat.

TABLE 4.—*Average dry-bulb temperatures, relative humidities, and effective temperatures maintained during the day at the 60-inch level in one of the bedrooms of each of the unimproved and improved houses*

House	Bedroom	Method of heating [1]	Average temperature of air when outside temperatures (° F.) were—			Average relative humidity when outside temperatures (° F.) were—			Average effective temperature when outside temperatures (° F.) were—		
			Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°	Below 11°	11° to 30°	Above 30°
			° F.	° F.	° F.	Percent	Percent	Percent	° E. T.	° E. T.	° E. T.
1	1	Gravity warm air [2]		72	72		43	41		67	67
1-R	1	do [3]	69	69	71	34	37	39	64	64	66
2	2	do [3 4]	65	68	71	27	36	39	61	64	66
2-I	2	do [3 4]	76	76	73	30	35	39	69	69	67
3	1	do [2]	46	53	62	62	51	49	46	52	51
4	5	Overflow heat		45	54						
4-R	3	Forced warm air [2 5]		64	63		48	52		61	60
5	3	Gravity warm air		37							
5-R	1	Gravity warm air, booster fan [2 5]		68	67		35	43		64	63
6	3	Overflow heat	64	69	62	33	47	81	60	65	61
6-N	1	Gravity warm air [3]	67	64		43	47		63	61	
7	1	Pipeless furnace [6]		81	77		33	40		73	71
7-R	2	Forced warm air [5 7]		68	68		41	46		64	64
8	4	One-pipe steam	55	59	59						
8-R	1	Forced warm air [2 5]	60	61		37	44		57	58	
9	1	Overflow heat			78			45			72

[1] For principal type of fuel used, see table 1.
[2] Water pan for humidification; water level controlled by float.
[3] Water pan for humidification; filled manually.
[4] No register in room.
[5] Thermostatic control of furnace.
[6] No humidifying device.
[7] Equipped with humidistat.

TABLE 5.—*Outside temperatures, wind velocity, heating equipment, average dry-bulb temperatures at various heights above the floor, and average temperature differentials in the most frequently used rooms of the unimproved houses*

House	Room	Average dry-bulb temperatures												Average temperature differentials between air 3 inches above floor and 1 inch below ceiling per foot of height		
		1 inch below ceiling			60 inches above floor			36 inches above floor			3 inches above floor					
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	Most used rooms:	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1	Dining room	80	60	68	83	55	64	71	50	60	66	43	53	2.4	1.1	1.8
2	do	85	61	74	84	61	74	81	59	71	74	40	62	2.6	.5	1.6
3	do	92	74	83	99	72	79	82	65	71	66	54	60	5.1	1.3	3.0
4	Living room	96	76	83	85	72	77	73	65	69	63	56	58	4.7	2.7	3.2
5	Dining room	98	71	80	90	70	77	82	66	73	71	55	65	3.3	1.4	2.1
6	do	112	89	97	106	83	91	94	70	79	79	56	63	5.3	4.0	4.6
7	Living room	98	70	85	93	68	82	82	64	75	69	58	66	3.8	1.2	2.2
8	Dining room	92	80	85	87	73	80	77	63	71	64	51	60	3.4	2.2	2.9
9	Living room	109	80	93	93	77	85	[2] 85	[2] 72	[2] 79	76	62	69	5.0	1.6	3.2
	Frequently used rooms:															
1	Living room	76	56	65	72	53	61	69	44	58	66	45	52	2.6	.9	1.6
4	Dining room	93	74	84	82	69	75	72	64	69	61	57	59	4.3	2.2	3.3
5	Living room	91	68	76	87	68	74	82	64	70	73	52	59	3.5	.9	2.1
6	do	100	83	92	96	81	88	85	70	77	73	57	66	4.0	2.9	3.6
7	Dining room	106	74	92	100	72	87	85	63	75	70	54	64	5.1	1.8	3.2
8	Living room	90	63	75	86	63	73	78	60	70	64	50	60	2.7	1.0	1.5
8	Music room	89	69	79	85	67	76	81	63	72	68	62	63	2.3	1.0	1.6
8	Sewing room	88	75	82	84	72	78	80	65	73	69	54	64	2.1	1.6	1.8
1	Kitchen	89	68	77	78	58	68	74	56	63	60	48	57	3.7	1.7	2.4
2	Kitchen	100	69	80	92	63	75	82	58	70	73	55	65	3.4	.3	2.0
3	Kitchen	96	76	87	87	73	80	76	65	71	66	52	58	4.8	2.6	3.8
4	Kitchen	80	72	76	75	69	74	70	65	68	57	53	55	3.4	2.3	2.7
5	Kitchen	102	72	86	92	72	83	83	70	76	69	53	62	6.5	2.4	3.3
6	Kitchen	104	81	89	100	78	85	88	68	74	68	45	54	4.6	3.1	4.0
7	Kitchen	104	69	91	99	67	85	88	63	77	71	50	59	4.5	2.2	3.7
8	Kitchen	98	75	85	90	72	80	76	62	69	63	51	55	4.7	2.1	3.5
9	Kitchen	93	83	90	89	83	87	82	76	[2] 80	75	67	71	3.3	2.0	2.9

House	Room	Average temperature differential per foot of height per degree of inside-outside temperature difference		Outside temperatures			Wind velocity			Average temperature difference between inside[1] and outside air	Method of heating and cooking equipment	Portable-stand readings	
		3 inches above floor to 1 inch below ceiling	3 inches above floor to 60 inches above floor	Maximum	Minimum	Average	Maximum	Minimum	Average			Sets of readings	Total readings
	Most used rooms:	° F.	° F.	° F.	° F.	° F.	M. p. h.	M. p. h.	M. p. h.	° F.		Number	Number
1	Dining room	0.026	0.018	31	−24	−6	11	2	6	70	Gravity warm air	26	66
2	do	.03	.044	39	2	20	16	5	11	54	do	13	103
3	do	.038	.049	9	−10	1	9	5	7	78	do	23	46
4	Living room	.063	.078	40	23	26	18	12	14	51	Circulator heater (oil)	11	65
5	Dining room	.047	.056	46	20	32	10	9	12	45	Gravity warm air	12	56
6	do	.055	.067	19	−3	7	21	5	11	84	Stove (wood)	7	175
7	Living room	.038	.055	47	7	24	13	4	8	58	Pipeless furnace	15	60
8	Dining room	.043	.059	29	−5	12	12	5	8	68	Steam	8	40
9	Living room	.084	.090	54	40	47				38	Circulator heater (oil)	8	72
	Frequently used rooms:												
1	Living room	.024	.016	31	−24	−6	11	2	6	67	Gravity warm air	25	50
4	Dining room	.067	.065	36	23	26	18	10	13	49	Stove (wood)	11	66
5	Living room	.05	.075	46	20	32	16	9	12	42	Gravity warm air	12	48
6	do	.044	.054	18	−5	6	21	6	11	82	Stove (wood)	7	197
7	Dining room	.051	.073	46	7	24	15	3	8	63	Pipeless furnace	15	75
8	Living room	.026	.045	27	−3	15	12	4	7	58	Steam	8	32
8	Music room	.025	.041	29	−4	12	12	6	9	64	do	8	32
8	Sewing room	.027	.024	29	−8	11	12	5	8	67	do	8	24
1	Kitchen	.035	.033	32	−24	−3	11	2	6	71	Wood range	25	55
2	Kitchen	.036	.036	38	2	20	16	4	11	55	do	13	52
3	Kitchen	.048	.056	9	−10	1	9	4	7	79	do	23	46
4	Kitchen	.055	.078	27	23	25	18	12	14	49	Electric range	9	9
5	Kitchen	.063	.085	46	20	31	16	9	12	52	Wood and coal range	9	9
6	Kitchen	.051	.080	19	−2	7	21	5	11	78	Wood range	7	99
7	Kitchen	.060	.084	46	7	23	15	4	8	62	do	15	75
8	Kitchen	.051	.074	29	−7	12	12	4	8	68	Wood and coal range	8	32
9	Kitchen	.071	.083	53	40	46				41	Wood range	8	56

[1] Average temperature 60 inches above the floor.
[2] Thermocouple located 42 inches instead of 36 inches above the floor.

TABLE 6.—*Outside temperatures, wind velocity, heating equipment, average dry-bulb temperatures at various heights above the floor, and average temperature differentials in bedrooms and miscellaneous rooms of the unimproved houses*

House	Room	Average dry-bulb temperatures												Average temperature differentials between air 3 inches above floor and 1 inch below ceiling per foot of height		
		1 inch below ceiling			60 inches above floor			36 inches above floor			3 inches above floor					
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
		° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
	Bedroom:															
1	1	74	55	64	72	50	61	71	48	59	65	42	50	3.1	0.9	1.7
2	2	80	56	68	80	56	69	79	54	67	73	48	60	2.7	.7	1.1
3	1	84	65	73	81	63	73	72	57	65	62	48	57	3.5	1.7	2.5
3	5	90	84	87	88	78	84	79	68	75	[2] 67	[2] 55	[2] 64	3.8	2.7	3.0
4	2	58	47	50	47	43	46	45	42	44	41	39	40	2.3	.9	1.3
5	1	71	69	70	70	66	68	67	63	65	60	59	60	1.4	1.1	1.3
6	1	97	76	84	95	71	80	86	65	73	74	50	60	3.8	3.0	3.3
6	2	69	57	62	67	55	60	64	49	57	55	36	46	2.7	1.3	2.1
6	3	75	63	69	72	59	65	69	55	61	61	46	51	2.9	1.8	2.4
6	4	68	55	63	66	53	60	63	50	57	56	39	49	2.1	1.6	1.8
6	5	66	55	62	64	52	60	61	50	57	55	44	51	1.6	1.3	1.4
7	1	81	65	76	79	63	74	77	62	71	68	56	62	2.4	.6	1.6
7	3	83	70	77	82	70	77	80	69	75	75	66	71	1.1	.5	.8
9	1	95	73	84	83	72	80	[3] 84	[3] 70	[3] 77	72	61	67	3.0	1.6	2.2
9	2	86	73	81	84	73	80	[3] 80	[3] 70	[3] 77	70	61	67	2.7	1.5	2.1
2	Living room	65	22	42	58	19	40	53	17	38	51	15	34	2.2	.7	1.1
2	Bathroom	85	65	76	83	63	74	80	59	70	75	52	63	2.8	.5	1.6
2	Washroom	94	67	78	86	64	76	80	61	72	73	57	67	3.3	.4	1.5
9	do	91	72	84	86	71	81	82	70	[4] 78	74	60	70	2.4	1.6	1.8

House	Room	Average temperature differential per foot of height per degree of inside-outside temperature difference		Outside temperatures			Wind velocity			Average temperature difference between inside[1] and outside air	Method of heating	Portable-stand readings	
		3 inches above floor to 1 inch below ceiling	3 inches above floor to 60 inches above floor	Maximum	Minimum	Average	Maximum	Minimum	Average			Sets of readings	Total readings
	Bedroom:	° F.	° F.	° F.	° F.	° F.	M. p. h.	M. p. h.	M. p. h.	° F.		Number	Number
1	1	0.027	0.035	31	−22	−2	11	2	6	63	Gravity warm air	13	30
2	2	.022	.037	39	2	20	16	4	11	49	Overflow heat	12	15
3	1	.032	.041	3	−10	−6	8	5	7	79	Gravity warm air	12	12
3	5	.043	.054	9	1	6	9	5	7	78	do	8	8
4	2	.062	.057	27	23	25	18	12	14	21	Overflow heat	7	7
5	1	.055	.070	46	43	45	15	11	14	23	do	3	3
6	1	.046	.056	18	−5	8	20	5	11	72	do	8	24
6	2	.039	.052	9	1	6	20	5	11	54	do	[illegible]	5
6	3	.041	.047	9	1	6	20	5	11	59	do	[illegible]	5
6	4	.033	.039	9	1	6	20	5	11	54	do	5	5
6	5	.026	.033	9	1	6	20	5	11	54	do	5	5
7	1	.033	.050	47	7	26	13	6	9	48	Pipeless furnace	3	12
7	3	.015	.022	25	17	22	8	7	8	55	do	3	12
9	1	.067	.082	55	39	47				33	Overflow heat	8	64
9	2	.064	.082	53	40	47				33	do	8	40
2	Living room	.055	.060	37	0	20	16	4	12	20	Gravity warm air[4]	11	22
2	Bathroom	.033	.041	39	2	20	16	4	11	54	Gravity warm air	13	16
2	Washroom	.027	.033	31	2	21	16	4	11	55	Overflow heat	12	15
9	do	.053	.068	53	40	47				34	do	8	8

[1] Average temperature 60 inches above the floor.
[2] Taken at floor grill (overflow heat from first floor).
[3] Thermocouple located 42 inches instead of 36 inches above the floor.
[4] Register shut off.

TABLE 7.—*Outside temperatures, wind velocity, heating equipment, average dry-bulb temperatures at various heights above the floor, and average temperature differentials in the most frequently used rooms of the improved houses*

House	Room	Average dry-bulb temperatures												Average temperature differentials between air 3 inches above floor and 1 inch below ceiling per foot of height		
		1 inch below ceiling			60 inches above floor			36 inches above floor			3 inches above floor					
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
		° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
	Most-used rooms:															
1-R	Dining room	74	72	73	73	71	72	72	70	71	67	65	66	0.86	0.86	0.86
2-R	do	82	74	79	82	72	76	77	71	73	69	63	65	2.4	1.5	1.9
4-R	Living room	79	70	74	77	69	73	75	67	71	71	64	67	1.3	.5	.9
5-R	do	89	67	77	87	67	76	85	67	74	80	64	68	1.3	.4	1.1
6-N	do	85	73	78	85	72	77	80	70	75	72	64	68	1.4	.8	1.3
7-R	do	79	73	75	77	72	74	74	69	71	70	64	66	1.6	.6	1.1
8-R	do	82	65	76	79	65	73	76	63	71	70	61	67	1.7	.5	1.1
	Frequently used rooms:															
1-R	Living room	72	71	72	71	71	71	71	70	71	67	65	66	.74	.61	.74
2-R	do	73	67	71	73	66	70	71	63	68	63	55	59	2.0	1.1	1.6
5-R	Dining room	87	70	77	84	69	76	80	68	73	73	60	70	2.0	.4	.9
6-N	do	84	77	80	81	75	79	78	72	75	73	67	70	1.9	1.0	1.3
7-R	do	80	71	74	75	69	72	73	67	70	69	63	66	1.4	.4	.9
8-R	do	71	71	71	71	70	70	69	65	68	67	65	66	.8	.5	.6
8-R	Music room	77	66	73	77	65	72	76	64	71	72	62	68	.8	.5	.6
1-R	Kitchen	76	74	75	76	74	75	72	70	71	67	65	66	1.0	.86	1.10
2-R	Kitchen	94	76	85	86	76	81	78	70	75	71	65	69	3.4	.9	2.2
4-R	Kitchen	86	71	77	81	68	75	76	65	71	72	62	67	1.8	.7	1.3
5-R	Kitchen	88	71	77	80	70	75	77	69	73	74	66	70	2.3	.3	.9
6-N	Kitchen	95	84	89	90	80	85	81	74	77	77	69	73	2.7	1.7	2.0
7-R	Kitchen	79	69	72	78	68	71	75	67	70	69	64	66	1.3	.5	.7
8-R	Kitchen	70	60	66	70	60	65	70	59	65	66	56	62	.6	.3	.5

House	Room	Average temperature differential per foot of height per degree of inside-outside temperature difference		Outside temperatures			Wind velocity			Average temperature difference between inside[1] and outside air	Method of heating and cooking equipment	Portable-stand readings	
		3 inches above floor to 1 inch below ceiling	3 inches above floor to 60 inches above floor	Maximum	Minimum	Average	Maximum	Minimum	Average			Sets of readings	Total readings
	Most-used rooms:	° F.	° F.	° F.	° F.	° F.	M. p. h.	M. p. h.	M. p. h.	° F.		Number	Number
1-R	Dining room	0.017	0.026	25	21	23	5	7	8	49	Gravity warm air	3	15
2-R	do	.037	.044	32	12	24	16	6	11	52	do	8	206
4-R	Living room	.020	.026	40	13	27	25	6	15	46	Forced warm air	14	192
5-R	do	.022	.033	42	5	25	15	4	9	51	Gravity warm air, booster fan	15	154
6-N	do	.024	.033	36	9	23	15	6	11	54	Gravity warm air	8	168
7-R	do	.027	.039	50	16	33	20	9	15	41	Forced warm air	12	240
8-R	do	.022	.024	45	3	23	14	8	10	50	do	5	175
	Frequently used rooms:												
1-R	Living room	.016	.023	25	22	24	8	6	7	47	Gravity warm air	3	15
2-R	do	.035	.046	34	11	24	17	5	10	46	do	10	295
5-R	Dining room	.018	.025	42	5	25	15	4	9	51	Gravity warm air, booster fan	15	134
6-N	do	.024	.033	35	10	24	15	6	11	55	Gravity warm air	8	168
7-R	do	.023	.030	50	16	32	18	9	14	40	Forced warm air	12	216
8-R	do	.010	.014	19	6	12	12	8	11	58	do	3	63
8-R	Music room	.012	.016	45	1	22	15	8	10	50	do	5	120
1-R	Kitchen	.022	.039	25	21	23	8	6	7	52	Gravity warm air, electric range.	3	15
2-R	Kitchen	.039	.042	31	13	24	12	7	10	57	Gravity war air; gas range	8	72
4-R	Kitchen	.027	.033	40	13	27	26	7	13	48	Forced warm air; electric range	15	50
5-R	Kitchen	.019	.023	40	10	28	11	4	7	47	Gravity warm air, booster fan; electric range.	13	26
6-N	Kitchen	.033	.039	36	10	24	15	6	11	61	Gravity warm air; wood range	8	128
7-R	Kitchen	.018	.026	44	20	32	27	8	15	39	Forced warm air; electric range	12	168
8-R	Kitchen	.012	.015	46	4	24	13	5	8	41	do	5	110

[1] Average temperature 60 inches above the floor.

TABLE 8.—*Outside temperatures, wind velocity, heating equipment, average dry-bulb temperatures at various heights above the floor, and average temperature differentials in the bedrooms and miscellaneous rooms of the improved houses*

House	Room	Average dry-bulb temperatures												Average temperature differentials between air 3 inches above floor and 1 inch below ceiling per foot of height		
		1 inch below ceiling			60 inches above floor			36 inches above floor			3 inches above floor					
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	Bedroom:	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1-R	1	71	70	71	71	70	71	71	70	70	67	64	65	0.74	0.49	0.74
1-R	2	72	70	71	72	70	71	71	69	70	67	64	66	.74	.49	.61
1-R	3	69	67	68	68	67	68	68	66	67	65	64	65	.49	.37	.37
1-R	6	69	67	68	69	69	69	68	68	68	66	65	66	.37	.25	.25
2-R	1	71	64	67	71	64	67	69	63	66	63	57	59	1.2	.8	1.0
2-R	2	80	71	74	77	70	73	74	68	72	67	61	65	1.4	.9	1.2
2-R	3	58	50	54	56	51	54	55	50	53	53	47	50	.67	.4	.55
4-R	1	68	53	59	68	52	58	67	51	57	66	50	56	.7	.13	.4
4-R	2	66	47	57	66	46	57	66	45	56	63	43	54	.7	.13	.4
4-R	3	70	60	64	70	59	63	67	58	62	65	57	60	.9	.14	.6
5-R	1	79	67	73	78	66	72	76	65	70	73	62	67	1.7	.3	.8
5-R	2	75	61	70	75	56	68	74	53	68	71	47	64	1.6	.3	.8
5-R	3	72	52	63	71	51	61	70	50	60	66	50	57	2.0	.1	.8
5-R	4	74	60	64	71	57	62	66	54	60	64	52	58	1.4	.3	.8
6-N	3	70	62	67	70	62	67	69	60	66	67	55	64	1.0	.4	1.0
7-R	2	71	68	70	70	67	68	69	66	67	67	63	65	1.0	.6	.7
8-R	1	68	61	65	69	61	64	69	60	63	62	55	59	1.1	.6	.8
8-R	2	73	68	70	73	68	70	72	68	70	69	63	67	.6	.3	.3
8-R	3	75	73	74	75	74	74	75	73	74	70	69	69	.6	.5	.6
8-R	4	71	70	70	72	70	71	71	69	70	68	65	67	.5	.3	.3
8-R	5	77	72	75	77	72	76	76	71	75	72	68	71	.6	.5	.5
1-R	Office	75	72	74	74	72	73	73	71	72	67	66	67	.98	.61	.86
1-R	Washroom	74	72	73	72	72	72	73	71	72	68	67	68	.74	.49	.61
2-R	Bathroom	84	74	79	81	72	77	77	71	74	69	64	67	2.0	1.2	1.6
4-R	Office	88	69	75	83	68	73	77	65	70	73	60	66	2.0	.4	1.2
4-R	Rear entry	83	70	76	77	68	72	75	64	69	72	60	65	2.0	.7	1.4
4-R	Hall (first floor)	71	58	63	69	56	61	68	54	60	64	52	58	1.0	.4	.7
4-R	Hall (second floor)	73	55	63	72	54	62	71	54	62	69	51	60	.8	.13	.4
4-R	Bathroom	74	67	70	73	68	70	73	68	70	73	64	66	.8	.13	.5
5-R	Sunroom	81	67	74	83	67	75	81	67	74	76	65	69	1.2	.3	.7
5-R	V. shroom	79	69	74	79	69	74	78	68	72	72	63	67	1.7	.5	.9
5-R	B. hroom	86	67	78	86	65	78	82	67	76	64	78	72	1.0	.4	.8

House	Room	Average temperature differential per foot of height per degree of inside-outside temperature difference: 3 inches above floor to 1 inch below ceiling	Average temperature differential per foot of height per degree of inside-outside temperature difference: 3 inches above floor to 60 inches above floor	Outside temperatures: Maximum	Outside temperatures: Minimum	Outside temperatures: Average	Wind velocity: Maximum	Wind velocity: Minimum	Wind velocity: Average	Average temperature difference between inside[1] and outside air	Method of heating	Portable-stand readings: Sets of readings	Portable-stand readings: Total readings
	Bedroom:	° F.	° F.	° F.	° F.	° F.	M. p. h.	M. p. h.	M. p. h.	° F.		Number	Number
1-R	1	0.016	0.027	25	22	24	8	6	7	47	Gravity warm air	3	15
1-R	2	.013	.023	25	22	24	8	7	8	47	do	3	12
1-R	3	.008	.014	25	22	24	8	7	8	44	do	3	15
1-R	6	.005	.014	25	22	24	8	7	8	45	do	3	15
2-R	1	.022	.027	32	11	21	13	5	9	46	Overflow heat	4	24
2-R	2	.023	.031	31	12	21	12	6	10	52	do	4	12
2-R	3	.015	.022	23	10	17	10	5	8	37	do	2	6
4-R	1	.013	.013	40	15	28	26	6	13	30	Forced warm air	14	36
4-R	2	.014	.021	40	17	29	25	5	13	28	do	14	25
4-R	3	.018	.018	40	17	29	25	5	13	34	do	14	30
5-R	1	.018	.022	42	6	27	13	4	8	45	Gravity warm air, booster fan.	13	13
5-R	2	.019	.010	42	6	20	13	4	8	42	do	14	14
5-R	3	.024	.024	42	6	27	13	4	8	34	do	13	13
5-R	4	.024	.024	42	0	28	13	4	8	34	do	12	12
6-N	3	.017	.024	37	11	25	15	5	10	42	Gravity warm air	8	168
7-R	2	.021	.018	39	25	31	24	13	17	34	Forced warm air	3	66
8-R	1	.018	.022	44	−2	19	18	9	14	45	do	6	132
8-R	2	.005	.010	26	0	8	18	15	17	62	do	4	96
8-R	3	.009	.015	27	1	8	17	15	16	66	do	4	96
8-R	4	.005	.013	26	−1	7	18	15	17	64	do	4	64
8-R	5	.007	.015	28	1	8	17	16	17	75	do	4	24
1-R	Office	.017	.026	25	21	24	8	6	7	49	Gravity warm air	3	3
1-R	Washroom	.012	.017	25	21	24	8	7	7	48	do	3	3
2-R	Bathroom	.029	.036	31	13	21	12	7	10	56	do	4	4
4-R	Office	.026	.030	40	15	27	26	5	13	46	Forced warm air	15	72
4-R	Rear entry	.032	.032	40	18	28	26	7	13	44	Overflow heat	14	14
4-R	Hall (first floor)	.012	.018	38	16	28	26	6	14	33	Forced warm air	11	18
4-R	Hall (second floor)	.012	.012	40	17	29	25	5	13	33	Overflow heat	16	19
4-R	Bathroom	.013	.020	40	17	30	25	5	14	40	Forced warm air	12	12
5-R	Sunroom	.014	.027	42	5	26	15	4	8	49	Gravity warm air, booster fan.	15	50
5-R	Washroom	.018	.031	40	6	25	13	4	8	49	do	14	40
5-R	Bathroom	.015	.023	42	6	26	13	4	8	52	do	14	14

[1]Average temperature 60 inches above the floor.

TABLE 9.—*Average temperatures of wall, floor, and ceiling surfaces*[1] *and the air adjacent to these surfaces in regularly heated rooms of the unimproved houses*

House	Room	Outside temperatures[2]			Average temperature difference between inside[3] and outside air	Method of heating and cooking equipment	Average temperature—						
							60-inch level			Air 3 inches above floor	Floor surface	Air 1 inch below ceiling	Ceiling surface
		Maximum	Minimum	Average			Air	Inside surface of exterior walls	Surface of interior partitions				
		°F.	°F.	°F.	°F.		°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	Living room	31	−24	−6	67	Gravity warm air	61	[4] 50	55	52	45	65	56
	Dining room	31	−24	−6	70	do	64	[4] 55	63	53	45	68	60
	Kitchen	32	−24	−3	71	Gravity warm air; wood range	68	[4] 53	60	57	57	77	65
2	Dining room	39	2	20	54	Gravity warm air	74	[5] 64	74	62	[6] 64	74	[7] 68
	Kitchen	38	2	20	55	Gravity warm air; gasoline range	75	68	72	65	[8] 67	80	[7] 73
3	Dining room	9	−10	1	78	Gravity warm air	79	65	64	60	[6] 59	83	69
	Kitchen	9	−10	1	79	Wood range[9]	80	62	68	58	[10] 54	87	78
4	Living room	40	23	26	51	Circulator heater	77	68	68	58	[11] 60	83	[7] 76
	Dining room	36	23	26	49	Wood stove	75	70	70	59	[11] 58	84	[7] 76
	Kitchen	27	23	25	49	Overflow heat; electric range	74	62	----	55	[12] 52	76	[7] 67
5	Living room	46	20	32	42	Gravity warm air	74	63	68	59	62	76	65
	Dining room	46	20	32	45	do	77	68	74	65	66	80	68
	Kitchen	46	20	31	52	Gravity warm air; wood range	83	74	----	62	73	86	75
6	Living room	18	−5	6	82	Wood stove	88	[13] 82	90	61	[14] 71	92	86
	Dining room	19	−3	7	84	do	91	[13] 79	90	63	[14] 68	97	78
	Kitchen	19	−2	7	78	Wood range	85	[13] 71	----	54	[14] 55	89	81
7	Living room	47	7	24	58	Pipeless furnace	82	71	74	66	66	85	78
	Dining room	46	7	24	63	do	87	73	78	64	64	92	83
	Kitchen	46	7	23	62	Wood range	85	79	85	59	60	91	83
8	Living room	27	−3	15	58	One-pipe steam	73	65	69	60	[6] 61	75	60
	Dining room	29	−5	12	68	do	80	[15] 66	71	60	[6] 62	85	76
	Music room	29	−4	12	64	do	72	66	72	63	[6] 65	79	[7] 72
	Sewing room	29	−8	11	67	do	78	65	72	64	[6] 64	82	[7] 74
	Kitchen	29	−7	12	68	Wood range[16]	80	[15] 66	64	64	64	85	77
9	Living room	----	----	----	38	Circulator heater	85	[17] 77	81	55	[10] 59	93	[7] 87
	Kitchen	----	----	----	41	Wood range	87	[17] 80	----	71	[10] 71	90	[7] 87

[1] Unless otherwise indicated exterior walls are constructed as follows: Bevel siding, building paper, and 1-inch wood sheathing on exterior 2 by 4 studs; wood lath and plaster on interior. Floors are double wood floors or subflooring covered with linoleum with no ceiling underneath with partially heated basement below. Ceilings are wood lath and plaster with single floor and partially heated room above. Interior partitions are wood lath and plaster on both sides with partially heated or heated room adjacent.

[2] The maximum wind velocity recorded during the time readings were taken was 21 m. p. h.

[3] Average temperature 60 inches above floor.

[4] Exterior wall: Stucco on wood lath backed by ½-inch insulation board (wood sheathing) on 2 by 4 studs; wood lath and plaster on interior.

[5] Exterior wall: Bevel siding on 2 by 4 studs, no sheathing; wood lath and plaster on interior.

[6] Floors, single.

[7] Area above unheated.

[8] Floors, double, covered with linoleum.

[9] No warm-air register in kitchen.

[10] Floors, single, covered with linoleum, unheated space underneath.

[11] Floors, single, unheated basement.

[12] Floors, double, covered with linoleum, unheated basement.

[13] Exterior wall: Two layers of bevel siding with building paper between on exterior; wood lath and plaster on interior.

[14] Floors, double, unheated space underneath.

[15] Exterior wall: Bevel siding on 2 by 4 studs on exterior; 1-inch sheathing boards on inside of studs, 1-inch furring strips, wood lath and plaster.

[16] No radiator in kitchen.

[17] Exterior wall: Split logs, vertical, 2 layers of building paper; 1-inch furring strips, ¼-inch boxboard on interior.

TABLE 10.—*Average temperatures of wall, floor, and ceiling surfaces*[1] *and the air adjacent to these surfaces in regularly heated rooms of improved houses*

House	Room	Outside temperatures[2]			Average temperature difference between inside[3] and outside air	Method of heating and cooking equipment	Average temperature—						
							60-inch level			Air 3 inches above floor	Floor surface	Air 1 inch below ceiling	Ceiling surface
		Maximum	Minimum	Average			Air	Inside surface of exterior walls	Surface of interior partitions				
		° F.	° F.	° F.	° F.		° F.	° F.	° F.	° F.	° F.	° F.	° F.
1-R	Living room	25	22	24	47	Gravity warm air	71	69	70	71	64	72	71
	Dining room	25	21	23	49	do	72	67	71	66	64	73	73
	Kitchen	25	21	23	49	Gravity warm air; electric range	72		73	66	68	75	78
2-I	Living room	34	11	24	46	Gravity warm air	70	[4] 65	65	59	58	71	67
	Dining room	32	12	24	52	do	76	[4] 72	73	65	[5] 67	79	74
	Kitchen	31	13	24	57	Gravity warm air; gas range	81	75	77	69	[6] 69	85	[7] 80
4-R	Living room	40	13	27	46	Forced warm air	73	69	71	67	68	74	70
	Office	40	13	27	49	do	73	69	68	66	68	75	72
	Kitchen	40	13	27	49	Forced warm air; electric range	76			67	69	77	74
5-R	Living room	42	5	25	51	Gravity warm air, booster fan	76	71	74	68	[8] 69	77	72
	Dining room	42	5	25	51	do	76	72	74	70	70	77	73
	Kitchen	40	10	28	49	Gravity warm air, booster fan; electric range.	77			70	[6] 73	77	76
6-N	Living room	36	9	23	54	Gravity warm air	77	[9] 65	74	68	66	78	73
	Dining room	35	10	24	55	do	79	[9] 71	78	70	69	80	77
	Kitchen	36	10	24	61	Gravity warm air; wood range	85	[9] 77	84	73	74	89	85
7-R	Living room	50	16	33	41	Forced warm air	74	69	72	66	66	75	72
	Dining room	50	16	32	40	do	72	67	69	66	65	74	70
	Kitchen	44	20	32	39	Forced warm air; electric range	71	66	70	66	65	72	69
8-R	Living room	45	3	23	50	Forced warm air	73	69	72	67	66	76	73
	Dining room	19	6	12	58	do	70	65	70	66	66	71	68
	Music room	45	1	22	50	do	72	68	71	68	66	73	70
	Kitchen	46	4	24	41	Forced warm air; electric range	65	59	63	62	61	66	60

1 Unless otherwise indicated exterior walls are constructed as follows: Bevel siding, 1-inch wood sheathing on exterior, 2 by 4 stud space filled with insulating material; gypsum or wood lath and plaster on interior. Floors are double wood floors or subflooring covered with linoleum with no ceiling underneath with partially heated basement below. Ceilings are wood or gypsum lath and plaster with single floor and partially heated room above. Interior partitions are lath and plaster on both sides with heated room adjacent.

2 The maximum wind velocity recorded during the time records were taken was 27 m. p. h.

3 Average temperature 60 inches above floor.

4 No sheathing.

5 Floors, single.

6 Floor, double, covered with linoleum.

7 Unheated storage above; roof insulated with 3⅝ inches of insulation.

8 Floor, subfloor, 2 layers of finish flooring.

9 Exterior wall: 6-inch stone veneer, 1-inch wood sheathing, 2 by 4 studs; 2 inches blanket insulation, gypsum lath, plaster.

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END