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INVESTIGATION OF HEATING ROOMS WITH DIRECT STEAM RADIATORS EQUIPPED WITH ENCLOSURES AND SHIELDS

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IN COÖPERATION WITH

THE NATIONAL BOILER AND RADIATOR MANUFACTURERS' ASSOCIATION AND THE ILLINOIS MASTER PLUMBERS' ASSOCIATION

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INVESTIGATION OF HEATING ROOMS WITH DIRECT STEAM RADIATORS EQUIPPED WITH ENCLOSURES AND SHIELDS

I. Introduction

1. *Preliminary Statement.*—This bulletin is a report of the results of the work of the last year and a half under the terms of a coöperative agreement between the National Boiler and Radiator Manufacturers' Association, the Illinois Master Plumbers' Association, and the University of Illinois, providing for an investigation of steam and hot-water heating systems. The agreement was formally approved March 9, 1926, and became operative on April 10, 1926. The results presented in this bulletin are based upon the work done since the publication of Bulletin No. 169 entitled "Effect of Enclosures on Direct Steam Radiator Performance," in which were reported the results of the first year's work under this agreement.

The two coöperating associations have been represented since the publication of the first bulletin by an advisory committee, the membership of which is as follows:

- C. D. Brownell, Chairman, representing the Illinois Master Plumbers' Association, Champaign, Illinois
- C. A. Bolton, representing the Illinois Master Plumbers' Association, Chicago Heights, Illinois
- C. K. Foster, representing the National Boiler and Radiator Manufacturers' Association, Chicago, Illinois
- H. R. Linn, representing the National Boiler and Radiator Manufacturers' Association, Chicago, Illinois
- R. F. Prox, representing the National Boiler and Radiator Manufacturers' Association, Terre Haute, Indiana
- F. W. Herendeen, representing the National Boiler and Radiator Manufacturers' Association, Geneva, New York
- O. J. Prentice, representing the Steam Specialties Manufacturers, Chicago, Illinois
- H. S. Ashenhurst, representing the Insulation Manufacturers, Chicago, Illinois
- W. H. O'Brien, representing the Southern Pine Association, Chicago, Illinois
- Seward Best, representing the Heating Contractors, Quincy, Illinois
- J. M. Robb, representing the Heating Contractors, Moline, Illinois

H. F. Burch, representing the Heating Contractors, Rock Island, Illinois

J. F. Powers, representing the Heating Contractors, Springfield, Illinois

It is the function of this committee to propose such problems for investigation as are of the greatest interest to the installer of small direct steam and hot-water heating systems, operating on gravity circulation. Of these problems, the Engineering Experiment Station Staff selects for study those which can best be investigated with the facilities and equipment available at the University. The coöperating associations provide funds for defraying a major part of the expense of this research work.

2. *Object of Investigation.*—The immediate object of the tests reported in this bulletin was to determine the effect of various types of present-day commercial radiator enclosures, shields, and covers on the heating effect produced and the steam condensed by a direct cast-iron radiator placed in an actual room subjected to zero weather conditions.

3. *Scope of Investigation.*—The effect of an enclosure, shield, or cover upon the heating effect produced in a room and the steam condensing capacity of a radiator depends upon many factors. The tests made in connection with the present investigation were planned to determine the influence of all of the factors which enter into this problem in the case of various commercial radiator enclosures and shields. In conjunction with the work on enclosures and shields, tests were run on an unenclosed radiator, a variety of cloth covers, and a special shielded radiator.

In order to provide for all the factors affecting the performance of bare, enclosed, and shielded radiators, actual rooms with typical outside walls, windows, and doors, and located in a specially constructed low temperature testing plant for maintaining constant outside temperatures of zero or less, were used. In such a plant it was possible to place the radiator in the actual environment existing in practice, and investigate not only the heat emission of the radiator itself, but also the heating effect produced in the room as well. The intelligent design and selection of radiators and enclosures depends fully as much on the effect produced in the room as on the conventional heat emission factor so generally taken as the sole criterion of excellence in the past.

The investigation which is reported in this bulletin is an elaborate extension of a previous investigation in this field, the results of which were published in Bulletin No. 169. The latter investigation was confined strictly to the heat emission or steam condensing capacity of bare and enclosed radiators under the usual laboratory conditions. The correlation of the results of that investigation with those of this investigation is entirely satisfactory.

4. *Acknowledgments.*—The investigation has been carried on as a part of the work of the Engineering Experiment Station of the University of Illinois, of which DEAN M. S. KETCHUM is the director, and of the Department of Mechanical Engineering, of which PROFESSOR A. C. WILLARD is the head.

Acknowledgment is also made to the manufacturers who furnished the radiators, enclosures, and shields used in this investigation.

II. DESCRIPTION OF APPARATUS

5. *Low Temperature Testing Plant.*—The plant is designed specifically for the purpose of accurately studying direct steam and hot water heating problems, including those phases of building construction and insulation which are of special interest to the heating contractor and engineer, as well as the building owner and manufacturer of heating equipment, under conditions approaching as nearly as possible those found in actual practice.

The general arrangement of the plant is shown in Figs. 1 and 2. The main portion of the plant, consisting of the cold room, the two test rooms with their respective attics and basements, and the refrigerating coils, is located on the upper floor of the Mechanical Engineering Laboratory. The auxiliary equipment including the refrigerating apparatus, with the exception of the coils, the thermocouple switchboard, and the steam control and weighing apparatus, is located on the lower floor of the laboratory.

6. *Test Rooms.*—Figures 1 and 2 show the arrangement of the two test rooms which are identical in construction, each one having two walls exposed to the air in the cold space in which the refrigerating coils are located. The cross-hatched walls in Figs. 1 and 2 are composed of corkboard. The two exposed walls of both test rooms, indicated by light lines, can be removed and replaced with any desired wall construction without disturbing the floors or ceilings. As shown in these figures, the insulated walls of the cold room form the two remaining walls of each of the test rooms. Both test rooms are identical in every detail, being 9 ft. by 11 ft. with 9-ft. ceiling heights.

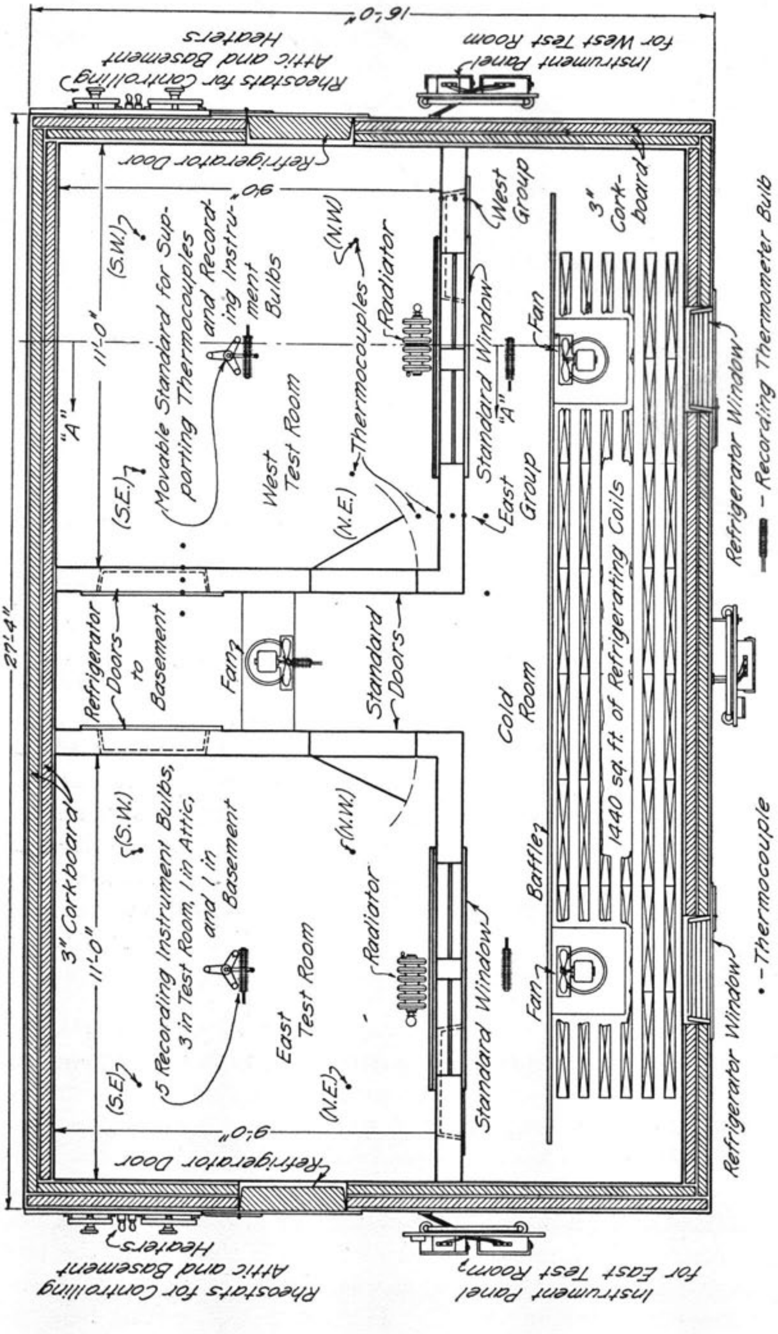


FIG. 1. PLAN SECTION OF LOW TEMPERATURE TESTING PLANT

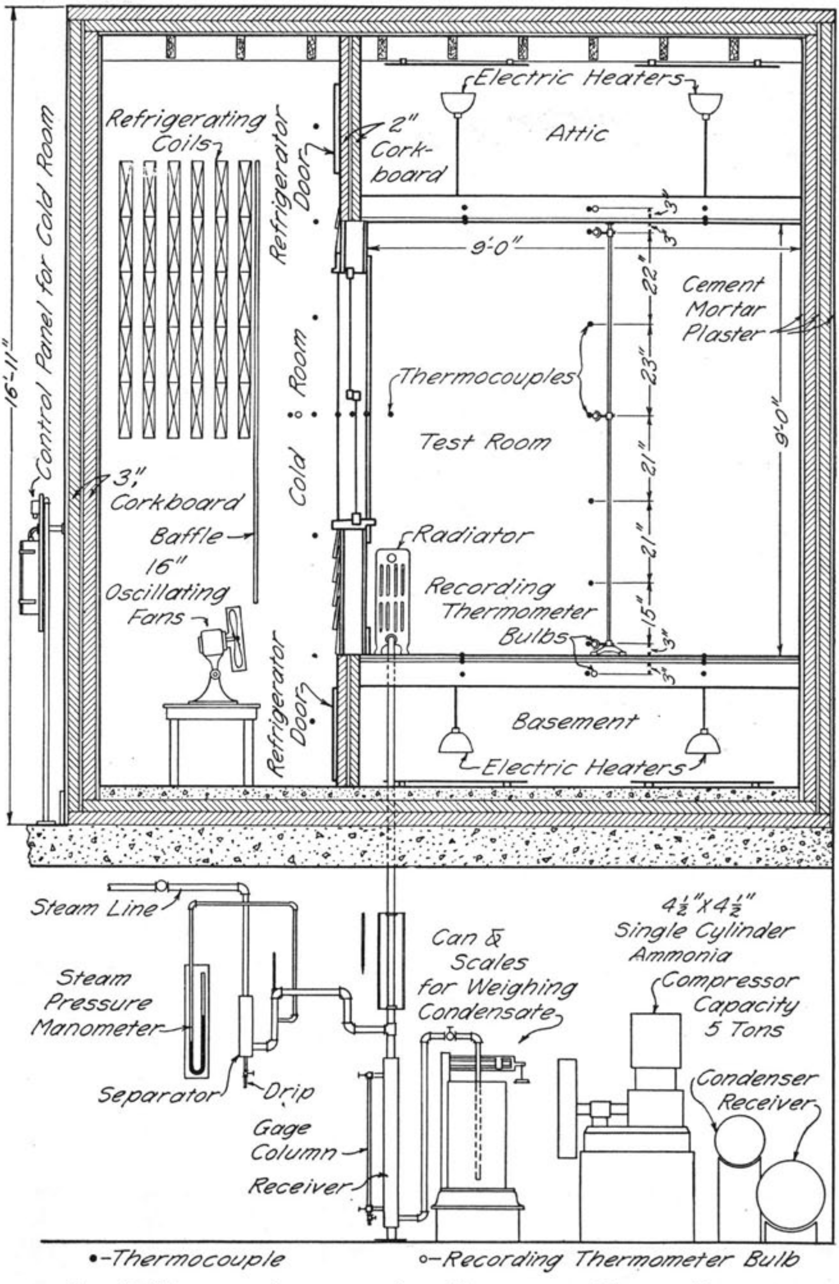


Fig. 2. Elevation Section of Low Temperature Testing Plant

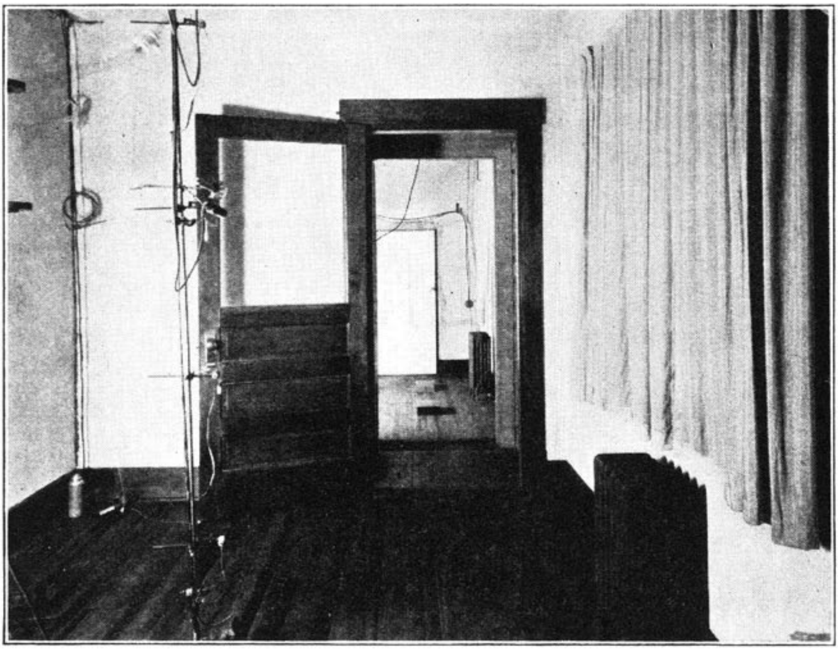


FIG. 3. INSIDE VIEW OF TEST ROOMS

The exposed walls at the present time are standard frame construction, consisting of ⅝-in. redwood siding, building paper, ¾-in. tongue and groove yellow pine sheathing, 2-in. by 4-in. yellow pine studding, and ⅜-in. wood lath with ½-in. gypsum plaster. The ceilings are made of ⅜-in. wood lath and ⅜-in. gypsum plaster, with no flooring in the attics. The floors are of standard 2¼-in. by 13/16-in. standard yellow pine flooring over building paper placed on ¾-in. thick tongue and groove yellow pine sub-floors.

Figure 3 shows the inside of both test rooms, with radiators in front of the windows, which are placed in exposed walls as shown in Figs. 1 and 2. Each test room has one double window 4 ft. 6 in. by 5 ft. overall. The window stools are 34 in. high, making it possible to test radiators with a height up to 32 in. The windows are fitted with shades and curtains as shown in Figs. 3 and 7. Figures 1 and 3 show the locations of standard 1¾-in. thick yellow pine doors, 3 ft. by 7 ft., with glass upper panels. These doors lead directly from the test rooms into the cold space.

Figure 2 shows the attics and basements located above and below each of the test rooms. These attics and basements are for the pur-

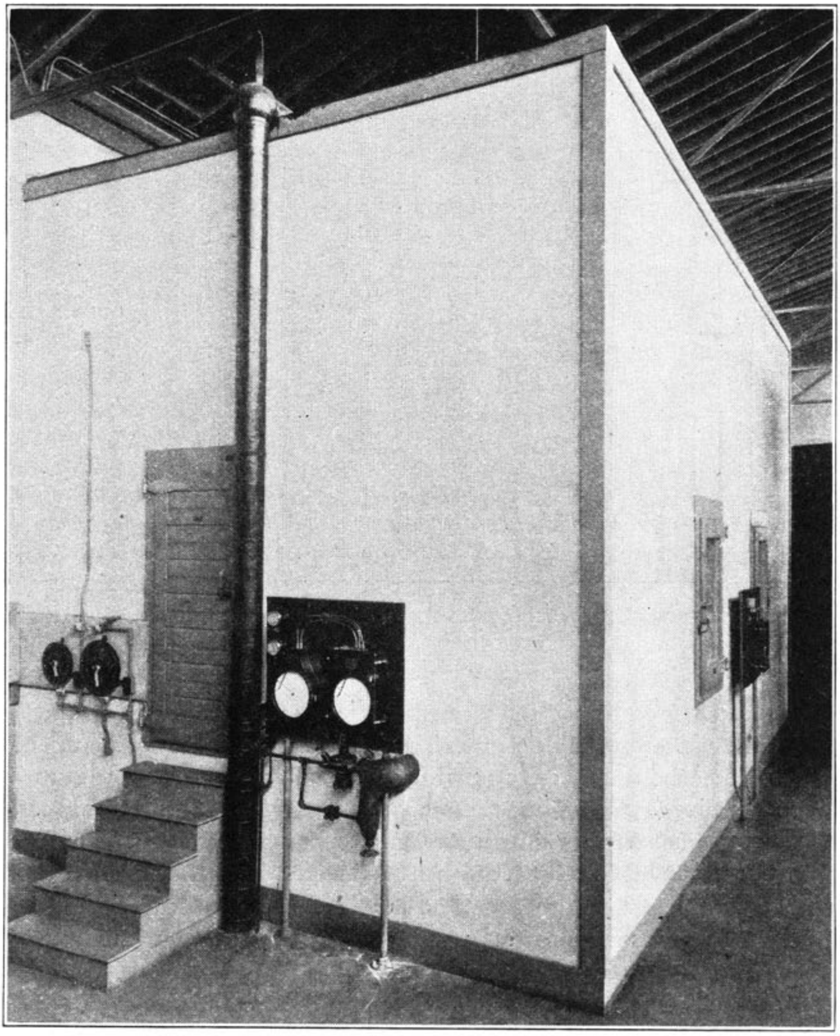


FIG. 4. OUTSIDE OF COLD ROOM, SHOWING RHEOSTATS, RECORDING INSTRUMENTS, AND AUTOMATIC EXPANSION VALVE

pose of exposing the ceilings and floors of the test rooms to air of any desired temperature. The attics were formed by building the ceilings of the test rooms about 3 ft. 10 in. below the ceiling of the cold room, and the basements were made by building the floors of the test rooms about 2 ft. 8 in. above the floor of the cold room. The exposed walls of the attics and basements are composed of 2 layers of 2-in. cork-

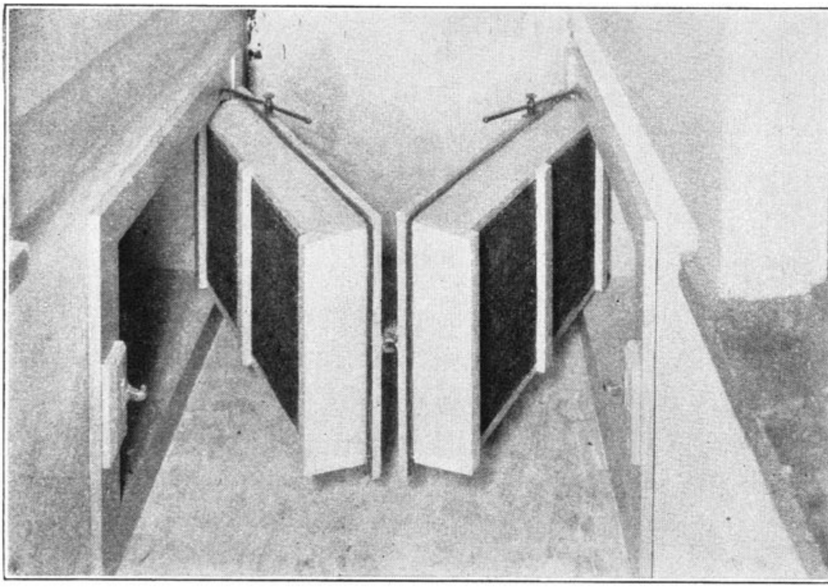


FIG. 5. REFRIGERATOR DOORS OPENING INTO BASEMENTS UNDER TEST ROOMS

board, and are equipped with refrigerator doors as shown in Fig. 5. Each wall contains one door, located as shown in Fig. 1, which opens directly into the cold area, and which may be adjusted to obtain any desired amount of opening. Each attic and basement is equipped with electric heaters, as shown in Fig. 2, consisting of shaded electric light bulbs, so placed that the heat is evenly distributed over the total floor and ceiling surfaces and shielded in order to prevent the floors and ceilings from receiving heat by direct radiation. The voltage to each group of heaters in each attic and basement is separately controlled by rheostats conveniently located outside of the cold room, as shown in Figs. 1 and 4. These heaters, so arranged and controlled, when used in conjunction with the refrigerator doors give a very flexible and sensitive method of controlling the temperatures in the attics and basements.

7. *Cold Room.*—In order that two walls of the test rooms might be exposed to conditions corresponding to those prevailing during the heating season, it was necessary to enclose the test rooms in a cold space in which the temperature and wind movement could be controlled. This makes it possible to run tests at any time of the year under exactly similar conditions. Figure 4 shows the outside of

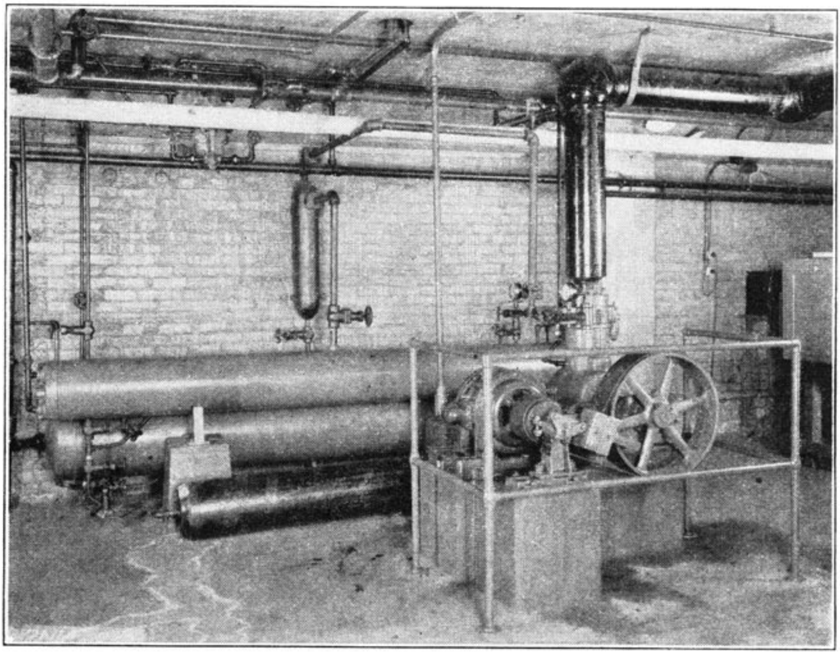


FIG. 6. REFRIGERATING APPARATUS, INCLUDING AMMONIA COMPRESSOR, CONDENSER, AND RECEIVER

the cold room, which is 16 ft. by 27 ft. 4 in. by 16 ft. 11 in. in height. Figures 1 and 2 show details of construction. The walls consist of 2 layers of 3-in. corkboard, with ½ in. of cement mortar between them, and ½ in. of cement plaster on the inner and outer surfaces. The ceiling is made of 2 layers of 3-in. corkboard laid in hot asphalt on a ¾-in. wood deck which is supported independently from the walls of the room. The floor consists of 4 in. of concrete laid on 6 in. of corkboard, which in turn is laid on the 10-in. concrete floor of the laboratory. Entrance to the cold room is through either test room, as shown in Fig. 1. The doors leading from the laboratory into the test rooms are of the heavy refrigerator type, as shown in Fig. 4. Two refrigerator windows, having four separate sheets of glass and three air spaces in each, are located in the north wall as shown in Figs. 1 and 4.

Wind movement in the refrigerated space is obtained by means of three 16-in., specially built, oscillating fans located as shown in Figs. 1 and 2.

8. *Refrigerating Apparatus.*—The plant is designed for an operating temperature of zero deg. F. in the cold room when the temperature at the breathing level in the test rooms is 70 deg. F. The temperature in the cold space is maintained by means of a 5-ton direct expansion ammonia refrigerating unit of the compressor type, located on the lower floor of the laboratory, as shown in Fig. 2. The compressor, which is motor driven and automatically controlled by a thermostat placed in the cold room, is shown in Fig. 6 together with the ammonia condenser and receiver. The ammonia is expanded through an automatic expansion valve directly into the coils shown in Figs. 1 and 2. These coils are special cast-iron refrigerating sections having a total area of 1440 sq. ft. A baffle, shown in Figs. 1 and 2, was erected between the coils and the test rooms for the purpose of increasing the air circulation over the coils and of shielding the walls and windows of the test rooms from direct radiation.

9. *Recording Instruments and Thermocouples.*—The type of tests conducted in this plant necessitates the accurate duplication and maintenance of conditions over comparatively long periods of time.

The selection and installation of apparatus, therefore, had to be based on considerations relative to the adaptability for controlling conditions as well as to accuracy of observations.

Figures 1, 2, and 4 show the location of the recording instruments which were installed for the purpose of control. Each test room, and the cold room, has separate instruments and instrument panels. Figure 7 shows the inside of one of the test rooms with the standard in the center of the room supporting the recording instrument bulbs and thermocouples. Three of these bulbs are located in each of the test rooms; one 3 in. above the floor, one at the breathing level, and one 3 in. below the ceiling. In the corner of the test room, Fig. 7, may be seen leads going to the recording instrument bulbs in the attic and basement. One bulb is located in the center of each attic and basement, 3 in. above the ceiling and 3 in. below the floor. Figure 1 shows the location of the three recording instrument bulbs in the cold room, each of which is placed at a height corresponding to the breathing level of the test rooms.

Figures 7 and 37 also show the apparatus used for generating fumes and making studies of the air circulation in the test rooms. It consists of a portable standard, supporting three pairs of concentric glass dishes which contain ammonium hydroxide and hydrochloric acid. The vapors from these two chemicals, when allowed to mix, form dense white fumes of ammonium chloride. The clamps and

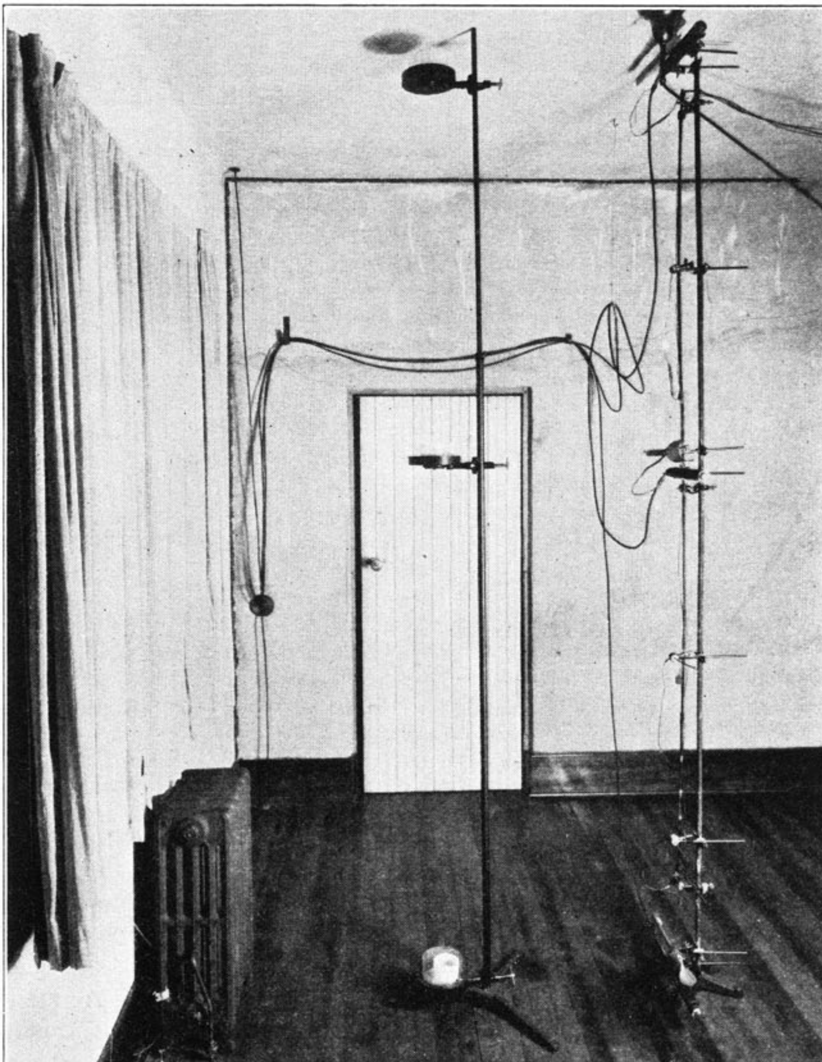


FIG. 7. INSIDE OF EAST TEST ROOM SHOWING FUME GENERATOR AND STANDARD SUPPORTING THERMOCOUPLES AND RECORDING INSTRUMENT BULBS

platforms holding the glass dishes may be adjusted on the standard in order to place the dishes at any desired level.

The plant is equipped with a complete thermocouple system for the purpose of observing both air and surface temperatures. The use of thermocouples makes it possible to obtain the necessary tem-

FIG. 8. THERMOCOUPLE SWITCHBOARD

perature data without entering the rooms or otherwise disturbing the test conditions. It also makes it possible to observe surface temperatures and certain air temperatures which could not be obtained accurately by means of thermometers. The thermocouples are made of No. 22 B. & S. gage, double cotton-covered copper and constantan wire. The leads from all the couples are formed into cables and connected to the switchboard, shown in Fig. 8, which is located on the lower floor of the laboratory directly beneath the cold room. Figure 7 shows one of the standards supporting six thermocouples used in determining air temperatures at six different elevations in the center of the test rooms. The height at which each one of these thermocouples is located is shown in Fig. 2.

Figures 1 and 2 show the location of thermocouples by means of which the temperature gradients through the walls, floor, and ceiling of the west test room were determined. These figures also show the thermocouples used in determining the temperature of the inside and outside surfaces of the wall back of the radiator, and the thermocouples located at each recording instrument bulb for the purpose of checking and adjusting these instruments. All thermocouples for observing surface temperatures had the junctions, and approximately 4 in. of the leads on both sides of the junctions, embedded in the surfaces. The wires were placed in a deep scratch in the surface, and were sealed into the surface itself by means of plaster of paris in the case of plaster surfaces, and shellac in the case of wood surfaces. The wires were then filed flush with the surface and thus became an integral part of it.

10. *Weighing System.*—The condensate weighing system, and the method of regulating the pressure of the steam in the radiators or heating units in the test rooms, is similar to that used in the tests described in Bulletin 169. As shown in Fig. 2, the piping, separator, receiver, weighing tank, and scales are placed on the lower floor of the laboratory, directly beneath the test rooms. Each test room is piped separately and is fully equipped to be operated independently of the other one. Separators are used to remove all entrained moisture from the steam, and mercury manometers are used to indicate the steam pressure. The temperature of the steam just before it enters the radiators is observed by means of thermocouples. Glass sections, $1\frac{5}{16}$-in. in inside diameter, are installed in the $1\frac{1}{4}$-in. vertical risers to the lower tappings of the radiators. The condensate leaves the radiators through these same connections, and is collected in receivers having gage columns. The weighing tanks are connected through water seals to the receivers, and the minimum subdivision of the scales used for weighing the condensate is 0.01 pound. The separators, receivers, and piping are all heavily lagged, and the glass sections in the vertical risers are enclosed in triangular glass observation boxes for protection and prevention of heat loss. Each radiator is equipped with a $\frac{1}{8}$-in. pipe leading from the tapping for the lower air vent on the last section to the lower floor of the laboratory, where the amount of venting is controlled by means of hand-operated gate valves.

11. *Unenclosed Radiators.*—The unenclosed radiators used for the tests included in this bulletin were 6-section, 26-inch, 5-tube, cast-iron radiators having rated areas of 21 sq. ft. The surfaces were brushed and painted (not dipped) with two coats of flat black paint. Figure 9 shows one of these radiators located under the curtained

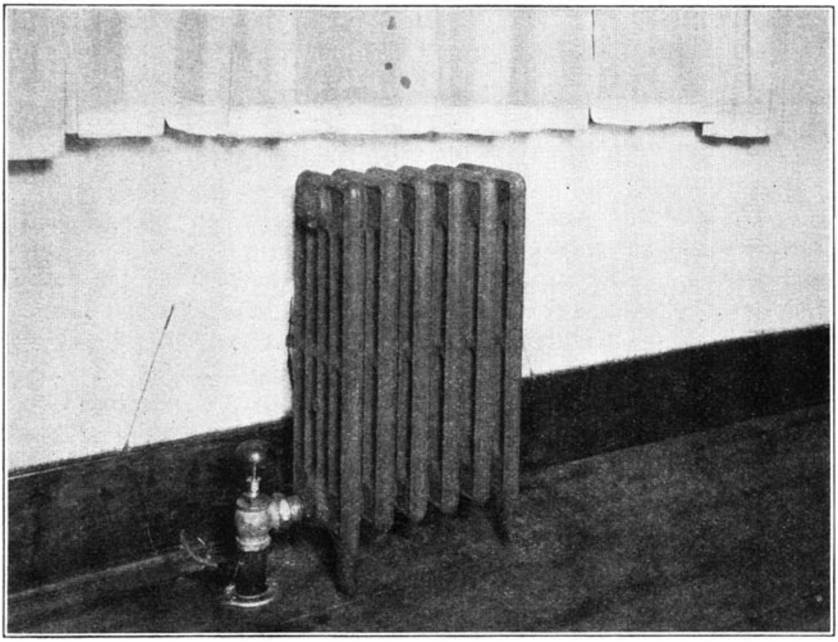


FIG. 9. UNENCLOSED RADIATOR

window with a space of 2½ in. between the back of the radiator and the plaster surface of the exposed wall.

12. *Enclosures.*—Figures 10 to 21 show the enclosures, covers, and shields tested. In all tables, and in the text, each piece of apparatus tested, whether it is an ordinary enclosure or a cloth shield, is designated as an enclosure. In order to differentiate between them and to simplify the presentation and discussion of results, each enclosure is numbered as shown in these figures. Figure 22 gives the important dimensions of each of the enclosures, including the clearances between them and the radiator.

Enclosure No. 1, shown in Fig. 10, is a common commercial type of metal shield.

Enclosures Nos. 2, 3, 5, 8, 8a, 9, and 10, shown in Figs. 11, 12, 14, 17, 18, 19, and 20, respectively, are commercial metal enclosures of different types. It should be noted in Fig. 22, column F, that the clearance between the top of the radiator and the bottom of the humidifying pan is practically the same in each case. The inside widths and lengths of these various enclosures, given in Fig. 22, col-

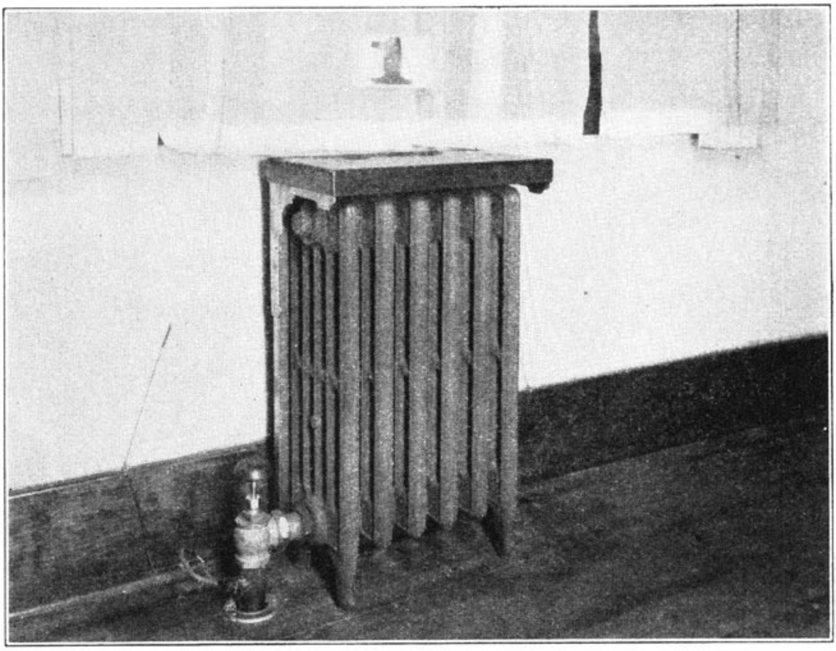


Fig. 10. Enclosure No. 1

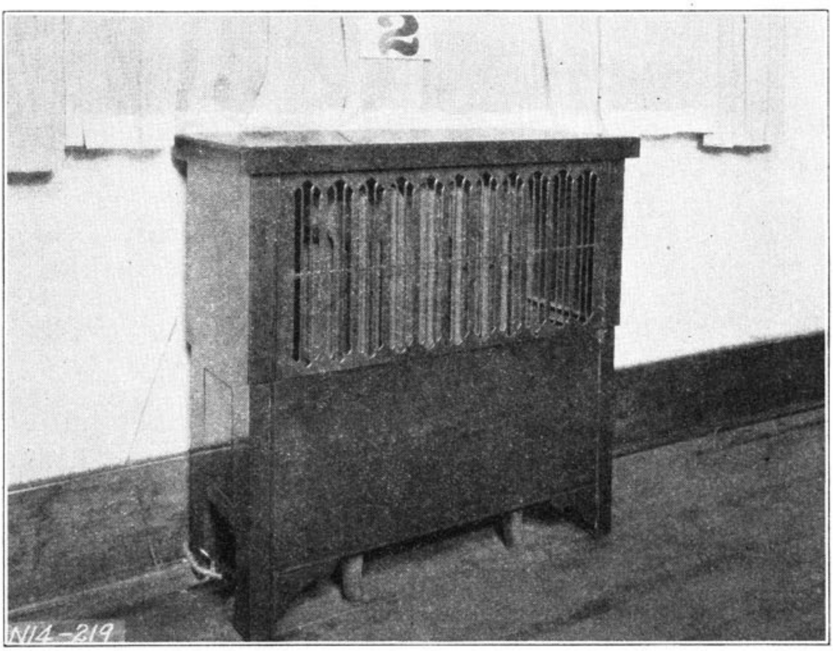


Fig. 11. Enclosure No. 2

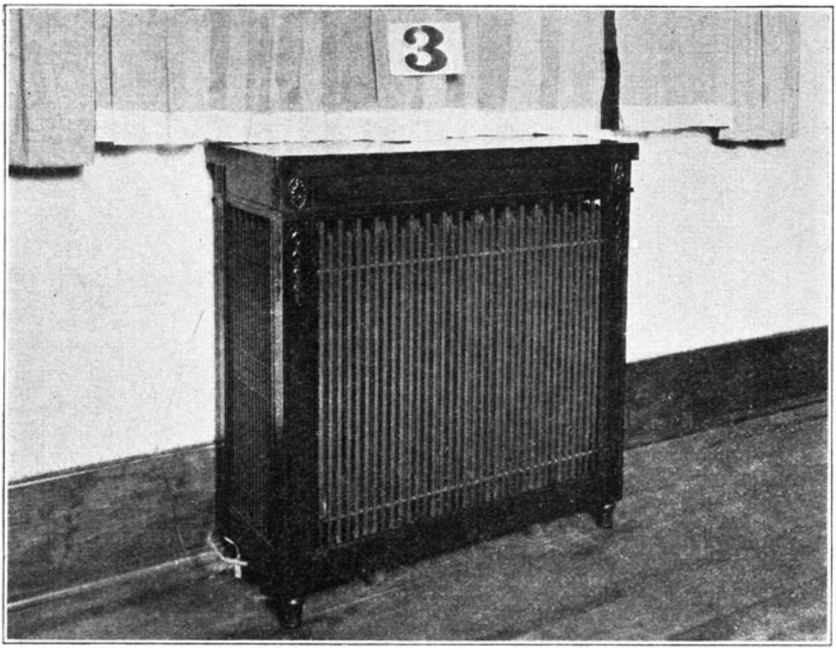


Fig. 12. Enclosure No. 3

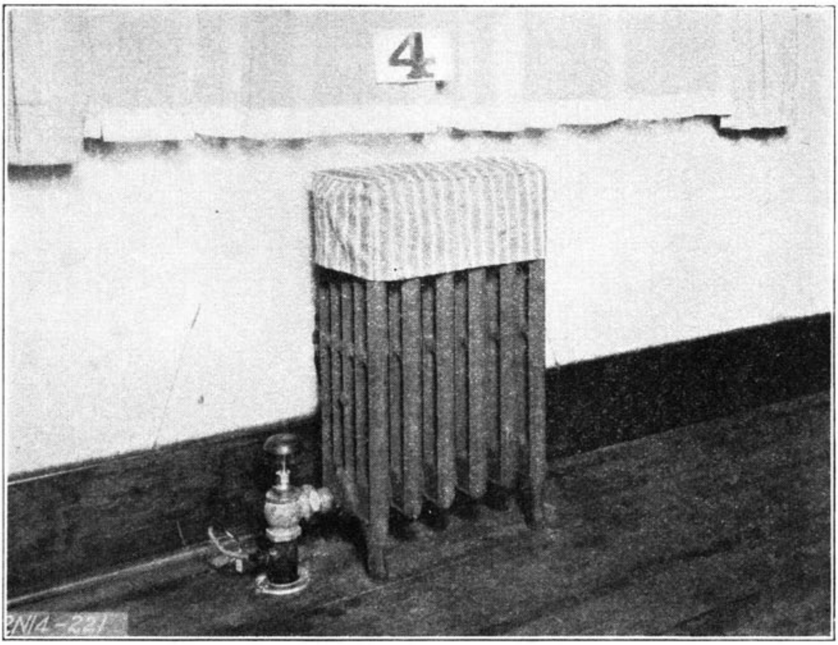


Fig. 13. Enclosure No. 4

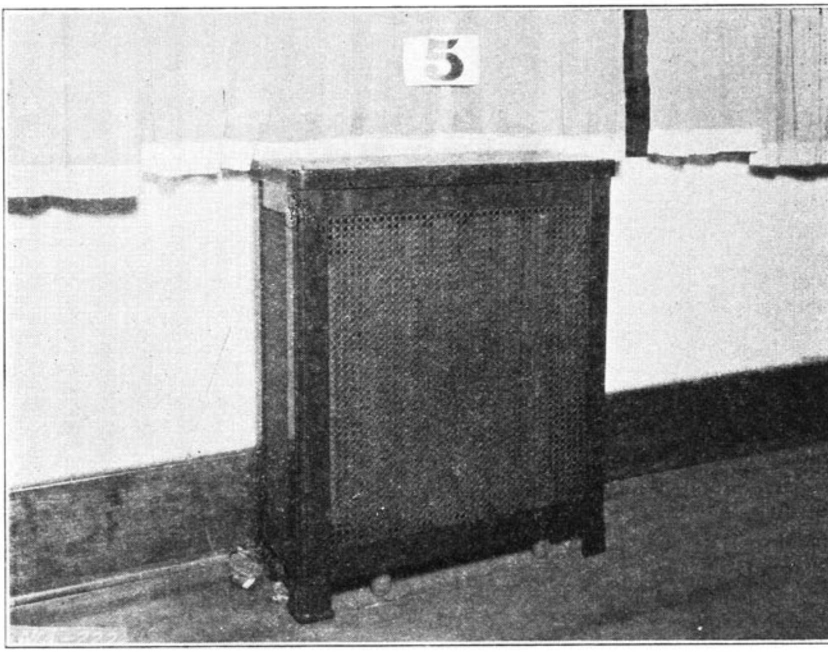


Fig. 14. Enclosure No. 5

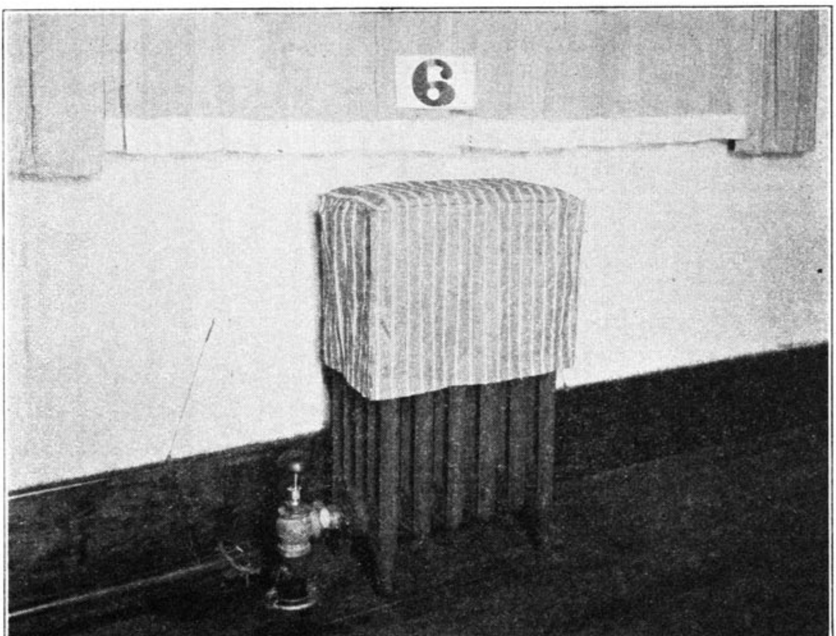


Fig. 15. Enclosure No. 6

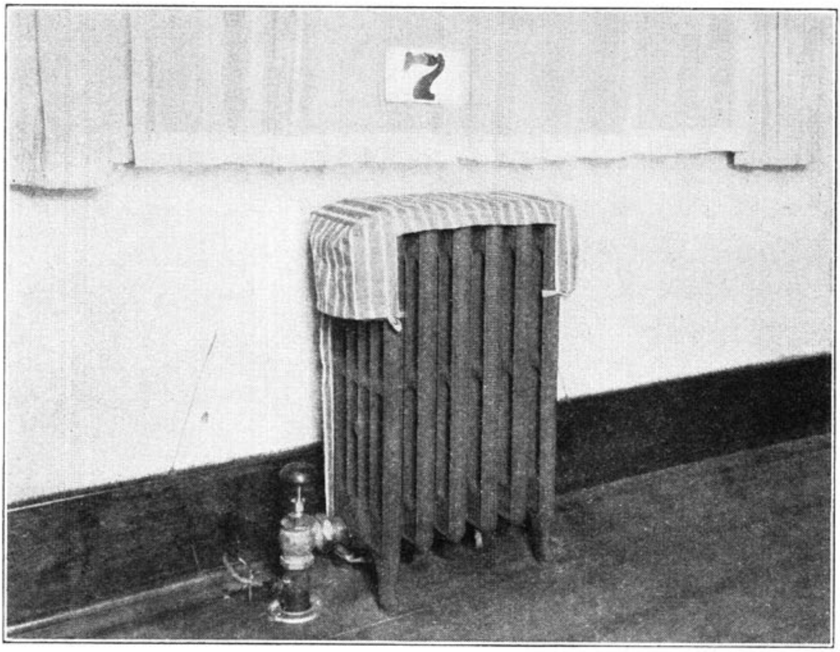


FIG. 16. ENCLOSURE No. 7

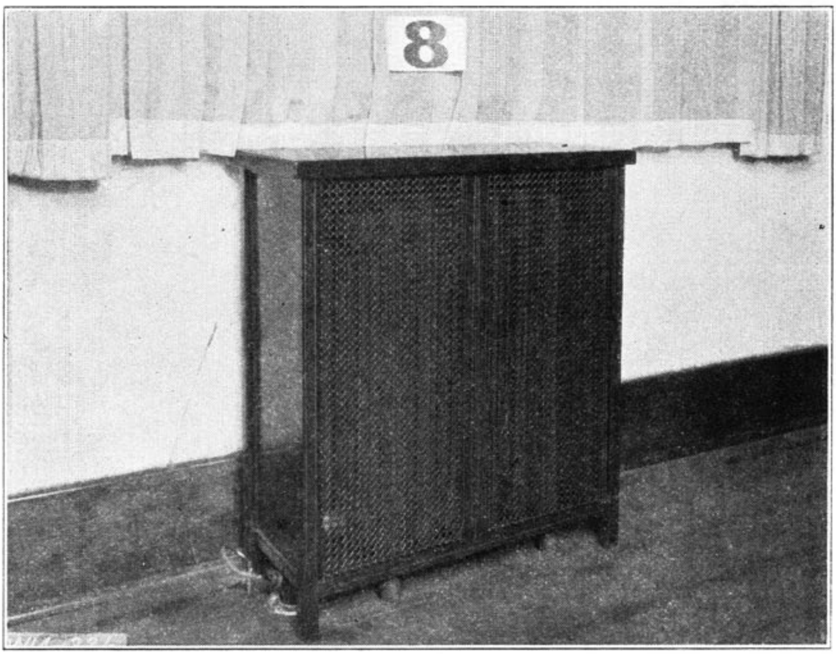


FIG. 17. ENCLOSURE No. 8

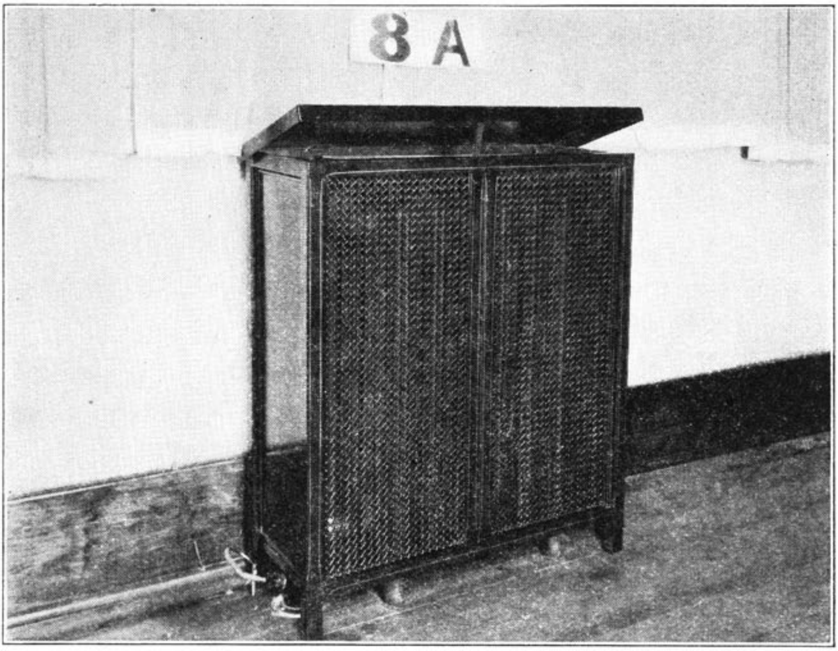


FIG. 18. ENCLOSURE No. 8a

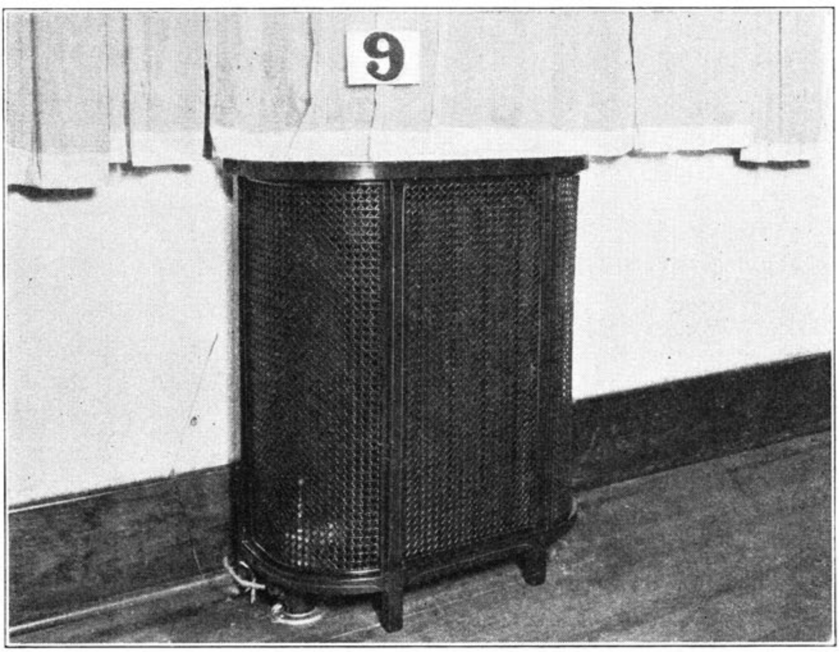


FIG. 19. ENCLOSURE No. 9

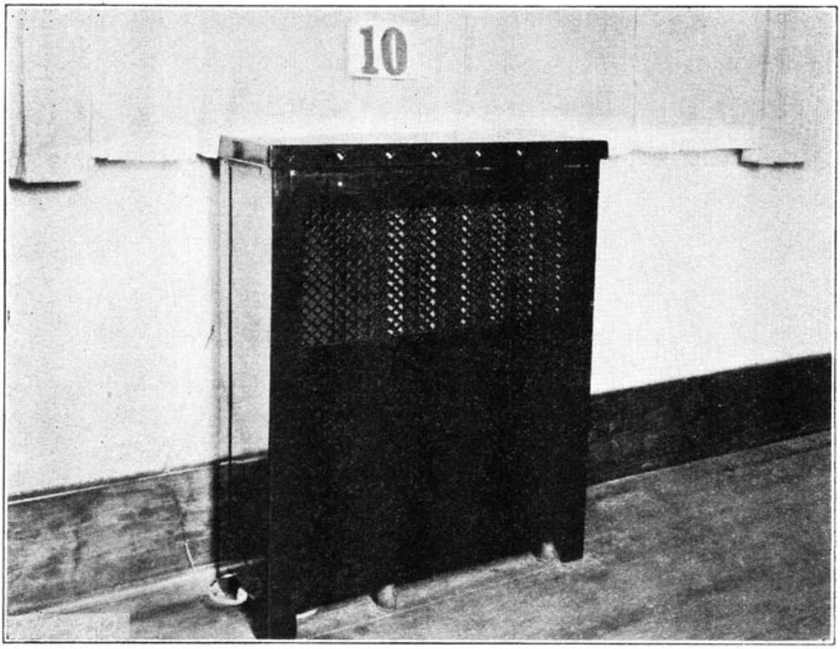


FIG. 20. ENCLOSURE NO. 10

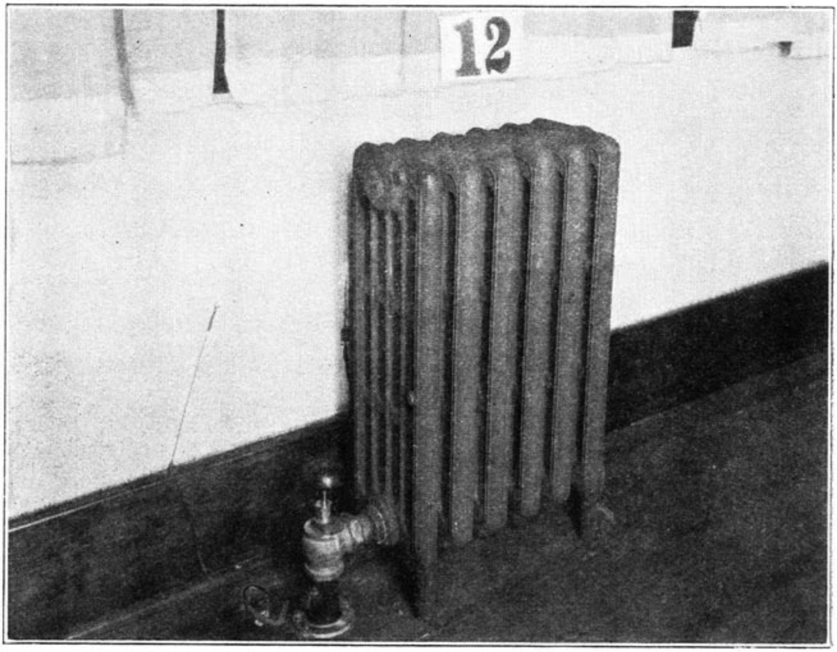
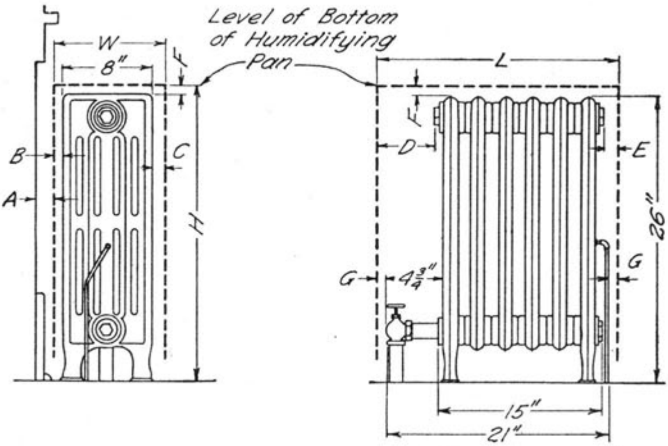


FIG. 21. ENCLOSURE NO. 12



Enclosure No.	Dimensions in Inches									
								Inside Dimensions		
	A	B	C	D	E	F	G	W	H	L
1	$2\frac{1}{2}$	0	—	—	—	$\frac{1}{4}$	—	9	$26\frac{1}{4}$	16
2	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$7\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{1}{4}$	3	$10\frac{1}{2}$	$27\frac{1}{4}$	27
3	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$6\frac{5}{8}$	$3\frac{1}{8}$	$\frac{3}{4}$	$1\frac{7}{8}$	$10\frac{7}{8}$	$26\frac{3}{4}$	$24\frac{3}{4}$
4	$2\frac{1}{2}$	—	—	—	—	0	—	8	26	15
5	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$5\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{2}$	1	$9\frac{5}{8}$	$27\frac{1}{2}$	23
5a	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$5\frac{3}{4}$	$2\frac{1}{4}$	3	1	$9\frac{5}{8}$	29	23
6	$2\frac{1}{2}$	—	—	—	—	0	—	8	26	15
7	$2\frac{1}{2}$	0	—	—	—	0	—	8	26	15
8	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{8}$	$5\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{4}$	1	$9\frac{1}{4}$	$27\frac{1}{4}$	23
8a	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{8}$	$5\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{4}$	1	$9\frac{1}{4}$	$27\frac{1}{4}$	23
9	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{8}$	$5\frac{1}{2}$	2	$1\frac{1}{4}$	$\frac{3}{4}$	$9\frac{1}{4}$	$27\frac{1}{4}$	$22\frac{1}{2}$-12
10	$2\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$5\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{8}$	1	$8\frac{1}{2}$	$27\frac{1}{8}$	23
11	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$5\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{8}$	1	10	$27\frac{1}{8}$	23
12	3	—	—	—	—	—	—	$7\frac{1}{2}$	26	15
12a	3	—	—	—	—	—	—	$7\frac{1}{2}$	26	15

FIG. 22. DIMENSIONS OF ENCLOSURES TESTED

umns W and L, vary a small amount. Several of the commercial enclosures are fitted with adjustable legs, but only one, enclosure No. 5, was tested at more than one height. This enclosure, designated as No. 5, when the legs are of minimum length, is designated as No. 5a when the legs are set at their maximum height. Enclosure No. 8 is fitted with a hinged top which may be raised as shown in Fig. 18. When tested with the top raised in this manner it is designated as enclosure No. 8a.

Enclosures Nos. 4 and 6, shown in Figs. 13 and 15, are crash cloth covers fitted over the tops of the radiator.

Enclosure No. 7, shown in Fig. 16, is a special shield made of crash cloth.

Enclosure No. 12, shown in Fig. 21, is a special cast-iron radiator, the back part of which is fitted with narrow strips of metal which slide in between the sections, and at the top extend toward the front of the radiator until they meet the upper hubs, thus forming a shield. When tested without the metal strips in place it is designated as enclosure No. 12a.

III. Discussion of Test Methods and Results

13. *Limiting Conditions for Tests.*—All tests were run under conditions approximating those found in typical rooms in residences, with two walls exposed to an outdoor temperature slightly below zero and with some wind movement over one wall. The motor-driven ammonia compressor was thermostatically controlled, and the temperature in the refrigerated space at a level corresponding to the breathing level in the rooms was automatically maintained at approximately −1.5 deg. F.

The temperatures in the air spaces above the ceilings and below the floors of the test rooms were regulated by means of electric heaters and rheostats under manual control. These heaters were shielded in order to minimize the effect of direct radiation on the surfaces of the floors and ceilings. The temperature of the air 3 in. above the ceilings was maintained at approximately 62 deg. F., while that 3 in. below the floors was maintained about 2 deg. F. higher than the temperature of the air 3 in. above the floors. In certain cases, temperatures in actual attic spaces may be somewhat lower and temperatures immediately under the floors may be somewhat higher, but the conditions selected correspond very closely with those found with a well constructed roof and unfloored attic, and with a well insulated heating plant, where the basement temperature is approximately 60 deg. F.

The amount of standard 5-tube radiation required to maintain a temperature of 70 deg. F. at the breathing level, or 5 ft. above the floor, under the conditions outlined, was determined by trial from preliminary runs. This amount proved to be 21 sq. ft. for the unenclosed radiator, and remained unchanged for all of the tests. The various enclosures, shields, and covers were selected to fit this radiator, and the performance of the unenclosed radiator was used as the basis for comparison. When enclosures, shields, or covers were installed, no other changes were made in the plant or in the temperature conditions external to the rooms. In case an enclosure was equipped with a humidifying pan, the pan was retained in its proper location but no water was used. The relative humidity in the rooms varied from 15 to 25 per cent. The temperatures at the various levels within the rooms were allowed to attain equilibrium conditions inherent with the type of apparatus being tested, and comparisons of the performance were all made on the basis of steam condensation in conjunction with the temperature conditions produced within the rooms as determined at six different levels (see Figs. 1 and 2).

14. *Temperature Measurements.*—The temperature of the air in the rooms was observed by means of thermocouples placed at six different levels on the central vertical axes of the rooms. These couples were of No. 22 B. & S. gage wire and were unshielded. Preliminary work with shielded and unshielded couples proved that no correction for radiation was necessary for the couples above the breathing level, and that the maximum correction for any couple below the breathing level was less than 0.5 deg. F. Hence the readings of the unshielded couples are considered as indicative of the actual air temperatures. Temperatures of the outside and inside surfaces of the walls were obtained by means of six thermocouples (see Figs. 1 and 2) embedded in the surfaces. Similar temperatures of the upper and lower surfaces of the floor and ceiling were obtained at four different points (see Figs. 1 and 2) on each surface.

15. *Operation of Plant.*—Both rooms were operated simultaneously, and in every case check runs were made with the same enclosure first in one room and then in the other. These check runs proved that the performance, both of the rooms themselves and of the apparatus in the rooms, was practically identical. For this reason, it has not been considered necessary to report the results of the duplicate tests. No attempt was made to have the doors and windows tighter than what could be considered fair average construction, and the amount of infiltration of cold air into the rooms appeared to be normal for the wind movement and temperatures existing.

In every case the plant was operated with the rooms under heat and with the fans in the cold room running for a preliminary period of sufficient length to allow all conditions to attain a state of equilibrium. This state was indicated when the temperatures of the walls, floors, and ceilings, as determined by the readings of the surface thermocouples, had become constant, and the temperatures of the air in the refrigerated space and in the spaces below the floors and above the ceilings had remained constant for several hours. No air was allowed to accumulate in the radiators during the preliminary period or during a test. When equilibrium had been attained, the condensation from the radiators was weighed at 10-minute intervals, and no test was accepted that showed a variation of more than 2½ per cent in the successive increments of weight. A thermocouple on the surface of the radiator at the point where air accumulation would first occur gave an immediate indication if there was any tendency for air to accumulate during a test. The tests were of sufficient length to prove that all conditions had remained constant, and were discontinued at the first indication that any air had accumulated in the radiator. The condensation was corrected for water condensed in risers and piping. This correction was determined from preliminary tests, and, since all piping was heavily lagged with hair felt, was extremely small.

The results of all tests are given in Tables 1 and 2, and by means of the curves in Figs. 23 to 31. A discussion of these curves may be found under the corresponding section headings.

IV. Tests of Unenclosed Radiators

16. *Results of Performance Tests.*—Several tests were run with two identical unenclosed radiators (Fig. 9) operated simultaneously in the two rooms. Other tests were run with an unenclosed radiator in one room and an enclosed radiator in the other room. In all cases the net steam condensed by the unenclosed radiator per hour and the temperature gradients in the rooms in which the unenclosed radiator was used were practically identical, provided that the control conditions were the same. Accordingly, a single curve was selected to represent the performance of the unenclosed radiator in each room, and this curve has been reproduced in each set of curves in Figs. 23 to 31 corresponding to the room in which the tests were run, in order to serve as a basis for comparison of the performance of the enclosed radiators. From these curves it may be noted that when an air temperature of 69.4 deg. F. was maintained at the breathing level in the west test room and a steam temperature of 216.5 deg. F. was maintained in the unenclosed radiator, the net weight of steam condensed per hr. was 5.44 lb. Under these conditions the temperature of the air 3 in. above the floor was 54.3 deg. F. and that 3 in. below the ceiling was 76.1 deg. F., or a difference of 21.8 deg. F. A fairly uniform temperature gradient in the air from floor to ceiling was obtained.

TABLE 1
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Date	Enclosure No.	Type Fig. No.	Description	Net Lb. of Steam Condensed Per Hour	Temperatures, Degree Fahrenheit							
							Steam in Radiator	Cold Room	Basement, 3 in. below Floor					
									S.W.	S.E.	N.E.	N.W.	Center	Average
1	R-5	6-23-28	..	9	6 Sec., 26 in., 5 Tube, C. I. Rad.	5.29	216.5	−1.9	57.0	55.2	54.3	56.3	56.5	55.9
2	R-7	10-30-28	..	9	6 Sec., 26 in., 5 Tube, C. I. Rad.	5.37	216.6	−2.6	61.2	56.5	55.8	65.7	59.4	59.7
3	*R-8	10-30-28	..	9	6 Sec., 26 in., 5 Tube, C. I. Rad.	5.44	216.5	−1.1	58.2	53.2	52.9	63.1	56.6	56.8
4	R-9	11- 5-28	..	9	6 Sec., 26 in., 5 Tube, C. I. Rad.	5.41	216.5	−1.4	56.1	50.9	50.6	61.2	54.5	54.7
5	*E-4	6-25-28	1	10	Metal Shield	4.81	216.5	−1.8	57.3	56.1	55.3	56.4	57.3	56.5
6	E-15	7-10-28	1	10	Metal Shield	4.81	216.5	+0.1	56.5	55.3	54.6	55.6	56.8	55.8
7	E-16	7-11-28	1	10	Metal Shield	4.78	216.5	−0.8	58.1	57.0	56.0	57.1	58.0	57.2
8	*E-3	6-24-28	2	11	Slotted Front Outlet	4.89	216.5	−1.4	58.3	57.2	56.1	57.5	58.4	57.5
9	E-12	7-26-28	2	11	Slotted Front Outlet	4.96	216.5	−0.3	56.5	55.4	54.5	55.4	56.9	55.7
10	*E-6	6-27-28	3	12	Rods on Front and Ends	4.71	216.3	−0.7	56.9	55.8	54.7	55.8	56.9	56.0
11	E-11	7- 3-28	3	12	Rods on Front and Ends	4.70	216.5	−0.2	56.4	55.3	54.2	55.3	56.9	55.6
12	*E-5	6-26-28	4	13	6 in. Cloth Cover	4.59	216.5	−2.0	55.8	54.8	54.0	54.8	55.9	55.1
13	E-8	6-29-28	5	14	Grilled Front and Ends	4.72	216.5	−2.0	57.0	55.9	54.8	55.8	57.0	56.1
14	E-9	6-30-28	5	14	Grilled Front and Ends	4.86	216.5	−1.0	56.7	55.5	54.6	55.5	56.9	55.8
15	E-10	6-30-28	5	14	Grilled Front and Ends	4.78	216.5	−0.8	57.1	55.9	54.8	55.9	57.3	56.2
16	*E-7	6-28-28	6	15	12 in. Cloth Cover	3.67	216.5	−1.4	51.5	50.6	49.9	50.6	51.9	50.9
17	*E-13	7- 7-28	7	16	Cloth Shield	4.68	216.5	−0.5	55.4	54.4	53.6	54.6	55.7	54.7
18	E-14	7- 9-28	7	16	Cloth Shield	4.63	216.5	−0.3	55.7	54.6	53.8	54.9	55.9	55.0
19	E-17	7-12-28	8	17	Grilled Front and Solid Ends	4.70	216.6	−1.0	55.8	54.7	53.7	54.6	55.8	54.9
20	E-20	7-16-28	8	17	Grilled Front and Solid Ends	4.76	216.5	−0.4	54.8	53.7	52.9	53.7	55.0	54.0
21	E-18	7-13-28	9	19	Grilled with Curved Ends	4.77	216.5	−0.9	55.6	54.6	53.5	54.4	55.7	54.8
22	*E-19	7-14-28	9	19	Grilled with Curved Ends	4.87	216.5	−1.0	55.6	54.5	53.6	54.4	55.6	54.7
23	*E-21	10-31-28	10	20	Punched Front Outlet (Narrow)	4.50	216.4	−1.5	54.0	48.4	47.9	57.8	52.1	52.0
24	E-22	11- 1-28	11	20	Punched Front Outlet (Wide)	4.57	216.4	−2.4	52.9	47.4	46.9	57.2	50.9	51.1
25	*E-23	11- 2-28	11	20	Punched Front Outlet (Wide)	4.58	216.5	−1.8	52.4	46.9	46.5	56.9	50.4	50.6
26	*E-24	11- 7-28	12	21	Special Rad.—Integral Shield	4.96	216.6	−1.3	55.5	50.3	49.9	60.5	53.9	54.0
27	*E-25	11- 8-28	12, A.	..	Special Rad.—Without Shield	5.06	216.6	−1.2	55.9	50.4	50.2	60.7	54.1	54.3

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.

TABLE 1 (Continued)
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit														
		Floor Surfaces										Difference between 3 in. below Floor and 3 in. above Floor	Difference between Floor Surfaces	Floor 3 in. above Upper Surface	Knee Height 18 in. above Floor	39 in. above Floor
		Lower					Upper									
		S.W.	S.E.	N.E.	N.W.	Average	S.W	S.E.	N.E.	N.W.	Average					
1	R-5	57.1	55.4	57.0	57.0	56.6	58.9	57.4	56.1	62.0	58.6	+2.1	+2.0	53.8	59.6	63.7
2	R-7	58.9	55.7	55.4	63.0	58.2	59.9	57.9	57.0	64.8	59.9	+4.4	+1.7	55.3	60.0	64.2
3	*R-8	56.3	53.0	52.7	60.1	55.5	59.0	57.0	56.0	63.3	58.8	+2.5	+3.3	54.3	60.1	64.4
4	R-9	54.4	51.1	50.8	58.4	53.7	58.0	55.9	54.9	62.2	57.8	+0.8	+4.1	53.9	59.6	63.8
5	*E-4	58.1	56.7	55.7	57.3	57.0	59.6	58.0	56.9	62.7	59.3	+1.9	+2.3	54.6	59.9	65.5
6	E-15	57.7	56.1	55.1	56.6	56.4	59.5	57.8	56.6	62.0	59.0	+1.4	+2.6	54.4	59.8	66.1
7	E-16	59.0	57.4	56.3	57.9	57.7	60.2	58.3	57.1	62.8	59.6	+2.8	+1.9	54.4	60.0	66.3
8	*E-3	59.1	57.8	56.2	57.8	57.7	60.4	59.0	60.4	61.3	60.3	+3.7	+2.6	53.8	60.3	66.2
9	E-12	57.7	56.2	54.7	55.8	56.1	59.1	57.6	55.1	59.6	57.9	+1.7	+1.8	54.0	60.5	65.8
10	*E-6	57.7	56.4	54.7	55.7	56.1	59.3	57.9	55.6	59.5	58.1	+1.0	+2.0	55.0	61.5	68.4
11	E-11	57.5	56.0	54.4	55.5	55.9	59.1	57.6	55.2	59.2	57.8	+1.0	+1.9	54.6	61.1	68.2
12	*E-5	56.7	55.2	54.3	55.7	55.5	58.0	56.5	55.0	60.5	57.5	+2.1	+2.0	53.0	58.6	63.1
13	E-8	58.0	56.5	54.9	56.2	56.4	59.5	57.9	55.5	60.1	58.3	+1.8	+1.9	54.3	60.5	67.0
14	E-9	57.9	56.3	54.7	55.9	56.2	59.4	57.9	55.6	59.8	58.2	+1.5	+2.0	54.3	60.5	67.6
15	E-10	57.9	56.6	54.9	56.1	56.4	59.6	58.0	55.6	60.0	58.3	+1.6	+1.9	54.6	60.9	68.0
16	*E-7	52.4	51.0	50.0	51.3	51.2	53.6	52.1	50.5	55.8	53.0	+2.1	+1.8	48.8	54.0	57.6
17	*E-13	56.5	54.9	53.9	55.3	55.1	58.0	56.2	54.8	60.3	57.3	+1.8	+2.2	52.9	58.2	64.6
18	E-14	56.7	55.1	54.1	55.6	55.4	58.3	56.6	55.0	60.4	57.6	+1.7	+2.2	53.3	58.7	64.7
19	E-17	57.0	55.4	53.9	55.0	55.3	58.5	56.7	54.2	58.9	57.1	+2.5	+1.8	52.4	58.7	64.6
20	E-20	56.1	54.5	53.1	54.2	54.5	58.0	56.0	53.7	58.4	56.5	+2.0	+2.0	52.0	58.7	64.6
21	E-18	56.9	55.3	53.9	54.8	55.2	58.6	56.8	54.7	58.6	57.2	+2.6	+2.0	52.2	59.0	65.7
22	*E-19	56.8	55.3	53.8	54.7	55.1	58.6	56.9	54.7	58.6	57.2	+2.1	+2.1	52.6	59.2	65.8
23	*E-21	52.1	48.5	48.0	55.2	51.0	54.7	52.7	50.6	56.7	53.7	+2.5	+2.7	49.5	55.1	60.6
24	E-22	51.1	47.7	47.1	54.5	50.1	54.2	52.1	50.3	56.2	53.2	+2.2	+3.1	48.9	54.6	59.9
25	*E-23	50.6	47.2	46.5	54.1	49.6	54.0	52.0	50.1	56.1	53.1	+1.7	+3.5	48.9	54.8	60.0
26	*E-24	53.8	50.3	50.1	57.6	53.0	56.8	54.4	53.4	60.8	56.4	+2.0	+3.4	52.0	57.9	62.4
27	*E-25	54.2	50.6	50.4	57.9	53.3	57.5	55.0	54.1	61.3	57.0	+1.9	+3.7	52.4	58.3	62.9

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.

TABLE 1 (Continued)
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit													
		Breathing Line—60 in. above Floor	83 in. above Floor	Ceiling 3 in. below Lower Surface	Ceiling Surfaces										Difference between Ceiling Surfaces
					Lower					Upper					
					S.W.	S.E.	N.E.	N.W.	Average	S.W.	S.E.	N.E.	N.W.	Average	
1	R-5	69.0	73.0	75.7	67.3	65.5	66.3	67.3	66.6	66.3	64.9	65.1	65.2	65.4	+1.2
2	R-7	69.2	73.8	76.1	67.5	65.7	67.0	67.7	67.0	66.0	64.9	65.4	65.0	65.3	+1.7
3	*R-8	69.4	73.8	76.1	67.1	65.3	66.4	67.4	66.5	65.5	64.5	64.9	64.4	64.8	+1.7
4	R-9	68.8	73.0	75.5	66.5	64.9	65.9	66.7	66.0	65.4	64.1	64.7	64.2	64.6	+1.4
5	*E-4	69.5	71.6	74.0	66.8	65.2	65.8	66.5	66.1	66.1	64.8	64.8	64.4	65.0	+1.1
6	E-15	70.2	71.9	74.2	66.9	65.2	65.7	66.6	66.1	66.2	64.7	64.6	64.6	65.0	+1.1
7	E-16	70.3	72.1	74.2	67.1	65.5	66.0	66.7	66.3	66.3	65.0	64.8	64.6	65.2	+1.1
8	*E-3	70.5	72.5	76.2	67.3	66.0	66.2	66.9	66.6	66.4	65.1	64.9	64.9	65.3	+1.3
9	E-12	70.2	72.1	75.7	67.2	64.1	65.5	66.6	65.9	66.9	62.9	64.5	64.8	64.8	+1.1
10	*E-6	69.5	71.7	73.2	66.2	64.5	64.1	65.8	65.1	65.8	64.3	63.8	64.0	64.5	+0.6
11	E-11	69.4	71.6	73.1	66.2	64.3	63.8	65.4	64.9	66.0	64.1	63.4	64.2	64.4	+0.5
12	*E-5	66.4	69.1	70.8	65.5	64.0	64.6	65.0	64.8	65.8	64.3	64.6	64.2	64.7	+0.1
13	E-8	69.8	72.4	74.7	66.9	65.1	65.7	66.5	66.1	66.3	64.9	64.8	64.7	65.2	+0.9
14	E-9	70.3	72.7	75.1	66.8	65.6	66.5	66.2	66.3	66.4	65.1	65.5	64.7	65.4	+0.9
15	E-10	70.3	72.8	75.0	66.9	65.2	65.4	66.6	66.0	66.1	64.7	64.6	64.5	65.0	+1.0
16	*E-7	61.2	63.5	65.0	62.2	60.9	60.7	61.8	61.4	63.9	62.3	62.0	62.4	62.7	+1.3
17	*E-13	68.6	70.2	73.0	66.0	64.4	65.0	65.6	65.2	65.8	64.2	64.2	64.2	64.6	+0.6
18	E-14	68.7	70.4	73.2	65.8	64.2	64.7	65.5	65.0	65.2	63.9	63.7	63.7	64.1	+0.9
19	E-17	70.1	71.8	75.2	66.5	65.2	66.0	66.0	65.9	65.7	64.8	64.8	64.0	64.8	+1.1
20	E-20	69.9	72.1	75.4	66.2	65.0	65.7	65.9	65.7	65.5	64.6	64.6	63.8	64.6	+1.1
21	E-18	69.5	72.0	74.3	66.3	64.8	65.4	66.0	65.6	65.4	64.3	64.3	63.9	64.5	+1.1
22	*E-19	69.7	72.1	74.3	66.6	65.0	65.6	66.5	65.9	66.0	64.8	64.8	64.5	65.0	+0.9
23	*E-21	66.2	69.8	72.5	64.4	63.1	64.0	64.9	64.1	64.6	63.4	63.9	63.5	63.9	+0.2
24	E-22	65.7	69.2	72.0	64.4	63.2	63.9	64.5	64.0	64.8	63.6	63.9	63.6	64.0	0.0
25	*E-23	65.9	69.1	71.9	64.2	62.9	63.5	64.5	63.8	64.5	63.3	63.5	63.3	63.6	+0.2
26	*E-24	67.5	71.7	74.0	65.7	63.9	65.0	66.2	65.2	65.0	63.4	64.0	63.9	64.1	+1.1
27	*E-25	67.7	71.9	74.3	66.1	64.4	65.3	66.4	65.5	65.3	63.9	64.4	64.2	64.4	+1.1

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.

TABLE 1 (Continued)
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit								
		Attic, 3 in. above Ceiling						Difference between 3 in. below Ceiling and 3 in. above Ceiling	Wall Surfaces back of Radiator	
		S.W.	S.E.	N.E.	N.W.	Center	Average		Inside	Outside
1	R-5	62.4	62.7	62.5	59.5	64.7	62.4	+13.3	121.1	...
2	R-7	62.2	62.1	62.9	59.1	64.3	62.1	+14.0	121.1	2.9
3	*R-8	61.8	61.9	62.4	58.8	64.1	61.8	+14.3	.....	...
4	R-9	61.7	61.7	62.4	58.7	64.2	61.7	+13.8	120.5	3.8
5	*E-4	62.3	62.8	62.8	59.1	64.4	62.3	+11.7	54.5	...
6	E-15	62.4	62.5	62.6	59.2	64.6	62.3	+11.9	55.3	...
7	E-16	62.1	62.8	62.6	58.7	64.3	62.1	+12.1	55.4	...
8	*E-3	62.3	62.8	62.3	59.4	64.5	62.3	+13.9	78.3	...
9	E-12	62.0	57.8	60.3	58.3	64.6	60.6	+15.1	77.0	...
10	*E-6	62.0	62.5	62.5	58.7	64.4	62.0	+11.2	76.5	...
11	E-11	62.2	62.1	62.0	59.2	64.5	62.0	+11.1	75.6	...
12	*E-5	62.2	62.5	62.5	59.0	64.4	62.1	+ 8.7	118.5	...
13	E-8	62.4	62.7	62.9	59.1	64.6	62.4	+12.3	61.8	...
14	E-9	62.6	63.0	63.3	59.5	64.9	62.7	+12.4	.....	...
15	E-10	62.3	62.5	62.6	59.1	64.6	62.2	+12.8	61.9	...
16	*E-7	61.3	61.6	61.7	58.3	64.2	61.4	+ 3.6	101.4	...
17	*E-13	62.4	62.1	62.3	59.3	64.6	62.2	+10.8	79.3	...
18	E-14	61.7	62.0	61.8	58.5	63.9	61.6	+11.6	79.7	...
19	E-17	61.6	62.6	62.4	58.4	63.9	61.8	+13.4	77.8	...
20	E-20	61.6	62.2	62.3	58.3	63.8	61.6	+13.8	72.6	...
21	E-18	61.6	62.0	62.3	58.3	63.8	61.6	+12.7	74.5	...
22	*E-19	62.0	62.7	62.9	58.8	64.5	62.2	+12.1	76.8	...
23	*E-21	61.5	61.8	62.2	58.6	63.7	61.6	+10.9	75.6	1.2
24	E-22	61.7	62.4	62.2	58.8	63.9	61.8	+10.2	73.4	0.2
25	*E-23	61.6	62.1	62.0	58.8	63.8	61.7	+10.2	73.9	1.1
26	*E-24	61.8	61.5	62.0	58.9	64.1	61.7	+12.3	116.0	3.9
27	*E-25	61.9	61.7	62.2	59.1	64.2	61.8	+12.5	121.6	4.2

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.

TABLE 1 (Continued)
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit — Temperature Gradient through North Wall—With Wind								
		A Inside Air	B Inside Surface	C Studding Space	D Outside Surface	E Outside Air	A–B	B–D	D–E	A–E
1	R–5	....	....	....	...	.....	....	....	...	....
2	R–7	†67.8	52.0	43.7	2.1	−5.2	15.8	49.9	7.3	73.0
3	*R–8	....	....	....	...	.....	....	....	...	....
4	R–9	†67.7	51.3	43.3	2.2	−4.1	16.4	49.1	6.3	71.8
5	*E–4	....	55.3	44.2	7.4	.....	....	47.9	...	....
6	E–15	....	55.7	45.5	7.8	.....	....	47.9	...	....
7	E–16	....	56.1	45.7	7.5	.....	....	48.6	...	....
8	*E–3	....	....	....	...	.....	....	....	...	....
9	E–12	....	56.1	44.7	7.5	.....	....	48.6	...	....
10	*E–6	....	55.6	44.3	7.5	.....	....	48.1	...	....
11	E–11	....	55.2	44.1	7.3	.....	....	47.9	...	....
12	*E–5	....	53.1	42.2	6.5	.....	....	46.6	...	....
13	E–8	....	55.6	44.7	7.2	.....	....	48.4	...	....
14	E–9	....	....	....	...	.....	....	....	...	....
15	E–10	....	55.7	44.9	7.7	.....	....	48.0	...	....
16	*E–7	....	49.2	39.0	6.0	.....	....	43.2	...	....
17	*E–13	....	54.2	43.3	7.0	.....	....	47.2	...	....
18	E–14	....	54.6	43.8	7.4	.....	....	47.2	...	....
19	E–17	....	55.7	44.3	7.5	.....	....	48.2	...	....
20	E–20	....	52.7	45.3	4.1	.....	....	48.6	...	....
21	E–18	....	55.4	44.2	7.4	.....	....	48.0	...	....
22	*E–19	....	52.7	45.3	4.2	.....	....	48.5	...	....
23	*E–21	†66.0	49.5	42.0	2.4	−3.7	16.5	47.1	6.1	69.7
24	E–22	†65.7	49.2	41.3	1.4	−4.8	16.5	47.8	6.2	70.5
25	*E–23	†65.8	49.1	41.5	2.1	−4.2	16.7	47.0	6.3	70.0
26	*E–24	†66.7	50.7	43.0	2.5	−3.6	16.0	48.2	6.1	70.3
27	*E–25	†66.6	51.0	43.2	2.6	−3.1	15.6	48.4	5.7	69.7

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.
Note:—†Readings taken on East Group of Thermocouples; other readings taken on West Group of Thermocouples. See Fig. 1.

TABLE 1 (Concluded)
GENERAL RESULTS, WEST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit — Temperature Gradient through East Wall—With No Direct Wind								
		F Inside Air	G Inside Surface	H Studding Space	I Outside Surface	J Outside Air	F–G	G–I	I–J	F–J
1	R–5	....	....	....	....	.....	....	....	....	....
2	R–7	69.9	58.1	49.6	12.5	–4.8	11.8	45.6	17.3	74.7
3	*R–8	....	....	....	....	.....	....	....	....	....
4	R–9	69.4	57.4	49.0	12.7	–3.5	12.0	44.7	16.2	72.9
5	*E–4	....	58.1	49.5	13.5	.....	....	44.6	....	....
6	E–15	....	58.2	49.7	13.9	.....	....	44.3	....	....
7	E–16	....	58.7	50.0	13.7	.....	....	45.0	....	....
8	*E–3	....	....	....	....	.....	....	....	....	....
9	E–12	....	57.9	49.3	13.3	.....	....	44.6	....	....
10	*E–6	....	57.1	48.5	13.3	.....	....	43.8	....	....
11	E–11	....	56.9	48.4	13.3	.....	....	43.6	....	....
12	*E–5	....	55.8	47.5	12.4	.....	....	43.4	....	....
13	E–8	....	57.8	49.2	12.7	.....	....	45.1	....	....
14	E–9	....	....	....	....	.....	....	....	....	....
15	E–10	....	58.4	49.5	13.1	.....	....	45.3	....	....
16	*E–7	....	51.2	43.7	11.8	.....	....	39.4	....	....
17	*E–13	....	56.7	48.1	13.0	.....	....	43.7	....	....
18	E–14	....	57.1	48.6	13.4	.....	....	43.7	....	....
19	E–17	....	58.3	50.2	13.8	.....	....	44.5	....	....
20	E–20	....	58.0	50.0	13.9	.....	....	44.1	....	....
21	E–18	....	58.0	50.0	13.8	.....	....	44.2	....	....
22	*E–19	....	58.0	50.0	13.6	.....	....	44.4	....	....
23	*E–21	67.1	54.6	47.0	12.3	–3.7	12.5	42.3	16.0	70.8
24	E–22	67.1	54.3	46.5	11.5	–4.8	12.8	42.8	16.3	71.9
25	*E–23	67.1	54.2	46.6	12.3	–3.7	12.9	41.9	16.0	70.8
26	*E–24	69.0	56.6	48.6	13.1	–3.6	12.4	43.5	16.7	72.6
27	*E–25	68.5	56.9	49.0	13.3	–3.1	11.6	43.6	16.4	71.6

Note:—*Plotted in Figs. 29, 23, 24, 31, 25, 27, and 30.

TABLE 2

GENERAL RESULTS, EAST TEST ROOM

Item No.	Test No.	Date	Enclosure No.	Type Fig. No.	Description	Net Pounds of Steam Condensed Per Hour	Temperature of Steam in Radiator deg. F.
1	R-5	6-23-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.33	216.5
2	R-6	7- 3-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.33	216.5
3	R-7	7-19-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.37	216.5
4	R-8	10-30-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.49	216.5
5	R-9	10-30-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.47	216.5
6	*R-10	11- 3-28	...	9	6 Sec., 26 in., 5 Tube, C. I. Radiator	5.40	216.6
7	E-2	6-24-28	1	10	Metal Shield	4.78	216.5
8	E-14	7- 9-28	1	10	Metal Shield	4.74	216.5
9	E-3	6-25-28	2	11	Slotted Front Outlet	4.83	216.5
10	E-13	7- 7-28	2	11	Slotted Front Outlet	4.92	216.5
11	E-4	6-26-28	3	12	Rods on Front and Ends	4.65	216.3
12	E-12	7- 6-28	3	12	Rods on Front and Ends	4.68	216.5
13	E-5	6-27-28	4	13	6 in. Cloth Cover	4.49	216.3
14	*E-7	6-28-28	5	14	Grilled Front and Ends	4.68	216.5
15	E-11	7- 1-28	5	14	Grilled Front and Ends	4.57	216.5
16	E-10	7- 1-28	5	14	Grilled Front and Ends	4.61	216.5
17	E-21	7-17-28	5	14	Grilled Front and Ends	4.69	216.5
18	*E-23a	7-19-28	5a	..	Legs 1½ in. higher than No. 5	4.73	216.5
19	E-8	6-29-28	6	15	12 in. Cloth Cover	3.29	216.5
20	E-9	6-30-28	6	15	12 in. Cloth Cover	3.37	216.5
21	E-15	7-10-28	7	16	Cloth Shield	4.51	216.5
22	E-16	7-11-28	7	16	Cloth Shield	4.56	216.5
23	E-18	7-13-28	8	17	Grilled Front and Solid Ends	4.67	216.5
24	*E-19	7-14-28	8	17	Grilled Front and Solid Ends	4.75	216.5
25	*E-22	7-18-28	8a	18	No. 8 with Top raised	4.84	216.5
26	E-17	7-12-28	9	19	Grilled with Curved Ends	4.77	216.5
27	E-20	7-16-28	9	19	Grilled with Curved Ends	4.76	216.5
28	E-24	11- 1-28	10	20	Punched Front Outlet (Narrow)	4.46	216.5
29	E-25	11- 2-28	10	20	Punched Front Outlet (Narrow)	4.46	216.6
30	E-23	10-31-28	11	20	Punched Front Outlet (Wide)	4.61	216.5
31	E-26	11- 5-28	12	21	Special Radiator—Integral Shield	4.92	216.5
32	E-27	11- 6-28	12a	..	Special Radiator—Without Shield	5.10	216.5

Note:—*Plotted in Figs. 26 and 28.

TABLE 2 (Continued)
GENERAL RESULTS, EAST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit									
		Cold Room	Difference between 3 in. below Floor and 3 in. above Floor	Basement 3 in. below Floor						Floor 3 in. above Upper Surface	Knee Height 18 in. above Floor
				S.W.	S.E.	N.E.	N.W.	Center	Average		
1	R-5	−2.5	+1.3	55.1	56.0	55.6	55.2	57.1	55.8	54.5	58.7
2	R-6	−0.7	+1.3	56.7	57.8	56.9	56.5	58.7	57.3	56.0	60.4
3	R-7	−1.2	+1.3	55.2	56.8	55.8	55.0	57.4	56.0	54.7	59.6
4	R-8	−2.5	−0.1	49.2	54.1	55.9	49.4	56.0	52.9	53.0	57.5
5	R-9	−1.5	+0.6	51.2	56.2	57.7	51.3	57.9	54.9	54.3	58.8
6	*R-10	−2.2	+2.6	54.7	59.3	61.6	54.9	61.0	58.3	55.7	59.6
7	E-2	−2.0	+1.6	56.1	57.1	56.3	56.0	57.9	56.7	55.1	59.2
8	E-14	−0.6	+1.6	55.2	56.5	55.7	55.0	57.2	55.9	54.3	59.0
9	E-3	−2.2	+3.7	56.7	57.8	56.8	56.5	58.0	57.2	53.5	60.7
10	E-13	−1.2	+1.7	54.9	56.3	55.0	54.5	56.7	55.5	53.8	59.7
11	E-4	−2.5	+1.7	56.6	57.7	56.6	56.1	58.0	57.0	55.3	60.3
12	E-12	−1.1	+1.4	56.6	57.7	56.6	56.1	58.3	57.1	55.7	60.7
13	E-5	−2.4	+1.8	54.5	55.6	54.7	54.3	56.3	55.1	53.3	57.4
14	*E-7	−1.5	+1.3	56.1	57.3	56.3	55.8	57.9	56.7	55.4	59.8
15	E-11	−0.5	+0.9	57.3	58.4	57.6	57.0	59.3	57.9	57.0	60.9
16	E-10	−0.8	+1.1	57.6	58.8	57.9	57.3	59.4	58.2	57.1	61.0
17	E-21	−0.3	+1.2	58.1	59.3	58.3	57.9	59.8	58.7	57.5	61.0
18	*E-23a	−2.5	+2.2	56.1	57.6	56.5	55.7	57.9	56.8	54.6	59.9
19	E-8	−2.1	+1.4	49.7	51.5	50.4	49.6	52.4	50.7	49.3	52.6
20	E-9	−1.6	+1.4	49.7	50.8	49.9	49.5	51.9	50.4	49.0	52.0
21	E-15	−0.3	+1.8	55.7	57.1	56.1	55.6	57.8	56.5	54.7	58.8
22	E-16	−1.0	+1.8	55.9	57.2	56.3	55.7	57.7	56.6	54.8	58.9
23	E-18	−1.2	+2.2	55.1	56.5	55.3	54.7	56.7	55.7	53.5	57.7
24	*E-19	−1.4	+1.7	56.1	57.2	56.1	55.7	57.6	56.5	54.8	58.3
25	*E-22	−0.6	+1.7	56.2	57.7	56.5	55.8	58.0	56.8	55.1	60.4
26	E-17	−1.3	+1.7	55.5	56.9	55.7	55.1	57.1	56.1	54.4	58.6
27	E-20	−0.7	+1.6	57.4	58.4	57.4	57.1	58.7	57.8	56.2	59.7
28	E-24	−2.8	+3.1	51.1	55.9	56.0	51.2	57.9	54.4	51.3	55.2
29	E-25	−1.9	+1.7	49.8	54.8	54.2	49.9	57.0	53.1	51.4	55.3
30	E-23	−1.8	+2.2	49.3	54.1	55.0	49.8	55.8	52.8	50.6	54.9
31	E-26	−1.8	+1.7	51.8	56.7	58.0	52.1	58.4	55.4	53.7	57.2
32	E-27	−2.0	+2.7	53.7	58.3	61.0	53.7	59.8	57.3	54.6	58.2

Note:—*Plotted in Figs. 26 and 28.

TABLE 2 (Concluded)
GENERAL RESULTS, EAST TEST ROOM

Item No.	Test No.	Temperatures, Degree Fahrenheit										
		39 in. above Floor	Breathing Line 60 in. above Floor	83 in. above Floor	Ceiling 3 in. below Lower Surface	Attic, 3 in. above Ceiling						Difference between 3 in. below Ceiling and 3 in. above Ceiling
						S.W.	S.E.	N.E.	N.W.	Center	Average	
1	R-5	64.1	69.1	73.9	76.6	63.2	65.1	64.3	63.2	65.5	64.3	+12.3
2	R-6	65.5	70.5	75.2	78.1	62.1	64.7	62.1	63.4	67.8	64.0	+14.1
3	R-7	64.5	70.0	74.3	77.2	59.0	62.2	57.8	61.4	65.6	61.2	+16.0
4	R-8	62.5	68.0	73.0	75.7	62.9	63.8	62.1	62.7	65.2	63.3	+12.4
5	R-9	63.6	68.9	73.7	76.5	62.9	63.8	62.2	62.7	65.4	63.4	+13.1
6	*R-10	64.3	69.6	74.3	77.1	63.7	64.7	62.8	63.4	66.3	64.2	+12.9
7	E-2	65.8	68.9	71.8	73.4	63.2	64.6	63.6	62.9	65.0	63.9	+ 9.5
8	E-14	65.0	68.9	71.5	73.8	60.3	61.6	57.8	61.2	65.1	61.2	+12.6
9	E-3	66.5	69.7	72.5	76.0	63.5	65.0	64.0	63.1	64.8	64.1	+11.9
10	E-13	65.5	69.9	72.3	76.0	60.7	63.2	60.5	61.7	65.7	62.4	+13.6
11	E-4	67.8	68.6	71.2	72.9	63.8	65.4	64.3	63.2	65.8	64.5	+ 8.4
12	E-12	67.6	68.9	71.6	73.1	61.6	63.4	60.5	61.8	65.9	62.6	+10.5
13	E-5	62.4	65.8	69.0	70.5	63.5	65.0	63.9	63.0	65.5	64.2	+ 6.3
14	*E-7	66.4	69.1	72.0	74.3	63.4	65.1	63.9	62.9	65.7	64.2	+10.1
15	E-11	67.4	70.1	73.1	75.2	63.9	65.6	64.6	63.5	66.7	64.9	+10.3
16	E-10	67.5	70.0	73.0	75.1	64.0	65.8	64.7	63.6	66.0	64.8	+10.3
17	E-21	67.2	70.0	72.9	75.0	60.7	62.2	58.0	62.1	65.8	61.8	+13.2
18	*E-23a	66.5	69.7	72.8	74.9	64.0	65.9	64.6	63.4	66.6	64.9	+10.0
19	E-8	56.6	60.1	63.2	64.5	63.3	65.1	64.1	62.3	65.5	64.1	+ 0.4
20	E-9	56.4	59.9	63.5	64.7	63.5	65.6	64.6	63.0	66.2	64.6	+ 0.1
21	E-15	64.9	68.8	71.0	73.6	61.3	62.0	58.0	62.0	65.9	61.8	+11.8
22	E-16	64.4	68.7	71.1	74.0	61.6	62.3	58.3	62.2	65.9	62.1	+11.9
23	E-18	64.0	69.2	72.0	75.0	61.0	61.9	57.9	62.2	65.4	61.7	+13.3
24	*E-19	64.4	69.6	72.2	75.3	60.4	62.1	58.0	62.2	65.6	61.7	+13.6
25	*E-22	67.7	71.1	73.6	76.8	61.4	62.2	58.2	62.2	65.9	62.0	+14.8
26	E-17	65.1	68.7	71.9	73.9	60.8	62.0	58.0	62.2	65.4	61.7	+12.2
27	E-20	65.9	69.7	73.1	75.2	60.7	62.3	58.2	62.3	66.1	61.9	+13.3
28	E-24	60.4	66.1	69.8	72.4	63.2	64.1	62.2	62.5	65.5	63.5	+ 8.9
29	E-25	60.6	66.3	70.1	72.6	63.0	63.8	62.0	62.3	65.5	63.3	+ 9.3
30	E-23	60.5	66.5	69.7	72.7	63.2	64.1	62.4	62.5	65.4	63.5	+ 9.2
31	E-26	62.1	67.1	71.3	73.4	63.0	64.1	62.5	62.6	65.8	63.6	+ 9.8
32	E-27	62.5	67.3	71.8	74.1	63.3	64.3	62.5	62.7	65.7	63.7	+10.4

Note:—*Plotted in Figs. 26 and 28.

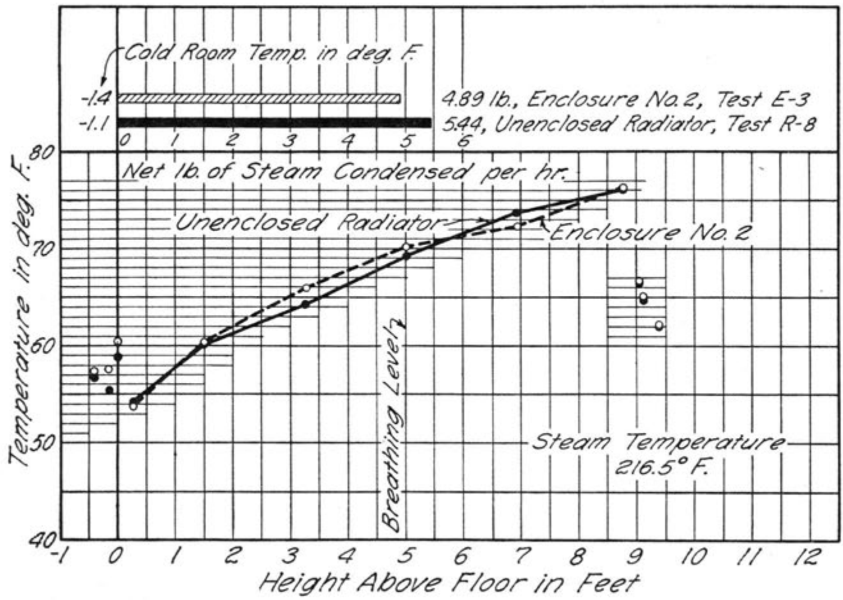


Fig. 23. Room Temperature Gradient and Steam Condensing Rate for Radiator with Enclosure No. 2 in West Test Room

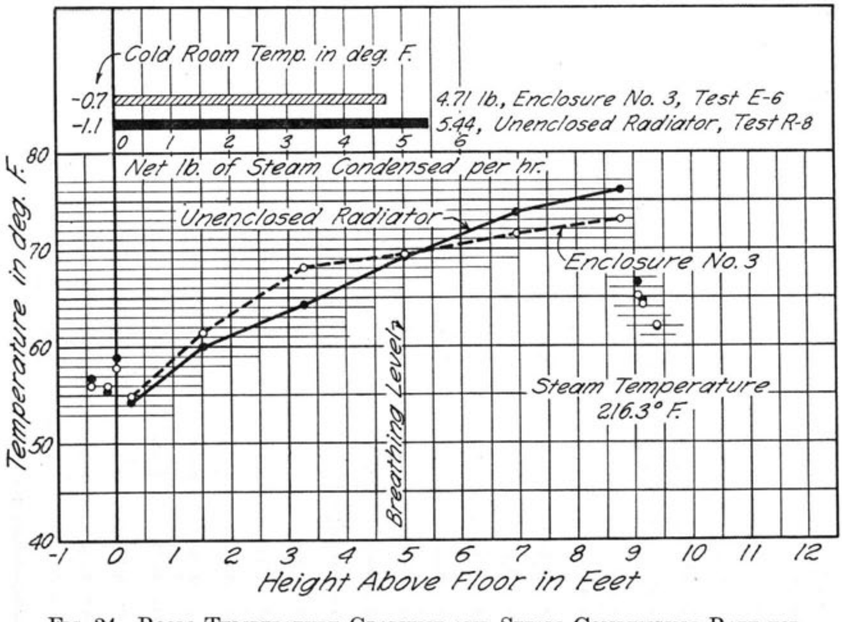


Fig. 24. Room Temperature Gradient and Steam Condensing Rate for Radiator with Enclosure No. 3 in West Test Room

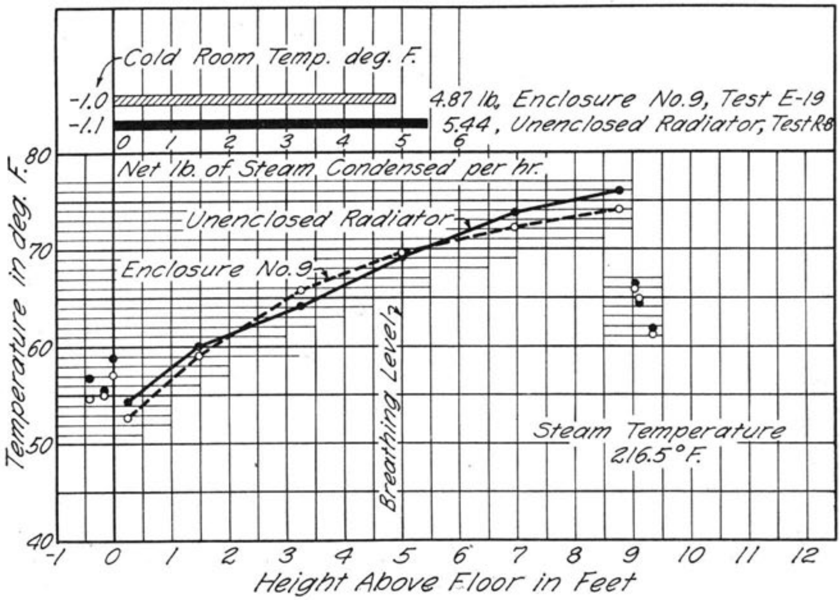


FIG. 25. ROOM TEMPERATURE GRADIENT AND STEAM CONDENSING RATE FOR RADIATOR WITH ENCLOSURE NO. 9 IN WEST TEST ROOM

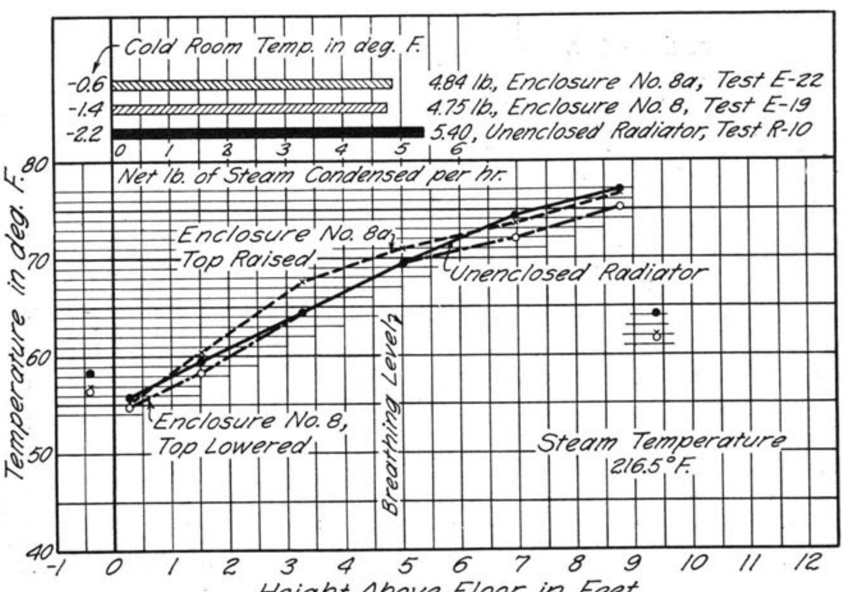


FIG. 26. ROOM TEMPERATURE GRADIENTS AND STEAM CONDENSING RATES FOR RADIATOR WITH ENCLOSURES NOS. 8 AND 8a IN EAST TEST ROOM

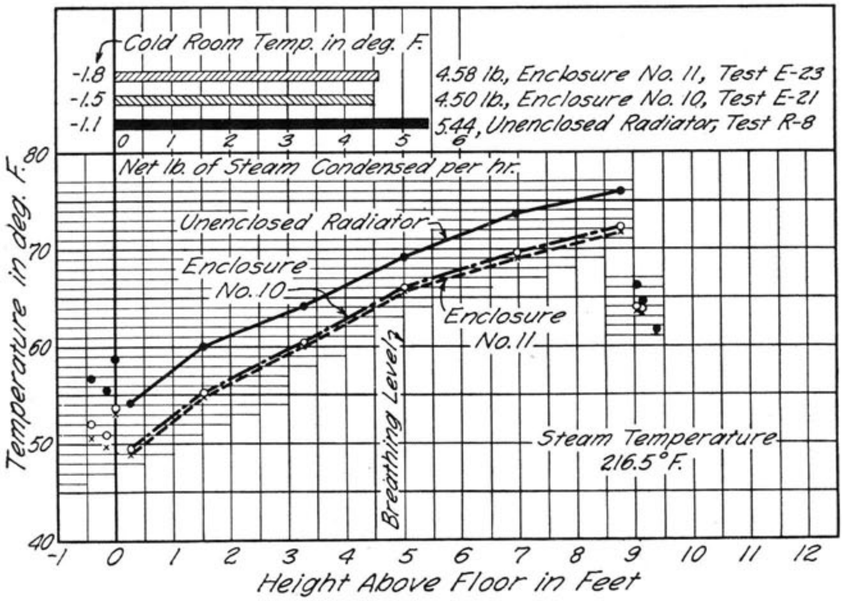


FIG. 27. ROOM TEMPERATURE GRADIENTS AND STEAM CONDENSING RATES FOR RADIATOR WITH ENCLOSURES NOS. 10 AND 11 IN WEST TEST ROOM

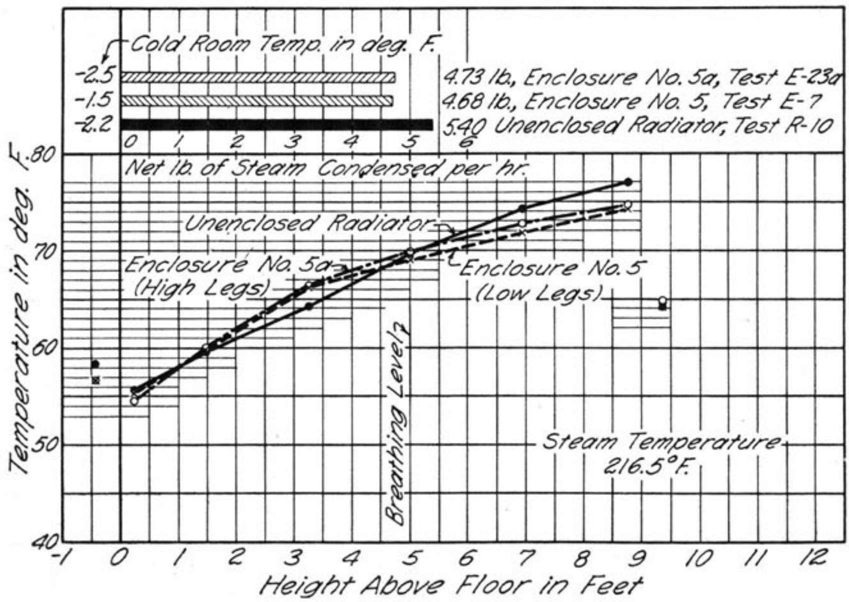


FIG. 28. ROOM TEMPERATURE GRADIENTS AND STEAM CONDENSING RATES FOR RADIATOR WITH ENCLOSURES NOS. 5 AND 5a IN EAST TEST ROOM

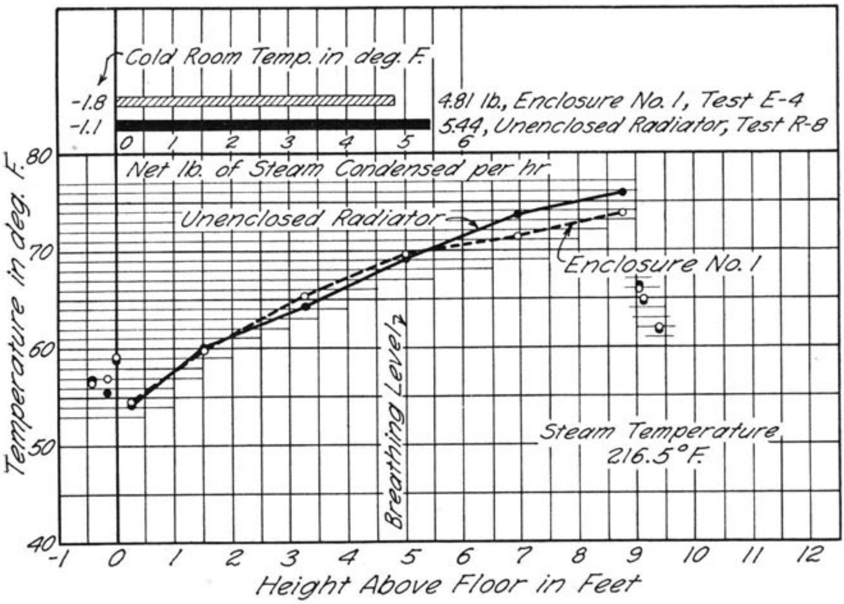


FIG. 29. ROOM TEMPERATURE GRADIENT AND STEAM CONDENSING RATE FOR RADIATOR WITH ENCLOSURE NO. 1 IN WEST TEST ROOM

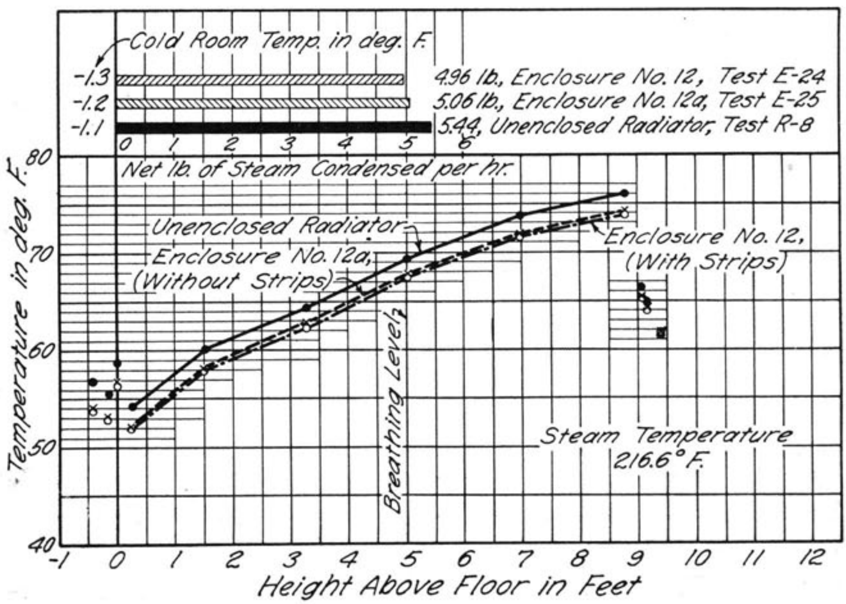


FIG. 30. ROOM TEMPERATURE GRADIENTS AND STEAM CONDENSING RATES FOR RADIATOR WITH ENCLOSURES NOS. 12 AND 12a IN WEST TEST ROOM

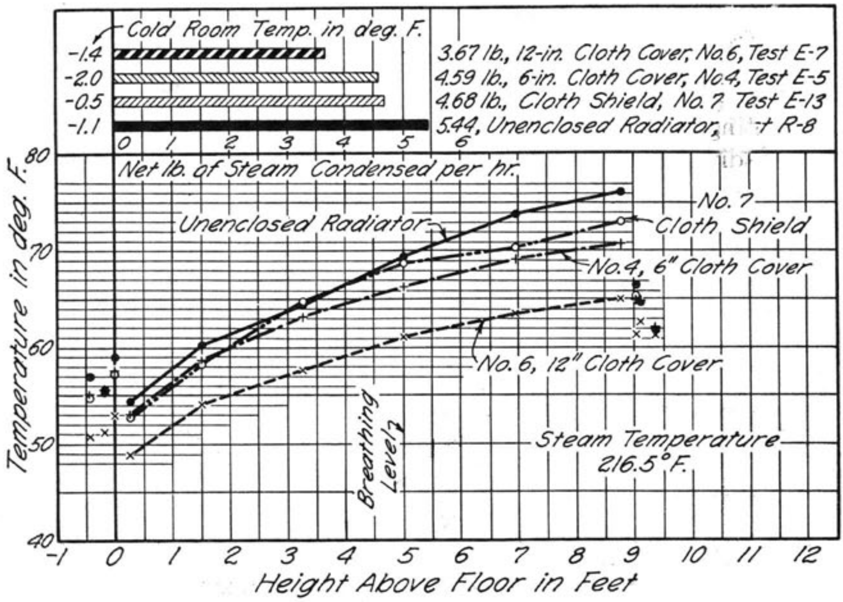


Fig. 31. Room Temperature Gradients and Steam Condensing Rates for Radiator with Enclosures Nos. 4, 6, and 7 in West Test Room

With 69.4 deg. F. at the breathing level the whole zone below the breathing level, which may be regarded as the living zone, was too cool for satisfactory comfort. The high temperature at the ceiling resulted in an excessive heat loss through the ceiling itself.

The temperature gradients from air to air through the floor and ceiling are shown at the ends of the curves. These gradients are discussed in Chapter VIII.

17. *Radiator Rating.*—The catalog rating for the type of unenclosed radiator used, based on the Engineering Standard* of 240 B.t.u. emission per sq. ft. per hr. with steam at 215 deg. F. in the radiator and air at 70 deg. F. surrounding it, was 21 sq. ft. The actual superficial area of the radiator by measurement was 19.3 sq. ft. The total heat emission under the test conditions, based on steam at 216.5 deg. F. in the radiator and a temperature of 69.4 deg. F. at the breathing level, was $5.44 \times 969.1 = 5270$ B.t.u. per hr. Hence, the total heat emission under standard rating conditions would be $5270 \dfrac{(215 - 70)^{1.3}}{(216.5 - 69.4)} = 5180$ B.t.u. per hr., and the rating as deter-

*American Society of Heating and Ventilating Engineers, Journal, Vol. 33, No. 3, March 1927.

mined from these tests should be $\frac{5180}{240} = 21.6$ sq. ft. based on the Engineering Standard as compared with 21.0 sq. ft. given as the catalog rating. Therefore the catalog rating is approximately correct if the radiator is used in a room with an air temperature of 70 deg. F. at the breathing level, and a steam temperature of 215 deg. F.

Let K = the coefficient of heat transmission in B.t.u. per sq. ft. per deg. F. difference in temperature between steam and air per hr.

Then
$$K = \frac{5180}{19.3(215 - 70)} = 1.85$$

for the standard conditions, based on measured surface.

V. Tests with Enclosures

18. *Introduction.*—The results of tests with six characteristic types of commercial enclosures are shown in Figs. 23 to 28. The corresponding types are shown in Figs. 11, 12, 14, 17, 18, 19, and 20, and the dimensions in Fig. 22.

In comparing the performance of the enclosed or shielded radiators with that of the unenclosed radiator, several factors in conjunction must be taken into consideration. These are: (1) the effect on the temperature at the breathing level; (2) the effect on the temperature at the ceiling, or the difference in temperature between the floor and ceiling; (3) the effect on the mean temperature in the "living zone," or the zone below the breathing level; (4) the relative steam condensation per hour. In general, an enclosed radiator may be regarded as better than the unenclosed radiator if: (1) a breathing level temperature within one deg. F. above or below 69.4 deg. F. was maintained; (2) if the temperature at the ceiling was lowered; (3) if the floor temperature was maintained the same or raised; (4) if the mean temperature in the "living zone" was raised; and (5) if the steam condensation was the same as, or less than, that of the unenclosed radiator.

19. *Results of Tests.*—From Fig. 23 it may be noted that enclosure No. 2 shown in Fig. 11 maintained a higher temperature both at the breathing level and in the living zone than that maintained by the unenclosed radiator. The temperatures at the floor and ceiling were practically the same as for the unenclosed radiator, and the steam condensation was less. Hence this enclosure showed some improve-

ment over the unenclosed radiator with respect to both air temperature conditions in the room and steam economy.

Figure 24 indicates that enclosure No. 3 shown in Fig. 12, as compared with the unenclosed radiator, maintained the same breathing level temperature, a lower ceiling temperature, a higher floor temperature and materially higher temperature in the living zone. The steam condensation was also materially less than that for the unenclosed radiator. This enclosure was unquestionably superior to the unenclosed radiator both from the standpoint of air temperature conditions in the room and of steam economy.

Figure 25 shows the results from enclosure No. 9, Fig. 19. As compared with the unenclosed radiator this enclosure gave a lower ceiling temperature, the same breathing level temperature, and a lower mean temperature in the living zone. The latter condition resulted from lower temperatures in the zone between the floor and 26 in. above the floor. While somewhat greater steam economy was obtained than for the unenclosed radiator, it is doubtful whether this enclosure would be as satisfactory as the unenclosed radiator on account of the lower temperatures near the floor.

Enclosure No. 8, Fig. 17, was provided with a hinged top that could be raised, as shown in Fig. 18. The results from this enclosure, with the top lowered and raised, are shown in Fig. 26. It may be noted that with the top lowered, while a lower ceiling temperature and steam condensation was obtained than for the unenclosed radiator, the lower part of the living zone was cooler and the performance of this enclosure with the top down could not be regarded as being as satisfactory as that of the unenclosed radiator. When the top was raised (Fig. 18), however, as indicated by the curve for enclosure No. 8a in Fig. 26, conditions in the living zone were much improved. The steam condensation was also less than that for the unenclosed radiator, and with the top raised this enclosure may be regarded as being more satisfactory than the unenclosed radiator.

Figure 27 shows the results obtained with enclosures Nos. 10 and 11. These enclosures were both of the same type, as shown in Fig. 20, except that No. 10 fitted the radiator snugly while No. 11 had relatively large side clearance (see Fig. 22). The performance of this type of enclosure was far from satisfactory. The steam condensation was very much reduced over that of the unenclosed radiator. This reduction cannot be regarded as an economy, however, because the enclosed radiator failed to heat the room. All of the air temperatures in the room were from 4 to 5 deg. F. lower than those obtained with the unenclosed radiator. This condition is particularly objectionable near the floor and in the living zone as shown by the air temperatures in this zone. The results with the snugly fitting enclosure were slightly better than those for the one with large side clearance. This seems to indicate that on the whole large clearances for this type are undesirable.

Enclosures Nos. 5 and 5a were both of the same type as shown in Fig. 14, except that the legs on No. 5a were 1½ in. longer than the ones on No. 5, thus giving more free opening at the bottom of the enclosure, and more clearance between the top of the radiator and the top of the enclosure. The results obtained are indicated in Fig. 28. This enclosure with both high and low legs gave more satisfactory air temperature conditions and better steam economy than the unenclosed radiator. Some gain resulted from increasing the length of the legs, but within the limits fixed by the height of the window stool, the benefit that might be obtained is not sufficient to warrant the sacrifice in the appearance of the enclosure.

VI. Tests with Metal and Cloth Shields

20. *Metal Shield.*—The metal shield tested has been designated as enclosure No. 1, and the type is shown in Fig. 10. The results of the tests on this shield are shown in Fig. 29, from which it is evident that the use of the shield resulted in a lower temperature at the ceiling than that obtained with the unenclosed radiator. The temperature at the floor was the same as, and the mean temperature below the breathing level was slightly higher than the corresponding temperatures for the unenclosed radiator. The net steam condensation was less than that for the unenclosed radiator. This shield, therefore, was more advantageous than the unenclosed radiator in that it produced more satisfactory air temperature conditions accompanied by greater steam economy.

21. *Special Radiator with Integral Shield.*—A special type of radiator having removable metal strips that could be inserted at the rear between the radiator sections is shown as enclosure No. 12, Fig. 21. The metal strips extended over the top of the radiator as far as the connecting hubs between the radiator sections, thus forming a shield which terminated at the hubs. The radiator sections were cast with webs closing the openings between the tubes of each section. Thus each section formed a solid curtain that prevented any cross-circulation of air around the tubes. The actual area of this radiator, by measurement, was 20.0 sq. ft.

Tests were run on this radiator both with and without the metal strips in place. The results are shown in Fig. 30. The radiator with the metal strips in place, designated as No. 12, condensed less steam per hour than the standard unenclosed radiator. All temperatures in the room were uniformly less than those produced by the standard unenclosed radiator. Hence the reduced steam condensation cannot be regarded as steam economy, since it was accompanied by failure to heat the room satisfactorily. This condition was probably caused by the solid web-like construction of the radiator sections, and seems to indicate that such construction is not so desirable as open spaces between the tubes. When the metal strips were removed, the radiator was designated as No. 12a, and the air temperature conditions were slightly improved, but the failure to heat the room was still apparent.

22. *Cloth Covers.*—Tests were run with two types of cloth covers completely enclosing the upper part of the radiator. These covers are shown as enclosure No. 4 in Fig. 13 and as enclosure No. 6 in Fig. 15. The results are indicated in Fig. 31. Both of these covers reduced the steam condensation very materially, and produced entirely unsatisfactory air temperature conditions in the room. The 6-in. cover reduced the breathing level temperature to 66.4 deg. F. and the 12-in. cover reduced it to 61.2 deg. F. Corresponding reductions in the mean temperatures below the breathing level and in the temperatures at the floor were also observed. These covers had nothing to recommend them, and their use may be expected to result in underheated rooms, unless a correspondingly greater amount of radiation is installed.

Since it was considered that the unsatisfactory performance of the two standard types of covers was caused by failure to provide for proper circulation of air over the radiator and for protection of the wall back of the radiator from the effect of direct radiation, a cloth cover of the type shown as enclosure No. 7 in Fig. 16 was tested. This cover had part of the front cut away in order to permit air circulation, and the back extended to near the floor in order to protect the wall against direct radiation. The results are also shown in Fig. 31. This cover reduced the steam condensation and the temperature at the ceiling below those obtained with the unenclosed radiator. There was also a reduction in the temperature at the floor and in the mean temperature below the breathing level. The reduction in steam condensation cannot therefore be regarded as a gain in steam economy,

TABLE 3

COMPARISON OF PERFORMANCE FACTORS FOR ENCLOSURES

Enclosure No.	Type Fig. No.	Performance Fig. No.	Temperature at Breathing Level deg. F.	Difference in Temperature Ceiling-Floor deg. F.	Mean Temperature below Breathing Level deg. F.	Net Steam Condensed lb. per hr.
Unenclosed	9	23–28	69.4	21.8	62.0	5.44
2	11	23	70.5	22.4	62.7	4.89
3	12	24	69.5	18.2	63.6	4.71
5	14	28	69.1	18.9	62.7	4.68
8	17	26	69.6	20.5	61.8	4.75
8a	18	26	71.1	21.7	63.6	4.84
9	19	25	69.7	21.7	61.8	4.87
10	20	27	66.2	23.0	57.8	4.50

and the performance of this cover was not so satisfactory as that of the unenclosed radiator.

VII. COMPARISON OF THE PERFORMANCE OF THE VARIOUS TYPES OF ENCLOSURES

23. *Performance of Enclosures.*—A comparison of the six types of commercial enclosures tested may be made from Table 3. From this table it is evident that the most satisfactory combination of all of the factors involved was obtained with enclosure No. 3. Since the degree of comfort produced is probably the final criterion for judging the performance of any given heating unit, the mean temperature in the zone from the floor to the breathing level is the most important factor involved. With one exception, the highest mean temperature below the breathing level was obtained with enclosure No. 3. In this respect enclosure No. 3 and enclosure No. 8a gave the same result. As compared with enclosure No. 8a, enclosure No. 3 gave a lower temperature difference between the floor and ceiling and also lower steam condensation. Hence enclosure No. 3 would produce a greater degree of comfort with greater steam economy than enclosure No. 8a. Accordingly enclosure No. 3 is ranked first and enclosure No. 8a second. There is not much choice between enclosures No. 5 and No. 2, but enclosure No. 5 should probably be rated third on the basis of greater steam economy and less temperature difference between floor and ceiling than that obtained with enclosure No. 2.

On comparing the various enclosures with respect to structural differences, it may be noted that the ones giving the most satisfactory results were the ones having the greatest free area of openings, thus offering the least restriction to the flow of air over the radiator. This may be made clear by comparing enclosures Nos. 3, 8a, 5, 2, and 10 as shown in Figs. 12, 18, 14, 11, and 20 in the order designated. This comparison makes it immediately evident that the reason for the unsatisfactory performance of enclosure No. 10 is that the total area of the grilled slot is entirely too small, and that the slot is placed too low in the front.

24. *Heat Losses from the Room.*—Since, in every case, the flow of heat was out of the room through the walls, floor, and ceiling, and the only heat available for making up this heat loss was derived from the condensation of steam in the radiator, the only possible conclusion that can be drawn is that in the cases of the enclosures for which satisfactory air temperature conditions were maintained with less condensation than that obtained with the unenclosed radiator, the reduced condensation was also accompanied by reduced heat losses from the room itself. For practically all of the satisfactory enclosures the temperature at the ceiling was less than that for the unenclosed radiator; hence a reduction in heat loss through the ceiling resulted.

Inspection of Table 1 indicates that for the unenclosed radiator, and for the enclosures having no protecting back, the temperature of the inside surface of the wall just back of the radiator was from 116 deg. F. to 121 deg. F. For the satisfactory enclosures, this temperature was approximately 76 deg. F., and in one case was as low as 54.5 deg. F. Accordingly the flow of heat through the wall back of the radiator was decreased by the use of the enclosures.

In the case of the unenclosed radiator, the air that became heated by passing over the radiator rose and passed directly over the window. The velocity of this air was comparatively high, and its temperature was considerably higher than the temperature at the breathing level. When an enclosure was used the air passing over the radiator was deflected out into the room and did not pass directly over the window. Accordingly a greater loss of heat occurred by transmission through the glass in the case of the unenclosed radiator than in that of the enclosed radiator.

The use of an enclosure undoubtedly reduced somewhat the amount of direct radiant heat received by the inside surfaces of the walls, thus reducing the surface temperature. A very small reduction in this temperature would not cause a noticeable reduction in the comfort of the occupants, but, owing to the comparatively large area of the wall surfaces, might represent a very appreciable reduction in

TABLE 4

COMPARISON OF STEAM CONDENSING CAPACITIES OF SIMILAR ENCLOSURES ON TWO DIFFERENT SIZED RADIATORS

Type of Enclosure	From Room Tests		From Bulletin 169	
	Enclosure No.	Relative Condensing Capacity per cent	Enclosure No.	Relative Condensing Capacity per cent
Unenclosed Radiator	..	100.0	..	100.0
Solid top, grilled front and ends, large free area	3	86.6	14	85.5
Solid top, grilled front and ends, small free area	5	86.7	13	84.2
Solid top and ends, full grilled front	8	87.9	12	85.1
Solid top and ends, solid front with wide slot	10	82.7	11	83.5
Metal Shield	1	88.4	Shield	91.9
6-in. cloth cover	4	84.4	Cover	88.0

heat loss through the walls as compared with the loss in the case of the unenclosed radiator.

It may be noted that all of the reductions in heat losses are in themselves small, but that the sum of these reductions may easily be enough to account for the 0.73 lb. of steam per hr., or approximately 700 B.t.u. per hr., which represents the difference in condensing capacity between the unenclosed radiator and the radiator with the best enclosure.

25. *Relative Steam Condensing Capacity.*—In Bulletin No. 169 the relative steam condensing capacities of a radiator with various types of enclosures as compared with the steam condensing capacity of a 38-in., 20-section, 3-column unenclosed radiator were reported. Since all of these tests were carried on in a large laboratory with the radiator placed near a warm wall and surrounded by air at a comparatively uniform temperature, no account could be taken of the actual heating effect produced by the different amounts of steam condensation. All conclusions in that bulletin were accordingly confined to the effect of the enclosures on steam condensing capacity alone.

In Table 4 a comparison of the relative steam condensing capacities reported in Bulletin No. 169 and those obtained from the present series of tests on enclosures of similar construction is given. The agreement between the two series of tests is remarkably close when it is considered that the two series were run under different conditions. Furthermore, the two radiators were of materially different size and the construction of the enclosures was not identical. Hence the present series of tests does not serve to alter any of the conclusions drawn in Bulletin No. 169 with regard to the effect of enclosures on steam condensing capacity, but does serve to present additional data on the relative heating effects to be expected in an actual room with cold outside wall and glass surfaces.

VIII. Surface Temperature and Gradients of Walls, Floors, and Ceilings

26. *Temperature Gradients through Floor and Ceiling.*—The temperature gradients through the walls, floors, and ceilings were determined from the readings of thermocouples embedded in the respective surfaces.

The temperature gradient from the air 3 in. below to the air 3 in. above the ceiling is shown by the points at the right end of the curves in Figs. 23 to 31. In every case these gradients are consistent with the temperatures of the upper and lower ceiling surfaces lying between the temperatures of the air.

The temperature gradients from the air 3 in. below to the air 3 in. above the floor are shown at the left end of the curves in Figs. 23 to 31. The gradient from air to air indicates a flow of heat into the room, while that from the upper to the lower surface of the floor indicates a flow of heat out of the room. A reasonable explanation for this apparent inconsistency may be made. The upper surface of the floor received direct radiation from the radiator and the warm ceiling, and also reflected radiation from the walls, with the radiator acting as the primary source. This operated to raise the temperature of the floor surface above that of the air 3 in. away from the surface. In the same manner, the lower surface of the floor radiated heat to the colder surfaces of the concrete floor and the corkboard walls surrounding the space below the floor of the room proper. This radiation effect resulted in lowering the temperature of the lower surface of the floor below that of the air 3 in. away from the surface. The inconsistency, therefore, is only apparent and the actual heat flow was out of the room. The flow was very small, however, and since it was always approximately the same, no disturbing condition resulted from it.

27. *Temperature Gradients through Walls.*—The temperature gradients through the north and east walls of the west test room were obtained by means of five thermocouples at each wall, as shown in Fig. 32. The thermocouples in the air were located six inches away from the inside and outside wall surfaces. Corresponding thermocouples were located on the inside and outside wall surfaces, and at

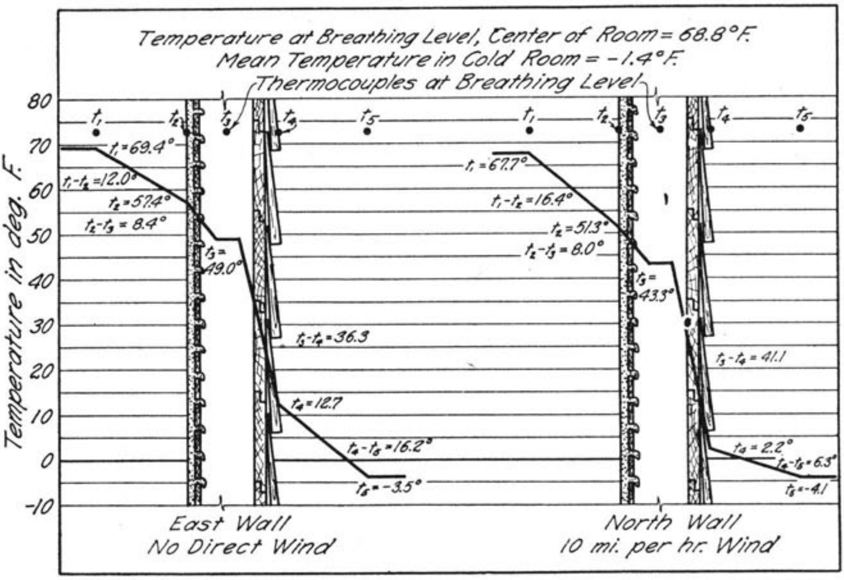


FIG. 32. TYPICAL TEMPERATURE GRADIENTS THROUGH WALLS OF WEST TEST ROOM, TEST NO. R-9

the center of each studding space. All thermocouples were placed at a height corresponding to the breathing level of the test room.

The fans in the cold room produced air currents against the north wall that had the same effect as direct wind movement. The east wall, however, was free from any effect of direct wind movement.

The temperature gradients for a typical test, No. R9, are shown in Fig. 32. The total temperature drop from air inside to air outside was 72.9 deg. F. for the east wall and 71.8 deg. F. for the north wall, indicating that wind movement did not have an appreciable effect on the overall temperature difference. A very marked effect of wind movement, however, may be observed on the temperature drop from outside wall surface to outside air. This drop was only 6.3 deg. F. for the north wall, where wind movement occurred, as compared with 16.2 deg. F. for the east wall, where there was no direct wind movement; this indicated that the wind movement decreased the resistance of the air film on the outside surface of the wall.

The temperature drops from inside air to inside wall surface were nearly equal, 16.4 for the north wall and 12.0 for the east wall. The slightly greater drop corresponds to conditions of greater wind movement, as would naturally be expected. Considering the temperature drops at each surface exposed to normal convection or "still air conditions," i.e., at the inside surface of both walls and the outside surface of the east wall, it may be noted that they are nearly the same. A temperature drop of 12.0 deg. F. was obtained at the inside surface of the east wall where practically normal convection occurs over both outside and inside wall surfaces. A temperature drop of 16.4 deg. F. occurs at the inside surface of the north wall. Since the wind movement against this wall results in a greater heat transfer per unit of time than that for the east wall, it is to be expected that a greater drop in temperature would occur at the inside surface of the north wall than at the inside surface of the east wall. The temperature drop of 16.2 deg. F. obtained at the outside surface of the east wall may be explained by the fact that convection currents over this surface were probably somewhat retarded by the irregular surface of the wood siding. These irregularities, no doubt, served to trap air immediately in contact with the surface, and increased the resistance of the air film. Hence, a greater temperature differential was required to produce the same flow of heat as through the film on the inside surface.

When heat flows through a wall under conditions of equilibrium, the temperature drops through the two surface air films are directly proportional to the resistances of the films. Hence, the surface coefficients of heat transmission are inversely proportional to the temperature drops. If the north wall alone is considered, it may be noted that the temperature drop at the inside surface under "still air conditions" is 16.4 deg. F. and the temperature drop at the outside surface, where direct wind movement occurs, is 6.3. The ratio of these drops is 2.6. Hence, the ratio of the inside surface coefficient to the outside surface coefficient should also be 2.6, or the outside surface coefficient is equal to 2.6 times the inside surface coefficient. Approximately this same relation holds between the temperature drops at the outside surface of the east wall which is under "still air conditions" and the outside surface of the north wall under direct wind conditions, or $\frac{16.2}{6.3} = 2.57$.

Let K_1 = the coefficient of heat transfer, or surface coefficient for the inside surface under "still air conditions" and K_2 = the surface coefficient for the outside surface under various conditions of wind movement. Table 5, given by Harding and Willard,* based on re-

*Harding, L. A. and Willard, A. C., "Mechanical Equipment of Buildings," Vol. I, p. 56.

TABLE 5

MULTIPLIERS FOR DETERMINING K_2

Wind Velocity, Miles per Hour	Multipliers for K_1	
	Brickwork	Wood
5	2.38	2.19
10	3.20	2.71
15	3.76	2.95
20	4.22	3.02

sults from Engineering Experiment Station Bulletin No. 102,* gives the multipliers to be used in determining K_2 from K_1.

From the values given for wood it may be noted that the 2.71 for a wind velocity of 10 miles per hour corresponds very closely with the ratio 2.6, determined from the temperature drops. Hence, it is reasonable to assume that the air movement over the north wall of the west test room corresponded to a direct wind movement of approximately 10 miles per hour.

From the wall construction given, i.e., ⅝-in. redwood siding, building paper, ¾-in. yellow pine sheathing, 3⅝-in. studding, and ½-in. gypsum plaster on wood lath, and from the following values of constants,† conductivity of redwood per inch = 0.60, conductivity of yellow pine per inch = 1.00, conductance of building paper as applied = 4.02, conductance of wood lath and plaster as applied = 2.00, $K_1 = 1.34$, K_2 for still air = 1.34, and K_2 for 10-mile wind velocity = $1.34 \times 2.7 = 3.62$; the values of the overall heat transmission coefficients U_0 for still air and U_{10} for 10-mile wind velocity may be calculated.

$$U_0 = \frac{1}{\frac{4}{1.34} + \frac{0.625}{0.600} + \frac{1}{4.02} + \frac{0.75}{1.00} + \frac{1}{2.00}} = 0.181 \qquad (1)$$

$$U_{10} = \frac{1}{\frac{3}{1.34} + \frac{1}{3.62} + \frac{0.625}{0.600} + \frac{1}{4.02} + \frac{0.75}{1.00} + \frac{1}{2.00}} = 0.197 \qquad (2)$$

*"A Study of the Heat Transmission of Building Materials," Univ. of Ill. Eng. Exp. Sta. Bul. 102.
†American Society of Heating and Ventilating Engineers' Guide, 1928.

On certain tests, a Nicholls heat meter* was used on the east wall of the west test room. From the conductance of the wall determined from the readings of the meter, and from the observed temperature gradients through the east and north walls, values of the coefficients U_0 and U_{10} could also be calculated. These observed values of U_0 and U_{10} were 0.157 and 0.177, respectively. Hence the calculated value of U_0 for still air was 13 per cent higher than the observed value, and the calculated value of U_{10} for a 10-mile wind velocity was 10 per cent higher than the observed value. This agreement is fairly close, taking into consideration certain assumptions necessary in obtaining the calculated values. The effects of the studding and of the air entrapped between the siding, the paper, and the sheathing have been neglected. This served to increase the calculated values, and accordingly higher values obtained by calculation than by observation would be expected.

Figure 32 shows that, depending on wind movement, the drop in temperature from the air enclosed within the studding space to the outside wall surface was from four to five times the drop from the inside wall surface to the enclosed air in the studding space. Therefore, the corresponding resistances to heat flow must also be in the ratio of approximately five to one, using the north wall as typical. The resistances used for the calculation of U_{10} are given in equation (2). They may be subdivided as follows: resistance of outside portion of wall and air film inside the studding space $= \frac{0.625}{0.600} + \frac{1}{4.02} + \frac{0.75}{1.00} + \frac{1}{1.34} = 2.789$; resistance of inside portion of wall and air film inside the studding space $= \frac{1}{2.00} + \frac{1}{1.34} = 1.249$. The ratio of the resistances is $\frac{2.789}{1.249} = 2.2$ instead of approximately 5 as demanded by the observed temperature drops. Therefore, it is evident that the summation of resistances used in the outside portion of the wall for the calculation of U_{10} by the conventional method was too small, and that used for the inside portion was too large. Since a fair check was obtained between the values of U_{10} determined by calculation and those obtained by the use of the heat meter, the errors made in the assumptions for the calculation must have been compensating. They may be accounted for on the basis that the conductivity of the lath

*Nicholls, P., "Measuring Heat Transmission in Building Structures and a Heat Transmission Meter," Transactions of the American Society of Heating and Ventilating Engineers, Vol. 30, 1924, p. 65.

and plaster is greater than 2.00 as assumed, and that the entrapped air between the siding and sheathing, which was neglected in the calculation, adds a material resistance to the outside portion that should have been taken into account.

Casual inspection of the temperature drops might lead to the conclusion that the proper location for insulation would be in the outer portion of the wall, since the drop through this portion is greater than through the inner portion. However, calculation for the two cases will prove that the overall heat transmission coefficients, U, are identical irrespective of whether the insulation is placed in the inner or outer portion; and that, while there is a different distribution of temperature through the wall between the inside and outside surfaces, the actual temperatures of the inside and outside surfaces are also identical for the two cases. Therefore, from considerations of heat transfer alone, it is immaterial where the insulation is located provided that the same amount is used in either case. The walls of the test rooms, however, were tight and offered no chance for cold air to leak into the walls and to be circulated within the studding space. In actual building walls this possibility is always present. Hence, from the practical standpoint, it is desirable to place the insulation on the inner portion to serve as an added protection from any cold air that might leak into the studding space.

It was observed that when the temperature of the air at the breathing level was 70 deg. F., or slightly higher, the rooms felt somewhat too cool for comfort. This may be partly explained by the fact that the mean temperature in the zone below the breathing level was approximately 63 deg. F. An additional explanation is indicated in Fig. 32. It may be noted that the temperature of the inside wall surface was 57.4 deg. F. for the east wall and 51.3 deg. F. for the north wall when the cold room temperature was -1.4 deg. F. The presence of these two comparatively cold wall surfaces would undoubtedly increase the radiation from the body and therefore tend to produce a feeling of coolness. The use of some form of heat insulation in the walls would probably increase the inside surface temperatures and might add to the feeling of comfort experienced for any given temperature of air at the breathing level. This in itself would be an advantage distinct from any actual reduction in heat loss from the room brought about by the use of insulation. Data on this phase of the problem are meagre, however, and definite conclusions may not be drawn without further investigation.

The temperature gradients through the walls of the test room are in close agreement with similar gradients observed through the walls

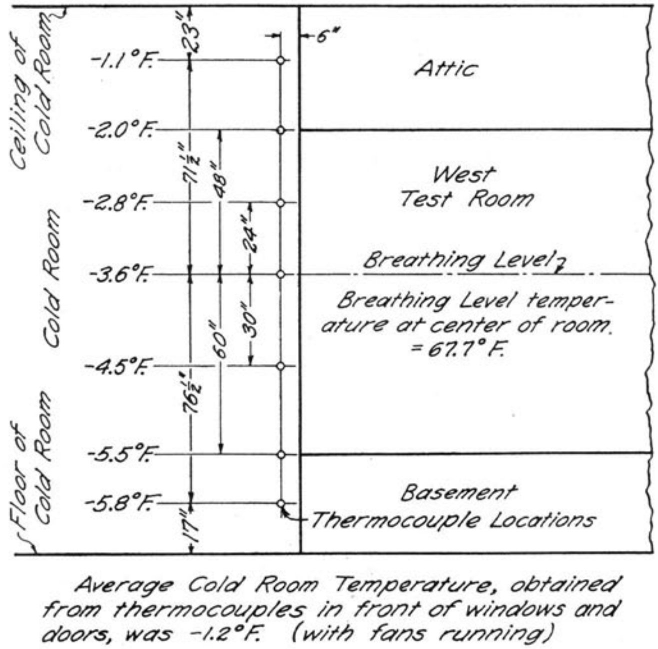


FIG. 33. VERTICAL TEMPERATURE GRADIENT IN AIR IN COLD ROOM

of similar construction in an actual residence. Some observations made in the residence on January 2, 1929 gave the following results: temperature at the breathing level, 71 deg. F.; temperature outdoors, 0.0 deg. F.; temperature of inside surface, south wall, 61.3 deg. F., north wall, 60.5 deg. F.; temperature of outside surface, south wall, 10.5 deg. F., north wall, 7.0 deg. F. These observations were made when there was no sunshine and with a slight wind movement over the north wall.

28. *Temperature Gradient in the Air in the Cold Room.*—Figure 33 shows typical temperatures observed by means of thermocouples located at various heights in the cold room. The maximum variation in the total height of the cold room was 4.7 deg. F. while the variation over the walls of the test rooms was only 3.5 deg. F. The recorded temperature for the cold room was the temperature at a height corresponding to the breathing level in the test rooms.

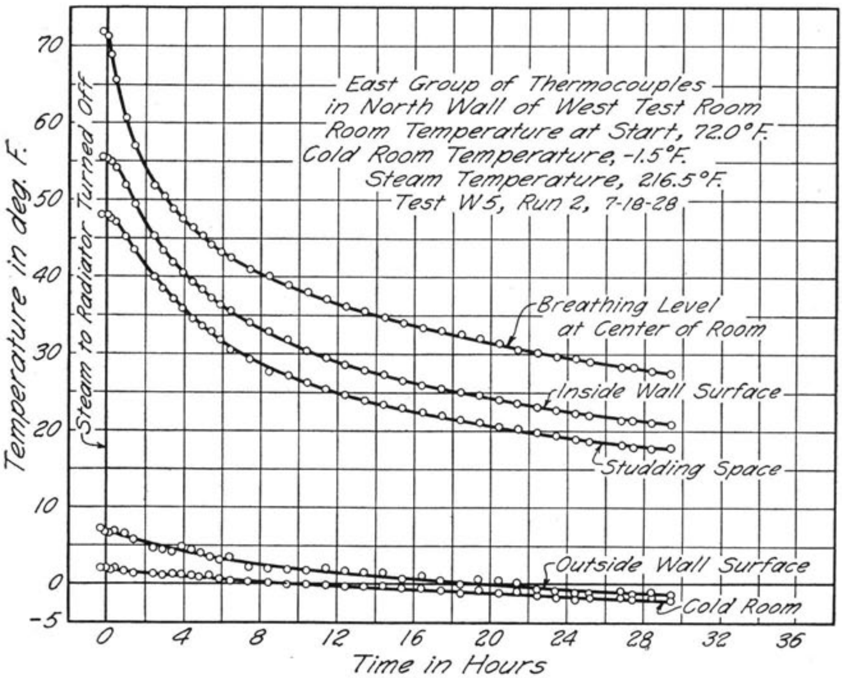


FIG. 34. COOLING CURVES FOR WEST TEST ROOM

IX. WARMING AND COOLING TESTS OF ROOMS

29. *Preliminary Statement.*—One test was conducted on the rate of cooling, and two tests on the rate of heating of the air and walls of the test room. The temperatures of the wall and air were observed by means of thermocouples placed at the breathing level of the room. The location of the thermocouples is shown in Figs. 1 and 2, and the temperatures at the east panel of the north wall of the west test room were selected for plotting. In all of the tests an air movement of approximately ten miles per hour was maintained over the outer wall surface by means of three 16-in. oscillating fans, located as shown in Figs. 1 and 2.

30. *Cooling Test.*—In test W-5, Fig. 34, the rate of cooling of the air and walls was determined without steam in the radiator and with the outside temperature maintained at approximately 0 deg. F. Conditions of temperature equilibrium were maintained in the room

by means of an unenclosed radiator for several hours previous to the start of the cooling test. The temperature of the air at the breathing level at the beginning of the test was 72.0 deg. F., the attic temperature was 63.5 deg. F., and the basement temperature was 61.0 deg. F. The steam valve at the radiator was then closed, the circuits of the electric heaters in the basement and attic were opened, and temperature readings were made at intervals of approximately one hour. The various temperatures were plotted against the total elapsed time from the beginning of the test, and the resulting curves are shown in Fig. 34.

The rates of cooling of the wall surfaces and of the air at the breathing level in the center of the room were comparatively high during the first six hours of the test, but as the temperature difference between the cold room and the test room became less the rate of cooling decreased and the plotted curves tended to flatten out into a horizontal line. The test was terminated at the end of thirty hours, and at this time the temperature at the breathing level at the center of the room was 27 deg. F. The curves for the inside wall surface and for the air in the studding space were practically parallel over the range of the test, thus indicating that there was very little lag in the relative rates of cooling at these points. The curves for the outside wall surface and for the cold room, which influenced the former directly, were also nearly parallel; but these curves were not parallel to the ones for the temperatures of the air in the studding space, the inside wall surface, and the air at the breathing level. This indicates a comparatively greater lag in the time required for the heat to penetrate the outer portion of the wall than for the inner portion; resulting from the fact that the resistance to heat flow through the siding and sheathing was greater than that of the lath and plaster. The difference in temperature between the air at the breathing level in the center of the room and the inside surface of the wall after the first hour was fairly constant at a value of about 7.0 deg. F., while the difference between the inside surface of the wall and the air in the studding space was about 4.0 deg. F. The temperature difference between the air in the studding space and outside surface of the wall varied from about 40 deg. F. at the beginning to about 20 deg. F. at the close of the test.

31. *Heating Room with Unenclosed Radiator.*—Test W-4 (Fig. 35) shows the temperature curves obtained when the room was being heated up. The temperature of the air at the breathing level in the center of the room at the beginning of the test was 24.2 deg. F., the attic temperature was 25.0 deg. F., and the basement temperature

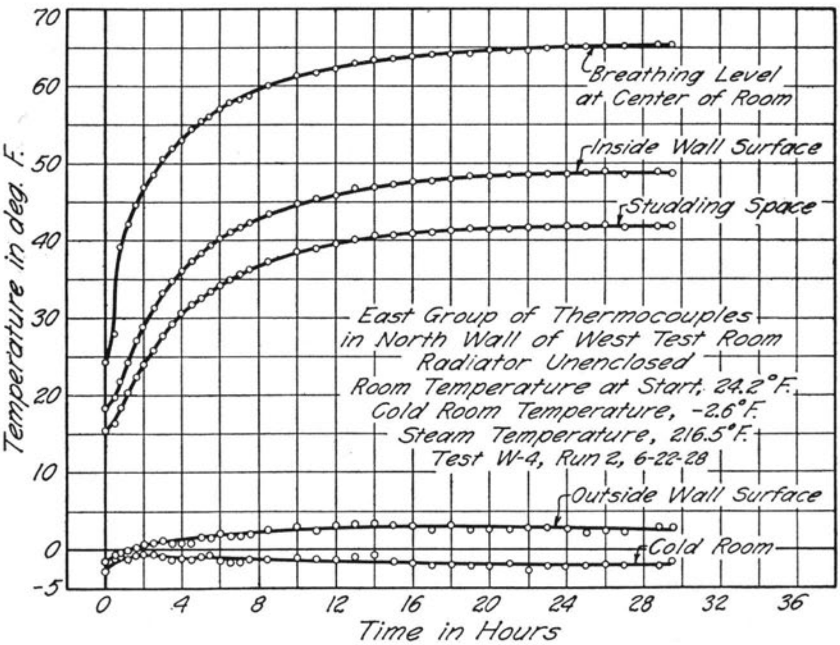


FIG. 35. WARMING CURVES FOR UNENCLOSED RADIATOR IN WEST TEST ROOM

was 31.5 deg. F. The outside cold-room temperature was held between −1.0 deg. F. and −2.0 deg. F. during the 30 hours' duration of the test. At the beginning of the test steam was admitted into the unenclosed radiator and was maintained at a constant temperature of 216.5 deg. F. during the test period. Observations of temperature were made as in the previous test. This test differs from the ones made using enclosures, discussed in Chapter III, in that the attic and basement spaces were unheated. This serves to explain the fact that the temperature at the breathing level in the center of the room attained a maximum of only 65.5 deg. F., instead of approximately 70 deg. F. as observed in the tests on enclosures.

Almost 24 hours elapsed before the temperature of the air at the breathing level in the center of the room rose from 24 deg. F. to 65.0 deg. F. The radiator used in this test had just sufficient surface to maintain a temperature of 70 deg. F. at the breathing level with a warm basement and a temperature of 62 deg. F. in the attic. No excess surface had been allowed for warming-up service or for the extra load imposed by the cold basement and attic. If some extra surface had been provided, undoubtedly the temperature of the air

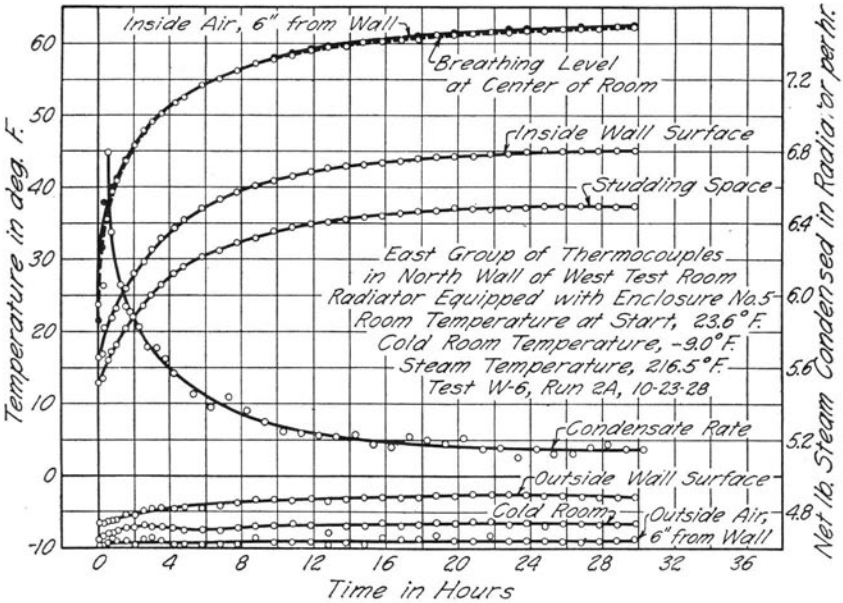


FIG. 36. WARMING CURVES AND CONDENSATE RATE FOR RADIATOR EQUIPPED WITH ENCLOSURE NO. 5 IN WEST TEST ROOM

at the breathing level would have attained a value of 70 deg. F. instead of 65 deg. F., and the time required for warming to this temperature would have been reduced. The curves seem to indicate that it is advisable to provide some excess radiation in cases where the building is allowed to cool and where short warming-up periods are desirable. After about the tenth hour of the test, the curves were very nearly parallel and the following temperature differences were maintained:

Air at center of room to inside wall surface...	=	17.0 deg. F.
Inside wall surface to air in studding space...	=	6.5 deg. F.
Air in studding space to outside wall surface..	=	39.0 deg. F.
Outside wall surface to air in cold room......	=	4.5 deg. F.

The temperature drop at the inner wall surface was about four times that at the outer wall surface. The rise in temperature of the air at the breathing level in the center of the room was very rapid for the first two or three hours of the test.

In Chapter VIII a discussion of temperature differences when the room temperature was maintained near 70 deg. F. was presented, and although the temperature gradients are slightly different for this case, in general the conclusions presented in Chapter VIII are substantiated by the results obtained in this test and in test W-6, Fig. 36.

32. *Heating Room with Enclosed Radiator.*—Test W-6, Fig. 36, shows the rate of heating of the room air and walls with the same radiator used in test W-4, except that a commercial enclosure, No. 5 (metal grille on front and ends), was used on the radiator. The temperatures at the beginning of the test were as follows:

Breathing level in center of room...........	= 23.6 deg. F.
Attic temperature........................	= 29.0 deg. F.
Basement temperature....................	= 38.0 deg. F.

The temperature of the air in the cold room was about −7.0 deg. F. as indicated by the average of the three thermocouples placed at the same height as the breathing level in the test rooms, whereas it was about −9.0 deg. F. at a distance of 6 in. from the outside wall surface. This difference probably resulted from some irregularity in the air circulation in the cold room. For this test an additional thermocouple was also placed 6 in. from the inner wall surface at the breathing level and opposite the thermocouple on the inner wall surface. The locations of these two air thermocouples are shown in Figs. 1 and 2.

The shapes of the temperature curves for this test were substantially the same as those of test W-4 (Fig. 35). The cold room temperature was about 5 deg. F. lower for test W-6, which partially accounts for the greater length of time required for heating up the room. In both cases, the importance of allowing enough time for heating and sufficient radiator surface for heating-up periods, is well illustrated by the curves of Figs. 35 and 36.

The temperature differences that were maintained after the tenth hour were approximately as follows:

Inside air 6 in. from wall to inside wall surface	= 17.0 deg. F.
Inside wall surface to air in studding space...	= 7½ deg. F.
Air in studding space to outside wall surface from..................................	37.0 to 40.0 deg. F.
Outside wall surface to outside air 6 in. from wall................................	= 6½ deg. F.

The differences obtained were of the same order as those obtained in test W-4 (Fig. 35).

The weight of steam condensed was observed hourly during this test, and the steam condensate per hour was also plotted in Fig. 36. The curve obtained was almost an exact reflection of the temperature curve for the room air temperature. The condensate weights obtained near the beginning of the test, when the inside air was below 40.0 deg. F., were fully 25 per cent greater than those obtained toward the end of the test, when the room air temperature was about 62.0 deg. F.

In Chapter V, Fig. 28, it was indicated that enclosure No. 5 produced approximately the same temperature conditions at the breathing level in the room as the unenclosed radiator. This temperature with enclosure No. 5 was maintained at 69.1 deg. F., while with the unenclosed radiator it was maintained at 69.6 deg. F. Results consistent with those shown in Fig. 28 were obtained from the warming-up tests W-4 and W-6, Figs. 35 and 36. The latter also prove that the use of a fairly well designed enclosure results in a temperature at the breathing level practically the same as that obtained with the unenclosed radiator. In addition, a really well designed enclosure produced a mean temperature below the breathing level that was higher than that obtained with the unenclosed radiator.

X. Air Circulation within Rooms Heated by Direct Radiators

33. *Air Circulation with Unenclosed Radiator.*—Studies of the movement of the air within the test rooms were made with the ammonium chloride apparatus shown in Figs. 37 and 7. A typical chart of the air circulation within the room heated with an unenclosed radiator is shown in Fig. 38. The relative air movement over a vertical transverse section of the room taken at the radiator (Fig. 1) is represented by the relative spacing and number of arrows in a unit area of the diagram. The areas containing the greatest number of arrows spaced very closely are representative of the zones in which the air movement was most rapid.

In the case of the unenclosed radiator, the warm air rose from the radiator in a comparatively thin vertical sheet, extending about one foot beyond each end of the radiator. The width of the sheet was slightly greater than that of the radiator, and a very decided upward movement of air occurred over the inner, or room surface of the curtain. This curtain extended over the whole window and the lower edge was three inches above the radiator. As a result, a thin layer of warm air also moved upward over the outer surface, or surface facing the window. The air movement between the shade and the glass in the upper sash, and between the curtain and the glass in the lower

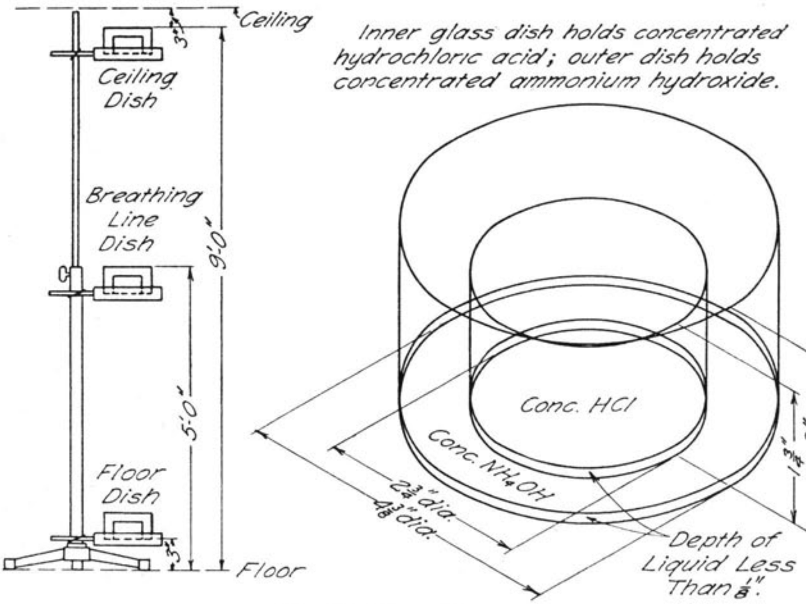


FIG. 37. FUME GENERATOR

sash, was downward. The air then turned at the window stool and joined the layer of air moving upward over the outer surface of the curtain. No movement into the room through the curtain was observed.

The upward moving stream above the radiator rose and spread over the ceiling to a depth of about six inches. The greatest movement occurred in a direction toward the rear wall of the room. At the rear wall some of the air followed the wall down to a height just below the breathing level, before turning, but most of it turned and passed forward toward the windows where it again joined the upward stream above the radiator. The major part of the rapid air circulation took place above the breathing level. Toward the front of the room between the top of the radiator and the breathing level, the circulation was uncertain; but the tendency seemed to be for the air to turn downward and finally enter between the sections of the radiator. The air entered the radiator in a similar manner between the tubes at each end, and at both front and ends the entry took place over the whole height of the radiator.

The zone below the breathing level formed a practically stagnant pool, with a slight drift toward the radiator. The sluggish circula-

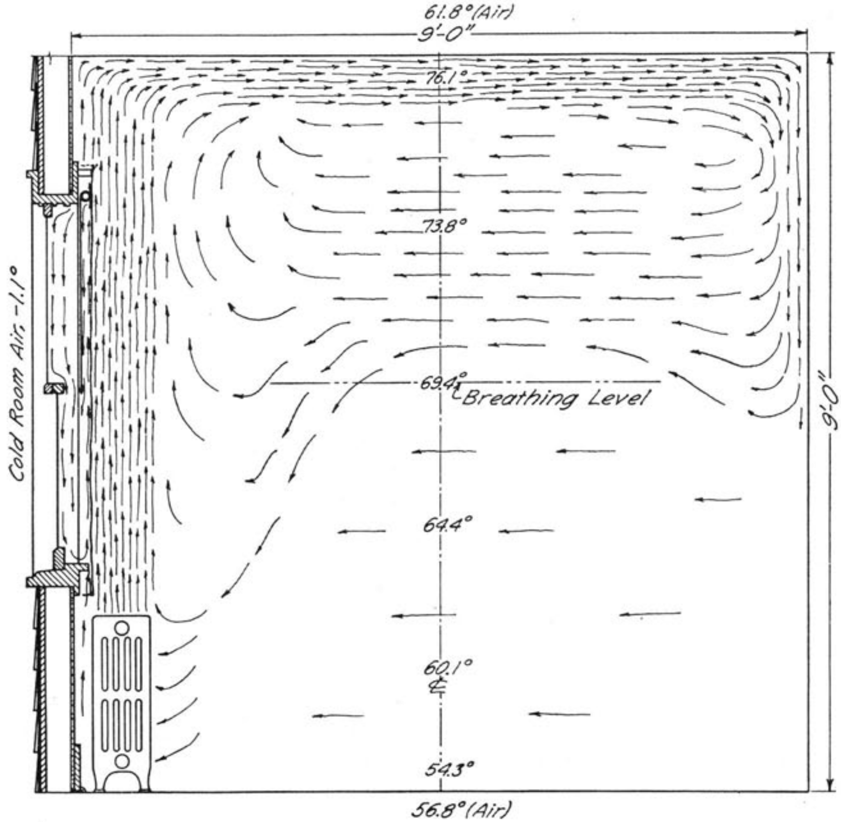


FIG. 38. AIR CIRCULATION IN WEST TEST ROOM (SECTION A-A, FIG. 1) WITH UNENCLOSED RADIATOR

tion in this part of the room serves as an explanation of the low temperatures observed in the living zone, and indicated by the curves for the unenclosed radiator as shown in Figs. 23-31.

34. *Air Circulation with Enclosed Radiator.*—A typical chart for the air circulation within the room heated by the radiator with enclosure No. 3 is shown in Fig. 39. In this case, warm air came out of the upper one-third of the grilles at the front and ends of the enclosure, and turned upward, thus forming a sheet about three feet deep from the curtain to the outer edge of the stream. The greater part of this air rose to the ceiling and spread in a sheet about eight inches deep, moving toward the rear wall. Part of the air, however, moved upward over the inner surface of the curtain, turned toward

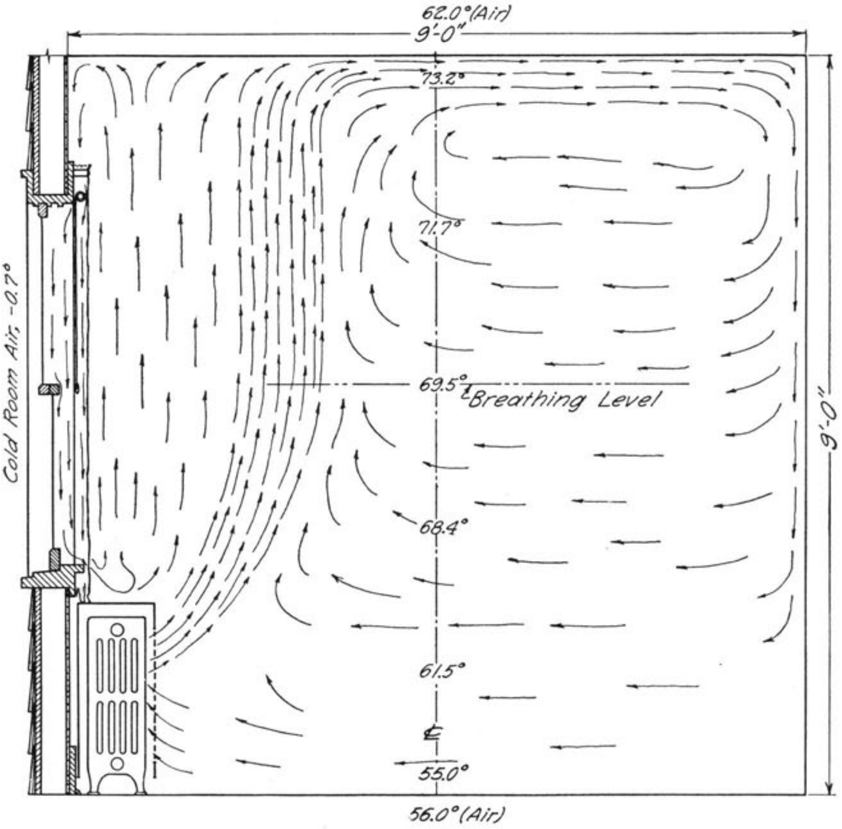


FIG. 39. AIR CIRCULATION IN WEST TEST ROOM (SECTION A-A, FIG. 1) WITH ENCLOSURE NO. 3

the exposed wall at the ceiling and came downward between the curtain and the shade. This case differed from that of the unenclosed radiator in that no distinct layers of upward and downward moving air were observed between the curtain and the shade, but all of the air movement between the curtain and the glass was downward. This downward moving air cascaded over the window stool and through the meshes of the curtain, joining the stream of upward moving air in a plane just above the top of the enclosure. This action is probably explained by the fact that the lower edge of the curtain rested on the top of the enclosure.

The air in the layer at the ceiling moved to the rear wall and turned downward, as in the case of the unenclosed radiator, but part of it followed the rear wall downward to within about 18 in. of the floor. The main body of the air, however, turned forward toward the windows and a marked positive movement was observed in the upper zone of the room to a level as low as 26 in. above the floor. The movement was sluggish in the zone below this level, but was greater than that for the unenclosed radiator. The air entered the grilles in the lower two-thirds of the enclosure. Thus more favorable conditions of air circulation were maintained by the enclosed than by the unenclosed radiator. This resulted in comparatively high temperatures in the living zone as shown by Fig. 24.

XI. Conclusions

35. *Conclusions.*—As a result of the investigation the following conclusions may be drawn:

(1) A reduction in steam condensing capacity of an enclosed radiator represents a sensible gain in steam economy if the reduction is accompanied by equally or more satisfactory air temperature conditions within the room.

(2) A reduction in steam condensing capacity of an enclosed radiator represents a sensible loss in steam economy if the reduction is accompanied by less satisfactory air temperature conditions within the room.

(3) More satisfactory air temperature conditions in the room are represented in general by higher temperatures of the air near the floor, higher mean temperatures of the air in the living zone, or below the breathing level, and lower temperatures of the air near the ceiling.

(4) The use of a properly designed radiator enclosure, or shield, results in a gain in steam economy, and equally or more satisfactory air temperature conditions in the room as compared with those obtained by the use of an unenclosed radiator.

(5) The use of an improperly designed radiator enclosure, or shield, results in unsatisfactory air temperature conditions in the room unless an amount of radiation in excess of that required for an unenclosed radiator is installed.

(6) A properly designed enclosure or shield should offer a minimum of resistance to the flow of air over the radiator under gravity head, and should protect the wall back of the radiator against the effect of direct radiation from the radiator. It should have the top of the opening in the face of the enclosure as high as possible, and permit free access of air over the lower half of the radiator, especially near the floor.

(7) The degree of comfort experienced by the occupants of a room is greatly influenced by the temperature of the inner surface of the walls as well as by the temperature of the air in the room.

(8) The temperature of the inside surface of exposed standard frame walls may be as low as 50 deg. F. after a long period of exposure to a temperature of zero deg. F. outdoors and 70 deg. F. at the breathing level indoors. This applies especially to north walls or any wall not exposed to a considerable amount of sunshine.

(9) The use of insulation in the exposed walls of a room will reduce the flow of heat through the walls, and result in higher temperatures for the inside surfaces of the walls than the corresponding temperatures for the same types of walls without insulation. This increase in surface temperature is of even more importance than the saving of heat, since its direct effect is to produce a greater degree of comfort for the occupants.

(10) The proper location for insulation in an exposed wall is not governed by considerations of relative resistance to heat flow through the various layers or materials of the walls nor by the temperature gradients, but is governed by practical considerations of wall construction and the possibility of air leaks into the studding space or other air circulating channels. From the latter viewpoint it is certainly advisable to place the insulation as near to the inner surface of the wall as possible.

(11) The maximum rate of cooling for a wall exposed to a constant outdoor temperature occurs immediately after the heating is discontinued, and is very high.

(12) In cases where short warming-up periods are desired after a stand-by period with no heat supplied, it is advisable to install both radiation and boiler heating capacity in excess of that required to maintain a given temperature of the air at the breathing level in the rooms of the building.

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