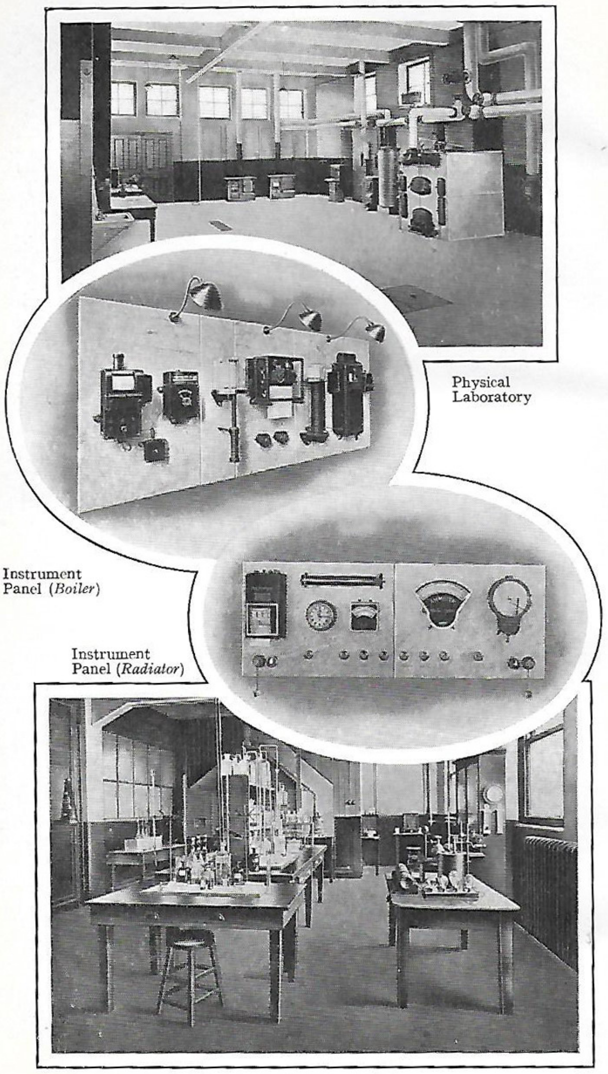
Chapter 6
Heat Emission from Pipes and Radiators



Physical Laboratory

Instrument Panel (*Boiler*)

Instrument Panel (*Radiator*)

Chemical Laboratory

NATIONAL RADIATOR LABORATORY
From IDEAL MANUAL 1930

13.9 HEAT EMISSION FROM PIPES AND RADIATORS

Early attempts to determine the heat emission from pipes and radiators were inevitably crude, and often unsound in theory. The work of Tredgold, Hood and others was typical. Both Tredgold and Hood applied their figures directly as the emission from heating pipes, even when steam was used as the medium.

Dulong and Petit studied the heat loss from surfaces by radiation and convection, and proposed appropriate physical laws. Péclet used their data to estimate the emission from the pipes and pipe coils then used for heating. Box adopted a similar approach, and gave emission tables for steam and water pipes of various diameters and at several temperatures.[12] He quotes the following formulae for the loss from cylinders:

horizontal cylinders: $h_c = 0.421 + 0.307/r$ Btu/ft²h F

where r is the radius in inches

vertical cylinders: $$h_c = \left(0.726 + \frac{0.2163}{\sqrt{r}}\right)\left(2.43 + \frac{5.49}{\sqrt{h}}\right) \times 0.2044$$

where h is the height in in and r the radius, also in in. He knew too that the convection from a vertical surface depended on its height, the coefficient decreasing with increasing height.

Dye, writing at the turn of the century, gave values for pipe emission identical with those of Box for single pipes. For pipe banks, 5% was to be deducted for each additional pipe. For vertical pipes, the emission was taken as 10% less than for horizontal pipes.

The heat loss from pipes has been extensively studied during the past half-century. Rietschel, and Fishenden and Saunders, carried out much experimental work, especially on heat exchangers. Prandtl and Nusselt developed the theoretical aspects, and their use of dimensionless numbers enabled vast quantities of experimental data to be correlated.

These values were, of course, not applicable to radiators or convectors. When these came to be used, in the latter part of the 19th century, it became necessary for manufacturers to state how much heat would be emitted. The first tests to determine the output of steam radiators were made by Mills and others in the 1870's, by Barrus, by Monroe (1884-96), by Baldwin (*ca.* 1888) and by Carpenter (1900-1) in America. Köerting in Germany and Ser in France gave figures appropriate to their hot water equipment.

Baldwin refined Tredgold's method.[4] The water capacity and water equivalent of the radiator were first found. The radiator was then filled with hot water and allowed to cool from 200°F to 150°F in a constant temperature room. From the data so obtained, the "heat units" lost per hour could be computed. He obtained a value of 2.01 Btu/ft^{2}h°F. He also used a more soundly based method, in which he measured the temperature drop through the radiator and the flow rate, or the volume of condensate, in the steady state. He recommended an output of 2 Btu/ft^{2}hF as the design figure for both direct and indirect radiators.

Barrus used a free-standing steam radiator, and found the emission to be 2 Btu/ft^{2}h°F. Monroe used the same method in his earlier tests, obtaining 2.07 Btu/ft^{2}h°F. In his later tests, the radiator was placed against the wall of a test room, and thus in a more practical position. He found the emission to be 1.6 Btu/ft^{2}h°F. Carpenter used a free-standing radiator in a small cubicle, and because the air circulation round the appliance was less restricted, his emission figures were higher than Monroe's later data.

Professor Carpenter showed (1900–1) that the emission from a radiator was less when superheated steam was used than with saturated steam at the same temperature. Tests by Mills, and reported by Carpenter, showed that for small radiators the emission was greater than that estimated from Péclet's radiation and convection coefficients; but for large radiators the emission was smaller, due to the mutual re-radiation between sections. Mills found emissions of the order of 2 Btu/ft^{2}h$^{\circ}$F, and it was assumed to vary linearly with temperature difference. Carpenter recommended lower values — 1.8 for a temperature difference of 150°F and 1.7 for a difference of 110°F between radiator and air.

Writing in 1902, Monroe[42] commented that the practice of rating radiators in terms of their surface area was an arbitrary one, which had been adopted for want of a better. He himself measured the area by carefully covering the surface with pieces of paper.

He recognised that only part of the surface could radiate to the enclosure. For a single-column radiator, only about 80% of the surface could "see" the room and radiate to it; for 2- and 3-column radiators, the corresponding figures were 45–55% and 35–45%. The implication is that the emission per ft^2 of a multi-column radiator is less than that of a single-column one, and moreover the ratio of convection to radiation rises. Monroe deduced that since, for a single pipe in still air, about half the emission is by radiation, the relative emissions for radiators would be:

pipe	100%	50% convection	50% radiation
1-col radiator	90%*	56% convection	44% radiation
2-col radiator	75%*	67% convection	33% radiation
3-col radiator	70%*	71% convection	29% radiation

*taking pipe as 100%.

Rietschel embarked on an extensive programme of testing at Charlottenburg in 1896, and this work was continued by Brabbée between 1917 and 1927. Rietschel's tests were probably the first scientific and comprehensive trials on a wide variety of radiator patterns, and on tube banks, both plain and finned. The appliance was placed in a test room 6.5 x 4.5 x 4 m, itself within a large laboratory. It is not clear from his book how, or if, the test room temperature was controlled. The output from a hot water radiator was determined in the steady state from the weight of water passing and its temperature drop. For steam, the weight of condensate was measured. Rietschel studied the effect of fluid velocity, of air speed over the surface, of the spacing between the panels of a multi-panel radiator, and of the number of sections in a sectional radiator. His data were used by engineers throughout Europe for many years.

Barker quoted extensively from Rietschel's data. He believed, however, that the results, obtained some years before Barker's book appeared in 1912, were probably 15 to 20% low compared with more recent tests. For 2-column radiators, with sections at 3-in centres, the emission was taken by Barker to be 1.5 Btu/ft^{2}h$^{\circ}$F, though this value was known to depend on the temperature. The total emission, from Rietschel's data, appeared to be proportional to the temperature difference between the radiator and the air. Rietschel expressed his results in terms of the mid-temperature (i.e. mean of flow and return) though Barker criticised this as not being the true mean temperature of the surface.

The reduction in output due to shelving, casing or shielding of the radiator was known, and estimated at a maximum of 20%.[23]

SECTION 8 HEAT EMISSION

8.1. HEAT EMISSION FROM EXPOSED PIPING

8.1.1. Fundamental Expressions

The theoretical heat transfer coefficients for a single horizontal pipe to the surrounding air and enclosure, assuming draught-free laboratory conditions, may be calculated from the following fundamental equations:

$$h_c = 0{\cdot}53\,\frac{k}{D_o}\,(\text{Gr. Pr.})^{0\cdot25} \quad \ldots \quad 8.1$$

$$h_r = 0{\cdot}173 \times 10^{-8} E\,(T_s^2 + T_m^2)\,(T_s + T_m) \quad \ldots \quad 8.2$$

where:

h_c	= heat transfer coefficient for natural convection ..	Btu/ft² h degF
h_r	= heat transfer coefficient for radiation	Btu/ft² h degF
k	= thermal conductivity of air ..	Btu ft/ft² h degF
D_o	= outside diameter of pipe ..	ft
Gr	= Grashof number	dimensionless
Pr	= Prandtl number	dimensionless
E	= emissivity of pipe surface ..	dimensionless
T_s	= temperature of pipe surface ..	°F absolute
T_m	= mean radiant temperature of enclosure	°F absolute
T_a	= ambient air temperature ..	°F absolute

For steel pipes having an emissivity of 0·9 and assuming both ambient air and mean radiant temperature to be 60°F*, these equations may be evaluated as listed in Table 8.1. In the preparation of this Table the fundamental convection expression was used but for some purposes the following approximation may be found useful:

$$h_c = 0{\cdot}27\left(\frac{\Delta t}{D_o}\right)^{0\cdot25} = 0{\cdot}50\left(\frac{\Delta t}{d_o}\right)^{0\cdot25}$$

where:

d_o = outside diameter of pipe .. inches

8.1.2. Unit Heat Emission—Horizontal Steel Pipes

The heat transfer coefficients listed in Table 8.1 may be used in the following equations to produce unit values for heat emission per foot run of horizontal steel pipe:

$$q_1 = h\pi D_o \Delta t \quad \ldots \quad 8.3$$

where:

q_1	= heat emission per foot ..	Btu/h per foot run
h	$= h_c + h_r$	Btu/ft² h degF
Δt	$= T_s - T_m$	degF
	$= T_s - T_a$ (assumed)	

* For a fixed temperature difference a change in air temperature of ±10°F has a negligible effect. A similar change in mean radiant temperature is slightly more significant, although still small, being more noticeable at low temperature differences.

Table 8.1. Theoretical heat transfer coefficients for a single horizontal bare steel pipe freely exposed in ambient air at temperatures between 50°F and 70°F

Temp. diff. degF	Convection heat transfer coefficient, Btu/h ft² degF for the following nominal sizes of pipe, inches														Radiation heat transfer coefficient, Btu/h ft² degF, for all pipe sizes
	½	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12	
70	1·58	1·49	1·40	1·33	1·29	1·22	1·15	1·11	1·04	0·99	0·95	0·88	0·83	0·80	1·07
80	1·61	1·52	1·43	1·36	1·32	1·25	1·17	1·13	1·06	1·01	0·97	0·90	0·85	0·82	1·10
90	1·65	1·55	1·47	1·39	1·35	1·28	1·20	1·15	1·08	1·03	0·99	0·92	0·87	0·84	1·13
100	1·69	1·59	1·50	1·42	1·38	1·31	1·23	1·18	1·11	1·05	1·01	0·95	0·89	0·86	1·16
110	1·73	1·63	1·54	1·46	1·41	1·34	1·26	1·21	1·14	1·08	1·04	0·97	0·92	0·88	1·19
120	1·76	1·66	1·56	1·48	1·43	1·36	1·28	1·23	1·16	1·10	1·06	0·98	0·93	0·89	1·23
130	1·80	1·70	1·60	1·51	1·47	1·39	1·31	1·26	1·19	1·13	1·08	1·01	0·95	0·91	1·26
140	1·83	1·73	1·63	1·54	1·49	1·41	1·33	1·28	1·21	1·15	1·10	1·02	0·97	0·93	1·30
150	1·87	1·77	1·67	1·58	1·53	1·44	1·36	1·31	1·24	1·18	1·13	1·05	0·99	0·95	1·33
160	1·90	1·80	1·70	1·51	1·56	1·46	1·38	1·33	1·26	1·20	1·15	1·07	1·01	0·97	1·37
175	1·92	1·81	1·71	1·61	1·57	1·48	1·40	1·35	1·27	1·21	1·16	1·08	1·02	0·98	1·42
200	1·97	1·85	1·75	1·65	1·61	1·52	1·43	1·42	1·29	1·23	1·18	1·10	1·04	1·00	1·52
225	2·01	1·89	1·78	1·68	1·64	1·55	1·46	1·45	1·31	1·25	1·20	1·12	1·06	1·01	1·63
250	2·06	1·94	1·83	1·73	1·68	1·59	1·50	1·49	1·35	1·29	1·23	1·15	1·09	1·04	1·73
275	2·09	1·97	1·85	1·76	1·70	1·61	1·52	1·41	1·37	1·31	1·25	1·16	1·10	1·05	1·85
300	2·12	2·00	1·88	1·78	1·73	1·63	1·54	1·48	1·39	1·33	1·27	1·18	1·12	1·07	1·97
350	2·18	2·05	1·93	1·83	1·78	1·68	1·58	1·54	1·43	1·37	1·31	1·22	1·15	1·11	2·22
400	2·22	2·09	1·97	1·87	1·81	1·71	1·62	1·50	1·46	1·39	1·34	1·24	1·18	1·13	2·50
450	2·26	2·14	2·01	1·91	1·85	1·75	1·65	1·55	1·49	1·42	1·36	1·26	1·20	1·15	2·81
500	2·31	2·18	2·05	1·94	1·88	1·78	1·68	1·62	1·52	1·45	1·39	1·29	1·22	1·17	3·14

range and for conditions where edge insulation is or is not incorporated. These losses should be allowed for in estimation of boiler power, etc.

It should be noted that authorities[8] recommend that edge insulation should be provided wherever practicable.

8.6. HEAT EMISSION FROM RADIATORS

8.6.1. Traditional Data

The traditional method of presenting data for estimation of heat emission from radiators has been based upon the use of:

(*a*) Catalogue data by various manufacturers listing radiator characteristics, by type, in terms of square feet of heating surface.

(*b*) Multiplying factors, sometimes produced by manufacturers and sometimes as a result of independent research, expressing emission as a function of the heating surface area for a given temperature difference, mean water to room air.

(*c*) Further multiplying factors, following the law $(\triangle t)^{1\cdot3}$, for conversion of emissions at a given temperature difference to other conditions.

8.6.2. Recent Publications

The publication of B.S. 3528[11] introduced a standardized method of test and called for heat emission to be expressed as:

$$q = ks(\triangle t)^n \qquad 8.17$$

where:

q = heat emission .. .. Btu/h
k = a constant
s = number of radiator sections
$\triangle t$ = temperature difference, mean water to room air .. .. degF
n = an index

Table 8.20. Values of $(\triangle t \times 100^{-1})^{1\cdot3}$

$\triangle t$ degF	0	1	2	3	4	5	6	7	8	9
40	0·30	0·31	0·32	0·33	0·35	0·36	0·37	0·37	0·38	0·39
50	0·41	0·42	0·43	0·44	0·45	0·46	0·47	0·48	0·49	0·50
60	0·51	0·52	0·53	0·54	0·56	0·57	0·58	0·59	0·61	0·62
70	0·63	0·64	0·65	0·66	0·68	0·69	0·70	0·71	0·72	0·74
80	0·75	0·76	0·77	0·78	0·80	0·81	0·82	0·83	0·85	0·86
90	0·87	0·88	0·90	0·91	0·92	0·94	0·95	0·96	0·97	0·99
100	1·00	1·01	1·03	1·04	1·05	1·07	1·08	1·10	1·11	1·12
110	1·13	1·14	1·16	1·17	1·19	1·20	1·21	1·23	1·24	1·25
120	1·27	1·28	1·30	1·31	1·32	1·34	1·35	1·37	1·38	1·39
130	1·41	1·42	1·43	1·45	1·46	1·48	1·49	1·50	1·52	1·53
140	1·55	1·56	1·58	1·59	1·61	1·62	1·64	1·65	1·66	1·68
150	1·69	1·71	1·72	1·74	1·75	1·77	1·78	1·80	1·81	1·83
160	1·84	1·86	1·87	1·89	1·90	1·92	1·93	1·95	1·96	1·98
170	1·99	2·01	2·02	2·04	2·05	2·07	2·09	2·10	2·12	2·13
180	2·15	2·16	2·18	2·20	2·21	2·23	2·24	2·26	2·27	2·28

To date insufficient authenticated results have been published to permit reference to be made here in a comprehensive manner.[12, 13] It is pertinent to note, however, that confirmation exists that the traditional value of the index at 1·3 is correct as first established in 1918.[14]

In consequence of the present incomplete research data Tables 8.20, 8.21 and 8.22 are here included, based upon the traditional approach.

Table 8.21. Heat emission from cast-iron and steel radiators for a mean water to room air temperature difference of 100°F

Radiator Detail: Type	Radiator Detail: Width, inches or pattern	Emission, Btu/h ft² heating surface
Column	$2\frac{1}{2}$ to $3\frac{3}{4}$	185*
	5 to $5\frac{5}{8}$	170
	$7\frac{1}{2}$ to $8\frac{5}{8}$	160
Hospital	3 to $3\frac{1}{2}$	185
	5 to $5\frac{3}{4}$	158
	7 to $7\frac{1}{2}$	151
Window	13 to $13\frac{1}{2}$	158
Panel	Cast iron	171
	Steel, single	195†
	Steel, double	165

* This applies to radiator sections $1\frac{3}{4}$ in long or more. For less lengths (i.e. closer sections) the emission should be taken as 160 Btu/h ft².

† Independent research suggests that this level of emission should be applied to the total projected area of the radiator (i.e. twice the elevation) and not to the total external area, including convolutions.[15]

Table 8.22. Effects of painting and enclosure upon heat emission from radiators

Type of paint or enclosure	Effect on heat emission
Ordinary paints and enamels	Nil, irrespective of colour
Metallic paints such as aluminium or bronze	Will reduce radiation by 50% or more and overall emission by between 10 and 15%
Open-fronted recess	Will reduce emission by 10%
Encasement with front grille	Will reduce emission by 20% or more, depending on design
Fresh air inlet at rear with baffle plate at front	May increase emission by up to 15% due to lower temperature of air passing over radiator*

* This increase should not be taken into account when selecting radiator size but should be allowed for in sizing pipes and boiler power.

The National Radiator Company, makers of the "Ideal" range of equipment, gave what was the most complete and accurate data on heat output available during the first half of the present century. The "Ideal" manual (though in essence a manufacturer's catalogue) was commonly used as a design guide in America and Britain, and perhaps in other European countries also. The Manual of 1930 quotes the results of experiments to determine the effect of painting radiators;[43] ordinary paint had no effect, but metallic paint reduced the radiation component of column radiators by some 45%, and the total output by 12% (a figure which had been found much earlier by Monroe). Varnishing over the metal paint restored the emission to the original value (because the emissivity of all non-metallic paints is close to 0.9).

Determinations of the heat output of "indirect" radiators were made by Richards, Baldwin, Mills and others in the period 1873-1885. Monroe[42] correlated the data on two appliances — the Gold pin radiator and the Whittier indirect radiator — plotting the total output (H) against the air flow (V) at constant steam and air inlet temperatures. He found:

$$H = a\ V^n$$

where n had the value 0.79 for the Gold and 0.68 for the Whittier radiator. He goes on to regret the lack of recent data on more products (this was written in 1902).

Modern radiator tests are carried out under closely specified conditions in either a warm-wall booth or a controlled-temperature cold-wall room. Neither exactly represents the practical situation. In the 1930's, the practice arose (in America) of adding a percentage (usually 15%) to the test output, the final figure supposedly being the output which would be obtained in real rooms. Coles[16] states that the origin of this addition for "heating effect" lies in the different vertical temperature gradients produced by convectors and radiators, so that different outputs were required to give a specified air temperature in the test room at 30 in above the floor (Fig. 13.6). These additions were codified in the USA in 1947 for convectors and in 1950 for baseboard heating. Similar additions were applied in Belgium, but they were deprecated in Britain.

Heat-Distributing Equipment

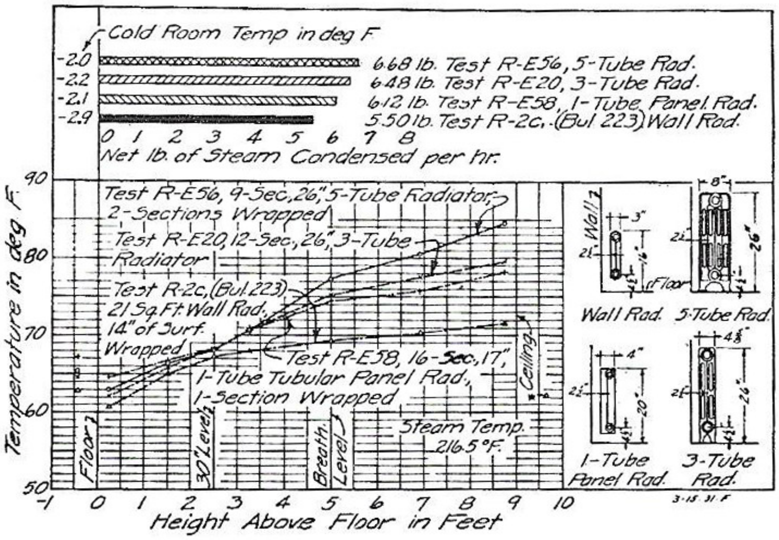


Fig. 13.6. Room-temperature gradients and steam-condensing rates for four types of cast-iron radiators with a common 30-in level temperature.

Radiator Heat Transmissions

The coefficient of heat transmission of a radiator is the amount of heat given off in the steady state by one square foot of radiator surface in one hour, when the mean temperature difference between the water or steam of the radiator and the average air temperature at breathing and knee height levels (5 ft. and 1½ ft.) is 1° Fah. The relation of the transmission to the temperature difference is, however, not a linear one, as the coefficient increases with the temperature difference.

Hitherto this has been admitted in transmission tables when comparing water and steam radiator emissions, although the emissions for the various water-air temperature differences are usually tabulated in direct proportion to the coefficient found for a 90-100° Fah. temperature difference. Actually, the radiator temperature which influences the heat transmission is that of the surface, but for practical purposes the mean water or steam temperature is taken as the factor.

Generally, column radiators whose surfaces are fully water or steam backed, have a surface temperature only a few degrees less than that of the fluid they contain. The Ideal Rayrad has, however, been developed with a view to a small water content and a comparatively low surface temperature. For this reason, this type of radiator has the water tubes so disposed that the mean surface temperature is appreciably less than that of the circulating fluid.

RADIATOR TRANSMISSIONS (DIRECT)

Method of Determining Transmission

The transmission tests of Ideal Radiators are performed by measuring the wattage consumed by electric elements fixed in a small insulated heater, to which the radiators are attached by means of suitable insulated piping. The units to be tested are placed about 12 ft. above the heater, and the circulation is by gravity.

The piping is arranged so that the radiator can be put out of circuit, and a correction made for the loss of heat from the heater and piping.

Several tests are made, and the nett electrical input found for different temperature differences. A number of elements are employed, so that the energy consumption may be controlled in order to obtain approximately any desired temperature. The plotted results give the emission for any practical temperature difference.

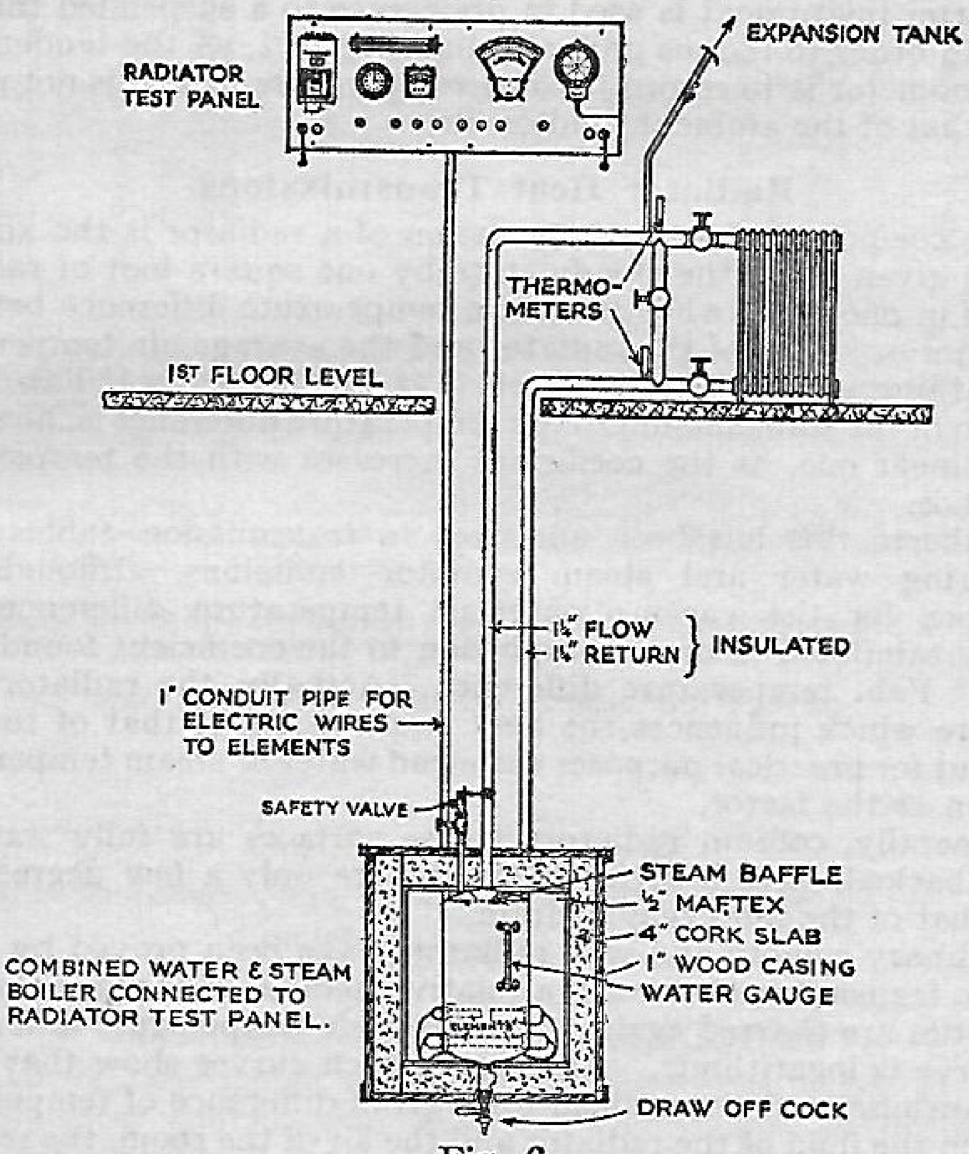


Fig. 6

Arrangement for Test of Radiators

TABLE 7

Ideal Radiator Transmissions

For Radiators placed 2⅜ in. from Wall.*†

British Thermal Units per square foot per hour.

Ideal Radiators	Temperature Difference (Degrees Fahrenheit)							
	Water						Steam	
	70	80	90	100	110	120	155	160
Neo-Classic No. 2	116	139	162	185	208	234	327	340
,, ,, 4	106	128	149	170	192	215	300	312
,, ,, 6	100	120	140	160	180	202	282	294
,, Window	99	119	138	158	178	199	278	290
Neo-Hospital 3 in.	116	139	162	185	208	234	327	340
,, 5⅜ in.	99	119	138	158	178	199	278	290
,, 7¼ in.	94	113	131	150	169	189	264	275
Classic Wall Fig. (iv)	106	128	149	170	192	215	300	312

*The transmission is approximately the same when the radiator is placed 1½ inches or more from the wall.

†Exception is Classic Wall fixed on standard brackets with 2 in. and 1⅓ in. centres.

TABLE 8

Average Radiator Transmissions

B.T.U. per hour per square feet for 100° temperature difference.

For other temperature differences apply 1·3 power law (see table on page 17)

Ideal Radiators	Placed 2⅜ in. from wall except Classic Wall fixed on standard brackets		With flat shelf or deflecting shield fixed 3¼" above radiator Fig. (i)		In open recess distance from top of radiator to top of recess 3¼" Fig. (ii)		Encased or with metal hangings in front Fig. (iii)	
	Water 160–60	Steam 215–60	Water 160–60	Steam 215–60	Water 160–60	Steam 215–60	Water 160–60	Steam 215–60
Neo-Classic No. 2	185	211	178	203	170	194	148	168
,, ,, 4	170	194	163	186	155	178	136	155
,, ,, 6	160	182	153	175	147	168	128	146
,, Window	158	179	152	172	145	167	125	143
Neo-Hospital 3 in.	185	211	178	203	170	194	148	168
,, 5⅜ in.	158	179	152	172	145	167	125	143
,, 7¼ in.	150	170	144	163	139	159	120	138
Classic Wall, Fig. (iv)	170	194	163	186	155	178	136	155

Average Radiator Transmissions

B.T.U. per sq. ft. per degree difference per hour.

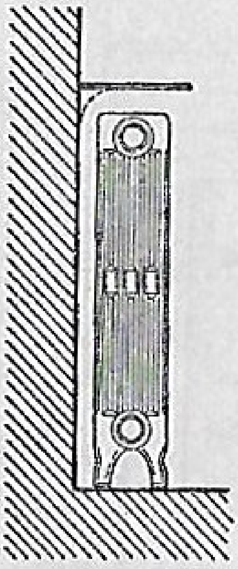


Fig. (i)

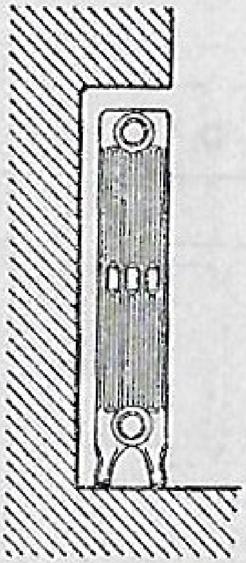


Fig. (ii)

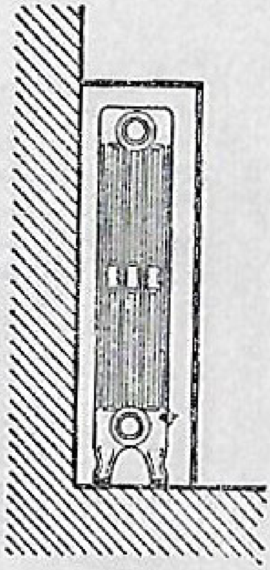


Fig. (iii)

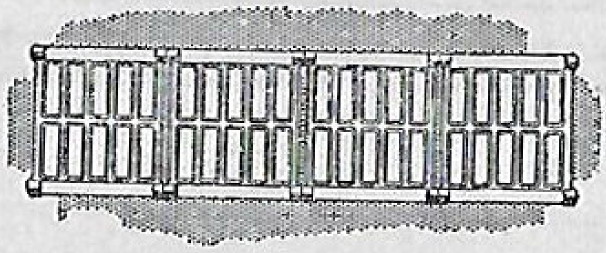


Fig. (iv)

The transmission of radiators painted with Ideal bronze powder and bronzing liquid is about 12% less than given in table.

Where bronzing liquid having a cellulose base is used the duty is reduced by about 17%.

The transmission of radiators painted or enamelled one or more coats is practically the same as given in table.

It is not known when it was first realised that the emission from radiators and convectors was not in fact proportional to the temperature difference between the medium and air. Dulong and Petit's and Péclet's work must have suggested this; yet all experimenters from Tredgold to Carpenter assumed a linear dependence on temperature difference. In America, of course, where steam heating was widely used, it was sufficient to quote emissions for temperatures around 212°F. For hot water radiators, Rietschel quoted values of K varying with the temperature, and Barker adopted the same procedure. Neither proposed the current 1.33 power law for radiators, nor the 1.25 power law for convectors. Barker and Kinoshita,(34) as a result of some 200 tests on radiator emission, showed that the expression

$$\text{Output} = k.(\Delta t)^{1.3}$$

applied to both steam and hot water radiators. Additionally, they showed that a shelf above a radiator reduced the output, by interfering with natural convection, that the emission was independent of the water flow rate, and that the (top, bottom, opposite ends) connections gave a 12% greater output than when connection at both ends were at the bottom.

Hoffman and Raber knew, in 1913, that radiator output depended on its height (increasing height leading to lower output per unit area, since the upper part is washed by warm air rising from the lower part). They found:(29)

Standard height	30 in	1.7 Btu/ft^{2}h$^\circ$F
	16 in	+10%
	48 in	−10%

The aspect ratio also affects the temperature gradient and uniformity, and hence the output. A long low radiator gives greater uniformity and a lower gradient — a fact which was known in 1899.(35)