No. 540

HEAT LOSSES FROM DIRECT RADIATION

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Member

It is the purpose of this article to bring together all of the data which seem reliable upon the subject of heat losses from direct radiation. There have been many experiments made by different persons. Some of the results have been reported and some have been allowed to lie dormant. It is the intention of this article to bring together these various results in an endeavor to show the effect which the changes in the shape and size of a radiator, together with the conditions of operation, have upon the heat transmission. This article also discusses the theory of heat transfer from direct radiation and the effect of radiation and convection. All the results in the tables and figures are expressed in B.t.u. given off per square foot per hour and not in the form of a constant. The reason for not using a constant will be seen when the theory of heat transfer has been considered. In work of this kind it is not possible to give results with great accuracy but it is the author's opinion that in most cases the accuracy will be close to 5 per cent, and probably in all cases within 10 per cent.

HEAT LOSSES FROM A DIRECT RADIATOR

A direct radiator is one that is located in the room to be heated, has the air passed over it by natural circulation, and is not connected with the outside air. Direct radiators lose heat in two ways—by radiation and by convection. The heat loss by radiation is the heat which leaves the radiator independently of any heat carried away by the air circulating around the radiator. It passes from the radiator in straight lines in the same way that light passes away from a source of light, and it does not heat the medium through which it passes.

The loss by convection or contact of air is the heat which is carried away by the air coming in contact with the hot surface of the radiator and being heated. This air, when it is heated, rises, new air comes in to take its place, and we have formed, a current of hot air rising from the radiator. The heat carried away by this current of hot air is the heat lost by convection.

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In the following paragraphs will be found a discussion of the effect of various factors upon the heat loss from a direct radiator. In all of this discussion, the formula given in the latter part of the article has been used to check the curves that are given and in many cases has been used to extend the curves beyond the field of investigation. It is the intention to show the effect of different heights, lengths, and widths of radiators upon the heat transmission; also the effect of steam and room temperature, and various other factors that have appreciable bearing upon the heat transmission from direct radiators. It has been customary to assume that a

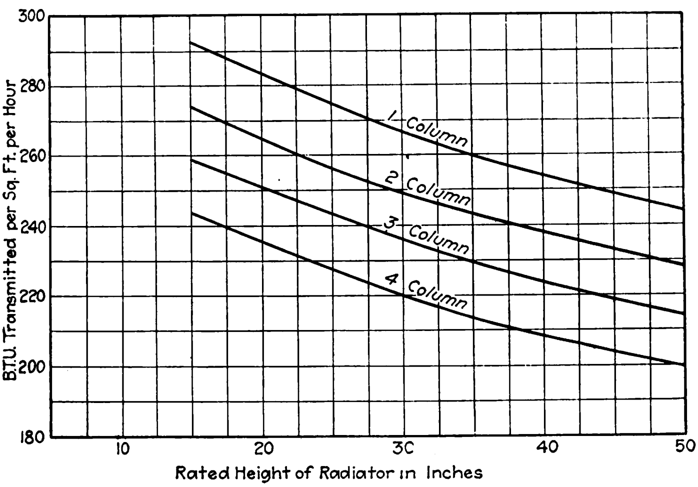

FIG. 1. HEAT TRANSMISSION FOR DIFERENT HEIGHTS AND NUMBERS OF COLUMNS OF RADIATORS

radiator lost about the same amount of heat irrespective of its form or size or condition of operation. It will be seen, however, that there are very wide ranges of heat transmission depending upon the conditions of operation.

EFFECT OF HEAT TRANSMISSION FOR DIFFERENT HEIGHTS AND NUMBERS OF COLUMNS OF RADIATORS

The width of a radiator is usually expressed as a certain number of columns and the height in inches from the floor to the top of the radiator. Table 1 and Fig. 1 show the heat transmission for cast-iron radiators in B.t.u. per hour per square foot of radiator surface in still air at 70 deg. with a steam temperature of 215 deg. The table is made up for radiators of 10 sections in length with different numbers of columns and height. For numbers of sections less than 10, as will be seen in a following paragraph, the heat transmission would be increased.

TABLE 1. B.T.U. TRANSMITTED PER SQUARE FOOT OF RADIATOR PER HOUR FOR DIFFERENT HEIGHTS AND NUMBERS OF COLUMNS

Steam Temperature 215 deg. fahr.—Room Temperature 70 deg. fahr.

Height of Radiator	1 Column	2 Column	3 Column	4 Column
45		233	218	204
38	256	240	226	210
32	265	247	234	218
26	273	255	242	226
23	278	260		
22			248	232
20	283	265		
18			254	238

EFFECT OF HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATORS

The comparison of heat transmission through radiators by different numbers of columns is not strictly correct, as the effect is not due to the number of columns, but is more nearly due to the actual width of the radiator in inches. In order to show this effect, Fig. 2 has been drawn and from this figure has been compiled Table 2. This figure shows the effect of width of radiators on heat transmission under the same general conditions as in Fig. 1. It will be noticed that the heat transmission varies, depending on the actual number of inches in width even including pipe coils approximately, and will be found to compare very favorably with the actual experiments that have been made.

TABLE 2. HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATOR EXPRESSED IN INCHES

Steam at 215 deg. fahr.—Room at 70 deg. fahr.—10 Sections of Radiator

Width of Radiator in inches	Height of Radiator			Width corresponds with
	20 in.	26 in.	38 in.	
3	310	297	288	Wall Coil
4½	287	274	258	Single Column
7⅛	264	251	236	Two Column
9	253	240	226	Three Column
12½	239	225	211	Four Column

EFFECT OF HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

The effect on heat transmission of increasing the length of a radiator is shown in Table 3 and Fig. 3. The curves show that the length of a radiator has a marked effect when the radiator is under 6 sections in length. Above 10 sections the effect of length, in most cases, can be neglected without introducing any appreciable error. The reason for this may easily be explained. In the short radiators the effect of the end is much more apparent than in the long radiators. The effect of the end is to increase the radiating surface in proportion to the convecting surface so that in a short radiator we get a larger proportion of radiant heat than in the long radiator. Curves are plotted for only two heights of radiator, as the relative effect of length remains practically the same in radiators of different heights.

A radiator may also be lengthened by increasing the spacing. A few experiments are available which show the effect of spacing. If the spacing of the standard two-column, 38 in. radiator is changed

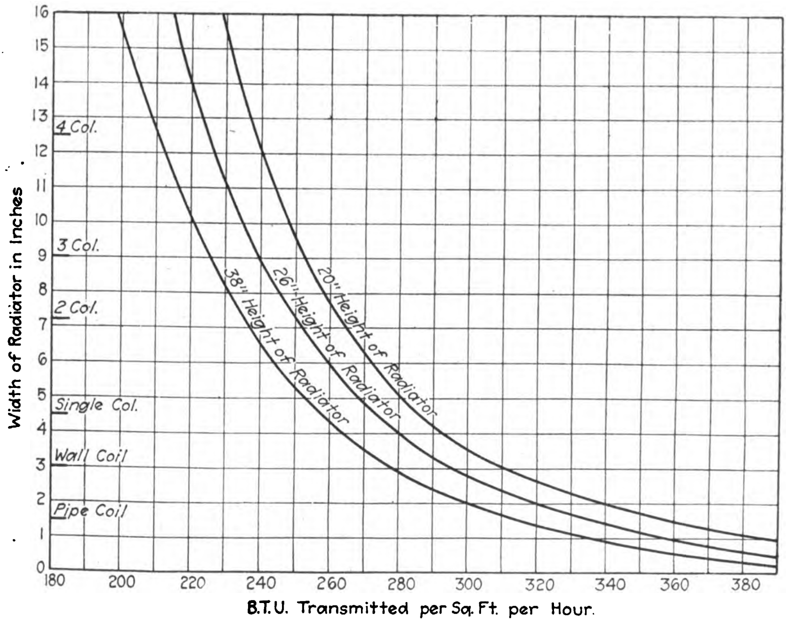

FIG. 2. HEAT TRANSMISSION FOR DIFFERENT WIDTHS OF RADIATORS

from 2 ½ in. to 3 in. the results show that the heat loss is increased about 7 per cent, which would correspond with the results obtained by using the general expression given at the end of this article. The hospital type of radiator is usually spaced ½ in. more than the standard type, so the hospital type may roughly be assumed to give off from 7 to 10 per cent more heat than the standard type.

EFFECT OF CHANGING STEAM AND AIR TEMPERATURES

The effect of changing the steam temperature on the inside of a radiator or the air temperature on the outside of a radiator has a very appreciable effect upon the heat transmission. The changing of the difference in temperature between the steam and air on the two sides of the radiator varies the transmission appreciably on ac-

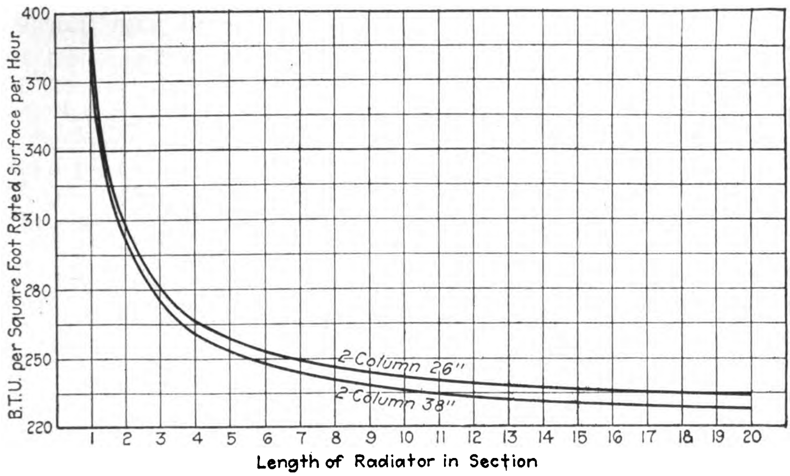

FIG. 3. HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

count of the fact that the radiant heat transmitted varies as the fourth power of the temperature. Table 4 and Fig. 4 show the heat transmission for a two-column 38 in. radiator 10 sections long at different steam and room temperatures. This table and figure have been obtained from actual experiment but have been extended beyond the field of the experiment by the use of the formula derived

TABLE 3. HEAT TRANSMISSION FOR RADIATORS OF VARYING LENGTHS

Steam at 215 deg. fahr.—Room at 70 deg. fahr.

Length of Radiator in Sections	Height of Radiator			
	38 in.	32 in.	26 in.	23 in.
1	387.8	389.0	393.7	391.6
2	302.4	304.0	305.8	308.4
3	274.0	275.8	280.0	282.3
4	260.6	263.3	265.8	269.2
5	252.6	254.0	257.8	259.6
6	247.0	249.2	253.3	254.7
7	242.8	244.9	248.5	251.2
8	240.0	241.7	245.7	248.5
9	237.8	239.8	243.4	246.5
10	235.8	237.8	241.6	244.8
11	234.4	236.4	239.6	243.1
12	233.0	235.2	239.1	242.0
13	232.1	234.2	238.0	240.5
14	231.2	233.6	237.1	239.5
15	230.4	232.6	236.2	238.7
16	229.7	232.0	235.6	237.9
17	229.1	231.1	235.1	237.2
18	228.5	230.6	234.6	237.0
19	228.0	230.2	234.0	236.5
20	227.6	229.7	233.6	235.9

at the end of this article. It will be noted in looking at the plate that increasing the steam temperature increases the heat transmission more rapidly than reducing the room temperature.

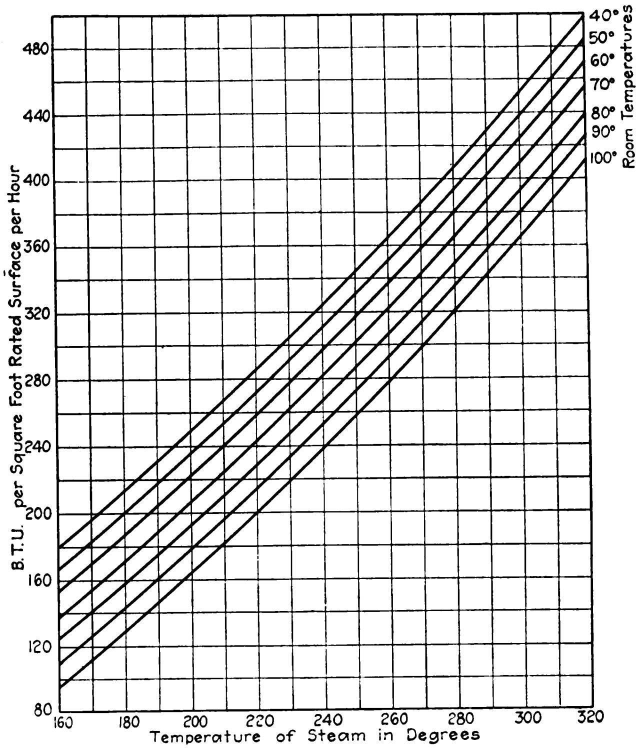

FIG. 4. HEAT TRANSMISSION FOR VARIOUS TEMPERATURES OF STEAM IN RADIATOR AND AIR IN THE ROOM

TABLE 4. HEAT TRANSMISSION FOR VARIOUS TEMPERATURES OF STEAM IN RADIATOR AND AIR IN THE ROOM

Temperature of Steam	Temperature of Air in Room						
	40	50	60	70	80	90	100
160	180	166.4	153.2	138.43	124.2	109.7	94.8
180	213	199.4	186.3	171.40	157.2	142.7	127.8
200	250	236.0	223.2	208.1	194.0	179.6	164.7
220	286.8	273.0	260.1	245.1	231.0	216.5	201.6
240	324.2	311.0	298.5	284.0	269.4	254.9	240.0
260	364.0	351.4	338.3	323.4	309.2	294.7	279.8
280	407.4	393.8	380.0	365.8	351.6	337.1	322.3
300	451.4	437.8	424.7	409.8	395.8	381.1	366.2

EFFECT OF HUMIDITY

Fig. 5 shows the effect of increasing the humidity upon the heat transmission. It will be noted that with extreme change of humidity there is a slight change in the heat transmission, the heat transmission reducing slightly as the humidity increases. Humidity can have very little, if any effect upon radiation, and the effect of humidity must therefore change the convected heat lost by the radiator. This change of convected heat is probably due to the change in the density of the air passing over the radiator.

EFFECT OF AIR CIRCULATION

The amount of heat given off by a radiator may also be increased by increasing the velocity of the air over the surface of the radiator. This increase in velocity will increase the amount of heat carried

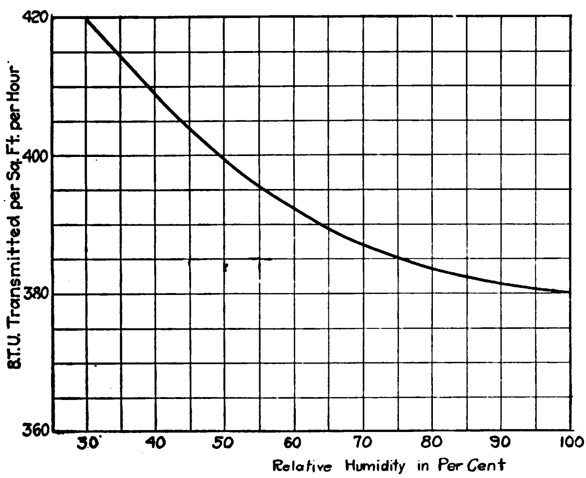

FIG. 5. EFFECT OF HUMIDITY ON HEAT TRANSMISSION

off by convection. No exact data are available on the effects that may be introduced by increasing these velocities over radiator surfaces, but in rooms with moving machinery the heat transmission may be increased as much as 10 per cent.

EFFECT OF PAINTING

The effect of painting was originally determined by experiments made with a cast-iron rectangle, and in applying these to radiators of standard type, corrections must be made to allow for the difference between the area of the radiating and convecting surfaces. The effect of painting is to change the radiation constant of the radiating surface and has practically no effect upon the heat lost by convection. It is, therefore, a surface effect and it makes no difference what paints are placed on the radiator as a priming coat; the re-

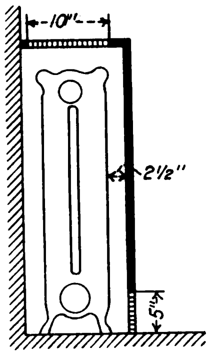

Fig. 6

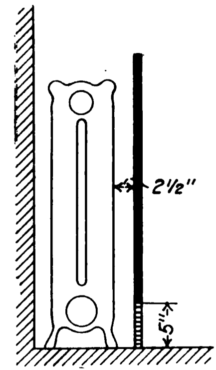

Fig. 7

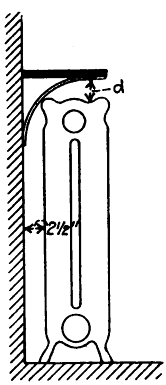

Fig. 8

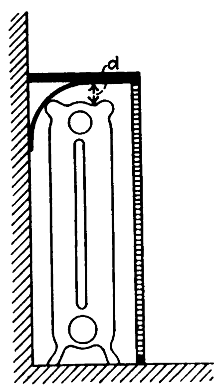

Fig. 9

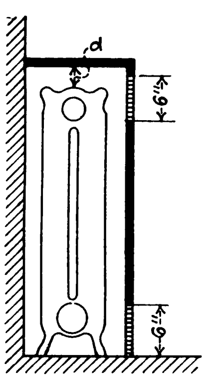

Fig. 10

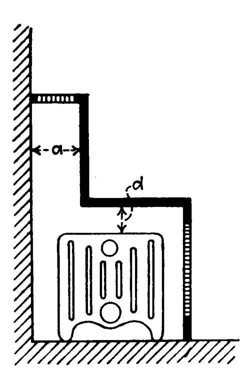

Fig. 11

DIFFERENT ARRANGEMENTS OF RADIATORS IN ENCLOSURES sults are always dependent upon the last coat of paint put upon the radiator. In radiators having a large proportion of radiating surface such as pipe coils or wall coils, the effect of painting will be more marked than in four-column radiators having a comparatively small radiating surface in proportion to convecting surface. All finely ground materials have about the same radiation constant. Therefore all paints having finely ground pigments will give about the same effect. Metals have a poor radiating effect so that any paint containing flake metal, such as bronze, will have a low radiating constant. Table 5 shows the heat loss from a two-column 38 in. radiator, 10 sections long, when painted with different kinds of paints:

TABLE 5. EFFECT OF PAINTING ON TWO-COLUMN 38 IN. RADIATOR

Steam Temperature 215 deg.—Room Temperature 70 deg. fahr.

Condition of Surface	B. t. u. transmitted per square foot of radiator per hour.
Cast iron bare	240
Painted with aluminum bronze	200
" " gold bronze	205
" " white enamel	242
" " maroon japan	240
" " white zinc paint	242
" " no-lustre green enamel	230

EFFECT OF ENCLOSING THE RADIATOR

It is very often desirable to partly enclose or conceal a radiator by means of screens or grills. All such enclosures in general reduce the heat transmission from the radiator, the effect being both to reduce the radiant heat and the convected heat. As in most radiators the convected heat is at least two-thirds of the heat transmission, these enclosures or screens largely affect the convected heat. It is therefore very desirable that the current of air passing over and through the radiator should be restricted as little as possible. There has been some experimental work done, particularly abroad, with reference to these screens. There are, however, so many different cases that may arise that it will not be possible to discuss all of them but only to take up typical cases.

Case No. 1. In this case, Fig. 6, the radiator is enclosed in a box with a screen in front at the bottom, and a screen at the top, these screens extending the full length of the radiator. This arrangement reduces the heat transmission of the radiator from 7 to 10 per cent and in all cases, the spaces between the radiator and the wall and the spaces between the casing and the radiator should be at least 2½ in. The reduction of heat transmission will be more in narrow radiators than in wide radiators. Experiments show that the best results are obtained when the opening at the top has twice the width of the opening at the bottom, and for radiators of ordinary type the width of opening at the bottom should be 5 in. and the opening at the top, 10 in.

Case No. 2. It is sometimes desirable to place a screen in front of the radiator, leaving the top entirely open with an opening at the bottom in front for the cold air to enter the radiator, as in Fig. 7. In a case of this kind the effect of the screen is to produce a strong current of air and if this screen is high enough it may even produce a chimney effect which will increase heat transmission from the radiator due to increased circulation. The effect of such screens depends entirely upon their height. Professor Brabbee states that with a screen 72 in. high and a 49 in. radiator, the heat transmission will be increased 12 per cent.

Case No. 3. Radiators often have placed over them a flat shelf, as shown in Fig. 8. In such case, they should be provided with a deflector as shown. The effect of the shelf very largely depends upon the height of the shelf above the radiator. When the distance *D*— that is the height of the shelf above the radiator—is 5 in. or over, the effect of the shelf may be neglected. When the distance *D* is reduced to 4 in., the heat effect may be reduced by 4 per cent.

Case No. 4. Radiators are often enclosed in boxes with a grill in front or recessed in the wall with a grill placed in front of them as in Fig. 9. In such cases, the height, *D*, is very important. With *D* equal to 2½ in., the heat transmission will be reduced 20 per cent, and with *D* equal to 6 in., the heat transmission is reduced 10 per cent. It is assumed in this case that the entire front of the box is provided with an open grill.

Case No. 5. Sometimes a grill, as shown in Case No. 4, is partly replaced by a solid panel with openings above and below as in Fig. 10. With the openings the full length of the radiator and 6 in. in height and with *D* not less than 4 in., the heat transmission will be reduced 25 per cent. As *D* is reduced in height, the heat transmission will also be reduced and with *D*, 2½ in., the reduction will be 40 per cent.

Case No. 6. Radiators are often placed under seats as in Fig. 11. In this case the distance between the top of the radiator and the bottom of the seat becomes very important and should be not less than 3 in. and if possible it should be made 6 in. Under favorable conditions, when *D* is at least 3 in. and *A* is equal to 6 in., the heat transmission will be reduced from 15 to 20 per cent. When *D* is small, however, say 2 in., and *A* is reduced to 4 in., this reduction may be 35 or 40 per cent.

In tests[1] by Prof. K. Brabbee will be found other cases than those cited above.

EFFECT OF POSITION

The effect of position on the heat transmission of a radiator is a subject that has been investigated only to a very limited extent. The experiments that are available show that the heat loss from a radiator is about the same whether it is placed at the floor, at the

[1] Reported by George Stumpf, Jr. in *Heating & Ventilating Magazine*, May, 1914, page 23.

ceiling, or in the center of the room. It seems to make very little difference whether it is placed close to the wall or in the middle of the room. Placing a radiator close to an outside wall heats the wall immediately behind the radiator and if no insulation is placed behind the radiator this may represent a loss of from 3 to 5 per cent.

WARMING THE RADIATOR

It is often very important to know the maximum condensation that occurs in a radiator when steam is turned on. Fig. 12 shows the condensation rate in pounds per hour for the time elapsing after

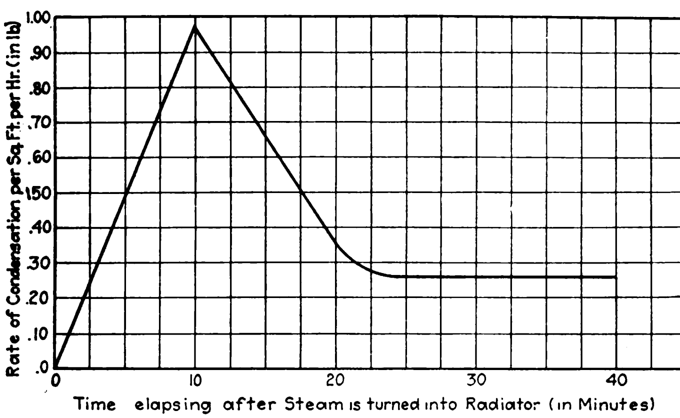

FIG. 12. RATE OF CONDENSATION WHEN STEAM IS TURNED INTO RADIATOR

steam is turned into the radiator. It will be noticed that the maximum condensation occurs 10 minutes after steam is turned on, and in that case it amounts to about 3½ times normal condensation. After the end of 25 minutes the radiator had reached a normal rate of condensation. This curve was made from observations at intervals of 10 minutes so that the intermediate points between the 10 minute points are not known, and the form of the curve is not exact. It shows, however, that in starting a plant, the demand made upon the boiler may be very much higher than the normal demand.

CONVECTION AND RADIATION

The importance of convection and radiation has been given very little consideration in heating literature. It may be more important than is realized as there is a distinct difference between heating by convection and heating by radiation. Where heating is done entirely by radiation, the objects in the room and the walls receive the radiant heat and the air in the room is warmed by coming in contact with these warmer walls and objects. Therefore, in a room heated by radiant heat the air is always at a lower temperature than the objects in the room. If sufficient radiant heat were introduced into a room, it might be possible to feel quite warm in a room where the air was at a temperature considerably below 70 deg. The best example of heating by radiant heat is the open fireplace where practically all of the heat given to the room is by radiation. Radiant heat has the same properties in general as light. and we may have heat shadows the same as light shadows, so that in heating by radiant heat any object that does not receive the direct rays of the radiant heat will be at a lower temperature than the object that does receive the radiant heat. Therefore, in rooms of this character there must be a more or less unequal heating throughout the room.

When heating is done by convected heat the air enters the room at a higher temperature than the objects in the room and the objects

TABLE 7. RELATION BETWEEN RADIATED AND CONVECTED HEAT IN DIFFERENT TYPES OF RADIATORS. 10 SECTIONS IN LENGTH

Room at 70 deg. fahr.—Steam at 215 deg. fahr.

Number of Columns	Height of Radiator	10 Section Rated Surface	10 Section Area of inclosing Envelope	*R* Ratio of Radiating to Total Surface	Radiated Heat per sq. ft. Rated Surface	Total Heat per sq. ft. Rated Surface	Convected Heat per sq. ft. Rated Surface	% Convected Heat to Total Heat
One	38	30	15.9	0.53	106	256	150	58.6
"	32	25	13.5	0.54	108	266	158	59.4
"	26	20	11.1	0.555	111	273	162	59.4
"	23	16⅔	9.9	0.595	119	279	160	57.4
"	20	15	8.75	0.584	117	283	166	58.7
Two	45	50	21.45	0.43	86	234	148	63
"	38	40	18.35	0.458	92	240	148	62
"	32	33⅓	15.65	0.47	94	248	154	62
"	26	26⅔	14.00	0.53	106	255	149	58
"	23	23⅓	12.70	0.544	109	260	151	58
"	20	20	11.20	0.56	112	265	153	58
Three	45	60	22.90	0.382	76	218	142	65
"	38	50	19.7	0.394	79	226	147	65
"	32	45	16.85	0.375	75	233	158	68
"	26	37½	14.10	0.376	75	241	166	69
"	22	30	12.20	0.407	82	248	166	67
"	18	22½	10.35	0.46	92	254	162	64
Four	45	100	28.05	0.28	56	205	149	73
"	38	80	24.16	0.30	60	210	150	71.5
"	32	65	21.52	0.331	66	217	151	69.5
"	26	50	17.5	0.35	70	225	155	69
"	22	40	15.27	0.382	76	232	156	67
"	18	30	13.05	0.435	87	238	151	63.5
Wall Coil		5 Section						
5A	13 5/16	25	21.34	0.854	171	323	152	47
7A	21⅞	35	27.24	0.78	156	310	154	49.7
9A	29 1/16	45	35.32	0.784	157	295	138	48

are heated by contact with the warmer air. It is therefore apparent that where a room is heated by convected heat, the objects in the room must always be at a lower temperature than the air in the room. In direct heating such as direct steam or hot water we have heating both by radiation and convection. It is possible by this means to have the objects and the air in the room at about the same temperature.

A study of the various forms of radiators is given in Table 7 which shows the proportion of radiant heat to convected heat in

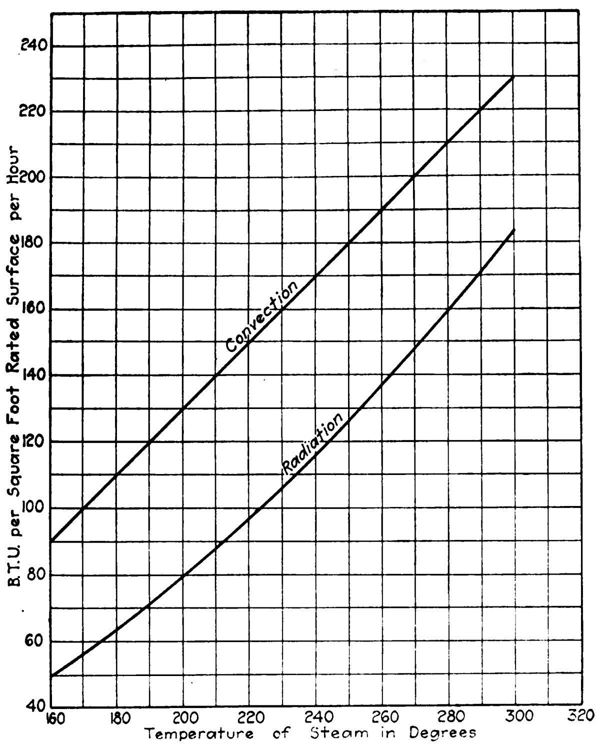

FIG. 13. HEAT TRANSMISSION BY RADIATION AND CONVECTION FOR VARIOUS TEMPERATURES OF STEAM

these various types. Radiant heat is greatest in a single horizontal pipe. The percentage of convected heat will be less in a wide radiator such as a four column type.

Column 5 in Table 7 shows the ratio of the radiating surface to the total surface of the radiator. Column 6 shows the radiant heat in various forms of radiators, and column 8 shows the convected heat. Column 9 shows the ratio of the convected heat to the total heat given off by the radiator. It will be noticed in wall coils that about one-half the heat is given off by radiation and one-half by convection, while in a four-column radiator, about 70 per cent is given off by convection and 30 per cent by radiation. In a single horizontal pipe about 60 per cent will be given off by radiation and 40 per cent by convection. It is apparent from this table, that all radiators do not give exactly the same effects in heating a room, and that the effect of heating a room with pipe coils might be called heating with radiant heat while heating a room with four-column radiation might be called heating with convected heat, so that different forms of radiators might give appreciably different results depending upon the proportion of radiation and convection. It would seem that engineers should give more consideration to this question than has been done heretofore.

DERIVATION OF FORMULA FOR HEAT TRANSMISSION

A direct radiator gives off heat both by radiation and by convection, and it will be necessary in deriving an expression for heat transmission to have terms in the expression representing both radiation and convection. It will not be possible to combine these two terms as the surface radiating heat is not the same as the surface giving off the convected heat.

In the discussion that follows, it is assumed that the surface radiating heat in a direct radiator is the area of the parallelopiped enclosing the radiator, or putting it in another way, the surface radiating heat is the area of an envelope enclosing the radiator. This surface is independent of the rated surface of the radiator.

The radiant heat lost by the radiator may be figured by Stefan and Boltzmann's law and is expressed as follows:

$$Q_1 = D\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_r}{100}\right)^4\right] \qquad (1)$$

in which

Q_1 = B.t.u. radiated per square foot of radiating surface per hour.

T_r = Absolute temperature of the surrounding objects assumed to be the temperature of the room.

T_s = Absolute temperature of the radiating body assumed to be the temperature of the steam.

D = A constant depending upon the substance of which the surface of the body is composed.

(The value of D for cast-iron radiators may be taken as about 0.157.)

In order to reduce the *radiating* surface[1] to the *rated* surface so as to reduce all heat losses to the same units the factor R has been introduced. R = the ratio of the radiating surface to the rated surface. Expression (1) now becomes (for a cast-iron radiator) in B.t.u. per square foot of *rated* surface:

[1]That is, surface of enclosing envelope.

$$Q_1=0.157R\left[\left(\frac{T_s}{100}\right)^4-\left(\frac{T_r}{100}\right)^4\right] \quad (2)$$

For example take a two-column 38 in. cast-iron radiator 10 sections long with steam at 215 deg., room temperature at 70 deg. Then:

$T_s = 215+460 = 675.$
$T_r = 70+460 = 530.$
$R = 0.458$, see Table 7, line 7.

Substituting these values in equation (2) we have:

$$Q_1=0.157\times0.458\left[\left(\frac{675}{100}\right)^4-\left(\frac{530}{100}\right)^4\right]=0.072(2075-789)=93$$

where

Q_1 = B.t.u. lost per hour per square foot of rated surface of the radiator.

In order to check the amount of radiant heat given off as determined by equation (2), a series of experiments was conducted on a radiator in an atmosphere of almost perfect vacuum. These experiments checked very closely with results given by equation (2).

The convection loss depends upon the difference of temperature between the air entering and the air leaving the radiator, also upon the density and velocity of the air passing the radiator.

The equation for convection may therefore be written as follows:

$$Q_2=mqV(t_h-t_r) \quad (3)$$

in which

Q_2 = B.t.u. lost by convection per square foot rated surface per hour.
m = A constant.
q = Density of the air passing the radiator.
V = Velocity of the air passing the radiator.
t_h = Temperature of air leaving the radiator. (fahr.)
t_r = Temperature of air entering the radiator. (fahr.)

Actual experiment show that t_h bears an almost constant ratio to the temperature of the steam. qV also bears an almost constant ratio to t_s. We can therefore write the expression for convection:

$$Q_2=K_c(t_s-t_r) \quad (4)$$

in which

Q_2 = B.t.u. lost by convection per square foot rated surface per hour.
K_c = The constant for convection which must be determined by experiment.
t_s = Temperature of the steam in the radiator. (fahr.)
t_r = Temperature of the air in the room. (fahr.)

Adding equation (2), the heat lost by radiation, to equation (4), the heat lost by convection, we have the total heat lost by the radiator. This expression for total heat loss becomes:

$Q=Q_1+Q_2$ or substituting values:

$$Q=0.157R\left[\left(\frac{T_s}{100}\right)^4-\left(\frac{T_r}{100}\right)^4\right]+K_c(t_s-t_r) \qquad (5)$$

Q = Total heat lost by the radiator.

For the ordinary forms of cast-iron radiation $K_c = 1$ and equation (4) becomes:

$$Q_2=(t_s-t_r) \qquad (6)$$

and equation (5) becomes:

$$Q=0.157R\left[\left(\frac{T_s}{100}\right)^4-\left(\frac{T_r}{100}\right)^4\right]+(t_s-t_r) \qquad (7)$$

The values of R in equation (7) will be found in Table 7 for radiators 10 sections or more in length. For a shorter radiator it should be computed from the actual dimensions of the radiator.

In the case of a single horizontal pipe the value of R is 1 and may be considered a limiting case.

The use of the formula can best be shown by assuming an example in which we have a two-column 38 in. radiator 10 section, steam temperature 215 deg., room temperature 70 deg.

$R = 0.458$ then:

$$Q = 0.157 + 0.458\left[\left(\frac{675}{100}\right)^4+\left(\frac{530}{100}\right)^4\right]+ (215-70) =$$

$0.072\ (2075 - 789) + 145 = 93 + 145 = 238$ B.t.u. per sq. ft. per hour.

The actual figure taken from experiment is 240 which gives a difference of less than 1 per cent between the computed and the measured results.

Constant K. The usual expression for heat loss from a radiator is:

$$Q=K(t_s-t_r) \qquad (8)$$

where K is a constant depending upon experiment.

This expression has a very limited application since t_r is usually 70, t_s usually from 215 to 225 and the most variable quantity in the expression is the constant K. Comparing equation (8) with equation (5) it is quite apparent that K must have a different value for every value of R. As R changes for every type of radiator, K must change. Also K will vary with every different value of t_s and t_r. It is therefore apparent that equation (5) will have a much wider application than would be possible with equation (8) which was originally deduced for a single horizontal pipe.