RATING EQUATIONS FOR HAND-FIRED
WARM-AIR FURNACES

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ABSTRACT

This circular presents revised gravity rating equations for hand-fired warm-air furnaces. The Standard Code rating equation, adopted by the National Warm Air Heating and Air Conditioning Association in 1922, related the physical dimensions of the furnace with the heat output stated in terms of heat delivery at the registers. The result of extensive tests conducted over a period of years on a number of gravity warm-air furnaces of widely varying design, this equation was used from 1922 to 1940 to rate more than 900 individual furnaces of this type.

More recently, with the advent of unusual models of gravity furnaces, some limitations of the original proposal for stating furnace performance have become apparent:

(1) With a given amount of heating surface, the rate of heat input was limited to the amount that could be evolved by burning coal at a combustion rate of 7.5 lb. on the particular size of grate used in connection with the amount of heating surface under consideration.

(2) No direct limit was placed on the temperature of the air leaving the registers.

(3) No limit was placed on the temperature of the flue gas.

(4) No limit was placed on the maximum temperature attained by any part of the heat transfer surface.

In view of these limitations, the original test data upon which the Standard Code rating equation was based have been restudied and the rating equation has been revised. This analysis has been made with the cooperation of the Research Advisory Committee and the Installation Codes Committee of the National Warm Air Heating and Air Conditioning Association. The essential details involved in the derivation of the revised rating equations were presented to these committees and to the Association December 14, 1944. Upon the recommendation of the two committees, the Board of Directors of the Association adopted the revised rating equations.

Revised equations are presented in this circular for (1) all hand-fired coal furnaces converted to stoker, oil, or gas firing; (2) hand-fired furnaces having ratios of heating surface to grate area of more than 15 and less than 25 to 1; and (3) hand-fired furnaces having ratios of heating surface to grate area of more than 25 to 1.

A comparison of the application of the revised rating equations with that of equations previously used is given, as well as discussions of the rating of forced-air furnaces and pipeless furnaces. Appendices offer further information and data on finned heating surfaces, firing periods for hand-fired furnaces, and heating surface and grate area.

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RATING EQUATIONS FOR HAND-FIRED
WARM-AIR FURNACES

I. INTRODUCTION

1. *History of Investigation.*—One of the main objects of the investigation of warm-air furnaces and warm-air heating systems was the development of a method of testing and rating furnaces. In this connection during the period from 1918 to 1930, extensive tests were conducted in a laboratory plant on a number of gravity warm-air furnaces of widely varying design. As a result of these tests a simple equation was proposed which related the physical dimensions of the furnace with the heat output stated in terms of heat delivery at the registers. This equation, which served as a statement of the predicted heat output of any given furnace, was adopted by the National Warm Air Heating and Air Conditioning Association in 1922, and will hereafter be referred to as the Standard Code* rating equation. During the period between 1922 and 1940, over 900 individual gravity warm-air furnaces were measured under the sponsorship of the Association and were rated by means of this equation.

One significant result of this standardized rating procedure was the elimination of much of the confusion existing prior to 1920 as a consequence of the independent and arbitrary evaluations of furnace performance by each and every manufacturer. For a period of more than 20 years the rating procedure has remained unchanged. The experience of this period has demonstrated that the basic concepts of the procedure were sound, and that the performance of a gravity warm-air furnace could be expressed in terms of the physical dimensions of the furnace.

In more recent years, particularly with the advent of unusual models of gravity furnaces, some limitations of the original proposal for stating furnace performance have become apparent, as will be discussed more fully in a later section. As a result of the need for a more complete analysis, the original test data have been restudied and the rating equation has been revised. This revised equation is not subject to some of the limitations that were inherent in the Standard Code rating equation. In connection with the restudy of the data, a brief

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* "The Standard Gravity Code for the Design and Installation of Gravity Warm-Air Heating Systems," published by the National Warm Air Heating and Air Conditioning Association, 145 Public Square, Cleveland, 14, Ohio. In 1945 the Standard Code was superseded by the "Gravity Code and Manual for the Design and Installation of Gravity Warm-Air Heating Systems."

review of the original test methods and a consideration of the factors that led to the development of the original equation will be discussed.

2. *Acknowledgments.*—This analysis has been made as a part of the investigation of warm-air furnaces and heating systems, a coöperative project sponsored jointly by the Engineering Experiment Station and the National Warm Air Heating and Air Conditioning Association. The investigation is being conducted in the Department of Mechanical Engineering of the University of Illinois under the general administrative direction of DEAN M. L. ENGER, Director of the Engineering Experiment Station and of PROFESSOR O. A. LEUTWILER, Head of the Department of Mechanical Engineering.

The analysis has been made with the coöperation of the Research Advisory Committee and the Installation Codes Committee of the coöperating Association. The essential details involved in the derivation of the revised rating equations were presented to these committees and to the Association on December 14, 1944. Upon the recommendation of the two committees, the Board of Directors of the Association adopted the revised rating equations, which now replace the rating methods incorporated in the Standard Code and the Technical Code.*

II. DESCRIPTION OF TEST PLANT AND FURNACES

3. *Test Plant.*—The laboratory test plant, in which all of the tests mentioned in Section 1 were made, is shown in elevation and plan in Figs. 1 and 2. This plant consisted of a skeleton framework supporting three platforms representing the three stories of a house complete with warm-air registers and stacks. A single return-air intake and duct was used. Ten warm-air leaders were provided, having a total cross-sectional area of 808 sq. in. All stacks were encased to simulate stacks enclosed in stud spaces. Two of the four stacks to the second story, and one of the two stacks to the third story were of single-wall construction, and the remainder were of double-wall construction. Instruments for the measurement of air flow, temperatures, draft, and flue gas analysis were provided.

4. *Furnaces.*—The six types of furnaces used in connection with the derivation of the rating equation, and the two furnaces used in the studies to evaluate the effectiveness of finned surfaces, are shown in

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* "The Technical Code for the Design and Installation of Mechanical Warm-Air Heating Systems," published by the National Warm Air Heating and Air Conditioning Association.
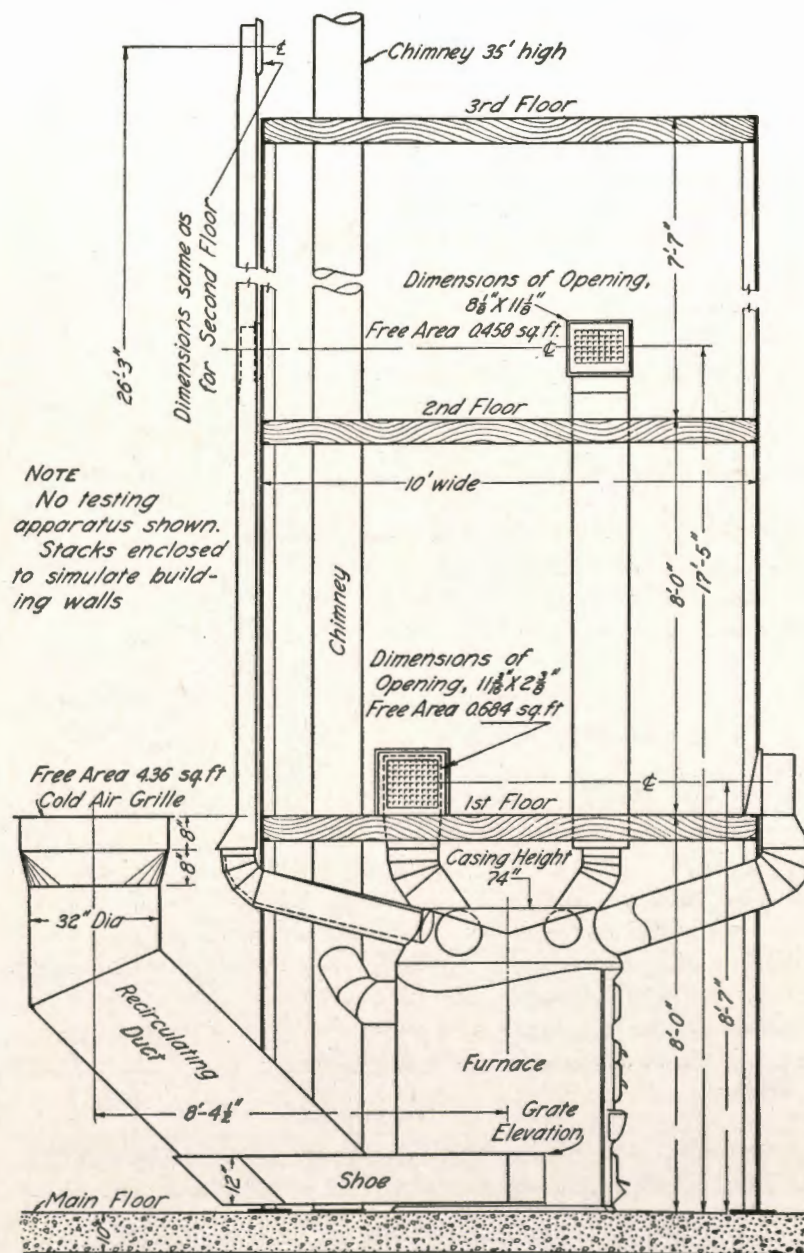
FIG. 1. ELEVATION OF MAIN FURNACE PLANT
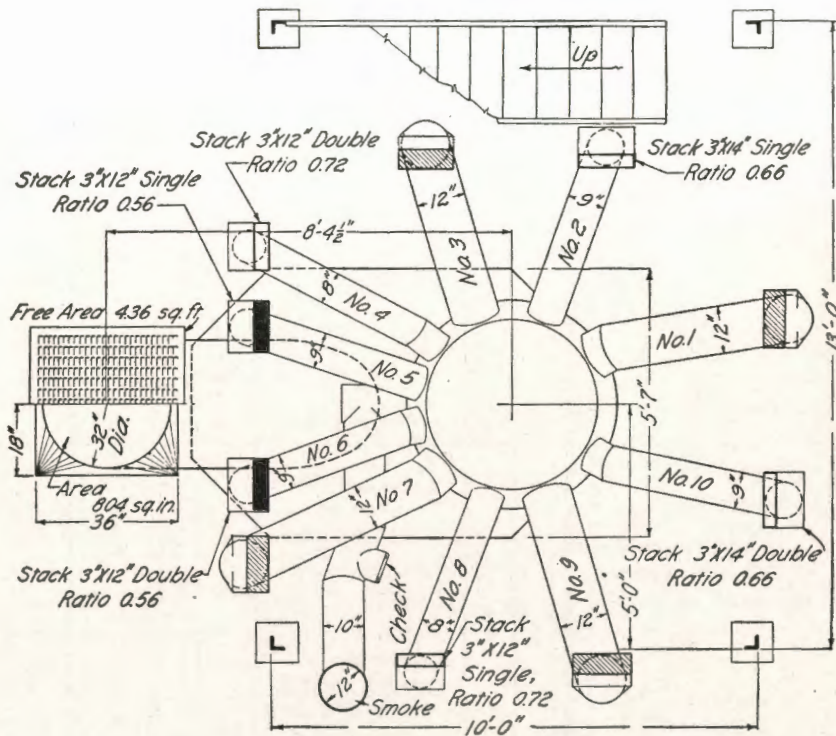
		Leaders		Stacks		Registers	
	No.	Size	Area	Dimensions	Type	Dimensions	Free Area
▨	1	12 in.	113 sq. in.	———		$11\frac{3}{16}$ in. x $12\frac{3}{8}$ in.	0.684 sq. ft.
	3	12 in.	113 sq. in.	———	Asbestos Covered	" "	"
1st. Floor	7	12 in.	113 sq. in.	———		" "	"
	9	12 in.	113 sq. in.	———		" "	"
▭	2	9 in.	64 sq. in.	3 in. x 14 in.	S'gle.	$8\frac{1}{8}$ in. x $11\frac{1}{8}$ in.	0.458 sq. ft.
	4	8 in.	50 sq. in.	3 in. x 12 in.	D'ble.	" "	"
2nd. Floor	8	8 in.	50 sq. in.	3 in. x 12 in.	S'gle.	" "	"
	10	9 in.	64 sq. in.	3 in. x 14 in.	D'ble	" "	"
▬	5	9 in.	64 sq. in.	3 in. x 12 in.	S'gle	" "	"
3rd Floor	6	9 in.	64 sq. in.	3 in. x 12 in.	D'ble	" "	"
Leader Area: 1st. Fl. 452 sq. in., 2nd. 228 sq. in., 3rd. 128 sq. in. Total 808 sq. in.							
Percent Leader Area: 1st. Fl. 55.9, 2nd. 28.2, 3rd. 15.8.							

FIG. 2. PLAN AND DIMENSION TABLE FOR MAIN FURNACE PLANT

23-in. grate, 27-in. firepot
Cast-iron, circular radiator

21½-in. grate, straight firepot
Steel, crescent-radiator

22-in. grate, 24-in. firepot
Cast-iron, crab-radiator

22½-in. grate, 26-in firepot
Cast-iron Open Dome

FIG. 3. TYPES OF FURNACES TESTED

Figs. 3 and 4. A summary of the significant dimensions is given in Table 1, presented in Section 11. The heating surfaces of the furnaces tested ranged from 33.6 square feet to 67.8 square feet.

In the case of the non-integral fin furnace shown in the upper left part of Fig. 4, tests were made both with the fins in place and with the fins removed. In the case of the steel crescent-radiator furnace, tests were first made without fins, as shown in the upper right part of Fig. 3. Fins were then continuously welded along one edge to the metal surfaces of the drum and radiator, as shown at the bottom of Fig. 4, and additional series of tests were made. The results of tests obtained with the two finned furnaces are separately discussed in Appendix A.

III. ADAPTABILITY OF THE GRAVITY WARM-AIR FURNACE TO A DIMENSIONAL RATING

5. *Development of Standard Code Rating Equation.*— In the simplest terms the rating of a warm-air furnace is a statement of the probable heat output of the furnace when operated under specified conditions. A necessary corollary is that the specified conditions do not deviate materially from those existing in service, and that they are readily duplicable. Such a rating may be made either by test or by relating the expected heat output to one or more dimensions of the furnace. In the latter case, if the rating is to be valid, some assurance must be had that the characteristics of the service installation will approximate those of the test plant from which the data for the dimensional rating were obtained, and that the performance of the furnace will be the same in the service installation as in the test plant. In any case, the data for a dimensional rating must be obtained from tests run in a test plant approximating service conditions.

For the purpose of developing some method of rating gravity warm-air furnaces, a large number of tests were run on six different types of furnaces in the test plant described in Section 3. Since it was found that the size of the casing influenced to some extent the output and efficiency, Figs. 5 and 6 were plotted from data for the best size of casing for each furnace. During each test the bonnet temperature was maintained constant. Measurements were made of the draft, flue gas temperature, metal surface temperatures, rate of air flow, fuel burned, and air temperatures, and from these observations the values of bonnet capacity, register delivery, bonnet efficiency, and combustion rate were calculated. A number of tests were conducted on each furnace in order to obtain a wide range of operating conditions.

21⅝-in. grate, straight firepot
Steel, small radiator type

22⅜-in. grate, straight firepot
Steel, double diving-flue type

Fin Description

	No.	Width	Length
On Radiator	10	2½"	36"
	3	2½"	22"
On Drum	2	3"	36"
	2	6"	36"
	4	4"	36"

Fins are of ⅛-in. metal arc-welded to furnace along one edge.

21½-in. grate, straight firepot Steel, crescent radiator
Integral fins on drum and radiator

FIG. 4. TYPES OF FURNACES TESTED

Curve →	A	B	C	D	E	F'
	Cast Iron, Circular Rad.	Steel, Crescent Rad.	Cast Iron, Crab Rad.	Cast Iron, Open Dome	Steel, Diving Flue	Steel, Small Rad.
Grate dia., in	23.0	21.5	22.0	22.5	22.1	21.6
Grate Area, sq. ft., G	2.88	2.47	2.64	2.76	2.67	2.55
Heat. Surf., sq. ft., S	60.3	67.8	51.5	48.6	58.6	33.6
Ratio S/G	20.9	27.5	19.5	17.6	21.9	13.2
Casing dia., in.	50	54	48	50	50	48

FIG. 5. PERFORMANCE CURVES FOR SIX TYPES OF FURNACES

Type of Furnace	Grate	Casing
A-C.I., Circular Radiator,	23.0"	50"
B-Steel, Crescent Radiator,	21.5"	54"
C-C.I., Crab Radiator,	22.0"	48"
D-C.I., Open Dome,	22.5"	50"

FIG. 6. EFFECT OF HEATING SURFACE ON UNIT CAPACITY

The principal data from the tests as shown in Fig. 5,* were plotted against the hourly combustion rate, expressed in terms of lb. of coal burned per sq. ft. of grate area per hour. The results obtained with the six types of furnaces showed that, in all cases, capac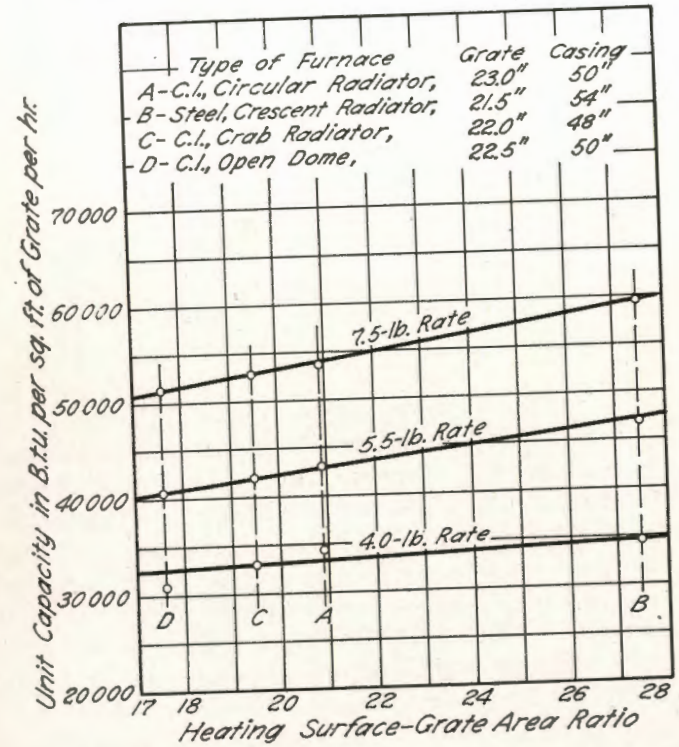ity increased as the combustion rates were increased. From these data it was also evident that the combustion rate of 7.5 lb.† was accompanied by a register air temperature of about 175 deg. F. Since a register temperature of 175 deg. F. represented the accepted design temperature for a gravity warm-air furnace system, it became evident that a statement of the heat output of the furnace at this register temperature should be accepted as the rating of the furnace. Furthermore, since a combustion rate of 7.5 lb. accompanied the register temperature of 175 deg.

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* This figure is a modification of Fig. 67 in University of Illinois Engineering Experiment Station Bulletin 246, in that the performance of the steel non-integral fin furnace (curve F') is based on the furnace with fins removed.

† For the sake of brevity, the combustion rate, in pounds of coal burned per square foot of grate area per hour, will hereafter be designated simply as lb.

F., the output of a given furnace could be stated in terms of the grate area, if a combustion rate of 7.5 lb. were accepted as standard. This formed the basis for the development of the Standard Code rating equation.

In the case of a hand-fired furnace the allowable heat release could be obtained immediately from the area of the grate. For a given heat release the amount of heating surface provided with the furnace determined the effectiveness with which the heat was transmitted to the circulating air. That a furnace having a large ratio of heating surface to grate area provided more effective transmission of heat than a furnace having a small ratio is shown in Fig. 6. In this figure, reproduced from Engineering Experiment Station Bulletin 188, unit capacities in B.t.u. per hour are shown plotted against the ratios of heating surface to grate area for each furnace. A uniform increase in unit capacity was obtained with increasing ratios at each of the combustion rates shown. A ratio of 20 to 1 was representative of a large number of furnaces on the market, and was therefore selected as a standard. Above this ratio, and at a combustion rate of 7.5 lb., a 2 per cent increase in capacity was obtained for each unit increase in the ratio. Below this ratio, a decrease in capacity of 2 per cent was obtained. The term $[1 + 0.02 \, (R - 20)]$ served as a correction factor used in connection with the heat release, and the following equation expressing the register delivery in terms of the two physical dimensions, grate area and heating surface, was derived:

$$H = 275G \left[1 + 0.02 \, (R - 20)\right] \tag{1}$$

in which

H = heat delivered at registers, in B.t.u. per hr.

G = grate area, in sq. in.

R = ratio of heating surface (S) to grate area (G), hereafter referred to as the ratio of S/G.

At that time it was considered desirable to rate the furnaces in terms of sq. in. of leader pipe. At a 175 deg. register temperature the average heat-carrying capacity had been proved to be 136 B.t.u. per sq. in. of leader pipe. Equation (1) was, therefore, converted to equivalent sq. in. of leader pipe by dividing by 136. At the same time the figures were rounded up and a safety factor was provided by expressing Equation (1) as

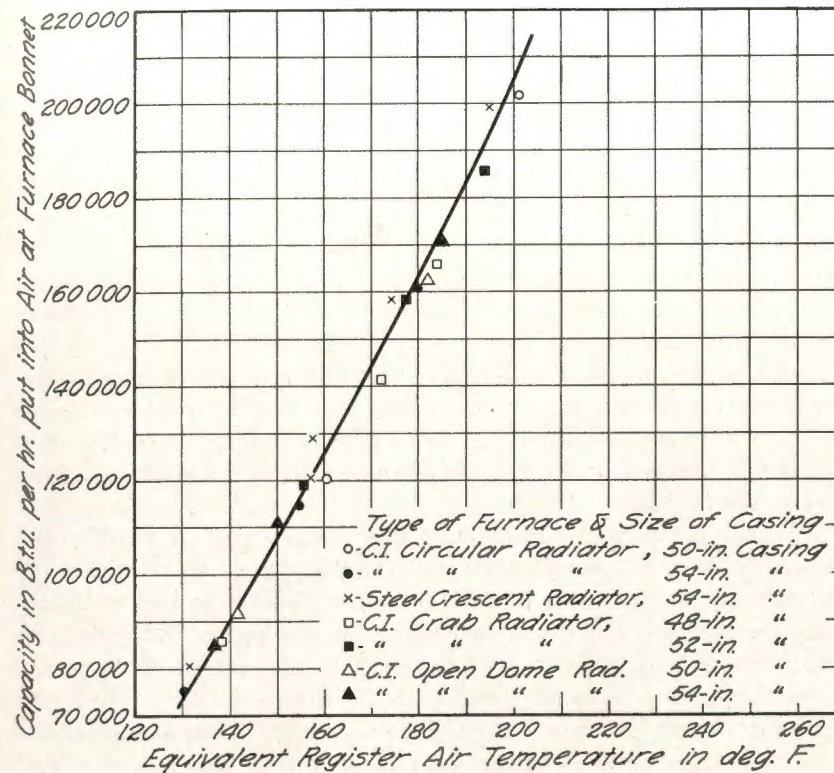$$L = 1.75G \left[1 + 0.02 \, (R - 20)\right] \tag{2}$$

FIG. 7. REGISTER AIR TEMPERATURE-CAPACITY CURVES FOR FOUR TYPES OF FURNACES

in which

L = leader pipe rating, in sq. in.

The equation in this form was then adopted as the Standard Code rating equation.

6. *Plant Design and Furnace Performance.*—The performance of a gravity warm-air furnace is determined by the plant in which it is used. The bonnet capacities obtained in the test plant, plotted against the equivalent register air temperature for four furnaces having different sizes of casings, are shown in Fig. 7, which is reproduced from Bulletin 188, Fig. 21. The equivalent register air temperature was obtained by adding 65 deg. F. to the actual temperature rise from the

inlet to the registers. Hence the equivalent register air temperature is a measure of the temperature rise above a standard inlet temperature of 65 deg. F. The capacity of a furnace is a function of the temperature rise and the weight of air flowing. Therefore, for any given equivalent register air temperature, a statement of the capacity is also equivalent to a statement of the weight of air flowing through the furnace and the duct system. All of the points in Fig. 7 representing the performance of various furnace types and casing sizes fell practically on a single average curve. Hence, it is evident that the weight of air circulated through each of the furnaces at a given equivalent register air temperature was the same, and that the frictional resistance of the test plant was the same, irrespective of the type of furnace used. That is, the main resistance to air flow was that imposed by the duct system alone. In other words, the performance, or heat output, of a gravity warm-air furnace is determined primarily by the resistance of the duct system.

From the previous discussion it may be assumed that if the performance of a furnace in an actual installation is to duplicate the performance of the same furnace in a test plant, it is only necessary that the resistance of the duct system in the actual installation be made to duplicate that in the test plant. In the case of the Standard Code rating, this duplication was assured through the use of the leader capacity curves, shown in Fig. 8. These curves are based on coordinates similar to those shown in Fig. 7 and are, therefore, also representative of the resistance in the duct system. Since they were derived from results obtained in the test plant, the resistance of a system designed by the use of these curves should approximate that of the test plant, and the performance in the actual installation should also approximate that in the test plant.

The validity of the rating procedure was confirmed from tests run in the Research Residence. The duct system in the Research Residence was designed from the curves in Fig. 8, based on the results from the test plant. After the Research Residence plant was put in operation, the results shown in Fig. 9 were obtained. For purposes of comparison the results obtained in the laboratory plant are also shown. From the curves it is evident that the capacities given by the Research Residence plant were only about 8 per cent less than those obtained from the laboratory plant. This may be considered a close correlation in view of the fact that all of the leader pipes in the Research Residence plant were longer than those in the laboratory plant, and some of them
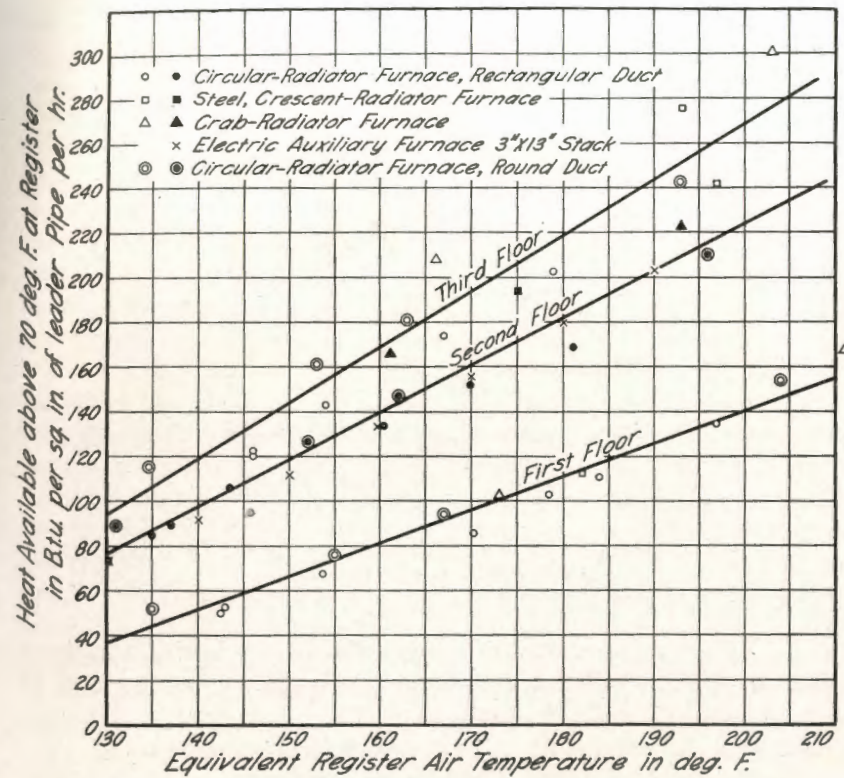
FIG. 8. CARRYING CAPACITIES OF LEADER PIPE FOR FIRST, SECOND, AND THIRD STORIES

contained more elbows. Provision for such deviations in length and number of elbows was later made in the Gravity Code and Manual.* For all practical purposes, however, the Standard Code method of design of the duct system and of rating the furnace was proved to be sound, and the actual experience over a period of some 20 years in the field has justified the procedure based on a dimensional rating of the gravity warm-air furnace.

7. *Limitations of the Standard Code Rating Equation.*—The principal limitations involved in the derivation of the Standard Code rating equation may be enumerated as follows:

* "Gravity Code and Manual for the Design and Installation of Gravity Warm Air Heating Systems," 2nd edition, 1945, published by the National Warm Air Heating and Air Conditioning Association.
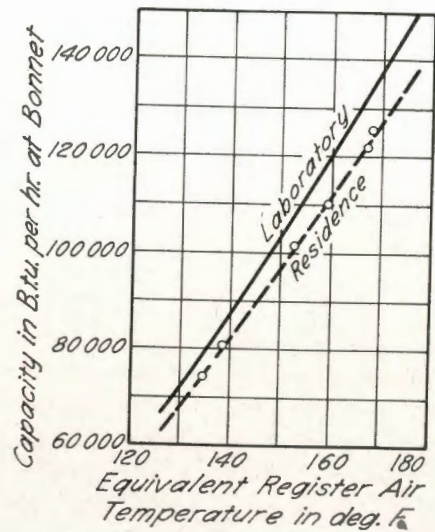
FIG. 9. COMPARISON OF CAPACITIES OBTAINED WITH SAME FURNACE
IN LABORATORY AND IN RESIDENCE

(1) With a given amount of heating surface, the rate of heat input was limited to the amount that could be evolved by burning coal at a combustion rate of 7.5 lb. on the particular size of grate used in connection with the amount of heating surface under consideration.

(2) No direct limit was placed on the temperature of the air leaving the registers.

(3) No limit was placed on the temperature of the flue gases.

(4) No limit was placed on the maximum temperature attained by any part of the heat transfer surface.

While it is true that no direct limit was placed on the register air temperature accompanying a combustion rate of 7.5 lb., the expression of the heat delivered at the registers in terms of square inches of leader pipe tacitly assumed that in all cases a register air temperature of 175 deg. F. accompanied a combustion rate of 7.5 lb. This assumption resulted from the fact that the leader-carrying capacity of 136 B.t.u. per sq. in. per hr., which was used in converting the heat delivery at the registers to terms of sq. in. of leader pipe area, was based on a register air temperature of 175 deg. F. The 136 B.t.u. per sq. in. per hr. also represented the average of the leader-carrying capacities of first and second story leaders. Figure 5 shows that actually the register air temperature accompanying a 7.5 lb. combustion

rate in any given furnace may deviate considerably from the assumed value of 175 deg. F. If a given amount of heating surface is installed in a plant with unrestricted leaders and return air ducts, or with adequate air-circulating capacity, the amount of heat transferred to the circulating air should be limited only by the temperature of the gases at the smoke outlet, or the maximum safe temperature of the metal, irrespective of the method by which the supply of heat is evolved. A number of different sized grates may be used in connection with any given amount of heating surface. As a result, when a limit is placed on the rate at which heat is evolved, as it is by the use of a 7.5 lb. combustion rate, there is no assurance on one hand that the maximum allowable effectiveness of the heating surfaces will be utilized, or on the other hand that such maximum effectiveness will not be exceeded, thus resulting in excessively high flue gas and metal temperatures. The correction factor $[1 + 0.02 \ (R - 20)]$, based on test results, was adopted as a means of evaluating the effect of variations in the ratio of heating surface to grate area. That it did not adequately accomplish this may be shown by the following discussion.

The heat transferred to the air, based on the heat delivery at the register in B.t.u. per hr. per sq. in. of heating surface, can be obtained by multiplying both sides of the rating formula shown in Equation (2) by 136, and dividing by the sq. in. of heating surface, S. The equation then simplifies to

$$\frac{\text{Reg. Del.}}{S} = \frac{143}{R} + 4.76. \tag{3}$$

From Equation (3) it may be shown that an S/G ratio of 15 represented a heat transfer rate of 14.3 B.t.u. per sq. in. per hr., and a ratio of 30 represented a heat transfer rate of only 9.5 B.t.u. per sq. in. per hr. A restudy of the performance data from six types of furnaces, as discussed in Section 11, proved that a heat transfer rate of 12.4 B.t.u. per sq. in. per hr. was the maximum that could be tolerated without the danger of obtaining flue gas temperatures above 800 deg. F., or metal temperatures above 1000 deg. F. Hence, the rate of 14.3, calculated from the Standard Code rating equation for the S/G ratio of 15, indicates that in the case of furnaces with relatively large grates, the allowance of a 7.5 lb. combustion rate would result in excessive flue gas and metal temperatures if these furnaces were actually operated at capacities as high as those permitted by the rating formula. On the other hand, the heat transfer rate of 9.5 B.t.u. per sq. in. per hr. calculated for the ratio of 30 indicates that, in the case of furnaces

with relatively small grates, the limit of a 7.5 lb. combustion rate precludes the utilization to the fullest extent of the potential value of the heating surfaces. Furthermore, in the case of stoker, gas, and oil firing, the heat evolution is not limited by an attainable combustion rate of 7.5 lb. per sq. ft. per hr. on a given sized grate, and the grate size as such has no bearing on the potential register air delivery to be expected from a given amount of heating surface. Hence, the use of the Standard Code rating equation to calculate the rating to be assigned to the installation converted from hand firing to stoker, gas, or oil firing would definitely penalize the use of these methods of firing in the cases of furnaces having high ratios of S/G.

The unit "square inch of leader pipe" served a useful purpose in the early days of the industry when a dimensional unit for register delivery was more acceptable than the engineering unit of B.t.u. per hour. Some confusion has resulted from the use of the term "leader pipe area" both as a unit of heat delivery and as a physical dimension for the leader pipes. When used as an equivalent of heat delivery the square inches of leader pipe represent the maximum allowable rating for the furnace.

The heat delivery of a given furnace rated by the Standard Code at 500 sq. in. of leader pipe would be 500×136 or 68 000 B.t.u. per hour, irrespective of whether the connected leader pipes led entirely to rooms on the first story, entirely to rooms on the second story, or to rooms on both the first and second stories. If, however, this furnace were installed with all leaders actually connected to first story registers, the 68 000 B.t.u. per hour would be sufficient to supply 68 000/111 or 612 sq. in. of leader pipe. With all second story connections it would supply 68 000 / 167 or 407 sq. in. of leader pipes, and with first and second story connections it would supply 68 000 / 136 or 500 sq. in. of leader pipe. The advisability of actually using different amounts of connected leader pipe with a furnace having a given rating, depending on the plant in which it was installed, was a source of confusion.

Furthermore, it was not understood that the total cross-sectional area of leader pipe does not in itself create the load on the furnace. The load is determined by the combustion rate required to satisfy the heat demand. If the heat demand is such as to require the combustion rate corresponding to the full rating of the furnace, means must be provided for the heat generated to be carried away from the furnace. If this is not done the heat will be retained in the castings or shell and the furnace will be burned out. A freely circulating system capable of

carrying away the heat can be assured only by providing ample leader pipe area. The physical cross-sectional area stated by the rated leader pipe capacity coincides with the areas actually proven satisfactory in the rating tests. Hence the rated leader pipe area also represents the probable minimum that should be installed to insure proper escape of heat from the furnace. Since the area of the leader pipe in itself does not load the furnace there can be no objection to installing a greater amount than that represented by the stated rating, provided that the furnace is not used in a situation in which the heat demand is greater than that represented by the stated square inches of leader pipe rating. For instance, if the heat loss from a given house were 86 400 B.t.u. per hr. a furnace having a rated leader pipe area of 600 sq. in. would be selected. This furnace would have a register delivery of 86 400 B.t.u. per hr., and not less than 600 actual sq. in. of leader pipe area should be installed. However, there would be no objection to installing a greater amount of leader pipe, since the 86 400 B.t.u. per hr. represents the maximum demand that the furnace would have to meet. In fact, there would be some advantage in installing the greater amount of leader pipe, inasmuch as the maximum demand of 86 400 B.t.u. per hr. would then be supplied at a register air temperature less than 175 deg. F.

The method of calculating heat losses has been standardized by the industry in terms of B.t.u. per hour for both gravity and forced-air installations. For this reason it is highly desirable that furnace ratings should also be stated in the same terms, so that different methods of calculating heat losses are not necessitated by differences in the method of rating furnaces used in gravity and forced-air installations.

In view of these limitations in the established Standard Code rating equation, it was deemed advisable to restudy the available data for the purpose of deriving a method of rating not subject to the existing limitations. The details of this study are presented in Chapter IV.

IV. ANALYSIS OF DATA FOR REVISED GRAVITY RATING EQUATION

8. *Test Data Available.*—The performance curves for the furnaces tested are shown in Fig. 5. In this figure the furnace output is stated in terms of bonnet capacity. However, for the purpose of restudying the data, it was found more convenient to express the furnace output in terms of register delivery. The latter was assumed to be 75 per cent of the bonnet capacity.

Flue gas temperatures obtained from the original tests are shown plotted against combustion rates in Fig. 10. In general, furnaces having higher S/G ratios operated at lower flue gas temperatures, indicating that in such furnaces the heating surface transmitted a relatively large proportion of heat to the circulating air.
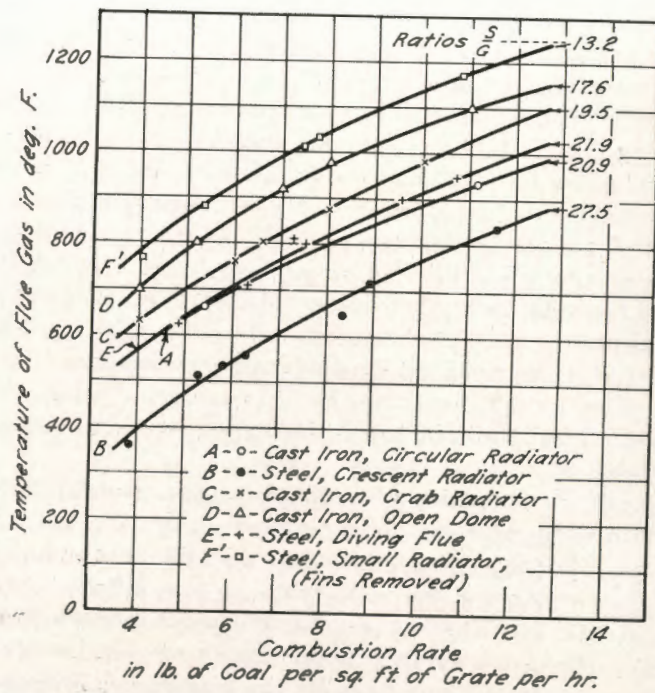

FIG. 10. FLUE GAS TEMPERATURES FOR SIX TYPES OF FURNACES

9. *Significance of Heating Surface.*—In the development of the Standard Code rating equation, the data were plotted against combustion rate, which in effect was equivalent to relating furnace performance to grate area. In the cases of furnaces converted to stoker, oil, or gas firing, the rate of heat input is independent of the grate area, and therefore grate area has no real significance. On the other hand, the rate of heat transfer to air circulated is a function of the amount and arrangement of the heating surface. For this reason it developed that, for all practical purposes, the performance of the furnace should be related to heating surface rather than to grate area.
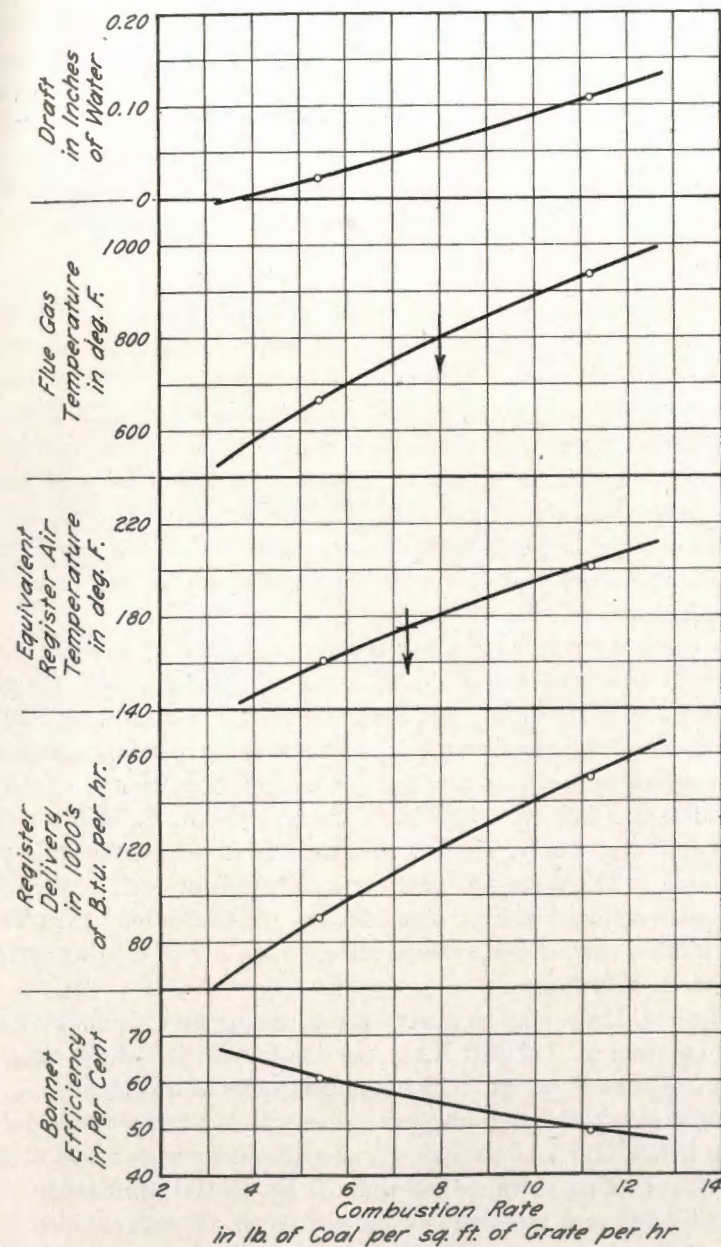

FIG. 11. TYPICAL PERFORMANCE CURVES FOR HAND-FIRED FURNACE

With a given amount and arrangement of heating surface, if no limit were placed on the combustion rate, or heat input, the rate of heat transfer would be almost unlimited, and very high register deliveries would be obtained. In this case, however, excessive flue gas temperatures, metal temperatures, and register air temperatures would inevitably result. In using heating surface as the correlating physical dimension it was therefore necessary to place practical limits on all of these temperatures.

10. *Register Delivery as Affected by Limitation of Register Air Temperatures Only.*—In practice, the design of gravity warm-air furnace plants is based on a register air temperature of approximately 175 deg. F. This temperature was, therefore, selected as a limit for register air temperature. It was also possible that, at this register air temperature, practical limits for flue gas temperature and metal temperature would not be exceeded. The register delivery obtained for the different furnaces at a register air temperature of 175 deg. F. was, therefore, first plotted against the corresponding square feet of heating surface for each furnace.

The method for doing this can best be illustrated by use of Fig. 11, reproduced from the performance curves for the cast-iron, circular-radiator furnace, shown in Figs. 5 and 10. At a 175-deg. F. register air temperature, a register delivery of 112 200 B.t.u. per hour is shown. Corresponding values of draft, flue gas temperature, bonnet efficiency, and combustion rate were 0.05 in. of water, 780 deg. F., 58.0 per cent, and 7.5 lb., respectively. These values were tabulated as shown in part B of Table 1. The same procedure was followed for each of the other six furnaces included in Figs. 5 and 10, and the values read from Table 1 were plotted against the corresponding square feet of heating surface, as shown in Fig. 12a.

From Fig. 12a it may be observed that the register air delivery was nearly constant at 112 000 B.t.u. per hour over the whole range of heating surfaces. However, with heating surfaces of less than 60 sq. ft., in order to obtain this high register delivery it was necessary to exceed flue gas temperatures of 800 deg. F., and efficiencies were low. Furthermore, with heating surfaces less than 53 sq. ft. the combustion rates exceeded 8 lb., and the draft exceeded 0.08 in. of water. Since these values of flue gas temperature and combustion rate were too high to be practical, it became evident that limits should be imposed on these as well as on the register air temperature.

TABLE 1

DIMENSIONS AND PERFORMANCE OF SIX TYPES OF FURNACES

| Item No.	Small Radiator, Steel	Open Dome, C.I.	Open Dome, C.I.	Crab Radiator, C.I.	Diving Flue, Steel	Circular Radiator, C.I.	Crescent Radiator, Steel
A. Physical Dimensions							
1. Heating surface, sq. ft.	33.6	43.7	48.6	51.5	58.6	60.3	67.8
2. Grate diameter, in.	21.6	20.5	22.5	22.0	22.1	23.0	21.5
3. Grate area, sq. ft.	2.55	2.29	2.76	2.64	2.67	2.88	2.47
4. Ratio of heating surface to grate area	13.2	19.1	17.6	19.5	21.9	20.9	27.5
5. Casing diameter, in.	48	48	50	48	50	50	54
B. Performance at 175 deg. F. Register Air Temperature							
6. Register delivery, B.t.u. per hr.	115 000	111 000	111 800	111 000	110 100	112 200	117 800
7. Bonnet capacity, B.t.u. per hr.	154 000	148 000	149 000	148 000	147 000	150 000	157 000
8. Input, B.t.u. per hr.	440 000	322 000	281 000	271 000	280 000	269 000	255 000
9. Bonnet efficiency, per cent	35.0	46.0	53.0	54.5	52.5	58.0	61.5
10. Combustion rate, lb. per sq. ft. per hr.	13.3	10.9	8.25	8.20	8.00	7.50	8.30
11. Maximum flue gas temp, deg. F.	1 210	1 010	990	890	835	780	680
12. Draft, in. water	0.20	0.13	0.12	0.08	0.09	0.05	0.08
13. Equivalent register air temperature, deg. F.	175	175	175	175	175	175	175
C. Performance at 800 deg. F. Flue Gas Temperature							
14. Register delivery, B.t.u. per hr.	57 000	76 000	80 600	95 000	105 800	120 000	143 500
15. Bonnet capacity, B.t.u. per hr.	76 000	101 500	107 600	126 700	141 000	160 000	191 300
16. Input, B.t.u. per hr.	138 000	197 000	188 500	219 000	261 000	288 000	317 000
17. Bonnet efficiency, per cent	55.0	51.5	57.0	57.8	54.0	55.5	60.3
18. Combustion rate, lb. per sq. ft. per hr.	4.2	6.6	5.3	6.6	7.5	8.0	10.9
19. Maximum flue gas temp, deg. F.	800	800	800	800	800	800	800
20. Draft, in. water	0.05	0.05	0.07	0.05	0.08	0.06	0.04
21. Equivalent register air temperature, deg. F.	132	146	150	161	170	180	191
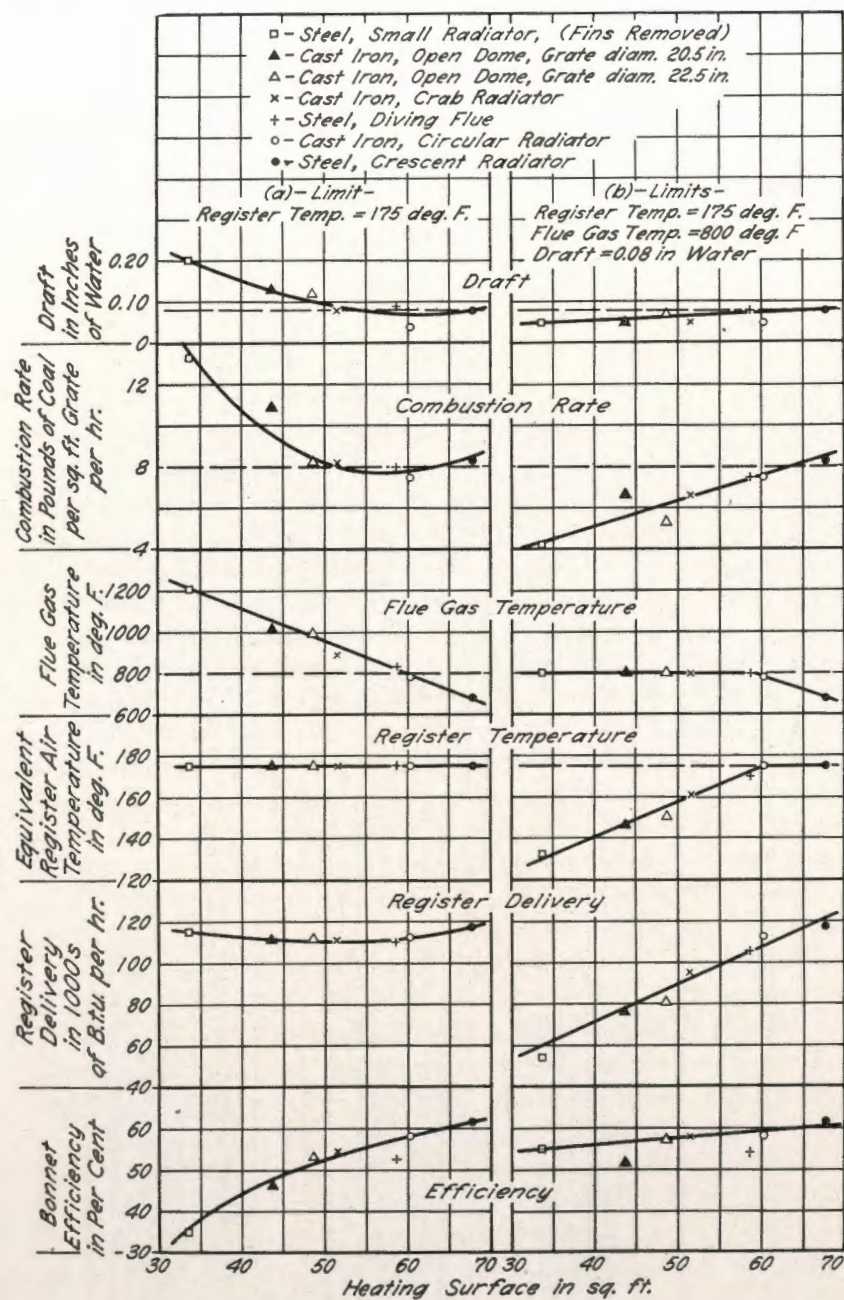
FIG. 12. RELATION BETWEEN PERFORMANCE AND HEATING SURFACE
FOR HAND-FIRED FURNACES

11. *Register Delivery as Affected by Limitations of Register Air Temperature, Flue Gas Temperature, and Draft.*—In recently-developed test codes,* flue gas temperatures have been limited to values not in excess of from 800 to 1000 deg. F., and metal surface temperatures to values not in excess of about 1000 deg. F. These limits were imposed to assure durability of the metal heating surfaces as well as reasonable efficiencies, and should be equally applicable to a rating equation based on physical dimensions. The relations between flue gas temperatures and metal surface temperatures were therefore investigated for each of the six furnaces. It was found that the temperature difference between the metal surface and the flue gas was largely dependent upon the design of the furnace, and that a flue gas temperature of 800 deg. F. was accompanied by metal surface temperatures ranging from about 900 to 1200 deg. F. A flue gas temperature of 800 deg. F. was therefore regarded as a reasonable limit for hand-fired furnaces.

In the case of the cast-iron circular-radiator furnace used as an example, the performance curves in Fig. 11 show that a flue gas temperature of 800 deg. F. corresponded to a register delivery of 120 000 B.t.u. per hour. Corresponding values of draft, register air temperature, bonnet efficiency, and combustion rate were 0.06 in. of water, 180 deg. F., 55.5 per cent, and 8.0 lb., respectively. These values were tabulated as shown in part C of Table 1, and the same procedure was followed for each of the other six furnaces, making use of Figs. 5 and 10.

The ability to produce a draft of at least 0.12 inch of water with a good fire has been commonly used as a criterion for an acceptable chimney. Since some draft loss occurs between the chimney and the smoke collar of the furnace, an available draft at the smoke collar of the order of 0.08 inch was considered as readily obtainable by a properly-built chimney, and hence was used as the upper limit. In the case of the performance curves, shown in Fig. 11, for the cast-iron, circular-radiator furnace, a draft of 0.08 inch was accompanied by a flue gas temperature of 870 deg. F. and a register air temperature of 192 deg. F. Similarly, for each of the other six furnaces, the limiting draft of 0.08 inch resulted in flue gas temperatures or register air temperatures exceeding the 800 deg. F. and 175 deg. F. previously adopted as limits. Therefore, the application of a limit on draft was not considered necessary.

For each furnace the two sets of performance values, shown in parts B and C of Table 1, were compared, and the set accompanying the lower delivery was selected for plotting. These values were then

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* See Chapter V.

plotted against the square feet of heating surface as shown in Fig. 12b. The limiting values are indicated by horizontal broken lines.

Figure 12b shows that the points for register delivery could be represented by a mean straight line, intersecting the axes at zero. Furthermore, only one point representing an individual furnace deviated from the curve by as much as 7 per cent, and the average deviation was only 3.7 per cent. This curve, which constitutes a rating curve, is expressed by the equation

$$\text{Reg. Del.} = 1785S \qquad (4)$$

in which Reg. Del. is the register delivery in B.t.u. per hour, and S is the heating surface in square feet. For furnaces not deviating greatly from conventional design, register deliveries calculated from this equation will be attained without the limits of 175 deg. F. register air temperature and 800 deg. F. flue gas temperature being exceeded.

It may be observed from Fig. 12b that for furnaces having heating surfaces of less than 60 sq. ft. the register air temperatures were less than 175 deg. F. The heating plant used for the tests on the seven furnaces was provided with 808 sq. in. of leader pipe, and was oversized for all furnaces having heating surfaces of less than 60 sq. ft. Hence, for a given small-sized furnace with a heating surface of less than 60 sq. ft. and with a heat input corresponding to the combustion rate shown on the curve, a register air temperature of less than 175 deg. F. would normally be expected.

The curves for leader-pipe carrying capacity shown in Fig. 8 were obtained from the same plant as that in which these furnaces were tested. They are based on a temperature of 175 deg. F., and involved the resistance of the oversized duct system. As explained in Section 6, a plant having a smaller leader pipe area, designed from these same curves, would circulate a proportionately less amount of air at the same input, but would have practically the same resistance. Hence it would be expected to operate at a register air temperature of 175 deg. F. if a register delivery corresponding to the square feet of heating surface were developed. Therefore, if these smaller furnaces having smaller areas of heating surface were installed in the proper-sized plant, as designed from the leader-carrying capacities shown in Fig. 8, they should develop the deliveries obtained from the curves of Fig. 12b, but the register air temperatures would approximate 175 deg. F. An analysis of available data also indicated that, under these conditions,

the register air temperature would not exceed 175 deg. F. if the plant were operated at its rated capacity.

12. *Grate Area as a Limit of Rating of Hand-Fired Furnaces.*— The register deliveries shown by the rating curves in Fig. 12b and Equation (4) are dependent only on the area of the heating surface. These register deliveries can be obtained without exceeding 175 deg. F. register air temperature and 800 deg. F. flue gas temperature provided that sufficient heat input is available. With small grates, high combustion rates would be required in order to obtain sufficient heat input to give the allowable rated capacity. The combustion rates shown in Fig. 12b have been represented by a single mean curve. This was possible because the grates in the furnaces tested did not vary greatly in size, variations in the S/G ratio being brought about by the variations in the amount of heating surface. Actually, the combustion rates should be represented by a family of curves, the higher curves corresponding to the smaller grates accompanying the higher ratios of S/G. Parts of these higher curves represent combustion rates greater than 8 lb., indicating that the required register air deliveries could not be obtained without exceeding an 8 lb. combustion rate. Such combustion rates are above the practical limits for house-heating service. It is, therefore, evident that in order that the maximum effectiveness of the heating surface may be utilized, some lower limit must be placed on the grate area to be used in conjunction with the heating surface.

Based on a fuel having a calorific value of 12 500 B.t.u. per lb., combustion rates corresponding to various S/G ratios were, therefore, calculated and plotted against the ratio of heating surface to grate area, as shown in Fig. 13. For the purpose of calculation, the efficiencies shown in Fig. 12b, corresponding to the ratios of S/G represented by the test points, were first plotted against the ratios of heating surface to grate area. This also has been shown in Fig. 13. The following equations give the relation between the combustion rate and the register delivery shown by the rating curve in Fig. 12b:

$$\text{Combustion Rate} = \frac{\text{Input}}{\text{Calorific Value of Fuel} \times \text{Grate Area}} \qquad (5)$$

$$\text{Input} = \frac{\text{Register Delivery}}{\text{Duct Transmission Efficiency} \times \text{Bonnet Efficiency}}. \qquad (6)$$
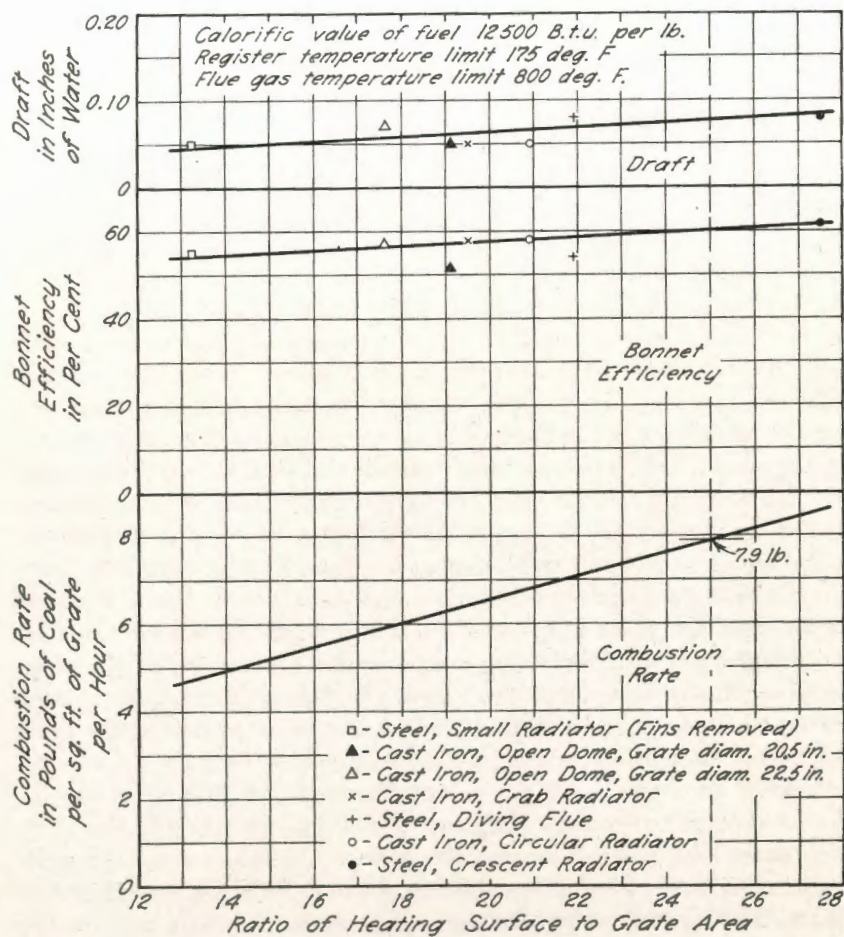
FIG. 13. COMBUSTION RATES REQUIRED WITH VARIOUS RATIOS OF
HEATING SURFACE TO GRATE AREA

By assuming a duct transmission efficiency of 75 per cent, Equations
(4), (5), and (6) may be combined and simplified as follows:

$$\text{Combustion Rate} = \frac{\text{Ratio of Heating Surface to Grate Area}}{5.25 \times \text{Bonnet Efficiency}}. \quad (7)$$

Combustion rates were evaluated from Equation (7) by assuming
various S/G ratios and using the corresponding bonnet efficiencies
shown in Fig. 13. These combustion rates are shown in the lower curve
in Fig. 13.

It may be observed from this figure that with S/G ratios above
25 the combustion rate and draft exceeded the practical limits of 8 lb.
and 0.08 in., respectively, applicable to hand-fired coal furnaces con-
nected to an average chimney. It is evident that even though the
heating surface were available with the smaller grates accompanying
the S/G ratios above 25, it would not be possible to utilize the effec-
tiveness of these heating surfaces and attain the potential rating given
by Equation (4) without exceeding an 8 lb. combustion rate. The
permissible rating for these higher S/G ratios should, therefore, be
limited to a register delivery that could be obtained with a 25 to 1
ratio and an 8 lb. combustion rate. By incorporating these limits in
Equation (4), the modified equation for hand-fired furnaces having
an S/G ratio greater than 25, then becomes

$$\text{Reg. Del.} = 1785 \times 25G \quad (8)$$

in which $25G$ represents the maximum amount of heating surface for
which credit is given.

The ceiling placed on the rating for furnaces having S/G ratios
greater than 25 should be regarded not as a penalty to discourage the
use of these higher ratios, but as a safeguard to prevent the publica-
tion of ratings that probably could not be attained in the average
residence. It is true that a larger amount of heating surface used in
conjunction with a given grate should result in a somewhat higher
efficiency. Such an increase in efficiency could have been provided for
in the rating equation. However, an inspection of the efficiency curve
in Fig. 13 indicates that such an increase would be only of the order
of one or two per cent; and it was therefore considered not advisable
to introduce further complications. Furthermore, with a given firepot
volume, as indicated in Appendix B, as the rating of a furnace in-
creases, the firing interval becomes shorter, and if firing interval
became an element in the rating, further limitations on register de-
livery would be imposed. Hence, taking everything into consideration,
Equation (8) was considered both reasonable and practical for the
rating of furnaces having S/G ratios in excess of 25. There is nothing
to prevent the extrapolation of the rating curve, shown in Fig. 12b, to
include furnaces with exceedingly low S/G ratios. However, the lower
range of test data did not go below an S/G ratio of 13. Furthermore, as
shown in Fig. 13, with furnaces having S/G ratios of less than 15, the
combustion rates required to develop full rated register delivery would
be of the order of 5 lb. or less, and under mild weather conditions
would be less than 2 lb. With normally fitting ash pit and feed doors
it would be difficult to maintain such low combustion rates. In addi-

tion, furnaces with relatively large grates, accompanied by low ratios, are not satisfactory, because there is always the possibility that they may be fired at rates above those advisable for the amount of heating surface involved, thus resulting in dangerously high metal temperatures. Hence, for the reasons enumerated, it has been considered advisable to limit the application of Equation (4) by excluding furnaces having S/G ratios of less than 15.

In the case of hand-fired furnaces converted to stoker, oil, or gas firing the heat input is not limited by a nominal grate area represented by the area of the bottom of the firepot. Hence the ratio of heating surface to grate area has no physical significance, and the limitations imposed by S/G ratios in the case of hand-fired furnaces are no longer applicable. On the other hand, the limitations imposed by register air temperature and flue gas temperatures are still valid throughout the range of the rating curve. It may seem that efficiencies in the case of the converted units should be somewhat higher than those obtained with hand firing, thus providing an extra safety factor. However, the data used in the derivation of the rating curves and equations were all based on the use of anthracite. Experience in the Research Residence, as discussed in Bulletin 246, pages 84-89 and in Bulletin 318, pages 39-45, indicated that the overall efficiency with gas was the same as, and with oil was less than, that obtained with anthracite. Hence, approximately the same sized furnace would be necessary in each case, and for hand-fired furnaces converted to stoker, oil, and gas firing, Equation (4) may be considered to apply without any limitations based on S/G ratios.

13. *Summary of Revised Gravity Rating Equations.*—For convenience the rating equations stated in the previous section, and the conditions under which they are to be used, may be restated as follows:

(a) For all hand-fired coal furnaces converted to stoker, oil, or gas firing,

$$\text{Reg. Del.} = 1785 \times S. \tag{4}$$

(b) For hand-fired furnaces having ratios of heating surface to grate area of more than 15 and less than 25 to 1,

$$\text{Reg. Del.} = 1785 \times S. \tag{4}$$

(c) For hand-fired furnaces having ratios of heating surface to grate area of more than 25 to 1,

$$\text{Reg. Del.} = 1785 \times 25G \tag{8}$$

in which

    Reg. Del. = register delivery, in B.t.u. per hr.

         S = heating surface, in sq. ft.

         G = grate area, in sq. ft.

If equivalent ratings in square inches of leader pipe are desired they may be obtained by dividing the results from Equations (4) or (8) by 136. Bonnet capacities in B.t.u. per hour may be similarly determined by dividing by 0.75, representing the duct transmission efficiency.

Since the original test data were obtained with furnaces having conventional design and arrangement of heating surfaces, and having ratios of free area to gross area of the casing of not less than 0.4, the rating equations should not be used for furnaces deviating materially from these specifications.

In any case, if the furnace is to deliver its rated output in a given installation, a chimney capable of giving drafts at the smoke outlet of the furnace of the order of those shown in Fig. 13 must be provided. Since these drafts are readily obtainable with reasonably good chimney construction, no necessity should arise for reducing the ratings calculated from the rating equations.

Owing to draft limitations, in the case of hand-fired furnaces having S/G ratios greater than 25, if anthracite having a calorific value of materially less than 12 500 B.t.u. per lb. is used, the register deliveries calculated from the rating equations probably cannot be obtained.

In the case of hand-fired furnaces using bituminous coal, since the draft requirements are less than for anthracite, it is probable that the calculated ratings may be obtained with fuels having a calorific value as low as 9 000 B.t.u. per lb.

14. *Comparison of Revised Rating Equations with Standard Code Equation.*—For hand-fired furnaces with ratios of heating surface to grate area between 15 and 25, the ratio of the revised ratings, Equation (4), to the Standard Code rating, Equation (2), is

$$\frac{\text{Revised Rating}}{\text{Standard Code Rating}} = \frac{1785S}{136 \times 1.75 \times 144G\left[1 + 0.02(R-20)\right]}$$

$$= \frac{R}{11.5 + 0.383R}. \tag{9}$$

For hand-fired furnaces with ratios of heating surface to grate area in excess of 25, the ratio of the revised rating, Equation (8), to the Standard Code rating, Equation (2), is

$$\frac{\text{Revised Rating}}{\text{Standard Code Rating}} = \frac{1785 \times 25 \times G}{136 \times 1.75 \times 144G \left[1 + 0.02(R-20)\right]}$$

$$= \frac{25}{11.5 + 0.383R}. \tag{10}$$

The values of the ratios computed from Equations (9) and (10) are shown plotted against S/G ratios in Fig. 14. The portion of the curves between the S/G ratios of 15 and 30 are shown as full lines, representing the limits originally adopted for the application of the Standard Code rating equation. It may be observed that at an S/G ratio of 18.7 the two equations gave identical ratings, and that, between the ratios of 16 and 22, the difference between the revised rating and the Standard Code rating lies between $+10$ per cent and -10 per cent. The majority of furnaces are represented by this range. Hence it is evident that in most cases no material change in ratings will be made necessary by the adoption of the revised rating equation.
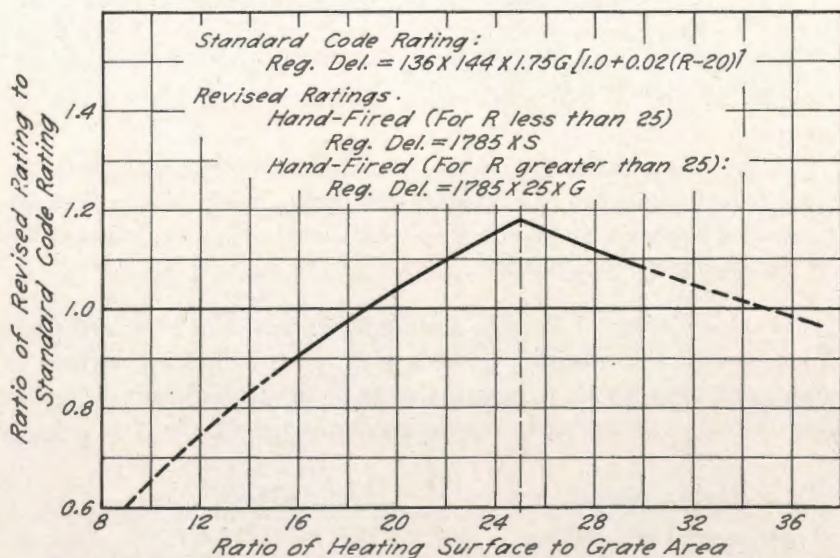
FIG. 14. COMPARISON OF REVISED RATING WITH STANDARD CODE RATING
FOR HAND-FIRED GRAVITY FURNACES

Furnaces having S/G ratios between approximately 19 and 34, which previously had been somewhat underrated, will all receive the advantage of higher ratings. Furnaces having S/G ratios less than 16, which previously had been overrated, will receive material reductions in rating, thus bringing the ratings more nearly in conformity with the performance as experienced in actual installations.

V. RATING OF FORCED-AIR FURNACES

15. *Scope of Revised Rating Equations.*—In the case of forced-air furnaces, the weight of air circulated is independent of the combustion rate. Hence there is no simple relation between the weight of air circulated, the rise in temperature of the air, and the combustion rate, as there is in the case of a gravity furnace. In the case of a forced-air furnace the weight of air circulated cannot be directly correlated with the physical dimensions of the furnace so as to derive a simple rating equation, which covers the whole range of possible conditions. For this reason the ratings of forced-air furnaces should be based on actual performance tests made under specified standard conditions, as formulated in test codes.

At the present time the following codes for testing and rating forced-air furnaces are either in use, or in the formative stage:

(1) "American Standards Approval Requirements for Central Heating Gas Appliances," American Gas Association, 420 Lexington Avenue, New York, 17, N.Y.

(2) "Tentative Code for Testing Oil-Fired, Fan-Furnace Units," National Warm-Air Heating and Air Conditioning Association, 145 Public Square, Cleveland, 14, Ohio.

(3) "Warm-Air Furnaces Equipped With Vaporizing Pot Type Burners," National Bureau of Standards, Commercial Standard No. CS 104-43.

(4) "Solid-Fuel-Burning, Forced-Air Furnaces," National Bureau of Standards, Commercial Standard No. CS 109-44. (Applicable to furnaces with bonnet capacities not exceeding 80 000 B.t.u. per hr.)

These four test codes do not specifically cover the following three classes of equipment, although it is probable that eventually such codes will be developed:

(1) Hand-fired furnaces having a bonnet capacity in excess of 80 000 B.t.u. per hour

(2) Hand-fired furnaces converted to stoker, oil, or gas firing

(3) Furnaces designed for stoker firing.

Meanwhile, the rating equation given in the Technical Code* has been used for rating hand-fired furnaces. This equation has not proved satisfactory because the safety factors and efficiencies used were not consistent with those employed in the Standard Code rating equation. As a result, the rating of a given furnace to be used in a forced-air plant was considerably higher than the rating of the same furnace to be used in connection with a gravity warm-air plant. Experience in the Research Residence, as discussed in Engineering Experiment Station Bulletin 266, pages 40-43, indicated that a material difference in the rating of the same furnace used in the two different types of plants was not justified.

Hence, in the absence of test codes for hand-fired furnaces having bonnet capacities exceeding 80 000 B.t.u. per hour, it was considered advisable to adopt a rating equation more nearly consistent with those used for rating gravity warm-air furnaces. For this purpose, it was decided that Equations (4) and (8), derived for the rating of gravity warm-air furnaces, could be modified with sufficient accuracy to apply to a range of air volumes usually encountered in forced-air installations.

16. *Derivation of Revised Rating Equations.*—At a constant heat input, the register delivery of the same furnace used for both forced-air heating and gravity heating is directly proportional to the products of the bonnet efficiency and the duct transmission efficiency applying to each type of installation. That is

$$\frac{\text{Reg. Del., Forced Air}}{\text{Reg. Del., Gravity}} = \frac{E_1 \times E_2}{E_3 \times E_4} \qquad (11)$$

in which

Reg. Del., Forced Air = register delivery for forced-air operation, in B.t.u. per hr.

Reg. Del., Gravity = register delivery for gravity operation, in B.t.u. per hr.

E_1 = bonnet efficiency for forced-air operation

E_2 = duct transmission efficiency for forced-air operation

E_3 = bonnet efficiency for gravity operation

E_4 = duct transmission efficiency for gravity operation.

* "The Technical Code for the Design and Installation of Mechanical Warm-Air Heating Systems." National Warm-Air Heating and Air Conditioning Association, 145 Public Square, Cleveland 14, Ohio.

As shown by the curve in Fig. 12b, an average bonnet efficiency, E_3, of 58 per cent is representative for the gravity rating Equations (4) and (8). A duct transmission efficiency, E_4, of 75 per cent was assumed for the derivation. A series of tests conducted on the cast-iron, circular-radiator furnace installed in a forced-air plant in the Research Residence, as described in Bulletin 246, indicated that a bonnet efficiency, E_1, of 65 per cent was representative of forced-air operation. A duct transmission efficiency, E_2, of 85 per cent has been generally used.

Substituting these efficiencies in Equation (11)

$$\frac{\text{Reg. Del., Forced Air}}{\text{Reg. Del., Gravity}} = \frac{0.65 \times 0.85}{0.58 \times 0.75} = 1.27. \qquad (12)$$

Multiplying the gravity rating equations, (4) and (8), by 1.27 the following equations are obtained for the rating of forced-air furnaces:

(a) For all hand-fired coal furnaces converted to stoker, oil, or gas firing,

$$\text{Reg. Del.} = 2265 \times S \qquad (13)$$

(b) For hand-fired furnaces having ratios of heating surface to grate area of more than 15 and less than 25 to 1,

$$\text{Reg. Del.} = 2265 \times S \qquad (13)$$

(c) For hand-fired furnaces having ratios of heating surfaces to grate area of more than 25 to 1,

$$\text{Reg. Del.} = 2265 \times 25 \times G \qquad (14)$$

in which

Reg. Del. = register delivery, in B.t.u. per hr.

S = heating surface, in sq. ft.

G = grate area, in sq. ft.

$25G$ = maximum amount of heating surface for which credit is given.

If bonnet capacities in B.t.u. per hour are desired they may be obtained by dividing the register deliveries by the duct transmission efficiency, 0.85.

17. Comparison of Revised Rating Equation with Technical Code Equation.—The following equation was used in the Technical Code for the purpose of rating hand-fired, forced-air furnaces:

$$\text{Reg. Del.} = 0.85\,(G \times E \times F \times C)\,[1 + 0.02\,(R - 20)] \quad (15)$$

in which

Reg. Del. = register delivery, in B.t.u. per hr.

0.85 = duct transmission efficiency

G = grate area, in sq. ft.

E = bonnet efficiency, assumed as 0.65

F = calorific value of fuel, in B.t.u. per lb.

C = combustion rate, in lb. per sq. ft. of grate area per hr.

R = ratio of heating surface to grate area.

Based on the values of 7.5 lb. for maximum combustion rate and 12 000 B.t.u. per lb. for calorific value, recommended in the Technical Code, Equation (15) reduces to

$$\text{Reg. Del.} = 49\,500G\,[1 + 0.02\,(R - 20)]. \quad (16)$$

For hand-fired furnaces with ratios of heating surfaces to grate area between 15 and 25, the ratio of the revised rating, Equation (13), to the Technical Code rating, Equation (16), is

$$\frac{\text{Revised Rating}}{\text{Technical Code Rating}} = \frac{2265 \times S}{49\,500 \times G\,[1 + 0.02\,(R - 20)]}$$

$$= \frac{R}{13.1 + 0.435R}. \quad (17)$$

For hand-fired furnaces with ratios of heating surface to grate area in excess of 25, the ratio of the revised rating, Equation (14), to the Technical Code rating, Equation (16), is

$$\frac{\text{Revised Rating}}{\text{Technical Code Rating}} = \frac{25}{13.1 + 0.435\,R}. \quad (18)$$
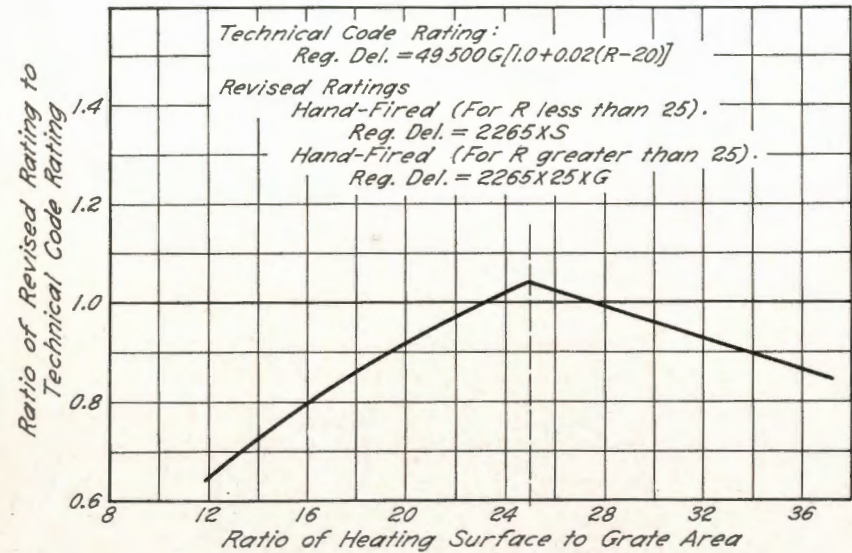
FIG. 15. COMPARISON OF REVISED RATING WITH TECHNICAL CODE RATING FOR HAND-FIRED FORCED-AIR FURNACES

The values of the ratios computed from Equations (17) and (18) are shown plotted against S/G ratios in Fig. 15. With the exception of furnaces having S/G ratios between 23 and 27.4, which are subject to slight increases in rating, the ratings of all other hand-fired furnaces will be reduced by the adoption of the revised rating equations. The adoption of the revised equations, however, will bring the rating of forced-air furnaces more nearly in conformity with the rating of gravity furnaces, and with the performance as experienced in actual installations.

VI. RATING OF PIPELESS FURNACES

18. Method of Rating.—A common form of pipeless furnace, shown in Fig. 16, is provided with an outer casing and a double-walled inner casing or radiation shield, both of which are connected to a single large floor register. Heated air rises in the space between the inner casing and the furnace, and is discharged through the center portion of the register. The return air enters the outer portion of the register and descends in the space between the outer and inner casings. In some
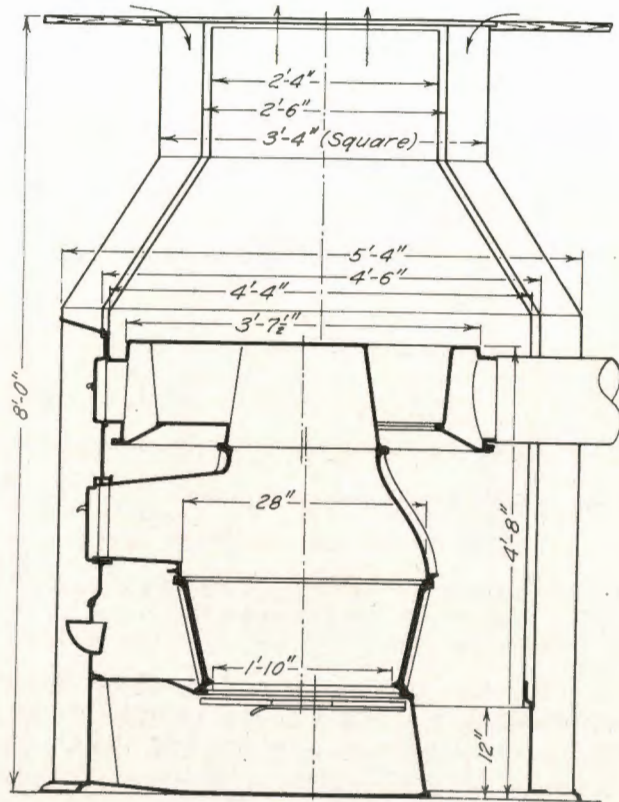
FIG. 16. SECTIONAL ELEVATION OF PIPELESS FURNACE

installations one or more separate return-air grilles, ducts, and shoes are provided, and the central register serves only to deliver heated air.

The Standard Code rating equation and the revised gravity rating equations apply strictly only to furnaces used in connection with central plants having pipes or ducts designed in accordance with Code specifications, and not to pipeless furnaces, for which there has been no equivalent rating procedure. However, there is a limited but consistent demand for such units, and some method for selecting the proper size of furnace should be available. It has been suggested that, owing to the elimination of duct transmission losses and to the radiation of heat from the top of the furnace directly into the heated space, an increase in rating would be justified for a furnace installed as a
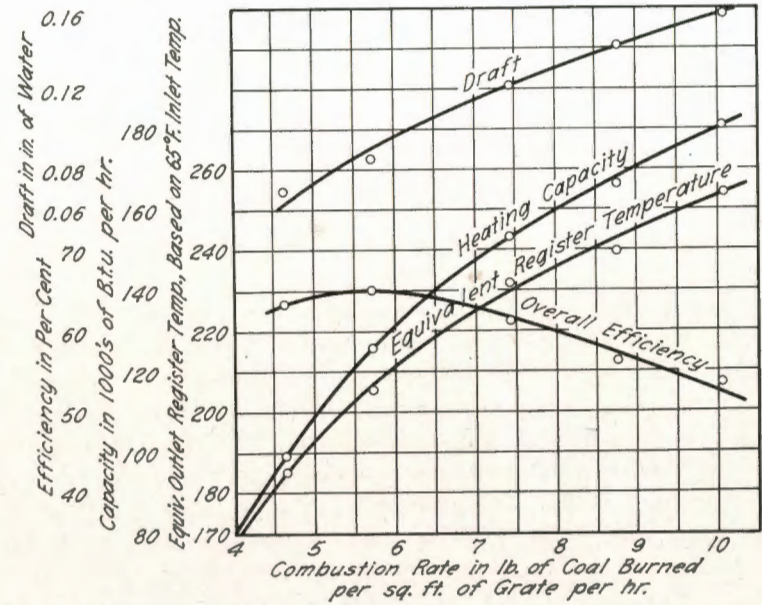
FIG. 17. PERFORMANCE CURVES FOR PIPELESS FURNACE

pipeless unit, as compared with the rating of the same furnace installed in a central plant.

The validity of the gravity rating equation, Equation (4), as applied to the pipeless furnace, can be examined by making use of the results of a series of tests reported in Bulletin 120. The furnace tested was of the cast-iron, circular-radiator type, and was installed as shown in Fig. 16. The grate area was 2.64 sq. ft., and the area of the heating surface was approximately 53 sq. ft.

The rated register delivery of a furnace of the same size used in a piped furnace plant, as calculated from the gravity rating equation would be: $1785 \times 53 = 94\ 600$ B.t.u. per hr. Since the gravity rating equation was originally based on test results, there is ample assurance that this furnace used as a pipe furnace would actually develop the 94 600 B.t.u. per hr. without exceeding an equivalent register air temperature of 175 deg. F.

The design temperature of 175 deg. F. for the piped furnace was originally selected as being reasonable, and consistent with minimizing stratification, thus giving the greatest amount of comfort. From this

standpoint there is no reason to believe that materially higher register air temperatures should be used in connection with the pipeless furnace. The application of the rating equation to the pipeless furnace having 53 sq. ft. of heating surface also results in a register delivery of 94 600 B.t.u. per hr. At a register air temperature of 175 deg. F., the performance curves shown in Fig. 17, reproduced from Bulletin No. 120, indicate that a bonnet capacity of 90 000 B.t.u. per hr. would actually be developed. Since there would be practically no loss between the bonnet and register, this bonnet capacity may also be considered as the register delivery. Further consideration of the curves in Fig. 17 indicates that a register delivery of 94 600 B.t.u. per hr. could be developed at a register air temperature of 180 deg. F. This increase above 175 deg. F. is not serious, and there is no indication that the rating of a given furnace should be greater for a pipeless than for a piped installation. Hence, there seems to be sufficient justification for a recommendation that the pipeless furnace be rated by application of the same rating equation, Equation (4), as that used for a piped furnace having the same amount of heating surface. For a given building, a pipeless furnace having a rated register delivery equal to, or greater than, the design heat loss from the structure would then be selected.

Appendix A

Finned Heating Surfaces

1. *Evaluation of Finned Heating Surfaces.*—The results of a limited study of finned, or extended, heating surfaces as affecting furnace performance were reported in Engineering Experiment Station Bulletin 246. An empirical rule was proposed giving full credit to both sides of the first two inches of the fin, measured from the direct heating surface, and one-half credit to the next two inches. The experimental evidence available at that time was meager and did not entirely support the rule, but the latter was provisionally accepted. Subsequent study of the data indicates that the rule was too liberal, and that fins not firmly attached and having only line contact with the heating surfaces are less effective than those continuously welded to, or cast, as a part of the direct heating surface.

There appears to be some relation between the ratio of direct heating surface to grate area and the effectiveness of the fins. When fins were attached to a furnace having a high ratio of heating surface

TABLE 2
ALLOWANCES FOR FINNED SURFACES

Distance from Direct Surface	Ratio of Effective Area to Total Area	
	Integral Fin	Non-Integral Fin
First Inch....................................	0.40	0.30
Second Inch.................................	0.30	0.20
Third Inch..................................	0.20	0.15
Over 3 Inches...............................	None	None

to grate area, they were not so effective as those attached to a furnace having a low ratio. Furthermore, fins attached to indirect, or secondary, heating surfaces were not so effective as those attached to direct, or primary, heating surfaces. There seems to be some evidence that the inclusion of additional surface in the form of fins is subject to the law of diminishing returns.

Data are not available on the rate of heat transfer in the case of finned surfaces used under the conditions existing in warm-air furnaces. For this reason it is probable that the rating of these furnaces should be considered as outside of the scope of the rating equations, and that all such ratings should be made by tests. Meanwhile, with the increasing trend toward compact furnaces, fins may become of increasing importance, and the allowances shown in Table 2 are proposed to serve as approximations. In computing the total area, both sides of the fin are to be considered as heating surface.

Appendix B

Firing Periods for Hand-Fired Furnaces

1. *Equations for Firing Periods.*—The present method of rating hand-fired, coal furnaces by means of the rating equations does not provide for any determination of the time required to burn an available charge of fuel. The latter is known as the firing period, and may otherwise be defined as the maximum number of hours that the furnace can be operated at rated capacity, starting with a full charge of fuel, before it becomes necessary to fire a succeeding charge. Since, in some cases, the firing period may have an importance equal to that of the rated capacity, a uniform method of calculation should be adopted.

The equations to be used for this purpose may be derived as follows:

$$\text{Firing Period} = \frac{HEr}{D} \tag{1}$$

in which

H = calorific value of the available portion of the fuel charge, in B.t.u.

E = efficiency based on register delivery, expressed as a decimal fraction

r = regain factor based on overall house efficiency

D = rated register delivery, in B.t.u. per hr.

By making certain assumptions, later discussed in Appendix B, Section 2, the calorific value of the available portion of the fuel charge may be expressed in terms of the firepot volume, and the density and calorific value of the fuel used. Equation (1) may then be written in the form:

$$\text{Firing period} = \frac{0.6VdFE_1E_2r}{D} \tag{2}$$

in which

Firing period = firing period, in hours

0.6 = portion of the volume of the firepot available for a fuel charge (see Appendix B, Section 2)

V = total volume of firepot available for containing both fuel and ash (see Appendix B, Section 2), in cu. ft.

d = density of fuel, in lb. per cu. ft.

F = calorific value of fuel, in B.t.u. per lb.

E_1 = bonnet efficiency, expressed as a decimal fraction

E_2 = duct transmission efficiency, expressed as a decimal fraction

r = regain factor based on overall house efficiency (see Appendix B, Section 3)

D = rated register delivery, in B.t.u. per hr.

A value of 12 500 B.t.u. per lb. is commonly used for the calorific value of fuel. The following are representative of the average densities of the more common fuels: anthracite, 50 lb. per cu. ft.; bituminous coal, 50 lb. per cu. ft.; and coke, 25 lb. per cu. ft.

With a given sized grate, the volume of the firepot can vary only within narrow limits. The heating surface, however, may vary over much wider limits. A furnace having a large S/G ratio, therefore, would have a small firepot volume as compared with the heating surface, and the firing period would consequently be much shorter than that for a furnace having the same sized grate and a small S/G ratio. The latter would be accompanied by a large firepot volume as compared with the heating surface.

2. *Available Firepot Volume.*—It is always possible to fill the firepot to a level above that of the bottom of the firing door. In this case, the portion above the level of the bottom of the firing door may be assumed to take the form of a truncated cone, as shown in Fig. 18. The total volume available for fuel and ash, V, is then the volume of the firepot included between the grate and the level of the bottom of the firing door, plus the volume of a truncated cone 3 in. in height and having sides making an angle of 45 deg. with the horizontal. For a straight-sided firepot this volume is

$$V = \frac{\pi\left[d^2h + 3\,(d-3)^2\right]}{4 \times 1728} \tag{3}$$

in which

V = total volume of firepot available for containing both fuel and ash, in cu. ft.

d = diameter of firepot, in inches

h = height of firepot from grate to level of bottom of firing door, in inches

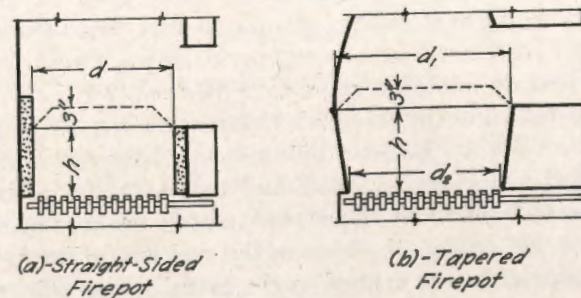π = 3.14, and

1728 = number of cu. in. in one cu. ft.

(a)-Straight-Sided Firepot   (b)-Tapered Firepot

FIG. 18. FUEL VOLUMES FOR TYPICAL FIREPOTS

In the case of a tapered firepot, the volume is

$$V = \frac{\pi \left[0.25H \left(d_1 + d_2\right)^2 + 3 \left(d_1 - 3\right)^2\right]}{4 \times 1728} \tag{4}$$

in which d_1 and d_2 are the diameters of the firepot at the level of the bottom of the firing door and at the level of the grate, respectively, and the other quantities are the same as those shown in Equation (3).

The volume of a firepot having sides other than straight lines may be approximated by use of Equation (4), or more exactly calculated by determining a mean diameter to be used in Equation (3). The volume of rectangular or elliptical firepots may be obtained by computing the mean cross-sectional area and multiplying by the height, then adding the volume of a fuel cap having a height of three inches and sides sloping at an angle of 45 degrees.

In order to ignite the new fuel charge it is always necessary for a considerable portion of the previous charge to remain in the firepot, thus reducing the volume available for a fresh charge. In a number of tests conducted on various types of gravity, hand-fired furnaces, as reported in Engineering Experiment Station Bulletin 141, it was found that from 60 to 65 per cent of the fuel charged could be consumed without causing any reduction in combustion rate. A fresh fuel charge could then be fired and a satisfactory rate of pick-up could be maintained. It was therefore considered that 60 per cent of the total volume of the firepot, V, would be available for the fresh charge, and the figure 0.6 was used in connection with Equation (2).

3. *Overall House Efficiency.*—It may be observed from Equation (2) that the length of firing period is a function of two efficiencies, the product of which represents the efficiency based on register delivery. If it is assumed that none of the losses from the smokepipe, the chimney, the furnace casing, and the ducts is regained within the house, and the efficiency based on register delivery is used, abnormally short firing periods would be given by Equation (2).

Results obtained in the Research Residence, discussed in Engineering Experiment Station Bulletin 189, indicate, however, that many of these so-called losses are regained, and that actually in the case of bituminous coal from 72 to 77 per cent, and in the case of anthracite from 92 to 96 per cent of the heat in the fuel was utilized. This percentage of utilization was defined as the overall house efficiency. It is, therefore, evident that an efficiency higher than one based on register

delivery, or bonnet capacity, should be used in Equation (2). In view of the fact that operating conditions in an average residence may not be so favorable as those obtained in the Research Residence, it seems advisable not to use efficiencies so high as the overall house efficiencies shown in Bulletin 189. Instead of using overall house efficiencies directly, it is recommended that the regain factors shown in Table 3 be used in Equation (2).

TABLE 3
RECOMMENDED REGAIN FACTORS

Type of Fuel	Automatic Control	Regain Factor
Bituminous Coal...	Without	1.1
Bituminous Coal...	With	1.3
Anthracite or Coke...	Without	1.3
Anthracite or Coke...	With	1.5

With the same furnace, the material effect of the fuel used and the method of operation on the length of firing period can best be illustrated by the following examples:

A gravity furnace with a grate diameter of 21.75 in. and a firepot volume, V, of 2.95 cu. ft. has a register delivery of 90 000 B.t.u. per hour. The bonnet efficiency is 0.58, and the duct transmission efficiency is 0.75. With the furnace fully equipped with controls, and anthracite having a calorific value of 12 500 B.t.u. per lb. used as a fuel, the firing period calculated from Equation (2) would be 8.0 hr. If this same furnace were not equipped with controls, and bituminous coal with a calorific value of 12 500 B.t.u. per lb. were used as a fuel, the firing period would be only 5.9 hr.

APPENDIX C

HEATING SURFACE AND GRATE AREA

1. *Definition of Heating Surface.*—Prime heating surface is defined as surface having *hot gases or live fuel on one side and circulating air on the other*. In all cases, it is measured on the air side.

(a) Total heating surface in hand-fired furnaces includes only that heating surface *above the top level of the grate*. The ashpit is not considered as heating surface unless the top level of the grate is below the top of the ashpit, or a portion of the top of the ashpit forms a

portion of the firepot. In this case, only the portion in direct contact with the live fuel is included.

(b) In the case of hand-fired units converted to stoker, oil, or gas firing, the heating surfaces of the original furnace shall be used. The area of the ashpit is disregarded.

(c) The areas of the outer casing, the inner lining, and the radiation shield shall not be included as heating surface.

Extended heating surface may consist of fins, ribs, webs, lugs, or other projections from the prime heating surface. Projections less than $\frac{1}{4}$ inch thick at the base and extending more than 1 inch from the prime surface are classified as fins.

(a) Integral fins are continuously welded to, or cast as a part of, the prime heating surface. Both sides are included as heating surface, subject to the allowances shown in Table 2.

(b) Non-integral fins are spot welded to, or otherwise held in line contact with, the prime heating surface. Both sides are included as heating surface, subject to the allowances shown in Table 2.

(c) In the case of ribs, webs, or lugs more than $\frac{1}{4}$ inch thick at the base and extending less than 1 inch from the prime surface, the entire surface in contact with circulating air is included as heating surface.

(d) In the case of ribs, webs, or lugs more than $\frac{1}{4}$ inch thick at the base and extending more than 1 inch from the prime heating surface, the areas of both sides of the first inch are included as prime heating surface. The portions projecting beyond 1 inch are treated as integral fins.

2. *Measurement of Heating Surface.*—In making the measurements for heating surface the following rules shall apply:

(a) All measurements shall be made on an actual production model, and not from drawings, blueprints, templates, or patterns.

(b) Measurements shall be made to the nearest $\frac{1}{8}$ in. with a steel rule or a flexible steel tape.

(c) Irregularities in dimensions may occur in the course of production. Measurements should be made at several equally-spaced sections and the results averaged.

(d) In the case of furnace parts extending beyond the outer casing, the line of the casing shall be marked, and areas outside this line shall not be included as heating surface.

3. *Definition of Grate Area.*—The *nominal* grate area is defined as the total cross-sectional area of the bottom of the firepot. In steel furnaces the nominal grate area is the cross-sectional area inside the firebrick lining.

The *actual* grate area, used for calculating the ratios of heating surface to grate area, is the nominal grate area minus certain areas that cannot be considered as part of the grate itself. The following rules govern these deductions:

(a) If a solid, continuous ledge extends around the grate and inside the firepot, any area of this ledge extending inside of a circle, the diameter of which is 1 inch less than the diameter of the bottom of the firepot, shall be deducted.

(b) If separate, solid projections extend from the firepot towards the grate, the areas of any portions of these projections extending inside of a circle, the diameter of which is 3 inches less than the diameter of the bottom of the firepot, shall be deducted.

In the case of grates which are inclined, or are conical, the projected area is the same as the nominal grate area. The latter should, therefore, be used, and any necessary deductions made.

4. *Measurement of Grate Area.*—In making the measurements of grate area the following rules shall apply:

(a) All measurements shall be made on an actual production model, and not from drawings, blueprints, templates, or patterns.

(b) Measurements shall be made to the nearest $\frac{1}{8}$ inch with a steel rule or flexible steel tape.

(c) Irregularities in dimensions may occur in the course of production. Measurements of circular firepots shall be made on four diameters and the results averaged. Similar averages should be obtained in the case of non-circular firepots.

Bulletins

358. A Study of Radiant Baseboard Heating in the $I=B=R$ Research Home, by Alonzo P. Kratz and Warren S. Harris. 1945. *Free upon request.*
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