THE ENGINEERING RECORD SERIES

STEAM HEATING
AND
VENTILATION

BY

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Preface.

The chapters comprising this book were originally written as a series of articles for The Engineering Record and have been somewhat revised for their present form.

It has been the aim of the writer to present briefly the theoretical considerations involved in the design of heating and ventilating plants, and to compile the best of the large array of empirical formulas and data in a way that will be of value to those interested in the current practice of the art.

The writer has taken the liberty to refer frequently to previous works on the subject, and principally to those of Mills, Baldwin and Carpenter. He wishes to acknowledge special indebtedness to Mr. Alfred R. Wolff for many valuable data.

WM. S. MONROE.

Chicago, August, 1901.

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STEAM HEATING AND VENTILATION.

CHAPTER I.—INTRODUCTORY.

The first really practical treatise on heating and ventilation seems to have been published in 1824 by Thomas Tredgold, and in that volume much space is given to the importance of securing adequate ventilation, and also to the merits of heating by systems of steam pipes. Mr. Tredgold gives accounts of several buildings which were successfully heated in this way. It is cited that the first factory in which steam was used for heating was a cotton mill belonging to a Mr. Neil Snodgrass, in which a steam heating system was installed in 1799. This was doubtless about the first instance of the employment of steam primarily and systematically for the purpose of heating. Mr. Tredgold describes a factory which was equipped with a steam-heating system in 1817 as a substitute for stoves, which had been previously used. The building was 90 feet by 30 feet, exposed on all sides, and four floors high. Each floor was warmed by a single pipe running the length of the building at the ceiling and midway between the sides. The system carried 30 pounds steam pressure, but besides embodying the most inefficient location for the radiating surface, the system, as described, did not have over 450 square feet of heating surface for a building containing 91,800 cubic feet of space. Mr. Tredgold states that the system showed great improvement, both in economy and results, over the previous method, adding that the employees suffered much less from "chaps and chills," so that one can only imagine the wretched condition of factory employees in cold weather previous to that time, even in the comparatively mild climate of England.

The problem of artificial ventilation antedates that of steam heating by more than half a century, though, of course, it does not antedate the heating of buildings by various methods more primitive. Mr. W. F. Butler, in a handbook on ventilation, published some years ago, states that the first scientific consideration of the subject of artificial ventilation occurred in 1723, when a certain Dr. Desaguliers was commissioned to institute some means for making the atmosphere in the House of Commons more habitable; and the doctor seems to have installed a system which proved satisfactory, although it had been previously attempted by no less a personage than the celebrated architect, Sir Christopher Wren. Since that time the question of ventilation has occupied increasing attention in the minds of physicians, architects and other scientific men interested in the public welfare, but even to this day what may be called "artificial" or forced ventilation remains to a large extent a luxury.

From the earliest times in the latitudes of northern Europe and North America, some form of heating in cold weather has been a necessity for all buildings, whether caves or palaces, but even as late as the latter part of the nineteenth century such a thing as a uniform temperature in heated rooms in severe weather was never expected, while ventilation was invariably secured only by such means as would be accomplished by the circulation of air through doors and other openings. In the days of our forefathers, when houses were built with large rooms and great, high-ceiling halls, and when people spent a large part of their time in the open air, there was in reality but little need of artificial ventilation; and in the rude homes of the poorer classes that which was secured through poorly constructed walls and through loose windows of oiled paper was generally much more than was desired. With the improvement of transportation facilities, however, and the gathering of large numbers of people into small areas, and comparatively large numbers in single buildings, the need of artificial ventilation, in order to secure anything like a wholesome atmosphere, gradually became apparent, and it is natural that the demand for such ventilation should be recognized first in a building like the House of Commons.

Out of the same economic conditions arose the necessity of heating buildings by steam. Buildings of all kinds had from the earliest days been heated by open fireplaces, in which logs, and later coal, were burned in considerable quantities, while the larger proportion of the heat escaped up the flue. But forests were in time reduced, cities grew, and buildings were made larger and with a much larger number of rooms; and people were forced to find more economical ways of heating than by laboriously carrying expensive fuel to separate fires in each individual room. Stoves were built to get more uniform combustion and save some of the heat lost up the flue, and gradually various forms of distributing heat through many rooms from one central fire were developed to economize labor. Heated air, heated water and steam were all in turn experimented with as a means of distributing heat, and systems employing them have been rapidly and scientifically evolved to meet various requirements, and are to this day very widely used. But since the time of Tredgold, heating by steam has increased in extent and popularity year after year, especially since the increase in size of buildings began to be very rapid, and its economy of operation and incidental advantages of convenience and simplicity have become more and more apparent, until at the present day, in some form or another, it is used almost universally in all installations requiring distribution of heat over any considerable area. In this country it is well within the memory of most men in active life when even our largest factories and office buildings were heated by means of open fires and stoves, but the development from a primitive life to a congested and complex civilization has been phenomenally rapid, especially in the last quarter century, and the greatest advances in steam heating, as well as in most practical sciences, have been made in that period. These have chiefly been due to the almost universal application of steam power and the tremendous economy effected by the use of exhaust steam for heating.

The problem of mechanical ventilation, therefore, though growing out of much the same economic conditions, was solved, to a large extent, independently of the question of heating; and with the development of heat distribution by steam much was lost in the way of ventilation. The old-time fireplace and stove insured a certain amount of ventilation, to say nothing of the mental exhilaration of the former, but heating by steam was accomplished with no ventilation whatsoever. Hygienically, therefore, it was a step in the wrong direction, but economically the lack of ventilation made it more advantageous, as ventilation requires the heating of all incoming air. Heat in cold weather was the prime essential, and it was always possible to obtain some amount of ventilation by what might be called the "natural circulation" of air through doors and windows. The fallacy of resorting to such methods exclusively has been pointed out in many tracts and treatises published since the latter part of the eighteenth century, but the fact remains that even to the present day a vast majority of our buildings, a large proportion even of our factories, churches and schoolhouses, and most of our fine office buildings, with their boasted modern improvements, have no mechanical means for insuring an adequate ventilation.

At the present day we have arrived at a considerable degree of advancement, however, and buildings might now be divided into two quite distinct classes—those which are "densely peopled" and those which are "sparsely peopled"—and our advancement is such that mechanical ventilation is generally looked upon as a necessity for all buildings of the former class, which may include schoolhouses, churches, hospitals, theaters, and other audience halls. In buildings of the second class, such as residences, office buildings and hotels, we have been, as a rule, satisfied with sufficient heat, and have relied upon such ventilation as is secured by the natural circulation methods. In such buildings, therefore, the system of heating most used is that known as "direct radiation," in which radiators, or some form of radiating surface, are located in each room, and connected by an arrangement of piping to a central source of steam or hot-water supply. The rooms are heated by radiation from the hot surface and by contact of the air with it, but no provision is made for the supply of fresh air.

Several adaptations of the ordinary direct-radiation system of steam heating have been developed, however, with a view of obtaining the advantage of ventilation which was secured in the old-time stoves and fireplaces. The principal one of these is what is known as the system of "indirect radiation," in which the radiators, instead of being located in the rooms to be heated, are all placed below them, generally in the basement of the building, and are enclosed in boxes, which are provided with air inlets from the outside of the building, and with flues running to the room to be heated. Fresh air coming through the inlet in contact with the radiator is heated and rises through the vertical flue by the natural upward tendency of hot air. Both heat and ventilation are in this way provided to the rooms by the incoming hot air. This system has been much used in residences, and also to a small extent in some buildings of the "densely-peopled" class, such as hospitals and hotels. But the system has a decided disadvantage, due to the fact that the amount of ventilation secured is practically proportional to the amount of heat required, and in warm weather but little, if any, ventilation is obtained. Furthermore, experience shows that in order to ensure reliability it is necessary to have a separate flue for almost every room and to locate the radiators directly beneath the vertical flue, so that in buildings of any size, especially those more than one or two stories in height, the arrangement of radiators in the basement becomes difficult, and the system of air flues, which are necessarily large, is complex and expensive in space and also in construction.

In order to avoid the difficulties of the system of "indirect radiation" and yet secure some ventilation, a combination has been developed which goes under the significant title of "direct-indirect radiation." In this the radiators are located in each separate room, but they are of special construction, and provided with air connections through the walls of the building so arranged that a certain amount of air can be admitted through this connection so as to pass around the radiator, becoming heated by contact with it. The room is therefore heated both by direct radiation and by the incoming current of fresh hot air, and considerable ventilation is secured.

In this system, as in the "indirect," ventilation in warm weather is dependent on open windows and doors, and it has been as yet but little used. It has, however, in a few cases been adapted to office buildings and hotels, and in the opinion of the writer we may look for a very decided development of the "direct-indirect" during the immediate future in buildings of the more sparsely-peopled character, where the amount of ventilation required per square foot of floor area is comparatively small. But for such buildings this system only achieves its best results when combined with a mechanical system for exhausting the air.

As already mentioned, we have, perhaps, arrived to-day at a point in the advancement of hygienic science where some system of artificial or mechanical ventilation is looked upon as necessary for all buildings of what the author has called the densely-peopled class. It is difficult to define the limits of such buildings, as the height and nature of the room and length of time occupied affect the question, but in a general way any room or apartment in which each individual occupies less than 40 square feet of floor area should be included in such a classification, especially if occupied more than two or three hours at a time. The systems which may be employed for mechanical ventilation are numerous and varied, but they all embody the use of fans of one kind or another for forcing the air into the rooms, or exhausting it, or both, with proper provision for heating the incoming air in cold weather, and some one of the three heating systems is frequently, if not generally, employed in connection with a system of mechanical ventilation.

CHAPTER II.—STEAM HEATING; SYSTEMS OF PIPING AND STEAM SUPPLY.

Systems of piping.—The three systems of steam heating as described in Chapter I.—the direct, indirect and direct-indirect radiation—are governed by much the same rules in the matter of piping arrangement and steam supply, the two latter requiring only special rules for proportioning the amount of heating surface and for the arrangement of air supply. As regards piping, there are the one-pipe and two-pipe systems, with several varieties and combinations of each; and as regards the steam supply, there are high and low-pressure systems, exhaust systems, gravity systems, vacuum systems—terms more or less indefinite and somewhat mixed in their application.

The essential requisites of a steam-heating system comprise: First, a source of steam supply, which may be either an independent boiler or a heater or tank of some description supplied with exhaust steam from an engine. Second, a system of piping to conduct the steam from the source of supply to the radiators. Third, a series of radiators or radiating surfaces consisting of enclosed spaces in which the steam is condensed by the cooler air of the room on the outside of the surface. Fourth, a system of return pipes through which the water condensed in the radiators is removed; and fifth, a receptacle into which this water is drained.

The second and fourth of these requisites may be either wholly or in part embodied in one, as may also the first and fifth. It might be more briefly stated, therefore, that the prime requisites are only the source of steam supply, the radiating surface and a system of piping connecting them. But even though the supply and the return pipes be embodied in the same system, it is just as necessary that they be so arranged as to dispose of the water of condensation as it is for them to supply steam to the radiator, which fact should never be lost sight of.

One-pipe system.—The simplest possible heating system, therefore, is one which would be known as a one-pipe gravity system;

such as is indicated in Figure 1. The steam is generated in the boiler, flows through the pipes to the radiators, the water condensation as it is formed in the radiators draining out along the bottom of the pipes and back to the boiler by gravity, to be re-evaporated into steam. Such a system as this could be applied only to a very small plant, and one in which the pipes could be made comparatively of large size and given a very decided fall toward the boiler from all directions.

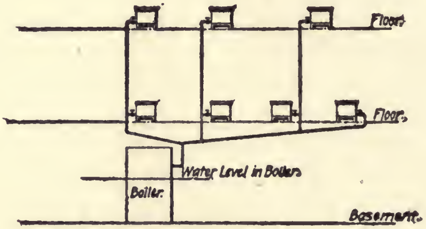

Figure 1.—The One-pipe System.

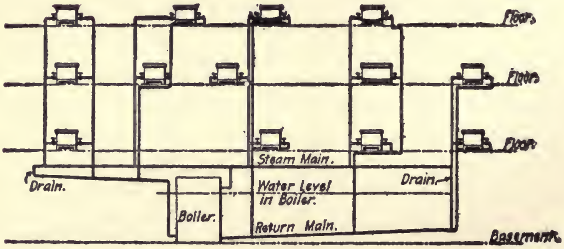

Figure 2.—The Two-pipe System.

Two-pipe system.—The more usual system of piping, and that first employed, is known as the "two-pipe system," and is represented in Figure 2. In this, each radiator has one pipe for supplying steam and another to remove the water of condensation. The only object in the two-pipe connection is to provide a freer and more positive flow of steam and condensed water, but this is a very important consideration. In a one-pipe system, such as indicated by Figure 1, the water of condensation flows from the radiators back to the boilers against the current of steam, falling through the steam in the vertical pipes and flowing along the bottom of the horizontal pipes. Such a simple system as this, shown in Figure 1, might be employed, and to a considerable extent, if the pipes are of ample size, and also if there are no valves on the radiators, so that steam can be turned on the entire system at all times. In this case there would be a constant and practically uniform flow of water through the pipes, and, if these were properly laid out, the system might give perfect satisfaction. But it is impracticable to have all the radiators of a system turned on at one time, and the difficulty with such a system is made evident the minute steam is turned into a cold radiator. When the steam comes in contact with a perfectly cold radiator a large amount is condensed at once in heating the cold iron, and as soon as the pressure becomes adjusted this bulk of water flows out of the radiator connection at one time and drops down the vertical pipe. When it reaches the horizontal main in the basement it is picked up by the current of steam and carried to other parts of the system, filling up the pipes in places; and as it is relatively much colder than the steam, the latter, in trying to get by it, is suddenly condensed, disturbing the equilibrium of pressure, as we might say, and producing the disagreeable crackling and pounding noises which are always encountered in poorly constructed heating systems, and which are commonly known under the name of water-hammer. This noise, besides being very annoying to the occupants of the building, interferes with the circulation of steam and also produces undue strains in the piping.

The two-pipe system to a certain extent does away with these difficulties; that is, in using the two-pipe connection it is generally easier to avoid the water-hammer and other annoyances incident to imperfect circulation; but unless the pipes are properly proportioned and properly drained the same difficulties will be encountered. The simple one-pipe system, indicated in Figure 1, is therefore, as before stated, rarely, if ever, used, but there are a number of modifications of it which are used with decided success, and in some of the largest installations.

One-pipe system with separate return main.—The simplest one-pipe system usually employed is represented in Figure 3. In this the horizontal steam main in the basement is pitched so as to drain away from the boiler, and at its extreme end a return pipe is connected and led back to the boiler, entering it below the water-line. In this way the flow of steam and water of condensation is in the same direction in the mains, and upon the sudden condensation of considerable steam, as will occur when turning steam into a cold radiator, the water falls down the risers against the current of steam; but in the main it is propelled along in the same direction as the steam current. If the mains are extensive they can, moreover, be drained at several different points. This system is extensively used for residences and buildings of only a few stories in height, and it has also been used in larger installations. The Chicago Athletic Club, a building ten stories in height, is heated by exhaust steam with this system of piping with a pressure of not over 2 pounds in the coldest weather, and with little, if any, difficulty with water-hammer. In such a plant the risers as well as the mains must be of ample size, and the latter must have sufficient pitch and be thoroughly drained. The consideration of these questions as affecting the size of the pipes will be taken up in a subsequent chapter.

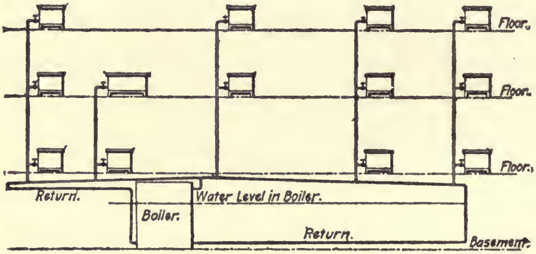

Figure 3.—A Common Type of One-pipe System.

Mills' system.—The only system of single-pipe connection which has been very extensively used in high buildings, such as the modern office building, is that known as the one-pipe overhead, or Mills' system, and is indicated diagrammatically in Figure 4. In this system the steam is conducted through a large main supply pipe to the attic of the building, or to the ceiling of the top floor, and from this the mains extend around the building to supply the risers. The risers are connected to the return mains in the basement. It will be seen that in this system the current of steam and water of condensation is everywhere in the same direction except in the connections to the radiators, and the risers should be sufficient in number so that these connections may be comparatively short. This arrangement has the very decided advantage over the ordinary upward-supply one-pipe system that the water of condensation that falls down the risers from the radiators does not, when it reaches the horizontal pipe at the bottom, encounter the main current of steam, as the horizontal pipe is only a drain pipe, in which there is practically no steam current, and which is designed solely to dispose of this water.

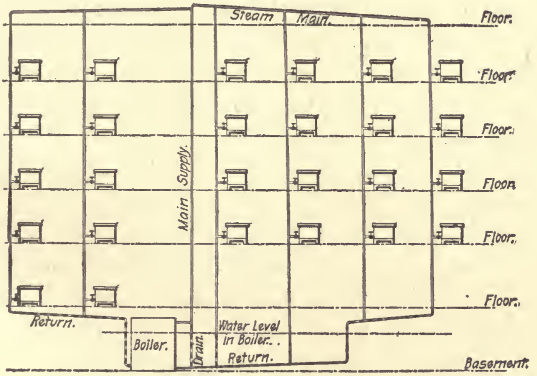

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Figure 4.—The Mills System.

Two-pipe overhead system.—The principle of the two-pipe system is much the same in all cases, but special adaptations of it are made to meet special conditions. There is, for example, a two-pipe overhead system in which steam mains are in the attic as well as in the one-pipe overhead, but there is a separate set of return risers which connect with the return mains in the basement. But each supply riser should also be drained into the basement returns. The arrangement has been but very little used.

Drainage of pipes.—It must be remembered that in any system there is always a certain amount of water in the supply mains and risers due to the radiation from the pipes themselves. If the pipes are thoroughly covered with a good non-conductor of heat there is but very little water from this cause; but little as it is, the mains must be so run that it will flow to certain points, where it must be drained into the return or into proper receptacles. If the steam pipes are arranged so that water can accumulate at any point, trouble is sure to follow. It is a fundamental principle in steam heating that pipes shall be so graded that water of condensation will tend, by the action of gravity, to flow with the current of steam to certain points, where it can be properly drained off.

The various systems of piping are sometimes more or less combined in the same installation, and when radiators are of very large size they should, if possible, be given both a supply and return connection, as the principal advantage of the double connection lies in the internal circulation which tends toward the more rapid removal of air and water. More will be said on the subject of radiator connections in a subsequent chapter on radiators.

Gravity systems.—In the preceding discussion and the accompanying diagrams we have assumed that the water of condensation returns through the return pipes directly to the boiler, there to be re-evaporated into steam by the fire on the grate. This is what is known as the "gravity system" of steam supply, and is self-regulating as to water consumption, except for such small amounts of steam and water as may be lost by leaks. It is but one of the many methods of steam supply, though the one now most employed where the plant is used only for heating and there is no steam power.

In the gravity system the water stands in the return pipes and risers at practically the same level as that in the boiler, though in the remote parts of the system it rises above the boiler level by a height equivalent to the pressure required to effect the circulation through the system. For this reason gravity systems should be designed for free circulation, with pipes of ample size, the difference of pressure required between the steam mains and the most extreme point of the returns never exceeding a pound or two per square inch. Gravity systems are therefore generally run at very low pressures, though frequently in very cold weather as much as 15 pounds is carried for the sake of the higher temperature of steam. The operation of this system is the same at any pressure.

The gravity system is a comparatively recent development, the earliest steam-heating systems being generally auxiliary to a steam-power plant. In these the steam was taken direct from the boiler supplying the engine, and the return water was run through a steam trap into an open tank, from which the water supply was taken for the boilers. This method is still employed in many old plants.

Exhaust steam heating.—The greater economy in high-pressure steam for engines, however, gradually increased the boiler pressure used for steam power, and with this increase in pressure it became difficult to heat a building directly from the same boiler that supplied steam to the engines, as steam heating at high pressure was found unsatisfactory for many reasons, principally on account of the very high temperature of the radiators and the liability to leaks and the increased danger from water-hammer. And furthermore, the same desire for greater economy which had increased engine pressures drew the attention of steam users to the value of the latent heat in exhaust steam for heating purposes.

A brief study of the steam engine shows us that not much over 12 per cent. of the heat energy supplied to an engine is transformed into mechanical work, and by far the major part of the wasted heat escapes in the latent heat of the exhaust steam. This heat, though it has been thus far impossible to transform it into mechanical energy, is readily available for heating purposes; but a generation ago, when it was first proposed to use exhaust steam for heating, the problem involved the then serious question of back pressure on the engines. Heating systems at that time were built to accommodate the high pressure then in use and with what would now be called very small pipes, and admitting exhaust steam into such a system required a considerable pressure on the exhaust side of the engine to force steam through the piping and radiators and the water of condensation out through the returns.

The back pressure necessary frequently amounted to 10 or 15 pounds per square inch, and certainly made a decided reduction in the economy of the engine. It at once became a question whether the saving by using exhaust steam exceeded the loss on account of the back pressure on the engine. If the back pressure was very high in comparison to the mean pressure in the engine cylinder there might be difficulties in the practical operation of the engine; but as far as the theoretical consideration of the coal pile goes, it is more economical to use exhaust steam even at a high back pressure.

As heating systems are now designed, one which requires a pressure of 5 pounds to ensure a good circulation is defective in design, and 2 pounds is more than ought to be required in most cases. A back pressure of this amount on an engine running at 50 pounds mean effective pressure would increase the coal consumption but a fraction of 1 per cent., while taking the heating power that is available in the exhaust steam directly from the boiler would increase the coal consumption over 60 per cent.

Another consideration enters, however, into the question of circulation in a steam-heating apparatus. Besides merely forcing the steam and water through the radiators and piping, it is necessary to force out the air which accumulates, and to do this the system must carry a pressure somewhat above that of the atmosphere, unless a vacuum system, which will be described later, be used.

Theoretically it would be possible to operate a simple gravity system below the atmospheric pressure if the whole system was perfectly air tight and the air was all boiled out of the water and forced out of the system in the first place. In such a case if the fires were put out and the system allowed to become cold, the condensation of steam would leave a perfect vacuum, and on starting up the fire, steam could be carried at any pressure below or above the atmospheric, according to the intensity of the fire.

But if it be attempted to run much below atmospheric pressure the slightest leak anywhere in the system will rapidly break the vacuum and allow air to accumulate. It is, however, impossible to make a system theoretically air tight, and steam invariably contains some air from the feed water, as water will absorb several times its own volume. Air in the radiators and piping is, therefore, an evil that cannot be avoided, and it rapidly accumulates in the radiators or ends of pipes where the flow of steam is slowest. Consequently an air valve is almost a necessity on every radiator, and those which are now almost universally used are automatic; that is, they close as soon as the hot steam comes in contact with them, and open if air accumulates and they become cold. To some extent these automatic air valves enhance the air problem, inasmuch as when the radiator is cold it entirely fills with air at atmospheric pressure. In any case the result of the presence of air is that the pressure of steam in the system must be sufficient to force the air out, though for this purpose a fraction of a pound above the atmospheric should suffice; and frequently better results are obtained with such a slight excess than with a greater pressure. A subsequent chapter on radiators will discuss the action of air and position of an air valve.

Arrangement of exhaust heating systems.—This brings us to a discussion of the methods by which low-pressure exhaust steam is employed for heating. The simplest method, and the one usually employed in exhaust-steam heating, consists in dividing the main exhaust pipe, which receives the exhaust steam from all engines and pumps about the steam plant, into two branches, one leading to the atmosphere, the other being connected to the heating system. On the pipe to the atmosphere is placed a back-pressure valve, the object of which is to automatically maintain a uniform pressure upon the exhaust and upon the heating system, so that the steam may flow into the heating system as fast as it condenses in the radiators. Two forms of back-pressure valves are shown in Figure 5, A and B, the essential feature consisting of a disk that is weighted so that when the pressure on the inlet side exceeds a certain amount the disk rises and allows sufficient steam to escape to the atmosphere. The water formed by the condensation of steam in the heating system is carried back through the main return pipe to some kind of receiver, and is pumped into the boilers. It is generally arranged to pass through some kind of an

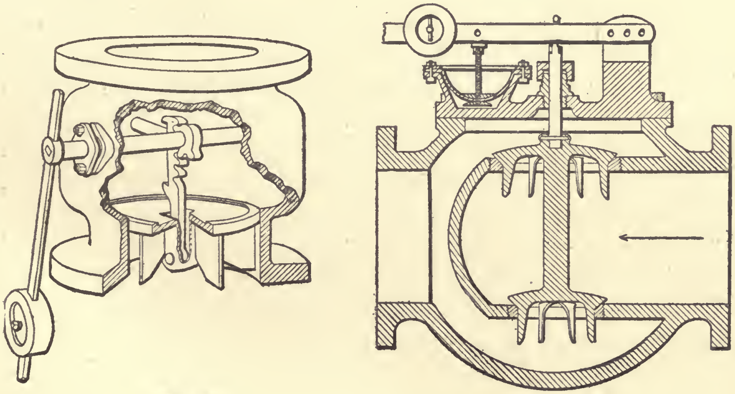

FIG. 5 A FIG. 5 B

Forms of Back-Pressure Valve.

exhaust-steam feed-water heater on its way to the boiler. The pump is also usually operated automatically, as will be discussed later.

The feed-water heater is an essential in all steam plants, and its purpose is to utilize as much as possible of the heat in the exhaust steam in heating the water fed to the boiler. As, however, not more than 18½ per cent. of the exhaust steam can in any case be required to heat the coldest feed water to the full temperature of the exhaust steam, 212 degrees Fahr., there is always a considerable quantity left, which can be utilized in heating the building; and furthermore, as the hot return water is always in one way or another fed back to the boiler, the more steam that is required for the building the more return water there is and the less steam is needed to heat cold feed water. If the heat in the exhaust steam is not thus used in heating the feed water or heating the building, or both, it would be wasted, and its equivalent in coal would have to be used under the boiler to replace it.

There are two distinct classes of exhaust-steam feed-water heaters; the closed or pressure heaters, and the open heaters. In the former the feed water is pumped through the heater against the boiler pressure; the exhaust steam passing into an inlet chamber, and generally through a series of tubes into the outlet chamber, the tubes being set in wrought-iron plates, which divide the inlet and outlet chambers from the water space around the outside of the tubes. In a water-tube heater the position of the steam and water is reversed. In the open heater the water and steam are practically together in the same chamber, the water flowing in from some source against only the pressure of the exhaust steam. The suction of the feed pump is connected to the heater and the delivery direct to the boilers. With the closed heater cold water is pumped through the heater to the boiler, while with the open heater hot water from the heater is pumped direct to the boiler.

The scheme of steam supply described is represented in Figure 6, and is, with various modifications of detail, almost universally employed in heating systems in which exhaust steam is used. It will be noticed that in the figure the pipe to the heating system is provided with a live-steam connection. This is necessary in a great many plants where, in extremely cold weather, the exhaust steam is not sufficient to heat the building. In modern practice such a connection is always provided with a reducing-pressure valve. These valves, one of which is represented by Figure 5 C, are of such construction that they can be set for any desired difference between the high and low-pressure sides. The reducing valve must always be set for a pressure somewhat lower than that at which the back-pressure valve opens, as otherwise some live steam from the reducing valve might pass through the back-pressure valve to the atmosphere and thus be wasted.

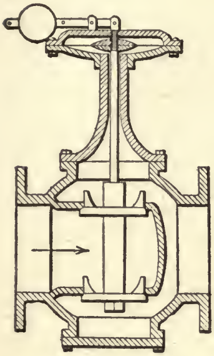

FIG.5C

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Figure 7 shows an arrangement with a pressure heater which is much employed in steam-heating systems. The exhaust steam enters the bottom of the heater and goes out at the top. The connection is also provided with a by-pass so arranged that in case it is necessary to shut out the heater for repairs or cleaning, the valve B in the by-pass may be opened and the valves A and C closed, so that the steam will pass around the heater. In ordinary use the valve B in the by-pass is closed and A and C opened. The arrangement of the supply to the heating system, which is connected to the outlet of the heater, and the back-pressure valve on the free exhaust, is the same as indicated in Figure 6. The main return pipe is run into a cylindrical receiving tank, from which the water is pumped through the heater. Attached to the receiving tank is an automatic pump governor, which, by means of a float operating on the steam sup-

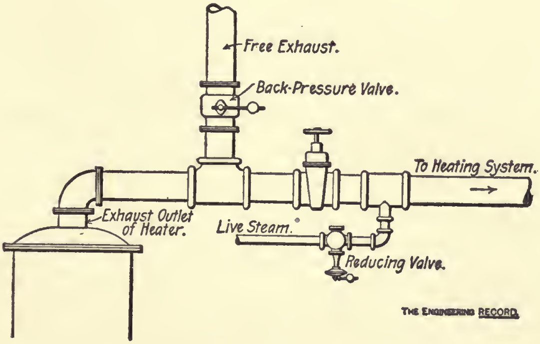

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Figure 6—Exhaust Steam-Heating Supply Connections.

ply to the pump, regulates the level of water in the receiving tank. As soon as the water in the tank rises above the proper level the pump is started by the float, and when it falls below this level the pump is stopped.

Figure 8 represents an arrangement with an open heater. The steam connection is precisely similar in principle, but a different arrangement of details is indicated, the valves being lettered to correspond with those in Figure 7. The returns are run into a receiving tank similar to the other arrangement, but this tank is connected directly to the heater, and practically forms a part of it. The automatic float which controls the operation of the pump is generally, in such cases, connected directly on to the heater, as indicated in the governor marked D.

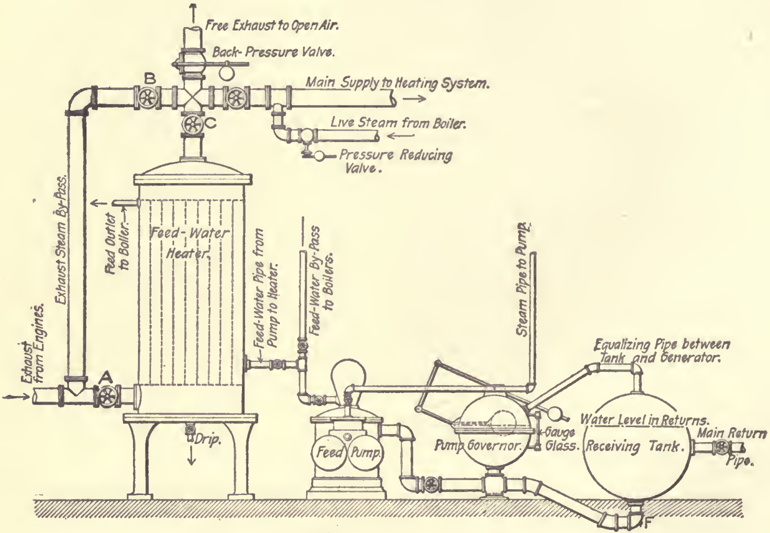

Figure 7—Arrangement with Pressure Heater.

In Figure 8, on the left of the heater, is indicated another float governor, E, which is frequently attached to heaters of this character. This operates on the cold-water supply. In this connection it will be noted that frequently in moderate weather only a portion of the exhaust steam is needed to heat the building, the remainder escaping through the back-pressure valve. In such cases it is necessary to make up the loss of water by taking a certain amount from the city mains or other source of supply. With the open type of heater this is generally run directly into the heater and sprayed through the current of exhaust steam. It is for the control of this cold-water supply that the governor, E, is provided. In this case the governor on the cold-water supply should be set for a level of water a few inches below the level which operates the feed pump. Otherwise the cold water might be let into the heater while the pump was running and when it was not needed. The open heater should in all cases be provided with an overflow connected to a low-pressure trap. This outlet should be a few inches above the water-line, but should be low enough to prevent the possibility of a sudden inflow of return water flooding the exhaust pipes.

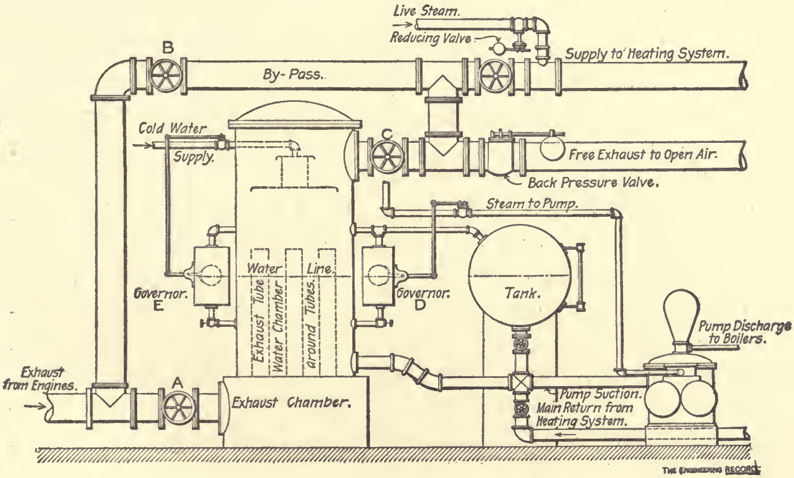

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Figure 8—Arrangement with Open Heater.

With the arrangement shown in Figure 7 the cold water may be supplied by a pipe running direct to the receiving tank, and it may be regulated by hand, according to the level of the water, shown by the gauge glass, or by a float governor similar to the one indicated on the open heater in Figure 8.

In large plants also there are frequently two or more feed pumps, one of which has a suction connected to the cold-water supply, or the boilers are provided with injectors. Further details of piping will be discussed in a subsequent chapter.

It will be seen that, in connection with the open heater, the receiving tank is merely a part of the heater, forming an additional reservoir for the return water. It is possible to do away with the tank entirely, connecting the returns direct into the water chamber of the heater, but as the water space of the heater is generally comparatively limited, the water level in such cases is subject to more or less extreme fluctuations, due to the fact that the return water does not always come back with a uniform flow. This is especially the case with large office buildings, when the building is being heated in the morning and a number of cold radiators are apt to be turned on at nearly the same time. In the same way it is possible also to do away with the receiving tank represented in Figure 7, but this is subject to the same objection as in the other case, only to a more extreme degree, as the small governor provides scarcely any reservoir volume for the return water and the pump is subject to sudden changes in speed. In the arrangement shown in Figure 7 the main return pipe is generally connected at the point, F, and not directly to the tank.

The writer has installed a number of large plants with open heaters and no receiving tanks whatever which have given perfect satisfaction; and recently installed a plant having over 16,000 square feet of radiating surface with practically the same arrangement as indicated in Figure 7, but without any receiving tank. This system requires rather careful attention, especially in the early morning, but it was impracticable on account of local conditions to put in a receiving tank, and the system has given thorough satisfaction.

It should be noted here that the system represented in Figure 8 is practically a gravity system, the heater and tank taking the place of the boiler represented in Figures 1 to 4, and acting both as steam-producing chamber and reservoir for return water, both being at this point under precisely the same pressure. The water level in the return pipes and return risers will stand at a higher level than in the heater or boiler in the case of Figures 1 to 4, by a distance representing the difference in pressure required to force the steam through the system, just as in the ordinary gravity system. As a matter of fact, also, it is found that in the system shown in Figure 7 the pump operates much more smoothly and uniformly if the system is made a gravity system by connecting a small equalizing steam pipe between the main steam supply of the heating system and the top of the receiving tank and governor.

If the plant referred to operates without a tank this equalizing pipe is found to be practically a necessity. In any case an equalizing pipe above the water line between the heater and its tank, or the heater and the governor, is necessary to maintain the same pressure upon the water in the tank as exists elsewhere in the return-water reservoirs.

The water-line of the heating system sometimes becomes an important consideration, especially when it is desired to place radiators in the basement of a building. If these are set so low that the return water is liable to rise above the connections, the radiators will fill with water when turned on, which will prevent the steam from circulating into the radiator and will be sure to give trouble from water-hammer. Besides this, with anything except the overhead-supply systems, the water from the returns will back through the radiator and run down the supply riser, and it is therefore generally necessary to set radiators several feet above the water-line, according to the maximum pressure which is necessary to create circulation of steam through the system in coldest weather. If the system is designed for very low pressure, 1 or 2 pounds, the radiator may be placed within 4 feet of the water-line, but should never be lower than this, especially in parts of the building far removed from the heater. For this reason basements are usually heated by steam coils suspended from the ceiling or placed on the walls, near the ceiling, although radiators are sometimes put on brackets attached to the walls; frequently, in order to lower the water-line, the pump, governor, and heater also, when the open heater is used, are placed in a pit. There are, however, special arrangements of radiator connections which may be used with safety, even though they are set below the water line. These are discussed in the chapter on radiators.

There are many combined automatic pumps and receivers designed for taking care of the return water which are very satisfactory, but all work on the same principle of a tank with a float governor to operate the pump. There are also automatic traps designed to return the water of condensation from the exhaust-steam heating systems, without using a pump, direct to a high-pressure boiler by means of an ingenious combination of float valves, traps, reservoirs and check valves, and some of these work with considerable satisfaction if carefully watched and kept in good repair.

In many mills and factories which use condensing engines, and in which, consequently, exhaust steam is not readily available for heating, steam for this purpose is taken direct from the boilers through a reducing pressure valve and used in the heating system at a pressure of 5 to 20 pounds per square inch. In such systems the water is generally returned to the boilers by an automatic pump and receiver, or by one of the special styles of traps referred to, which for operating at such pressures can be made much simpler than when used for the extremely low pressure of the ordinary exhaust systems.

Vacuum systems.—As a refinement of exhaust-steam heating there has been developed within the last decade what is known as vacuum systems of steam heating, the object of these being to exhaust the air from the system by artificial means so that circulation may be effected at atmospheric pressures with absolutely no back pressure on the exhaust pipes from the engines. There are two distinct forms, one known as the Paul system, the other as the Webster. The former system provides each radiator with an automatic air valve of special construction and connects a very small pipe, usually $\frac{1}{4}$ inch, to each of these valves, bringing them together in pipes of proper size in the basement of the building, and connecting to a special exhauster, which maintains a constant suction on the entire system of air piping. The steam and return pipes for this system are entirely independent of the air pipe and it may be installed on any of the systems previously mentioned.

The Webster system operates on an entirely different principle, in that it employs an automatic air-and-water valve at the return outlet of the radiator. This thermostatic valve, as it is called, is constructed on a principle much like the automatic air valve, but is of larger proportions. It is adjusted so that it closes automatically when it comes in contact with the steam temperature, and opens when water or air collects about it, and the temperature is reduced. The system is necessarily a two-pipe system, the returns being connected to these thermostatic valves, but no other air valves or air piping are used. The return pipes are connected in the basement to a vacuum pump which puts a strong suction on the returns, and by means of which both air and water are drawn through the thermostatic valves, the water being delivered by the vacuum pump to an open heater or receiving tank, while the air is separated by an automatic device. The return pipes of this system are very small, just sufficient to take care of the water, no steam being allowed to circulate in them. The steam mains, where necessary, are drained into the return pipes through thermostatic valves. The return mains being under suction, and having no direct connection with the steam pipes, can, [illegible] a certain extent, be run independent of the usual necessity of draining by gravity, in some cases the water being lifted out of radiators placed below the return mains.

In the Union Depot at Columbus, Ohio, which is equipped with this system, the radiators in the basement are about 13 feet below the supply and return mains, which run parallel along the basement ceiling, and the return water is drawn up out of the radiators without any water-hammer or other inconvenience.

A modification of the Paul system was recently installed in a large office building in Chicago which has given decided satisfaction. Instead of the air valve on each radiator, a small tee with an aperture only 1/16 inch in diameter was screwed into the air hole of the radiator, and these connected together into a system of small air pipes running to an air pump or exhauster. This maintains a constant suction on the air holes. Although there is apparently a continual leakage of steam in this system, it is not more than with the automatic air valves, as the latter are seldom maintained in perfect adjustment. The tees were made with a plug on the outside which could be removed for the purpose of cleaning the pin-hole by means of a wire.

Plants equipped with vacuum systems frequently operate slightly below the atmospheric pressure, and besides entirely doing away with back pressure on engines and removing the air from the system, there are many incidental advantages in the operation of plants of this character which will lead to a very extended adoption. The principal objection to vacuum systems lies in the fact that the exhausters or vacuum pumps take considerable live steam to operate them, and almost as much in moderate weather as on very cold days.

The recent development of vacuum pumps, however, has been of great value to steam-heating work. Pumps of this class are now made which will not run away when all the water is pumped out of the suction, the water end of the pump receiving only air and steam. They will run along slowly under such conditions, taking care of the water as it comes. If a pump of this description is connected to the lower point of the main return from a heating system, it can be made to maintain what is now called a dry return. This is in some cases valuable, as it obviates the necessity of considering the water-line, as before mentioned, in placing radiators in basements. Vacuum pumps used in this way are especially valuable in cases where return water is to be brought back from a heating system at some distance from the source of steam supply.

CHAPTER III.—STEAM-HEATING APPARATUS.

Boilers.—The questions of boiler design, construction, setting, etc., involve so many considerations requiring careful scientific study, that the entire problem is omitted from this work and the reader is referred to the valuable treatises devoted exclusively to the subject. There is, however, one kind of boiler which should be given some special mention in this place. This is the self-contained cast-iron sectional boiler which is used only for small, low-pressure gravity-heating systems in residences. These boilers are built up in sections of various shapes bolted together, the joints being kept tight merely by the pressure caused by the bolts. On account of their material, as well as the method of construction, they are not adapted for anything but very low pressures. For the larger plants in which cast-iron boilers are used, it is better to install two small ones than to attempt to use one large one, as it gives better economy in operation, and there is less danger of accident to small boilers than to those with large castings.

In selecting these boilers it should always be borne in mind that the demands of commercial competition cause them to be very generally overrated by their makers, so that in choosing sizes from catalogues it is advisable to make considerable reduction from the rated capacities. Mr. James R. Willett, in a pamphlet on the heating and ventilating of residences, gives the accompanying table for the sizes of cast-iron boilers. Where boilers of the kinds used for steam power are employed in simple heating plants of large size—of which there are to-day but few—there is an old rule for proportioning the size, to the effect that there must be 1 square foot of boiler surface to 10 square feet of radiating surface. This rule when applied to a boiler with a well-designed furnace, stack and setting should be very conservative. It is much better to estimate the steam consumption of the entire plant (see Chapter V., page 60 for steam consumption of radiation) and calculate the boiler requirements according to the rules of boiler design. The designs of the cast-iron heating boilers are innumerable and can only be selected by the careful judgment of the engineer. The chief points to be considered are efficiency of heating surface and capacity of grate in proportion to surface, strength of parts, tightness of joints, ease of cleaning and effectiveness of circulation—there should be no "dead ends" where the water is not kept in circulation by the heat of the fire.

Willett's Table of Cast-Iron Boiler Capacities.

Radiators; total sq. ft.	Area of boiler grate in sq. in.	Radiators; total sq. ft.	Area of boiler grate in sq. in.
400	500	1,600	1,420
500	580	1,800	1,560
600	650	2,000	1,700
700	740	2,250	1,880
800	820	2,500	2,020
900	890	2,750	2,230
1,000	970	3,000	2,400
1,200	1,120	3,500	2,770
1,400	1,270	4,000	3,120

There might also be classed under the head of steam-heating apparatus the various traps, automatic receivers and other special appliances which are used—especially in connection with exhaust heating—for returning the water of condensation to the boiler, and which were described in the preceding chapter. But besides these the only apparatus pertaining to a heating system without

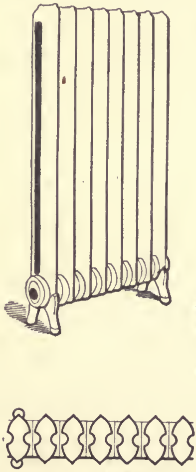
FIG. 9

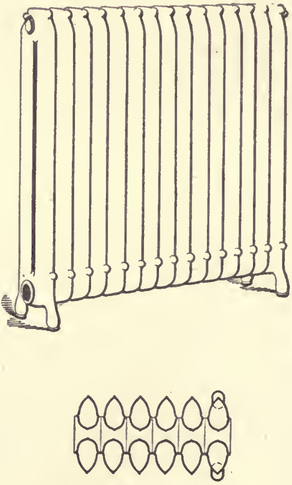
FIG. 10

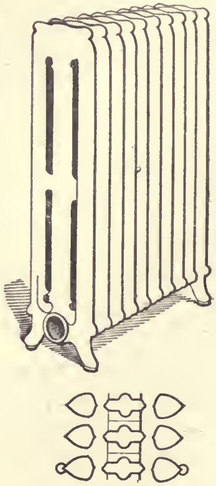
FIG. 11

One, Two and Three Column Radiators.

mechanical ventilation are the radiators, and in the design of the system the utmost consideration should be given to their selection and proportioning.

Radiators.—Radiators are made either of cast or wrought iron and are classified according to kind of heating for which they are used into direct, direct-indirect, and indirect radiators. A few years ago wrought-iron pipe made up with bends and headers into coils of various sizes and shapes was used very largely for radiators, and especially for indirect radiators; but on account of their greater economy of construction, cast-iron radiators are rapidly supplanting the wrought-iron pipes for all purposes. To-day wrought-iron pipe coils are used in direct heating where very large radiators are required spread over a large area of wall surface, such as in factory rooms or warehouses, where a series of long pipes connected into headers at each end are run along the walls either over or under the windows, preferably under. Pipe coils are also used for large indirect radiators, but in this case, as a rule, only in connection with ventilating fans, as will be described in subsequent chapters.

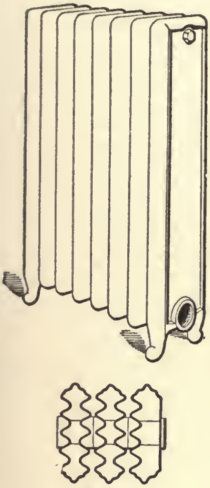

FIG. 12

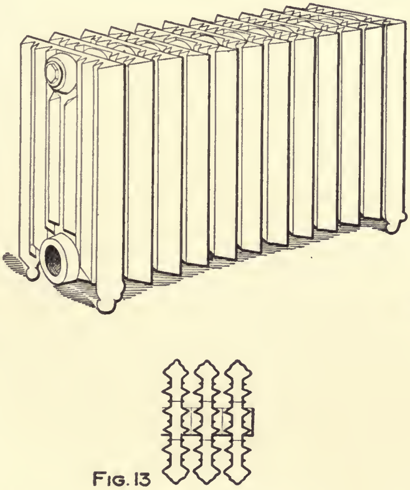

FIG. 13

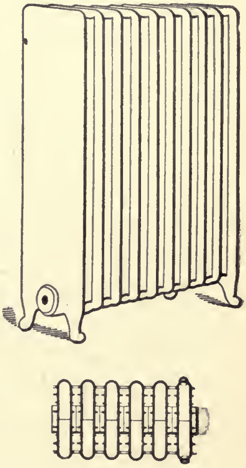

FIG. 14

Flue Radiators.

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The styles and kinds of cast-iron radiators are innumerable. They are made in sections or loops, which are fastened together by pipe nipples of various kinds, with a paper or thin metal gasket between the faced surfaces of the joint. These nipples are sometimes threaded and screwed up tight by special wrenches, but what is known as the push-nipple is extensively used. These nipples are not threaded but are turned to a close fit with the holes in the loops, at the joint, which are bored out perfectly true, and they are driven tight by pressure with jacks or presses made for the purpose.

Cast-iron radiators are classified according to the kind of surface, into plain-surface and extension-surface radiators, and according to their style of construction into open and flue radiators, and of the open one, two, three and four column type, according to the formation of the loops. The different classifications will be better understood from inspection of the accompanying illustrations. The extension-surface radiators, Figures 14 and 18, as the name implies, have extensions of various kinds in the form of ridges or pins cast on to the otherwise plain surface, and are used principally for indirect radiators. The flue radiators, Figure 16, are used extensively for direct-indirect radiation, but for such purpose are provided with shields and provision of some kind for connection with the outer air. Flue radiators, such as shown in Figures 12 and 13, are sometimes spoken of as veiled-surface radiators. Most low radiators of considerable width in proportion to the height are of the flue type. The radiator that has been used for direct radiation much more widely than any other is the two-column plain-surface radiator, such as is shown in Figure 10, but the numerous other forms are being more and more extensively introduced.

Most radiators for steam heating have all the loops connected by only one steam passage through the bottom, but some are also connected at the top as well. Such radiators are adapted to steam heating from hot-water heating practice, as they are the only kind that can be used in the latter, and are hence known as the hot-water type. See Figure 20. Almost all low and wide steam radiators are made in this way, and by some authorities this construction is preferred in all kinds. Further discussion of this subject will be taken up later.

Measuring radiators.—Radiators are universally rated by the number of square feet of surface which they contain. This, at the present time, is for many reasons a very arbitrary method and holds chiefly for want of a better. The main difficulty lies in the great difference in the value of the various kinds of surfaces, no distinction being made in such rating between plain, extension or veiled surface. The variation is enhanced also by the fact that radiators are to a large extent overrated, especially in the less common sizes and styles; and owing to the difficulty of accurately measuring the surface, this fact is very generally overlooked. A number of methods have been proposed and tried for measuring the surface of radiators which are made in ornamental design and with all kinds of irregular surfaces. In the course of a large experience with radiators of all kinds, the author tried many different methods and finally devised one which he has found comparatively simple and very reliable. By this method all irregular surfaces are measured by covering them with very thin flexible paper which must be carefully turned and folded into all irregularities of the surface. After being thus fitted, the paper should be rubbed by blackened fingers. They are generally sufficiently soiled for the purpose from handling the radiators. In this way when the paper is spread out, the part that was folded under can be readily distinguished, and the actual area of the surface can be determined by measuring the blackened parts with a planimeter. In lieu of a planimeter, thin cross-section paper can be used and the areas determined by counting the small squares. In measuring up a radiator loop, it is best to divide the surface by thin lines of white chalk or paint and measure each division separately. The parts

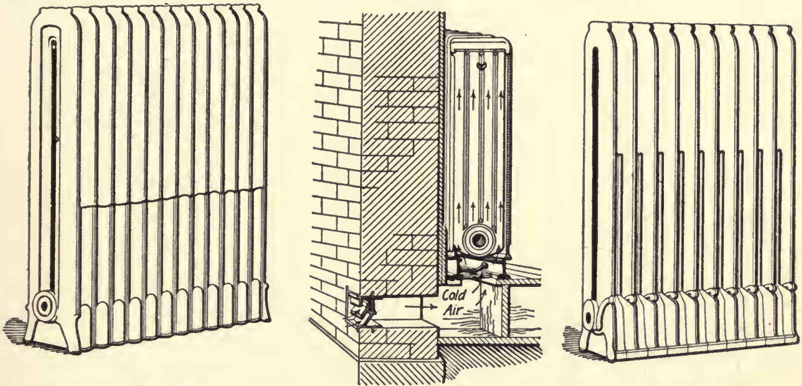

FIG. 15 FIG. 16 FIG. 17

Direct-Indirect Radiators.

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that have a uniform cross-section, as the columns of most direct radiators, can be measured by determining the actual circumference of the surface by fitting a paper around it and multiplying this by the length of the column. It was once objected to this method that it does not take into account the effect of the raised ornamentation on a radiator. This is not the case, or at least any ornament that it does not take into account would not increase the total surface to an appreciable degree. Measurements of radiators by this method by different observers acting independently have been found to check within less than 1 per cent.

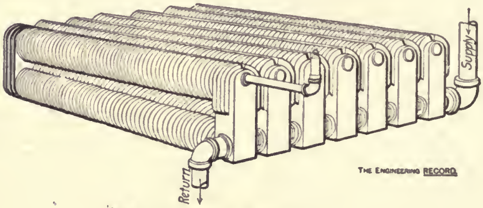

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Fig.18 Indirect Radiator.

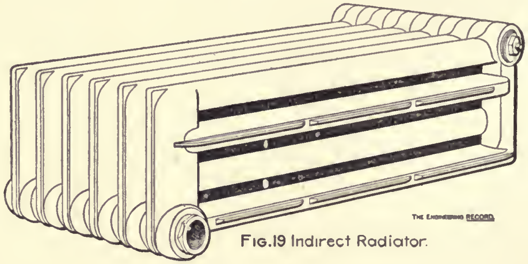

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Fig.19 Indirect Radiator.

Action of radiators.—Before proceeding further in the discussion of radiators, it may be well to consider some of the principles which govern their operation in practical use. The fundamental principle of their operation is undoubtedly the axiomatic theory that there is a universal tendency toward the equalization of temperature; in other words, that hot bodies give up their heat to the colder ones which surround them. In general this is accomplished by three different processes, namely: conduction, convection and radiation, the word radiation being used here in the special sense of radiant heat. These may best be defined by illustrations. When one part of a rigid body is in contact with a warmer body heat passes or flows from the latter through the former to its cold portions as long as there is any difference of temperature. This is conduction of heat, and the rate of flow under the same conditions of temperature varies as a factor known as the heat conductivity of the body concerned. The heat conductivity of fluids, liquids and gases is very low, practically zero, but heat is transferred in them by convection. The particles in direct contact with the source of heat are heated above the temperature of the rest, and an increase in temperature of any liquid or gas invariably decreases its specific gravity and causes an upward current of the hot particles, which brings the colder particles in turn in contact with the hot body, thus maintaining a circulation which tends to raise the temperature of the entire mass. Radiation or radiant heat is entirely different from either of these in its action. It is a wave motion and travels through air and all transparent bodies with the velocity of light without heating them, and only appears as sensible heat when its course is interrupted by opaque bodies by which it is absorbed.*

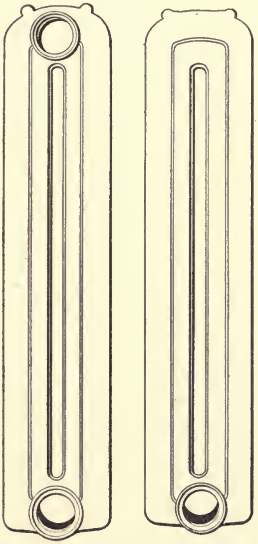

FIG. 20 Hot-Water and Steam Pipe Loops.

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*Some bodies which are quite opaque to light waves are more or less transparent to heat waves, and vice versa, and nothing except the immaterial ether is absolutely transparent to them. The earth's atmosphere absorbs a considerable amount of the radiant heat from the sun.

A radiator gives out its heat to its surroundings by radiation to the walls and objects and by convection to the air. What proportion is given out in each way it is difficult to measure in any case and depends principally on the construction of the radiator and the way it is set, but also more or less upon the conditions of temperature, nature of surface, etc. Péclet, the great French physicist, in the middle of the century, fully investigated the laws of radiant heat as well as those of convection in still air. The formulas which he deduced are applicable only in a limited degree to radiator practice. His investigations, as well as those of others since that time, showed that for a single iron pipe in still air* under conditions of temperature which prevail in radiator practice, the heat given off as radiant heat is just about equal to that given out by convection.†

But radiators are invariably built of clusters of pipes or surfaces, and as radiant heat travels only in straight lines and perpendicular to the surface of its source, a large proportion of the surface is wasted so far as radiant heat is concerned, due to what may be called the mutual interception of the rays. In the ordinary one-column cast-iron radiator, the proportion of surface from which no radiant heat takes place is nearly 20 per cent., in the two-column, 45 to 55 per cent. and in the three-column, 55 to 65. Assuming that the radiant heat amounts to one-half the total, the reduction of heat emitted would be one-half of these percentages. Another fact which further reduces the radiant heat is that radiators are usually set very close to a wall which becomes heated to a comparatively high degree and consequently radiates back a large portion of the heat to the wall side of the radiator. This is true to an extreme degree in the case of indirect radiators which are enclosed in boxes of wood or sheet metal and are not located in the room they are to warm. With these the heating is accomplished entirely by convection, while with direct radiators the radiant heat rarely amounts to 40 per cent., generally not over 30, and often in practice considerably less. For a radiator in any particular location the radiant heat is constant for the same conditions

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*By "still air" in this sense is meant the air of a room in which there are no currents except those created by a column of hot air rising from the heated surface.

†For a complete account of Péclet's experiments and his results see "A Treatise on Heat" by Thos. Box; London: E. & T. N. Spon.

of temperature of the radiator and surrounding objects, and is independent of currents of air. This is by no means the case with the convected heat, which is increased greatly by a slight draft from any extraneous source. In this connection it is very remarkable what a great effect an almost imperceptible draft will have on the heat given out by a radiator. This is partly due to the lowering of the temperature of the air between the loops, but also to the fact that with the same temperatures any increase in velocity increases the amount of heat the air absorbs.

Radiator tests.—Numerous tests of radiators have been made since those of Mills, Richards and others in the early '70's, but there is a wide variation in the results obtained, due partly to the different kinds of radiators tested and partly to the different methods of testing. As yet, no standard means of testing radiators has been adopted. The steam radiator as a heat-using device is theoretically perfect; that is, all of the heat that is put into the radiator by the latent heat of the steam condensed is given out to the air and objects surrounding. Its efficiency is therefore 100 per cent. The question of practical efficiency is, therefore, more strictly speaking, only one of effectiveness of surface. That is, of two radiators under exactly the same conditions of temperature and surroundings, that one which has such an arrangement of its surfaces as to give out the most heat per square foot is the most effective, usually called the most efficient. In all tests of radiators, the heat given off is measured by connecting them so that the steam which condenses can be accurately weighed, its pressure, quality and temperature being determined at the same time. The results are generally reduced to British thermal units given off per square foot per hour per degree difference of temperature between the air of the room and the steam of the radiator.

Tests of radiators have been made in various ways by Mr. George H. Barrus, by Profs. Denton and Jacobus of the Stevens Institute, by Prof. R. C. Carpenter, of Sibley College, Cornell University, and by the author. The results of Prof. Carpenter's tests are published in detail in his valuable work on "Heating and Ventilation of Buildings." In these tests the radiators were located in separate compartments, 7 x10 feet, built together in a large room, and as shown in Figures 21 and 22. In order to allow some circulation of air so that the temperature of air of the compartments might not get as high as that of the radiators, small openings were made in each at the bottom and top. In 1895 and 1896 the author had occasion to make comparative tests of a large number of radiators of various kinds and types, and the arrangement used by him for testing is shown in Figures 23 to 25. The two test rooms were built in the main floor of a large warehouse, and each was 15 feet by 11 feet 8 inches, and extended to the ceiling, 15 feet 5 inches high. The walls of the test rooms were built of matched and beaded pine and lined with lapped courses of heavy building paper. The warehouse room in which the test rooms were located was about 85 by 50 feet, with brick walls on both sides and wood and glass partitions at each end. Neither end of this large room, however, was open to the outside air and the side walls were party walls. Every effort was made to keep the air of the test rooms free from all drafts except those induced by the column of hot air rising from the radiators and to otherwise make the conditions as nearly as possible those of actual practice. To permit some circulation in the test room, so that the air would not get too hot, an opening 4 inches long and 18 inches high was cut in the front

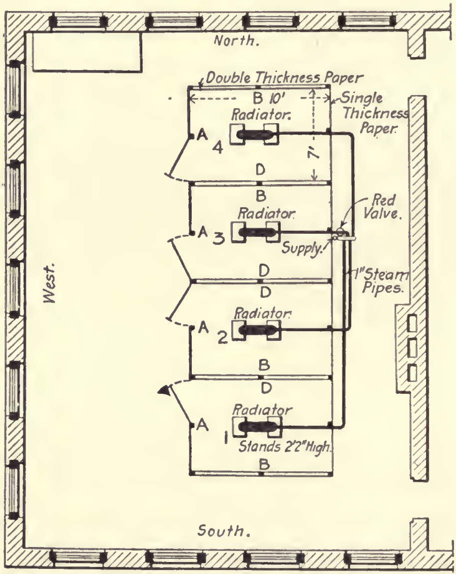

FIG.21 Prof.Carpenter's Arrangement for Testing Radiators.

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wall at the floor, and to prevent direct drafts on the radiators, those openings were surrounded inside by a wooden screen, 2 feet 8 inches high. The front partition was also opened 18 inches at the ceiling. The piping, as shown in Figure 25, was arranged so that the steam was supplied to the radiators on what is known as the one-pipe overhead system. Steam was supplied to the separator at a pressure of 2 or 3 pounds above atmosphere through a 2-inch pipe from a small heating boiler. The pressure carried at the boiler was slightly in excess of that on the separator, it being throttled at the latter. By this means and by leaving the drip on the separator slightly opened, the steam was supplied free from all entrained moisture. The piping, separator, etc., were all carefully covered. The heat given off was measured by drawing off the condensed steam from the drip pots into cold water and accurately weighing it.

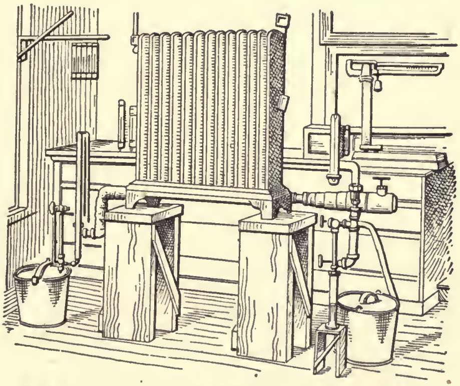

FIG. 22 Prof. Carpenter's Arrangement of Each Radiator and Compartment Removed.

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In practically all of the tests made in this plant, one radiator was used as a standard and all the others tested and compared with it. In each test the radiators were connected and a preliminary run made with open air-valves until the conditions became constant and uniform, and a test run made for two to three hours. The radiators were then interchanged and the test repeated. Even with these precautions it was only by exercising the greatest care that it was possible to obtain results which checked closely. It is very remarkable what a decided effect can be created by a very slight motion of the air from an external source. Opening a door at one end of the warehouse room, although, as before stated, these doors did not open outdoors, made a decided difference, and if a strong wind was blowing outside, the radiator to the windward side had some advantage, although no draft would be perceptible. However, with due care, the two tests for each comparison were made to check with fair accuracy.

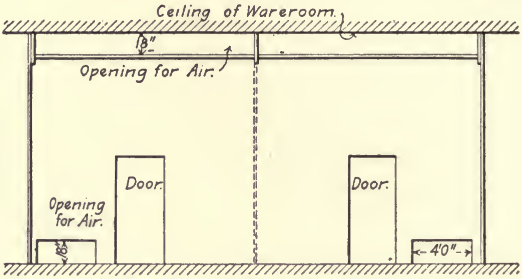

FIG. 23 Front Elevation of Testing Rooms.

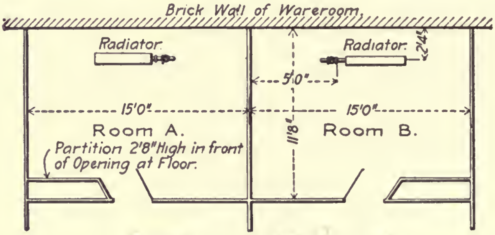

FIG. 24 Plan of Testing Rooms.

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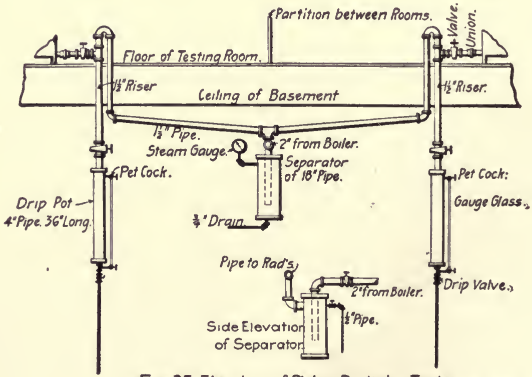

FIG. 25 Elevation of Piping. Radiator Tests.

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The radiator used as the standard on these tests was an ordinary cast-iron two-column steam radiator, 38 inches high, with but little ornamentation. The writer believes that this is the only way of accurately testing radiators, and the adoption of any one definite make of radiator as a universal standard of comparison would do much to extend the knowledge of the comparative effect and value of radiators. Tests of radiators made in different ways or in different locations are valueless for accurate comparison. But all comparative tests made against the same standard if accurately and carefully carried out, could be compared in percentages of the heating effect of the standard used. The writer found that under the conditions in his testing plant the 38-inch two-column cast-iron radiator used as a standard gave out 1.60 British thermal units per square foot per hour per degree difference of temperature with an average steam temperature of 224 degrees Fahr., and average temperatures of the rooms of 76.5 degrees. The average difference of temperatures was 147.5 degrees.

This cofficient of 1.6 B. T. U. per square foot per hour per degree difference of temperature between the steam and air is somewhat lower than that which Prof. Carpenter obtained for a radiator of almost the same size and design. Assuming that the radiators were exactly alike, such variation as there was can be due to two causes: 1, a variation in the difference of temperature between the steam and the surrounding room; and 2, the mode of setting and the consequent freedom of air circulation around the radiator. In regard to the first cause, all tests of radiating surfaces from Péclet down show that the coefficient is greater, the greater the difference of temperature, and for extreme variations in the difference of temperature, the coefficient is very much greater than in the limits of ordinary radiator practice, with steam temperatures from 212 to 230 and mean air temperatures from 40 to 70; within which range the variation in the coefficient from this cause is less than 9 per cent. In regard to the second cause—the freedom of the air-circulation around the radiator—this is by far the chief cause of difference in action of radiators. Profs. Denton and Jacobus of the Stevens Institute of Technology made some comparative tests of radiators, published in *The Engineering Record* of September 8, 1894, with a plant very similar to that used by the author, except, besides having an opening at the top, there was in each of the test rooms an outside window, "which was opened a certain amount during the tests"—a dangerous way, the author believes, to test radiators with the expectation of obtaining checking results—although "a screen was placed between the radiators and windows to prevent direct drafts from striking the radiators." These tests were unquestionably carefully made and were checked by reversing the position of the radiators, so that the comparative results obtained may be taken as reliable; but the coefficients were in the neighborhood of 20 per cent. higher than that obtained by the writer on similar radiators, due entirely to the greater freedom of air-circulation from the open windows. This is a matter of great importance in practice and in consequence the results obtained in radiator tests depend largely upon the setting of the radiator. It is this fact also which makes a radiator to some extent automatic or self-adjustable. Take for example, an ordinary room say with a north exposure and one direct radiator set, as they generally are and always should be, under the window. On a moderately cold day with the thermometer outside at 20 degrees and the wind from the south or east, the radiator will be turned on the entire time. On another day with the thermometer outside at zero and the wind from the north, the radiator very probably keeps the room at the same mean temperature with practically the same temperature of steam. The reason is that in the latter case the cold air which leaks in through the walls and around the window casing, besides keeping the air immediately in contact with the radiator at a lower mean temperature, causes a much more rapid circulation around the radiator, with the result that it gives out more heat units per square foot. It is for this reason, too, that one may put down for a positive and infallible rule in radiator design that the radiator which has the most open space around its surfaces and the most interrupted exposure to the surrounding air will give out the most heat per square foot under the same conditions of setting. In compliance with this rule, other things being equal, narrow radiators are more effective than wide ones, and low ones than high ones; but the effect of width and height can more than be offset by a slight increase in the distance between the loops; for example, the author found that a four-column 38-inch radiator gave out exactly the same heat per square foot of measured surface as a two-column 38-inch radiator, because the former had a mean distance between the loops about 16/100 of an inch greater than the latter; also a

38-inch flue radiator was improved 7 per cent. in heating effect by separating the loops ¼ inch.

It is largely for this reason of freer circulation around the surface that the ordinary wall coils of 1 or 1¼-inch wrought-iron pipe, which are extensively used in factories, are much more effective than cast-iron radiators. Some careful tests by Prof. M. E. Cooley of the University of Michigan showed that a single layer coil of horizontal pipes gives out 40 per cent. more heat per square foot than a two-column cast-iron radiator under the same conditions of setting.

It may be further stated in compliance with the same rule that the hot-water type of radiators is somewhat less effective than the steam type on account of the obstruction offered by the loop connection at the top, and also that flue radiators are less effective than the ordinary open type. Just how much less effective the flue types are depends upon the kind and design, but the wide low flue radiators, not considering extension-surface types, are sometimes over 23 per cent. less effective than the ordinary two-column radiators of the same height. It may also be stated that there is a greater difference between the high and low radiators of the flue type than of the open types. One make of two-column cast-iron radiator proved 6½ per cent. more effective in the 20-inch height than in the 38-inch, and another make nearly 10 per cent., while an 8-inch wide flue radiator showed over 20 per cent. improvement in the 20-inch over the 38-inch.

Condensation at different pressures.—Mr. W. J. Baldwin made some tests some years ago to determine the relative heating effect of radiators under different steam pressures, with the same conditions of setting. Taking the condensation at 1 pound steam pressure as 100, he found the condensation at other pressures to be represented by the following figures:

1 lb. pressure	100	15 lbs. pressure	126
5 lbs. pressure	108	20 lbs. pressure	134
10 lbs. pressure	118		

Extension-surface radiators.—In regard to what is known as extension-surface radiators, they are generally made in the flue form, and numerous tests show they are never as effective per square foot of actual surface as are the radiators which have no extension surface. Profs. Denton and Jacobus made some tests to illustrate this point. They tested two forms of extension-surface flue radiators and then planed off the extensions and re-tested them. They found that with one radiator, which had 43 per cent. more surface in the first condition than in the second, gave only about 17 per cent. more heating effect. This, however, is not exactly a fair comparison on the grounds of extension surface alone, as the radiators had a much more effective proportioning of air-space design with the extensions planed off.

Surface of radiators.—There are other considerations which alter the effectiveness of a radiator besides the design and setting, notably the condition of the surface. Radiators are rarely used with the natural iron surface, but are painted in all possible ways. The nature of the surface has practically no effect on the convected heat, but a very decided effect on the radiant heat; but as the latter is generally less than 35 per cent. of the whole, the effect on the total heat emitted is not so marked. Furthermore, usually only the top and outside surface of one side is painted at all. In general the dark and lustreless paints are the most effective, and may even improve the heating power, while the bright shiny metallic paints may reduce the effect quite decidedly.

But few tests as to the effect of paints have been made. Prof. Carpenter found that two coats of black asphaltum increased the total heating effect by 6 per cent., two coats of white lead 9 per cent., rough bronzing about 6 per cent., while a coat of glossy white paint reduced it by 10 per cent., although the kind of radiator considered is not mentioned. The author found that two coats of ordinary "radiator japan paint" had but little, if any, effect, but in one case, on a 38-inch flue radiator, three coats of gold bronze reduced the heating power by over 12 per cent. This loss was probably due partly to the reduction in radiant heat from the polished surface and also to the fact that the convected heat was somewhat reduced by the heavy coating of paint acting as a non-conductor. This is doubtless sometimes the effect with old radiators which have been painted several times.

Location of radiators.—As before stated, the setting of the radiator has a decided effect on its heat-giving power, and no two conditions can be considered exactly alike in this regard. For direct radiators, the best place to set them is unquestionably under a window. The reason of this is that the greatest leaks of cool air from outside are around the window frames and the greatest loss of heat by radiation is from the glass. There is in consequence a decided downward current of cold air at the window which, if the radiator is on the opposite side of the room, rushes across the floor and is accelerated by the upward current of hot air from the radiator. Such a condition tends very decidedly to make cold currents along the floor. If the radiator be placed under the window the cold drafts are interrupted and the heat more diffused—moreover, the upward current from the radiator, the downward current from the window and the leakage drafts, all combine to make a resultant draft of cold air against the side of the radiator which lowers the temperature between the loops and altogether tends to increase the effectiveness of the surfaces very considerably over what would be found in still air.

Direct radiators are often put in recesses under windows and low radiators are sometimes placed under window seats. Such settings, while highly desirable from an aesthetic consideration, decidedly change the effectiveness of the radiator both by shutting off the radiant heat and by lessening the free convection. From some rough experiments the author is led to believe that the ordinary marble top, which is often placed on radiators, will reduce the heating effect from 6 to 15 per cent., depending on the size, kind and height of the radiator; but this is not stated on the authority of a careful comparative test.

CHAPTER IV.—INDIRECT RADIATORS.

The preceding chapter comprised mainly a discussion of the principles involved in the action of radiators in giving out their heat to the air and objects surrounding, but was confined almost entirely to direct radiation. Many of. the deductions as to the relative value of different kinds of surface may be applied to indirect radiators as well, but a theoretical discussion of the latter requires some entirely different considerations from those presented in the last chapter on direct radiation. The indirect radiator is located below and outside of the room to be heated; it is enclosed by a casing, which has an air connection to the outside of the building, and a hot-air flue to the room to be heated. In this discussion it should be stated that the term indirect radiation is often applied to radiators or heating coils which are used in connection with a fan which creates a forced draft. In the author's opinion this is a mistake, as the element of forced draft involves still other considerations, and such radiators are merely heating coils for mechanical ventilation and should be discussed separately as such. The indirect radiator proper depends entirely upon the draft action of the heated column of air above it for its ventilating effect, and also for a means of communicating its heat to the room above.

Theory of indirect radiator.—The theory of the indirect radiator may be illustrated by the accompanying Figure 26, in which R is the radiator set in a box, B, and provided with a cold-air connection, C, to the outside air (generally having a damper, d), and a hot-air duct, D, to the room to be heated, with a register, r, in the floor or wall of the room. Steam is supplied to the radiator by the pipe, p, through the casing. The heat of the radiator causes a column of hot air to rise through D, and the current is maintained by the excess of pressure of the column of cold air outside over that of the column of hot air in D. The exact pressure which creates this current is found in the excess weight of a column of cold air of height H over that of a column of the same height and of the temperature of the air in D.

This may be calculated as follows, since the weight of a cubic foot of a gas of any temperature is inversely proportional to its absolute temperature, which is the temperature in degrees Fahrenheit + 460, or $W = c \div (t + 460)$, where W is the weight per cubic foot, t the temperature in degrees Fahrenheit, and c a constant, different for each gas and which, for air, equals approximately 40. If t be the temperature of the cold air and T be that of the air in D, then the pressure per square foot due to a column of cold air of height H feet would be $p = 40\ H \div (t + 460)$ and the pressure due to a column of hot air of the same height would be $P = 40\ H \div (T + 460)$. The difference of pressure which creates the flow of air then is

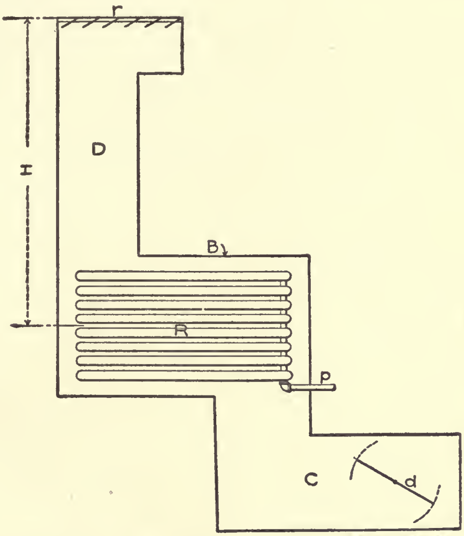

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Figure 26.—Diagram of Indirect Apparatus.

$$p = \frac{40\ H}{t + 460} - \frac{40\ H}{T + 460} = \frac{40\ H\ (T - t)}{(t + 460)\ (T + 460)}.$$

The head, h, which creates the velocity of flow, is equal to the height of a column of air of temperature T which would give the pressure *p*, or

$$h = \frac{p\,(T + 460)}{40} = \frac{H\ (T - t)}{t + 460}.$$

By the laws governing the flow of fluids the theoretical velocity with which the current of air would move through D is $v = \sqrt{2gh}$ where h is, as above, the head producing the flow. This would be the velocity produced in D by the difference in pressure p were it not for the resistance to the flow caused by the friction of the air in passing through the radiator and ducts and past dampers, registers, etc. This resistance often reduces the velocity to less than half of the theoretical velocity. Mr. Alfred R. Wolff, however, recommends that 50 per cent. of the theoretical velocity be taken in the case of ventilating flues which depend on a heated column for their action.

The practical application of this theory is, however, one of considerable difficulty. In an indirect radiator in a given situation we do not know the temperature of the heated column, and, what is most important, we do not know the resistance of the air passages. What we do know is that we have a radiator of so many square feet surface located in a certain system of boxing, ducts, etc., and supplied with steam, or hot water, at a certain temperature. The temperature of the air outside being also known, or assumed for extreme conditions, the question is how much air will be delivered by this radiator to the room and also to what degree it will be heated.

The amount of heat given off to the air depends upon the velocity and upon the difference between the temperature of the steam in the radiator and the mean temperature of the air around it; and the velocity depends, again, upon the difference of temperature between the entering and out-going air as well as upon the air resistance as embodied in the arrangement of ducts, structure of radiator, etc. All of these make a complicated system of variables which it is impossible to apply in theoretical formulas and anticipate what the actual result will be. In practice, a given radiator in a given setting, and with given temperatures of steam and outside air, condition of wind being constant, will deliver a definite amount of air heated to a definite degree and the velocity and final temperature adjust themselves until there is an equality between the temperature head acquired and the velocity head plus the head necessary to overcome the resistance. But exactly how this combination will adjust itself it is wellnigh impossible to say beforehand, inasmuch as the air resistance is a quantity very difficult to predetermine, it being very greatly affected by a slight change in the arrangement.

Mills' test of indirect radiators.—For these reasons, all rules thus far deduced for installing indirect radiators are entirely empirical. But very few tests have been made upon indirect radiators with a view to establishing the relation between any of the variables involved; but some valuable results might be obtained by a thorough series of experiments carefully and systematically carried out. Mr. J. H. Mills, in his work on Heat, published in 1883, presents the collected results of a number of tests on several indirect radiators of different types. These tests were made on various radiators at various times and by several different experimenters.

The writer has taken from the Mills table the results given for the two radiators upon which the greater number of tests were made and has endeavored by plotting some diagrams from them to determine something of the relationships between the existing variables. The results published by Mr. Mills on the Gold pin radiator and the Whittier radiator are presented in the accom-

TESTS ON GOLD'S PIN INDIRECT RADIATOR.

Experimenter.	Date.	Sq ft. of Radiation.	Temperatures.			Diff. Temp.		Oz. Water Condensed per sq. ft. per hr.	Air. Cu. ft. per sq. ft. per hr.	B. T. U. per sq. ft. per hr.
			Steam.	Entering Air.	Exit Air.	Enter'g and Exit Air.	Steam and Enter'g Air.			
C. B. Richards....	1873-4	..	215	0	160	160	215	5.44	111	340
W. J. Baldwin....	1875	60	239	71	168	97	168	3.83	128	239
W. Warner	1880	70	222	42	145	103	180	4.60	145	288
Dr. Gray	1875	90	259	33	125	92	226	6.54	231	400
C. B. Richards....	1873-4	..	215	0	139	139	215	9.15	214	572
J. R. Reed.........	1875	58	222	52	127	75	170	7.92	343	495
C. B. Richards....	1873-4	..	215	0	129	129	215	12.65	319	791
J. H. Mills........	1876	76	239	81	159	78	158	8.49	354	531
W. J. Baldwin....	1885	60	227	82	150	68	145	8.16	290	510
J. H. Mills........	1876	76	239	90	158	67	148	8.91	433	557
W. J. Baldwin....	1885	60	227	70	137	67	158	8.93	433	558
C. B. Richards....	1873-4	..	215	0	121	121	215	15.92	428	995
J. H. Mills........	1876	77	230	88	158	70	142	10.04	467	628
J. H. Mills........	1876	76	259	90	166	76	169	15.16	649	948
J. H. Mills........	1876	76	222	90	145	55	132	12.54	741	784
J. H. Mills........	1876	77	227	94	145	51	133	13.43	855	839
TESTS ON G. WHITTIER'S INDIRECT RADIATOR.										
C. B. Richards....	1873-4	..	215	0	135	135	215	4.40	106	275
J. R. Reed........	1875	68	222	45	129	84	177	5.09	197	318
C. B. Richards....	1873-4	..	215	0	102	102	215	6.66	212	416
J. R. Reed........	1875	68	222	52	110	58	170	5.50	308	344
J. R. Reed........	1875	..	222	52	114	62	170	5.86	307	366
C. B. Richards....	1873-4	..	215	0	87	87	215	8.53	319	533
C. B. Richards....	1873-4	..	215	0	77	77	215	10.14	428	634

panying table. In the accompanying diagrams, Figures 27 and 28, the relation between the British thermal units given off per hour per square foot of radiator and the cubic feet of air per square foot of radiator per hour has been plotted from these results. This last quantity is, of course, a measure of velocity and is the only one which is of practical value in the comparison of different radiators.* The author has marked each of the points on the diagrams with the difference of temperature between the steam and the entering air. At first inspection there seems to be but little uniformity in the arrangement of points, but a little study shows that for those representing the same difference of temperature the relation between the heat units per square foot and the cubic feet of air per square foot may be represented by a fairly uniform curve.

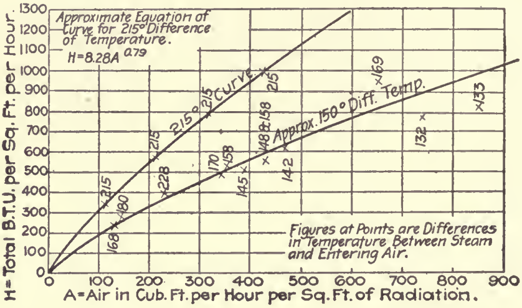

Figure 27.—Tests of Gold Pin Radiator.

On the diagram of the tests of the Gold pin radiator are plotted the curves representing the relation for a difference of temperature of 215 degrees Fahr., and also approximately that for a difference of 150 or 160 degrees. On the diagram for the Whittier radiator are plotted only the curve for tests at a difference of temperature of 215 degrees. There are some points, which are marked by a cross on the diagram, that seem to be decidedly out of place; that is, for the difference of temperature the ratio between the British thermal units per square foot and the cubic feet of air per square foot is too low. Considering the fact, however,

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* Mr. Mills gives a diagram somewhat similar to these, but the author cannot find that the points given are taken directly from the tests which he produces.

that the tests under discussion were made on radiators of different sizes, and several years apart, by different men, and under very different conditions of setting, the uniformity of the curves is very striking, and the few points which are evidently out of place are doubtless due either to some error of observation or in some marked difference in the way of taking measurements.

Inasmuch as in practice we are most concerned with extreme conditions, the curves for the difference of temperature of 215 degrees are of most value, as they may be taken to represent an initial air temperature of 0 degree and low-pressure steam at 215 degrees. It will be noticed that the 215-degree curve for the Gold pin radiator is quite different from that for the Whittier. As these curves show for a constant difference of temperature, the relation between the cubic feet of air per square foot of radiator, which is a measure of the velocity of air flow, and the heat given off per square foot, they take into consideration all variations in setting; and the similar curves for any two radiators indicate precisely the relative values of the two radiators. For example, the 215-degree curve of the Gold pin radiator shows a uniformly higher ratio between the British thermal units per square foot and the cubic feet of air per square foot than the similar curve of the Whittier. The former is, by just so much, therefore, the more effective radiator. Mr. Mills states of the Gold pin radiator, which was first introduced by Mr. Samuel Gold in 1862, that it "has proved the most efficient indirect-heating surface ever produced." It is still extensively used, although some modern makes are largely supplanting it. It is to be regretted tests have not been made on some of the more modern types in comparison with it.

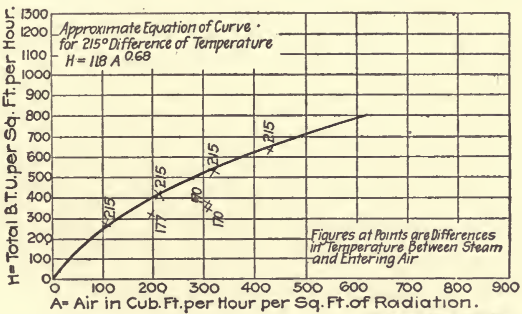

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Figure 28.—Tests of Whittier Indirect Radiator.

If it is desired to consider this question mathematically, the equation of the 215-degree curve of the Gold pin radiator is approximately $H = 8.28 A^{0.79}$, whereas the equation of the similar curve of the Whittier radiator is $H = 11.8 A^{0.68}$, in which H represents the British thermal units per square foot and A the cubic feet of air per square foot. In other words, with the Gold pin radiator the heat is proportional to the 79/100 power of the number of cubic feet of air per square foot of radiation (nearly equal to the fourth root of the cube), while with the Whittier it is proportional to the 0.68 power (nearly the cube root of the square); and the nearer this exponent approaches unity the more effective will the radiator be, unless there is a large variation in the coefficient.

As yet there is not very much practical data on indirect radiators. It would be of special value if some tests were made of the more modern forms of indirects to establish corresponding diagrams for them. Such tests should be made preferably in cold weather and with a constant difference of temperature between the steam and entering air of about 215 or 220 degrees. The setting of the radiator and air ducts should approximate practical conditions and the velocity (as cubic feet of air per square foot of radiator) could be varied by changing the resistance to air flow by means of dampers. In this connection some experiments of much practical value could also be made on the air resistance by determining the velocity in cubic feet of air per square foot of radiator attained for different temperatures in the hot-air duct, D, in Figure 26.

Indirect radiators are seldom installed except for rooms on the first or second floors; and in the former case the duct, D, is very short, and in the latter it is usually from 12 to 16 feet long. It should be stated in this connection that indirects of large size should be spread out as much as possible so as to give a large area against the current of air. If they are made of several radiators, one above the other, as is sometimes the case, by the time the air reaches the upper ones it is of so high a temperature that they have but little effect in comparison with the lower section.

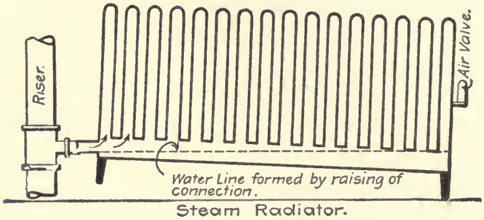
Direct-indirect radiators.—In regard to direct-indirect radiators, their action is much the same as that of the indirect; but they have the added effect of radiation, whereas with the indirect all heat is conveyed by convection. Furthermore, with the direct-indirect type, the flues are much shorter and the air resistance much less than with the indirect setting. As a matter of fact, the principal air resistance with the former is due to the passage of the air through the radiator itself.

The author knows of no tests that have been made on direct-indirect radiators, but considers they would be of value if they should establish the relation between the heat given out and the air delivery per square foot of radiator for constant differences of temperature between the steam and entering air. As stated in a previous chapter, in the opinion of the author the use of the direct-indirect radiator, which has been, up to this time, and is now, very limited, will be materially increased in the immediate future, as in connection with exhaust fans they form an effective means of introducing adequate ventilation into buildings which are not very densely populated but in which there is a decided need of ventilation. This class of buildings includes especially our palatial modern office buildings and also a certain class of factories. The more extensive introduction of these radiators, as well as of the indirects, is greatly delayed by the lack of accurate information as to what the different makes on the market will do in the way of heating under various practical conditions of temperature and setting. There seems, therefore, to be a considerable field for investigation in this regard.

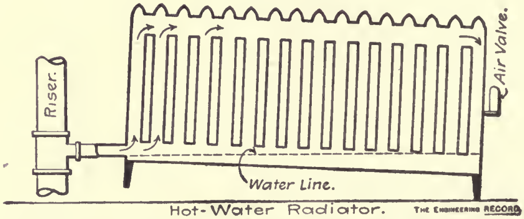
Circulation in radiators.—In the preceding chapter, and thus far in this one, we have discussed the action of radiators in doing the work they are intended for, and have pointed out the theoretical and practical considerations involved. Before discussing the bearing of these principles upon the design of a heating plant it is necessary to turn the attention to another consideration involved in the action of radiators, and one which is of much importance in the practical efficiency of a heating plant. This is the circulation of steam within the radiator.

Any one who has had even a slight experience with radiators well knows the troubles that arise on account of dripping air valves, water-hammer, and the pocketing of air, and other evils that are due to imperfect steam circulation. While evils of this kind are frequently attributable to imperfect circulation in the piping, yet there is a great difference in the operation of radiators in this respect.

As shown in a previous chapter, any heating system contains a considerable amount of air, and it is necessary to provide means for venting the piping and radiators so as to allow it to escape in the proper way. Ordinarily, when steam is shut off from a radiator it fills with air at atmospheric pressure, through the air valve; and when steam is turned on, this air must in some way be allowed to escape before all of the surface can have full heating effect. The rapidity with which the air will be displaced by the steam depends on where the air valve is placed and on the design of the radiator. In some radiators the air will flow out the air valve and be followed up by the steam rapidly and uniformly; while in others the air will pocket in places, and it may be hours before it all works out. The action of radiators in this regard is very peculiar, and it is frequently exceedingly difficult to predict beforehand whether or not a radiator will allow good circulation.



Steam Radiator.



Hot-Water Radiator. THE ENGINEERING RECORD

Figure 29.—A Cause of Retarded Air Expulsion.

As a general thing the simplest radiators are the most effective. Air is heavier than steam of the same pressure, but in a heating system the air will always find its way to the dead end, or point where there is no circulation. If a straight, vertical pipe, closed at the top, be connected to a source of steam supply, any air in the system will accumulate at its top. If steam is turned on an ordinary two-column steam radiator which is full of air and has a tight air valve, after some moments the first few loops will become filled with steam and perfectly hot, the remaining loops being full of air and cold. If the radiator has a two-pipe connection the air may work out to some extent through the return; but if it has only a one-pipe connection it will remain in this condition as long as the air valve is kept closed. If, however, the radiator be of the hot-water type—that is, it has its loops connected by openings through the top as well as at the bottom—the steam will run along the top of the radiator, and as long as the air valve is closed it will remain hot across the top and the lower part of the loops will be cold, with the possible exception of the two end ones. If now the air valves be opened, the air will flow uniformly from the regular steam type, the steam filling one loop after another; but with the hot-water type, as soon as the air valve is opened the steam will flow first across the top, then across the bottom, and the air will gradually work out, first from the loops near the air valve. This will serve to illustrate to some extent the action of air in radiators.

Circulation in direct radiators.—As regards direct radiators, the ordinary two-column steam type gives the most perfect circulation. When steam is turned on it compresses the air to the pressure of the steam, and immediately fills a portion of the bottom and the nearest loops to the inlet. Each loop then acts independently and the air syphons out of each, one after another, until all are full of steam. In the hot-water type, as shown, the steam has a free circulation around the radiator as a whole, which interferes with the air circulation in each loop, so that these radiators will often remain air bound in the center for a considerable length of time. In the same way three and four-column radiators will become air bound in the middle columns, the air syphoning out of the two outside columns and establishing a circulation there, while the contents of the inner columns remain quiet. In this connection it should be stated that a strictly one-column radiator would not allow circulation at all, or but very slowly, but the so-called one-column radiators are practically two columns, as they are cast with a partition running up the loop with an opening at its top. Radiators of the flue pattern always have one or two similar partitions. Direct radiators which are low and wide are almost universally built with the loop opening in the top as well as the bottom, under the impression that otherwise the outside portions of the loops would easily become air bound. Some of the author's experiences, however, lead him to think that as far as this is concerned the circulation in this type also is better without the top connection. There is, however, one practical advantage which the top-connection radiators have over the steam type, that is more especially marked in long, low radiators. If, with a one-pipe connection, the supply end is somewhat raised, on account of bad steam fitting, the unwarranted expansion of a riser, or other cause, it may trap the end loops of the steam type so as to shut off the air valve entirely, whereas the top-connection type would have a circulation in any such case, as is illustrated in Figure 29. Such a condition, though the result either of poor design or bad workmanship, is still a frequent occurrence in practice.

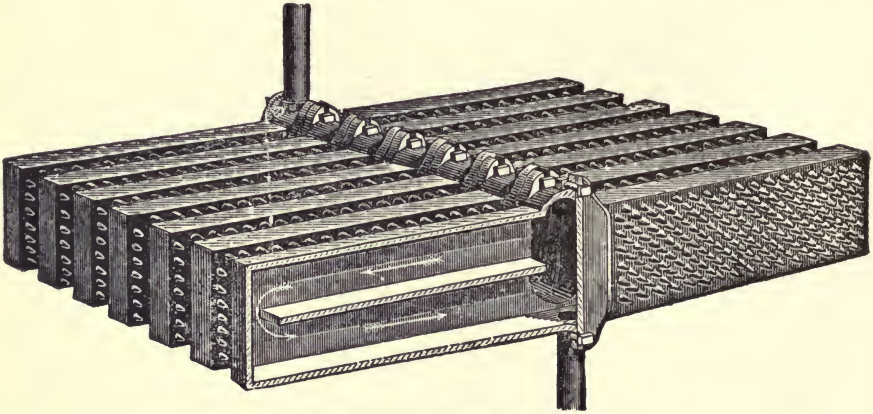


Figure 30.—Gold's Pin Radiator.

Circulation in indirect radiators.—Indirect radiators, which are always made to lie horizontal, are usually made with loops equivalent to the two-column form, but of greatly exaggerated width and very low, and have the steam connection at one of the lower corners. There are, however, some special forms, and one has to use his judgment as to their qualities in respect to circulation.

It is important that radiators be built and set so that but little, if any, water will stand in them. The openings for pipe connections should be at the lowest point and the radiator should drain perfectly. The loops of some radiators are built so that there is quite a pocket under the opening. This should be avoided, as the water which stands in them, and is allowed to become cold, is a fertile cause of water-hammer as well as dripping air valves. When the steam is turned into the cold radiator it is apt to gather up this water, together with the freshly condensed water, and drive it into the back end, clogging up the passages and causing water-hammer and dripping air valves, to the great discomfort of those in proximity.

Air valves.—In regard to air valves there is but little to be said. They are a necessity to every radiator; without them any radiator would soon become dead by being filled with air. Automatic air valves have almost entirely superseded the old-time hand air valves. They are made with a composition disc, with a high coefficient of expansion, which is arranged to close the valve as soon as the hot steam comes in contact with it. They are also provided with a screw attachment by which the valve opening can be adjusted after the valves are in place. The disadvantage of the automatic air valve is that when steam is turned on, the entire radiator will become heated. For this reason the author prefers the plain hand air valve on radiators in his own rooms, as the amount of the radiator heated can be very accurately regulated by means of them, especially when they are connected on a one-pipe system. The automatic air valve, however, takes the circulation in the radiator entirely out of the hands of persons who are not acquainted with their principles, and in the case of indirects is a necessity.

Air valves are generally placed about 18 inches from the bottom of the last loop. Theoretically the best location would be near the bottom of this loop, but if there is danger of much water in the radiator they are safer near the top. The author has cured several cases of a dripping air valve by tapping it into the extreme top of the loop. When so placed the last loop will sometimes remain partially air bound on one side, but otherwise they are quite effective in this position. The trouble referred to, however, is much more often due to improper piping than to anything in the design of the radiator.

CHAPTER V.—DESIGN OF RADIATION.

Heat loss in buildings.—There have been considered in previous chapters the various kinds of radiators in use and the amount of heat given off by them under different conditions; and the subject now approaches a study of the particular way in which the heat is utilized. The object of any heating system is, of course, to maintain a uniform temperature in the building in question, and to do this it is necessary: First, to replace the heat lost by convection and radiation from the windows and walls of the building to the colder surroundings outside; second, to heat to the required temperature any air that may be intentionally admitted for ventilation; and third, to heat also the air that may be admitted unintentionally through cracks of window frames and porous walls and opening doors. The amount of heat required for this last cause is much greater than is generally supposed.

The amount of air that will pass through the walls of an apparently tight room is incredible to those who are not familiar with it by actual experiment. The author knows of no experimental data on the subject, but Dr. John S. Billings, in his valuable work on "Ventilation and Heating," describes a simple and interesting experiment that may be undertaken by any one. Take a room of average proportions, heated by a hot-air furnace or indirect radiation, and the air will, on a fairly cold day, be coming through the register with a very considerable velocity. If now this velocity be measured by an anemometer, or other means, and all doors and windows be closed and the measure be again taken, it will generally be found that there is scarcely an appreciable reduction in this velocity. If now all the cracks of the doors and windows be carefully stopped up with cloth or paper, the reduction in the velocity of the incoming air will still be but very little reduced. Some of the air in such cases escapes directly through the plastered and papered walls, but more through floors and into the outside air through brick walls, between the floors, and at such points as are not plastered and papered. In cold weather it will generally be noticed that with all windows and doors closed, there is a decided current of air flowing through any building, in the same direction as the wind out of doors, and this is always most noticeable at the floors.

It may be stated in general that brick buildings are much tighter than wooden; and fireproof buildings which have wooden flooring laid on some kind of a concrete filling are much tighter than the ordinary brick buildings. It is perhaps a valuable thing that the walls of buildings are not less porous than they are, for in far too many cases there is no ventilation in winter, except what is obtained in this way. It is, however, much better to make the walls tight and provide some proper inlet for ventilation, especially as from a sanitary standpoint the floor is the worst place to let cold air into an otherwise warm room. An ordinary brick building can be much improved in this respect, if, during construction, the walls around the joists and for some inches above and below be painted with a heavy coat of asphalt paint. It is for these reasons mainly that all rules for proportioning radiation surface are very largely empirical.

The heat required for a definite amount of ventilation can be very accurately calculated. A cubic foot of ordinary air, at 60 or 70 degrees Fahr., weighs about 0.0745 pound, or there are 13.4 cubic feet per pound; and the specific heat is about 0.24, so that one British thermal unit will heat 55.8 cubic feet of air 1 degree Fahr. This factor is, however, subject to considerable variation according to the final temperature considered and the degree of moisture, and is usually taken at 55.

The heat lost by radiation and convection from the walls of buildings has been variously calculated by different authorities, from Péclet down, and a great variety of results have been given. It is unquestionably very difficult to determine it experimentally, because of the fact that the loss of heat from walls, etc., depends first upon the construction of the walls, but more especially upon the condition of the air outside, the loss of heat being very greatly increased by a slight wind blowing against the exposed surface. The loss of heat is greatest from the glass surface of windows. Mr. W. J. Baldwin, in his book on "Steam Heating for Buildings," which has for some years been a standard, publishes a table of the relative "heat-transmitting power of various building substances," which is given here.

BALDWIN'S TABLE OF HEAT-TRANSMITTING POWER OF BUILDING SUBSTANCES.

Window glass	1,000
Hardwood sheathing on walls	66 to 100
White pine and pitch pine	80 to 100
Lath and plaster, good	75 to 100
" " " common	100 to 150
Common brick, rough	150
" " hard finish	200
" " hollow walls, hard finish	150
Sheet iron	1,100 to 1,200

Mr. Baldwin further implies that the coefficient representing the amount of heat given off by glass surface per square foot per hour per degree difference in temperature between one side of the glass and the other is about the same as the similar coefficient for radiation, which may be taken at about 1.8 British thermal units.

The German Government made an investigation into this subject, and the results of its work have been translated into English measures by Mr. Alfred R. Wolff (Journal Franklin Institute, Vol. 134); and Prof. R. C. Carpenter has translated the results of Péclet's original investigations. The factors given differ very decidedly, as may be seen by the accompanying table, in which are given the coefficients of heat transmission for different surfaces:

TABLE OF COEFFICIENTS OF HEAT TRANSMISSION.

(British thermal units transmitted per hour per square foot of surface per degree difference of temperature.)

	Baldwin.	Péclet. (Carpenter.)	German Gov. (Wolff.)
Single skylight	...	..	1.12
Double skylight	...	..	0.62
Single window	1.8	.91 to .98	1.03
Double window	...	.60 to .66	.52
4-inch brick wall.	.27 to .36	.43	.68
8-inch brick wall.		.27	.46
13-inch brick wall.		.32	.32
17-inch brick wall	...	.26	.24
Wooden beams planked over as flooring			0.083
Wooden beams planked over as ceiling			0.104
Fireproof construction as flooring			.124
Fireproof construction as ceiling			.145
Wooden door			.414

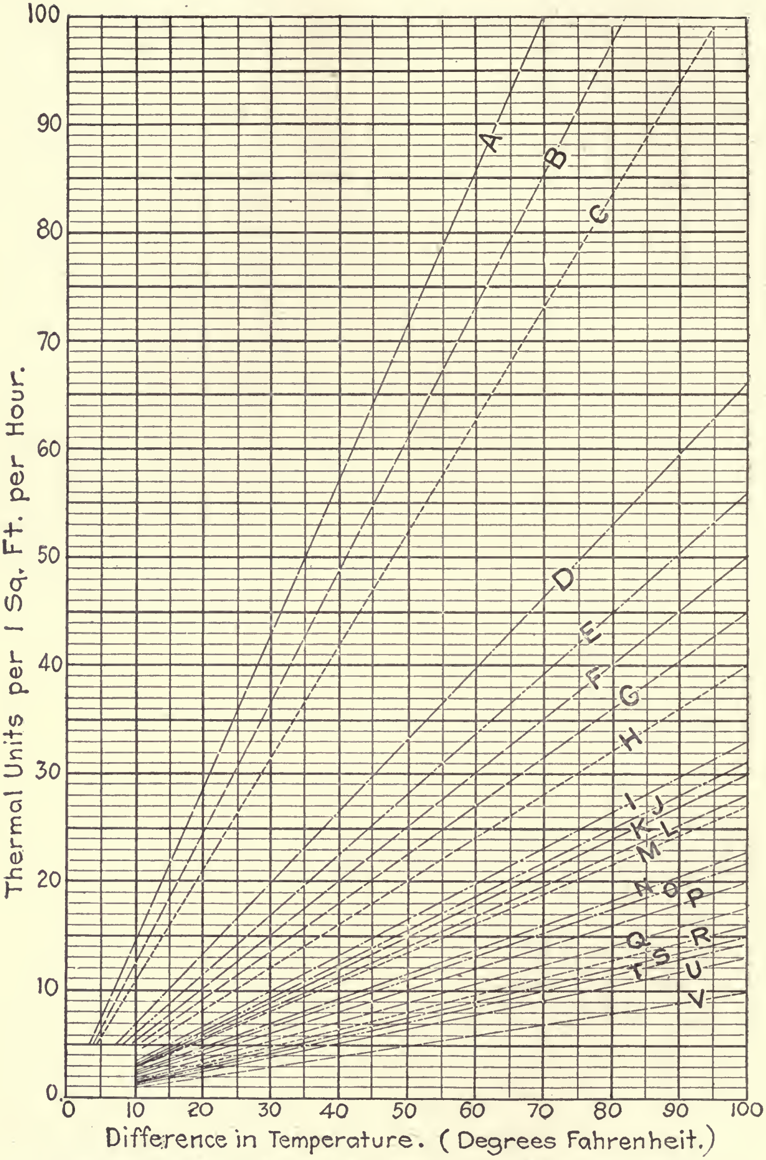
Mr. John J. Hogan gives 1.57 British thermal units as the coefficient for glass. Mr. Charles Hood, the English authority, states that one square foot of glass will cool 1.279 cubic feet of air one degree per minute per degree difference in temperature. This is equivalent to a coefficient of heat transmission of about 1.40 British thermal units per hour. Mr. Hood adds that this was determined in still air and that it is very greatly increased by the effect of wind. He states, however, that it is well known that in extremely cold weather there is invariably but little wind, so that he considers this a safe coefficient to use.

Mr. Wolff has constructed a diagram of heat transmission from buildings, which embodies the German coefficients with some slight modifications based on his own very extended practice. He states that he has used this diagram in the calculations of heating surface for buildings, during the past six years, with the most satisfactory results. This is a valuable recommendation, and the author takes much satisfaction in presenting the diagram herewith.

In using his diagram for proportioning radiation surface, Mr. Wolff calculates by it the number of heat units lost from the exposed wall and glass surfaces and further makes allowance for the direction of winds on the outside exposure, as shown on the small diagram on page 65 facing the main one. As indicated 5 to 25 per cent. is added to the calculated amount of heat dissipated in transmission through the actual wall surface and 10 per cent. for reheating the air constantly leaking in. An allowance is also advised, to the amount of 10 per cent., for the transmission of heat through floors, ceilings, etc. Where the rooms are not large, one calculation is made for all these factors by adding to the heat transmission as obtained by means of the main diagram, the percentage given in the small circle.

For "wooden floors" in cheaply constructed buildings, the author would recommend even more allowance than Mr. Wolff gives, since where such floors are used a great loss of heat comes from a large amount of cold air, which, even with a light wind blowing, will work through the brick walls where the joists are set in and where the walls are unsealed by lathing or plaster, and find its way into the rooms. This is a common source of heat loss in cheaply constructed brick houses and apartment buildings, and is the usual cause of the cold floors which are noticeable in many buildings in cold weather. In fireproof structures, on the contrary, the construction of the walls and floors is much more substantial and offers but little opportunity for air to blow in between the floor and ceiling.

Baldwin's rule for direct radiation.—The wide variation in these coefficients of heat transmission have led to a corresponding variation in the rules laid down for proportioning radiating surface.

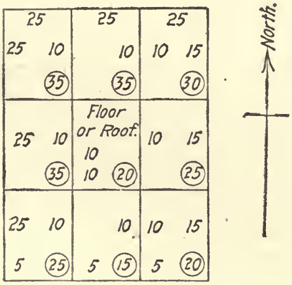


Alfred R. Wolff's Diagram of Transmission of Heat in Buildings.

A, vault light; B, single window; C, single skylight; D, 4-inch brick wall; E, double window; F, double skylight; G, 8-inch brick wall; H, 1-inch pine board door; I, 12-inch brick wall; J, concrete floor on earth; K, fireproof partition; L, 2-inch pine board—heavy door; M, 16-inch brick wall; N, 20-inch brick wall; O, concrete floor on brick arch; P, 24-inch brick wall; Q, 28-inch brick wall; R, 32-inch brick wall; S, wood floor on brick arch; T, 36-inch brick wall; U, 40-inch brick wall; V, wood floor, double.

In the early days of steam heating, radiating surface was generally figured by various rule-of-thumb methods, based chiefly upon the cubic contents of the room to be heated. These varied all the way from one square foot of radiation for 30 cubic feet of space, up to one square foot to 100 cubic feet, according to the building considered. Mr. Baldwin, in the earlier editions of the work mentioned, gives a rule which only takes into account the exposed surface of the building. According to this rule it is first necessary to figure what may be called the "glass equivalent surface." This is the actual glass surface in a room added to the wall surface reduced to its equivalent in glass. Mr. Baldwin refers to his table of relative heat transmitting powers, previously given, and his rule is as follows:

"In figuring wall surface, etc., multiply the superficial [exposed] area of the wall in square feet by the number opposite to the substance in the table, and divide by 1,000 (the value of glass), the product is the equivalent of so many square feet of glass in cooling power, and may be added to the window surface." Mr. Baldwin then gives a rule for finding the number of square feet of radiating surface for each square foot of glass, or the equivalent of other building substances in glass, which may be expressed by the following formula:



Exposure Diagram.

$$R = (t - t_1) \div (T - t) \times E$$

where t is the required temperature of the room, t_1 is the temperature of the outside air, T the temperature of steam in the radiator, R the radiation surface, and E, the glass equivalent surface.

With an outside temperature of — 5 degrees, an inside temperature of 70 and steam at temperature of 220, this formula would allow ½ square foot of radiating surface for each square foot of glass or its equivalent. Mr. Baldwin further adds: "It must be distinctly understood that [this] . . . offsets only the windows and other cooling surfaces it is figured against and does not provide for cold air admitted around loose windows, or [through walls] of poorly constructed . . . houses. These latter conditions, when they exist, must be provided for separately, and usually require as much as 50 per cent. additional; a good common rule for ordinary purposes being three-fourths of a square foot of heating surface to each square foot of glass, or its equivalent." He further states that he has used this rule in preference to any other for several years and found it very satisfactory. Following in Mr. Baldwin's footsteps, the writer has used this method of calculating surface in the design of a large number of heating systems, chiefly for large office buildings in Chicago and elsewhere. He has found, however, for low-pressure systems in office buildings that from 60 to 70 per cent. of the glass-equivalent surface in figuring radiation gives ample and satisfactory results. For such buildings he has counted each square foot of wall surface as being equivalent to one-tenth of a square foot of glass. For brick houses or apartment buildings of ordinary construction it is better to take the wall surface as 15 or 20 per cent. of the glass. For office buildings 65 per cent. of the glass-equivalent surface in radiating surface is ample in most cases, and it may average rather less. It should be greatest on the sides of the building which are exposed to the severest winds in winter, and may be less on the southern exposures.

Mills' rule for direct radiation.—Mr. Baldwin's method of calculating radiation surface calls for the exercise of careful judgment on the part of engineers using his rule, and many authorities have devised rules which are more specific. Most of these take into account the glass surface, the wall surface, and also the cubic contents of the room. The rule recommended by Mr. Mills in his work is

$$R = 0.50\,G + 0.05\,W + 0.005\,C$$

in which R is the number of square feet of radiating surface; G, the square feet of glass surface; W, the square feet of wall surface (exclusive of windows); and C, the contents in cubic feet. This rule is recommended where the rooms are to be heated to a temperature of 70 degrees with an outside temperature of — 10 to — 15 degrees Fahr. If the outside temperature is less or greater, the result should be multiplied by the proportionate factor. This is a very good rule and perfectly safe. The writer knows of a contractor who has had a very wide experience in steam heating who uses this rule universally, except that he multiplies the cubic contents by 0.004.

Willett's rule for direct radiation.—Mr. Jas. R. Willett, an architect of wide experience, who has given much study to heating and ventilation, formulated, several years ago, a very valuable rule for proportioning direct radiation, which is expressed by the following formula:

$$R = 0.9\,(t - t_1)\,(0.60\,G + 0.10\,W + 0.0025\,C)\,FJ \div t$$

where F is a factor depending on the method of heating (0.8 for low-pressure steam) and J, a factor depending on the exposure, which Mr. Willetts puts as 1.0 for ordinary south and east exposures and 1.4 for north and west. The other letters in the formula have the same reference as in the formulas previously given, but Mr. Willett states that t_1 should be taken 10 degrees higher than the lowest recorded temperature of the locality in question. With t_1 taken at minus 8 degrees; t, 70 degrees; F, 0.8; and J, 1, Mr. Willett's formula becomes:

$$R = 0.48\,G + 0.08\,W + 0.002\,C.$$

This equation compares very closely with Mills, though less allowance is made for the cubic contents and more for the wall surface. The writer considers that if J, in Mr. Willett's formula, be taken as 1. for south and east exposures, it is sufficient in most cases to take it as 1.2 for north exposures. For such exposures, therefore, the same formula can be used as for south and east rooms and the radiation increased one-fifth.

Carpenter's rule for direct radiation.—Prof. Carpenter, in his work on heating and ventilation, has devised a formula which is very carefully derived. He first calculates the amount of heat lost from the room in question and then the amount of radiating surface necessary to offset this heat, using coefficients for heat transmission which he substitutes in his formula. According to Prof. Carpenter's method, the heat in British thermal units lost from a room for every degree difference in temperature between the inside and outside air is $h = nC \div 55 + G + (W \div 4)$, in which G, C, and W represent the quantities previously assigned them, and n is the number of times the air of the room is to be changed per hour. Prof. Carpenter states that for direct radiation it is necessary to take $n = 2$ for ground-floor rooms and $n = 1$ for others, to allow for leakage of air. The quantity, $nC \div 55$ gives the number of heat units necessary to raise nC cubic feet of air 1 degree in temperature. Prof. Carpenter states that the radiating surfact should be equal to $R = \left[\,(t - t_1) \div (T - t)\,a\,\right] h$ in which t is the required temperature of the room, t_1 the outside temperature, T the temperature of the steam in the radiator, and a is a coefficient of heat transmission from a radiator which varies from 1.7 for low-pressure steam heating to 1.9 for steam pressure of 40 pounds and 2.4 for steam pressure of 100 pounds. Taking the usual conditions of $t = 70$ degrees and $t_1 = -10$ degrees and with low-pressure steam heating, the factor, $(t - t_1) \div (T - t)\ a$ becomes 0.324, so that with $n = 1$ the equation for radiation surface becomes:

$$R = 0.324\ G + 0.08\ W + 0.006\ C.$$

This formula differs very considerably, in the factors used, from those already cited, and it will be seen that it is based upon the coefficient of heat transmission for glass of 1 British thermal unit per square foot per degree difference in temperature, and the radiation surface due to the glass area is consequently much less than in the other formulas. The difference is more than made up, however, by the larger allowance for the cubic contents. In the opinion of the author, Prof. Carpenter's coefficient for glass is considerably too small, and his equation gives results which are too large for rooms having large cubic contents with comparatively small window surface, and results which are too small when the proportions are reversed.

Monroe's rule for direct radiation.—The author has recently deduced a formula which is a combination of Willett's and Carpenter's, and is as follows:

$$R = (1.3\ G + 0.25\ W + 0.008\ C)\ J\ (t - t_1) \div (T - t)\ a.$$

In this the letters stand for the quantities previously assigned, J being a coefficient depending upon the exposure (being unity in ordinary cases) and for the usual conditions as assumed in previous cases, this formula becomes

$$R = 0.42\ G + 0.08\ W + 0.0026\ C.$$

In the following table are given the proportions of four representative rooms of an office building for which the writer was en-

					Radiation Surface by					
Room.	Exposure.	G	W	C	Mills.	Willett	Carp'ter.	Monroe.	Baldwin.	Radiation Installed.
1.	West	59	160	3360	54.5	47	51	44	49	46
2.	N. & W..	118	312	2150	85	86	76	81	97	84
3.	NE. & E.	88.5	420	4070	85	84	87	82	85	80
4.	NE.	59	129	1730	44.5	42.5	40	46	47	40

gaged to design the heating system, and for which the heating surface has been figured out according to Mills', Willett's, Carpenter's and the author's formulas, and also according to Mr. Baldwin's formula taking 65 per cent. of the glass equivalent surface.

The table also gives the amount of surface which was installed in each of the four rooms, and which has given perfect satisfaction throughout two or three severe winters. The radiator used was the two-column cast-iron radiator, 32 inches high, except in room 2, which had a 26-inch flue radiator. The radiation in room 2 was made slightly less than the amount calculated, because a large portion of the wall surface was a 25-inch brick wall, for which the multiplier for W might be taken about 0.15 instead of 0.25.

It might be stated that in using the formula given, t_1 is to be taken 10 degrees above the lowest recorded temperature, and the factor, J, should be taken from 1.05 to 1.15 for severe exposures, and may also be increased 0.1 for ordinary brick buildings with wooden floor joists, and 0.2 for wooden buildings. The factor a is to be taken at 1.7 for ordinary conditions of exhaust-steam heating. It may be increased somewhat for heating at higher pressures and for buildings with low-pressure heating and no power, in which steam pressure of 10 or 15 pounds may be carried, it may be made equal to 1.8. In such cases, also, the temperature, T, may be taken at 235 degrees. The factor a should be decreased where the radiators are of an unfavorable pattern or are unfavorably located, according to their relative heat-giving power, under such conditions as has been pointed out in Chapter III. The last part of the formula need be calculated but once for each building. The factor a may be taken as high as 2.8 in some greenhouses and in some factories in which wrought-iron pipe coils are used, which are quite an effective type of surface. Unless the coils are especially favorably located, however, the factor should be somewhat less than 2.8.

In the general application of the formula given above it will be noted that the expression $(t - t_1)\ (1.3\ G + 0.25\ W + 0.008\ C)$ represents the total heat given off by the room, and it is equal to $R\ (T - t)\ a$, which is the heat given off by the radiation surface.

Mr. Wolff in his practice calculates the heat lost per hour from each room according to his diagrams previously given, with the allowance for exposure as shown thereon. He then divides this amount by the number of British thermal units given off per square foot of radiator per hour, which he takes as 250 for a two-column radiator (bronzed) set under the window, but this factor varies within wide limits, as before described, according to the kind of surface used and the nature of the setting.

Indirect radiation.—With indirect radiation the heat lost from the glass and wall surface must be made up by the heated air coming in from the indirect radiator, and to accomplish this the entering air must, in cold weather, have a temperature considerably above the mean temperature desired in the room. The total heat lost by the room is $(t - t_1)$ h where h is the expression $(1.3\ G + 0.25\ W + 0.008\ C)$ and the volume of air required in cubic feet per hour is $V = (t - t_1)\ h \times 58 \div (T - t)$ where T is the temperature of the air leaving the radiator. Now it is necessary for the indirect radiator to heat all of this air from the outside temperature to the temperature T, and the total heat required to be given off by the radiator is

$$U = V\ (T - t_1) \div 58 = (t - t_1)\ (T - t_1)\ h \div (T - t).$$

It will be seen that both U and V vary rapidly with a change in T, decreasing as T is increased. If $t = 70$ degrees and $t_1 = -10$ degrees for extreme conditions, and if $T = 150$, V will be one-half and U two-thirds of what they would be if T were taken at 110. It is this fact that makes the indirect radiator quite a flexible device, for in extreme weather it is possible, by partially shutting off the air supply, to maintain easily the required inside temperature at the sacrifice of a small amount of ventilation. If $T = 120$, $U = 208\ h$, and $V = 93\ h$; and with $T = 130$, $U = 186\ h$, and $V = 77\ h$. As a rule, it is safe to assume from 450 to 500 British thermal units per hour per square foot of surface for an indirect radiator, as will be seen by reference to the tests as described in the last chapter, and taking the former figure, with $T = 120$, $R = 0.46\ h$, and with $T = 130$, $R = 0.415\ h$.

Inasmuch as it has been found that for the same conditions of inside and outside temperatures R for direct radiation $= 0.325\ h$, it will be seen that according to this calculation from 28 to 40 per cent. more heating surface is required for indirect heating than for direct. The author has in his practice used these proportions for indirect radiators, usually installing about 30 per cent. more than for direct; although in some cases, where an exceptional degree of ventilation is desired and the room has a comparatively large amount of glass surface, more radiating surface is necessary. In such cases, and especially where a large amount of ventilation is desired, it is necessary to see that the quantity V, as obtained above, is equal to the amount of air required for ventilation. It will be found sufficient in all ordinary cases to change the air four times per hour, which is generally satisfactory for private houses; but where much entertaining is to be allowed for, six times per hour is better. In designing indirect radiators it is necessary to be very careful in the proportion of flues, but such details of construction will be considered in the next chapter.

In proportioning direct-indirect radiators the same rules apply as for the indirect type, although their action as direct radiators may be counted on to some extent. Where this kind of radiator is used in connection with an exhaust ventilating system very good results are obtained by using the author's formula for direct radiators, with an addition to the $0.008\ C$ of $2/3\ K \div 55$, where K is the cubic feet of air per hour required for ventilation. This gives additional surface necessary to heat $2/3\ K$ cubic feet of air from the outside temperature to that of the room. The author figures on $2/3\ K$ (in some cases $\frac{3}{4}$), as in extreme weather the degree of ventilation may be somewhat reduced. For these radiators also, the factor a in the formula may be taken as 1.9 or 2.

CHAPTER VI.—PIPING AND CONSTRUCTION DETAILS.

Having selected the system of heating to be employed according to the needs of the building in hand, and having proportioned the radiator surface according to the requirements of the various rooms, it then remains to lay out the system of piping and arrange the various details of construction.

In regard to piping connections, it should be stated at the outset that the flow of steam through any system of piping depends primarily upon the difference in pressure between that at the supply end and that at the delivery or return end, and without any difference of pressure no flow of steam can exist. In exhaust heating or low-pressure gravity systems, this difference of pressure is very slight, and consequently for such systems the pipes have to be larger than for high-pressure heating or vacuum systems in which the pressure in the returns is reduced by connecting them to a vacuum pump. Again, in most systems of steam heating there is another consideration which affects the sizes of pipes; that is, the water of condensation from the radiators. If the steam circulation were uniform and continuous and the water of condensation kept separate from the steam supply, as in properly arranged two-pipe systems, the pipes might be very small; but it is necessary to allow for sudden opening of radiator valves, so as to take care of the momentary demand for steam which this causes, as well as the rush of water of condensation which accompanies it. For exhaust and low-pressure gravity systems, it may be laid down as a general rule that pipe sizes should be larger for the simple one-pipe system than for any other arrangement. They may be smaller for the one-pipe overhead, or Mills system, and still smaller for the two-pipe systems. A description of various systems of steam distribution was given in Chapter II.

Baldwin's rule for pipe sizes.—In the early days of steam heating, pipe sizes were proportioned by various empirical rules, the usual basis of which was the principle of being sure to get the pipes large enough; and such rules are, to a large extent, blindly followed to-day. Mr. William J. Baldwin, in his earlier work on steam heating, gave a rule for proportioning steam pipes which is very convenient and has been very widely used. This rule states that in the sectional area of the pipe there should be allowed the area of a 1-inch pipe for every 100 square feet of radiator surface. Inasmuch as the areas of circles are proportional to the square of their diameters, this means a 1-inch pipe for 100 square feet, 2-inch pipe for 400 square feet, 3-inch pipe for 900 square feet, 8-inch pipe for 6,400 square feet, etc. These sizes are none too large for many cases, although in plants with the system carefully arranged so that the circulation is all in one direction and the water of condensation does not have to flow back against the current of steam, pipes can be very considerably decreased below the sizes given by this rule. Mr. Baldwin also gives a diagram of minimum sizes for short horizontal supply mains from which few branches are taken, which give sizes very much smaller than the rule above quoted. [See Table I.]

Mills' rule for pipe sizes.—Mr. J. H. Mills gives a diagram for the sizes of mains for one-pipe overhead systems of which he is the originator. This diagram gives sizes somewhat smaller than those obtained by Mr. Baldwin's rule. In the accompanying table are given the maximum square feet of radiation on pipes of each size according to the rules of Baldwin and Mills, as well as Mr. Baldwin's sizes for return pipes. In regard to his figures for minimum sizes for mains, Mr. Baldwin states that they represent minimum conditions for lengths of 50 feet or thereabout, but that for large buildings one size larger should be used.

Monroe's rule for pipe sizes.—In his own practice the author has divided mains and risers of steam-heating systems into the following classifications:

(a) Supply mains for one-pipe systems, which carry all water of condensation, but in the direction that the steam flows.

TABLE I.—PIPE SIZES FOR STEAM HEATING ACCORDING TO BALDWIN AND MILLS. SQUARE FEET OF HEATING SURFACE.

Size of pipe in inches..	1	2	3	4	5	6	8	10
A.—Mills—Supply mains and risers	...	900	1,750	2,500	3,300	4,000	7,250	10,500
B.—Baldwin — Supply mains and risers.....	100	400	900	1,600	2,500	3,600	6,400	10,000
C.—Baldwin — Minimum for mains	...	...	1,700	3,000	5,500	8,700	16,000	22,000
D.—Baldwin—Returns...	...	1,650	3,700	6,200	10,000	....	....	.....

(b) Mains for two-pipe or one-pipe overhead systems, into which there is no water of condensation from the radiators.

(c) Supply risers for ordinary one-pipe systems which carry all the water of condensation and in a direction opposite to the flow of steam.

(d) Risers for one-pipe overhead systems which carry all the water of condensation but in the same direction as the flow of steam, the lowest part of riser below last radiator being solely a return pipe.

(e) Supply risers for two-pipe systems which carry no water condensation, except that due to the pipes themselves.

In addition to these the following classification is made for return pipes:

(f) Return mains for two-pipe and overhead systems which are above the water-line of the system.

(g) Horizontal return mains for two and one-pipe systems which are below the water-line.

(h) Return risers for two-pipe systems.

Table II. herewith gives the maximum amount of radiation to be put on each size of pipe for the different classifications:

TABLE II.—PIPE SIZES FOR HEATING SYSTEMS (MONROE).

Size of pipe, in.	(a) Supply Mains. One-pipe.	(b) Supply Mains, Two-pipe or Overhead.	(c) Supply Risers, One-pipe.	(d) Supply Risers, One-pipe overhead.	(e) Supply Risers, Two-pipe.	(f) Return Mains, Above Water-line.	(g) Return Mains, Below Water-line.	(h) Return Risers, Two-pipe.
1	70	....	50	60	80	400	400	250
1½	150	....	120	150	200	900	900	700
2	300	400	250	300	400	1,600	1,600	1,200
2½	500	650	400	500	700	2,600	3,500	2,000
3	750	1,200	700	900	1,200	3,800	8,000	3,000
4	1,400	2,000	1,500	1,800	2,000	7,000	14,000	....
5	2,400	3,500	2,500	2,600	3,600	12,000	26,000	....
6	4,000	5,500	3,600	4,200	....	16,000	....	....
7	5,500	8,000	....	....	....	30,000	....	....
8	7,000	12,000	....	....	....	....	....	....
10	12,000	16,000	....	....	....	....	....	....
12	18,000	25,000	....	....	....	....	....	....

The table here given represents the conditions which are to be met with in ordinary buildings, and exceptional conditions will have to be met with by the judgment of the engineer conducting the work. It will be noted in general that this table gives less radiation on the small pipe sizes and more on the large than that by either Baldwin's or Mills' rules. In small plants, or in plants where a large number of small radiators are supplied from the risers, the number of radiators on a given riser may affect its size irrespective of the amount of radiation. Risers less than 1 inch in size are rarely used on a two-pipe system, or less than 1¼ on an ordinary one-pipe system, unless perhaps for only one small radiator. In an overhead system the height of the building and the consequent number of radiators on the riser affect the size, especially at the lower end. In such a system it must be borne in mind that all the water of condensation from the higher radiators is falling down the pipe, passing the connections to the lower radiators. For such systems in high office buildings it is therefore well to make the risers fairly large toward the bottom while the upper portion can be proportioned according to the sizes given in column (d). For buildings about ten stories high, the lower part of the riser should be not less than 2 inches, and if the amount of radiation on the riser is large or the building is over 15 stories high, this may better be 2½ inches. The table given is intended for low-pressure gravity systems and exhaust heating where not more than 2 or 3 pounds back pressure can be carried on the engine.

For high-pressure systems working at 20 or 30 pounds pressure, such as are used sometimes in factories, when engines are used with a condenser, the pipe sizes may be somewhat smaller than those given in columns (e) and (h), although for the smaller connections it is not advisable to reduce them on account of the possibility of water from the radiators backing into the supply pipes.

Pipes for vacuum systems.—In vacuum systems in which the vacuum is maintained on the return side, pipe connections may be reduced very materially, and Table III, given herewith, shows sizes recommended by Messrs. Warren Webster & Company for mains, risers and radiator connections for the vacuum systems which they install. As already described, their system is in principle an ordinary two-pipe system with a vacuum pump on the returns, but also having the special feature of an automatic thermostatic valve on the return connection, which valve closes automatically when it is heated to steam temperature and opens when it becomes cooler. From the author's experience he would consider the sizes given in this table somewhat too small and would in general recommend about one pipe size larger.

TABLE III.—PIPE SIZES—WEBSTER VACUUM SYSTEM.

Sizes of supply pipes, in.	¾	1	1½	2	3	4	5	6	8	10
Maximum sq. ft. on runs not over 50 ft.	100	150	400	900	2,000	4,000	8,000	12,000	30,000	60,000
Sq. ft. surf. for long runs, 300 to 400 ft.	40	100	300	600	1,500	3,000	6,000	10,000	22,000	40,000
Minimum for return for above, in.	⅜	⅜	½	¾	1	1¼	1¼	1½	2	2½

With vacuum systems which have a vacuum only on the air-valve connection, such as the Paul system, it is impracticable to reduce much the sizes of the steam pipes below those given in Table II, as the only feature of this system is that it keeps pipe and radiators perfectly free from air, and does not greatly affect the flow of steam and water of condensation.

Radiator connections.—The connections from the risers to the radiators are always made somewhat larger in proportion than the mains and risers, and Table IV gives sizes which represent good practice for low-pressure systems.

TABLE IV.—RADIATOR CONNECTIONS.

One-pipe Systems.		Two-Pipe Systems.		
in.	Max. surf. in rad. sq. ft.	Supply. in.	Returns. in.	Max. surf. in rad. sq. ft.
¾	25	¾	½	40
1	50	1	¾	75
1¼	85	1¼	1	120
1½	130	1½	1	180

Carpenter and Sickles' rule for steam pipe sizes.—In designing piping for large systems it must be borne in mind that there are many things which affect the flow of steam in a piping system, and special cases must have special consideration. Elbows, bends and valves greatly increase friction in the pipes. According to the recent investigation of Professor Carpenter and Mr. E. C. Sickles, as given in a paper before the American Society of Mechanical Engineers, Volume XX, a single 90-degree elbow is equal in frictional resistance to a length of pipe equal to about 520 times the diameter, while the resistance of a globe valve is equal to a length of 706 times the diameter, and a good gate valve does not add any practical resistance. They gave the following approximate formula for diameters of pipes, which they say is practically accurate for sizes over 2½ inches:

$$d = 0.184 \sqrt[5]{w^2 L \div pD}$$

in which d equals the diameter in inches; w, the weight of steam to be delivered in pounds per minute; L, the length of the pipe in feet; D, the density or weight in pounds per cubic foot, and p, the difference in pressure in pounds per square inch between the ends of the pipe. Transposed, this formula becomes:

$$w = \sqrt{pDd^5 \div 0.00021\ L.}$$

From this it will be seen that, other things being equal, the delivery is proportional to the square root of the fifth power of the diameter.

The accompanying table, Table V, is calculated from this formula, assuming p = 1 pound per square inch difference of pressure and D = 0.04, which is the density of steam at a pressure of about one pound above the atmosphere. In this table allowance is made also for two globe valves and two elbows to each length of pipe. The square feet of surface each pipe would supply, allowing 0.30 pound of steam per square foot per hour (0.005 pound per minute), which is very liberal for direct radiation, is also given in the table. This table is chiefly interesting when compared with Table II, but may be of value for long mains where the building to be heated is at a distance from the plant. It should be noticed, however, that the greatest resistance is due to the elbows and valves. For example, the 8-inch pipe, 600 feet long, with two elbows and

TABLE V.—CAPACITIES OF STEAM PIPES.

w = wt. of steam delivered per min. per 1 lb. difference of pressure.
R = sq. ft. of radiation supplied at 0.005 lb. per sq. ft. per min.

Diameter, in.		Length of pipe allowing for 2 valves and 2 elbows, feet.				
		100	200	400	600	1,000
3	w	8.5	7.7	6.9	6.3	5.5
3	R	1,700	1,540	1,380	1,22	1,100
4	w	15.0	14.2	12.9	12.	10.6
4	R	3,000	2,840	2,580	2,400	2,120
6	w	....	33.	31.	29.	26.2
6	R	....	6,600	6,200	5,800	5,240
8	w	....	59.5	56.5	54.	49.
8	R	....	11,900	11,300	10,800	9,800
10	w	....	95.	90.4	87.	81.
10	R	....	19,000	18,080	17,400	16,200
12	w	....	138.	132.	128.	120.
12	R	....	27,600	26,400	25,600	24,000

two valves is equivalent to 2,240 feet of straight pipe, and the addition of another elbow would be equivalent to 350 feet of straight pipe and would reduce the delivery in the ratio of $\sqrt{2,240 \div 2,590}$.

Draining pipes.—In laying out the piping system for a heating plant, besides the proper size of pipes there are two points which must be very carefully considered: (1) That pipes as well as radiators are properly drained so that the water of condensation will flow off easily and uniformly to its proper receptacle; and (2) that proper provision be made for the expansion of pipes, so that such expansion shall not interfere with the flow of steam or water or disturb the setting of the radiators.

Pipes for an ordinary one-pipe system, which are run around the basement of a building, should be pitched toward the extreme ends, from which the return connection should be taken and run back to the receiver below the water-line. If the mains are very long they should be drained at intervals into this pipe.

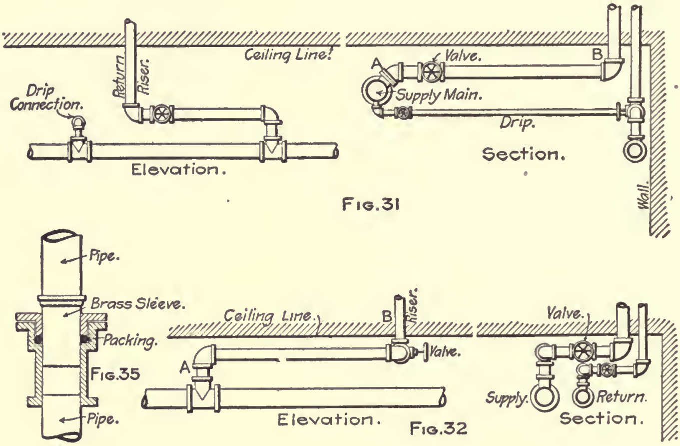
In a two-pipe system in which the mains are similarly run, they should be drained into the return pipes, and in making these drip connections care should be taken that the return pipes into which they drain are lower than the supply mains, so that there will be no opportunity for water to flow from the returns into the supply mains. The return pipes are generally, where possible, run under the basement floor, and should be lower than the supplies. Figures 31 and 32 represent typical connections from mains to risers. Where, on account of economy of space, it is necessary to run the supply and return mains on nearly the same level, as in Figure 32, the supply main must be dripped into a separate pipe run back under the floor or along the wall and connected into the principal return main below the water-line of the system. In two-pipe systems where the supply mains are short and properly covered, so that there is not much condensation, they may be given a slight rise from the boiler or source of supply and the water of condensation allowed to flow back. Riser connections should be taken out of the top of the mains so as to prevent any water of condensation that may be in the mains from getting into the risers.

In the one-pipe overhead system there is always a main supply riser running to the branch mains in the attic, and this should have a drain pipe from its lowest point extending back to the receiving tank. The attic mains are drained directly into the supply risers, which drop from the bottom of them.

In connecting up radiators on a one-pipe system they should be set so as to pitch slightly toward the connection from the riser, and the connection should always pitch toward the riser. Connections which, on account of carelessness in workmanship, were pitched in the opposite way, are a very fertile cause of water-hammer. Radiators set on two-pipe systems should be pitched slightly toward the return connection, which should not be connected from the same end as the supply. There are a number of plants in which radiators connected on two-pipe systems have both the supply and return connections at the same end of the radiator, but in the opinion of the author this is a very bad practice, as the radiator might very much better be connected on the one-pipe system. In fact, when radiators with such connections are in operation, unless the return connection is lower than the supply, which is not generally the case, the water of condensation is just as apt to run down the supply connection as down the return. Furthermore, when such radiators are turned on, if the supply valve is opened first, any water which may be in the radiator runs out of this connection, as well as the large amount that is formed by the first contact of steam with the cold radiator; and if the return valve is opened first, the water in the return pipe backs up into the radiator, so that when the supply valve is opened, a large amount of it will run out to the supply connection. At this point it should be stated that in turning on radiators with two-pipe connections the supply valve should always be opened first; and the fact that the uninformed occupants of rooms frequently do not know which is the supply valve is one of the objections of two-pipe systems.

Expansion of pipes.—The expansion of pipes is an important consideration in any case, and where there are long mains or in high office buildings, which consequently have long vertical risers, it becomes a consideration of vital importance. The coefficient of expansion of wrought-iron pipe is 0.000007 per degree Fahr. This amounts to about 1.5 inches in a 100-foot length for low-pressure steam pipes. In horizontal mains this can be generally taken care of by making turns or offsets in the mains in every 50 or 75 feet of pipe, the expansion being taken up by the spring of the pipe. All connections from mains or risers should be made with sufficient length of horizontal connection to allow for this expansion. In Figures 31 and 32 the expansion of the mains and risers is taken up in the spring of the arms, AB. An old rule for the length of such expansion arms is that the length in feet should be equal to twice the diameter in inches. This is a fair rule in most cases, but much depends on the amount of expansion to be taken care of, and no set rule can be given.

The most serious difficulties on account of expansion are met with in the long vertical risers of the modern high office buildings. In such cases any considerable movement of the riser is apt to result in trouble, as the radiator connections are generally short. Various means are employed to overcome this. In buildings over ten stories in height it can generally be taken care of by anchoring the risers rigidly in the middle so they expand in both directions, and allowing for the expansion by the connections to the supply main in the attic and to the returns in the basement. The radiators on the upper and lower floors, where most of the expansion takes place, must have connections sufficiently long to allow for it, and they must have sufficient pitch, so that they will not be trapped by the expansion of the risers. The author is familiar with one building 14 stories high in which expansion is entirely taken care of in this way. Radiators on the extreme floors



Provisions for Drainage and Expansion of Piping.

are made with extra high legs, and the connection from riser is as shown in Figure 33. In another case, in a 14-story building, an offset was made in each riser over the windows of the seventh floor, the upper part running on the opposite side of the tier of windows from the lower part, the spring of the pipe in this offset taking care of the expansion at this point. The risers were anchored rigidly in the center of each section. Arrangements of this kind are frequently used, and the chief objection is that unless they are concealed the offsets make an unsightly appearance, and it is frequently very inconvenient to put them in on account of the arrangement of the building.

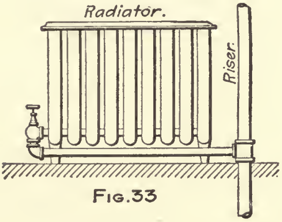


FIG. 33

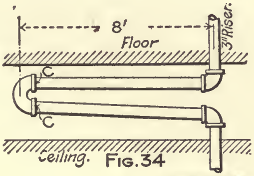


FIG. 34

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In one large 16-story building with which the author is acquainted, a loop, as indicated in Figure 34, was made with each riser and sealed in the seventh floor; but he would not recommend this arrangement, inasmuch as leaks are most apt to occur at the points marked C when the expansion and contraction works on the threads of the joint. Besides this, the framing of the building and extra construction details in the floor necessary to conceal these offsets are difficult and expensive. The expansion of such risers is frequently taken care of by means of expansion joints, a diagram of which is shown in Figure 35. The author has used these joints to a large extent, and although in some localities there is a prejudice against them, he thinks this rather unwarranted. By proper arrangement the expansion risers in any building not over 12 or 14 stories high can be taken care of with one set of expansion joints. In a 14-story building heated on the overhead system the author installed an expansion joint in each riser above the radiator connection at the seventh floor. The risers were anchored rigidly to the beams of the fifth and twelfth floors so that expansion was in both directions from these points. This gave about $\frac{3}{4}$ inch expansion downward at the first and eighth floors and about $\frac{3}{8}$ inch upward at the seventh and fourteenth. Radiator connections on the eighth floor were long enough to admit of

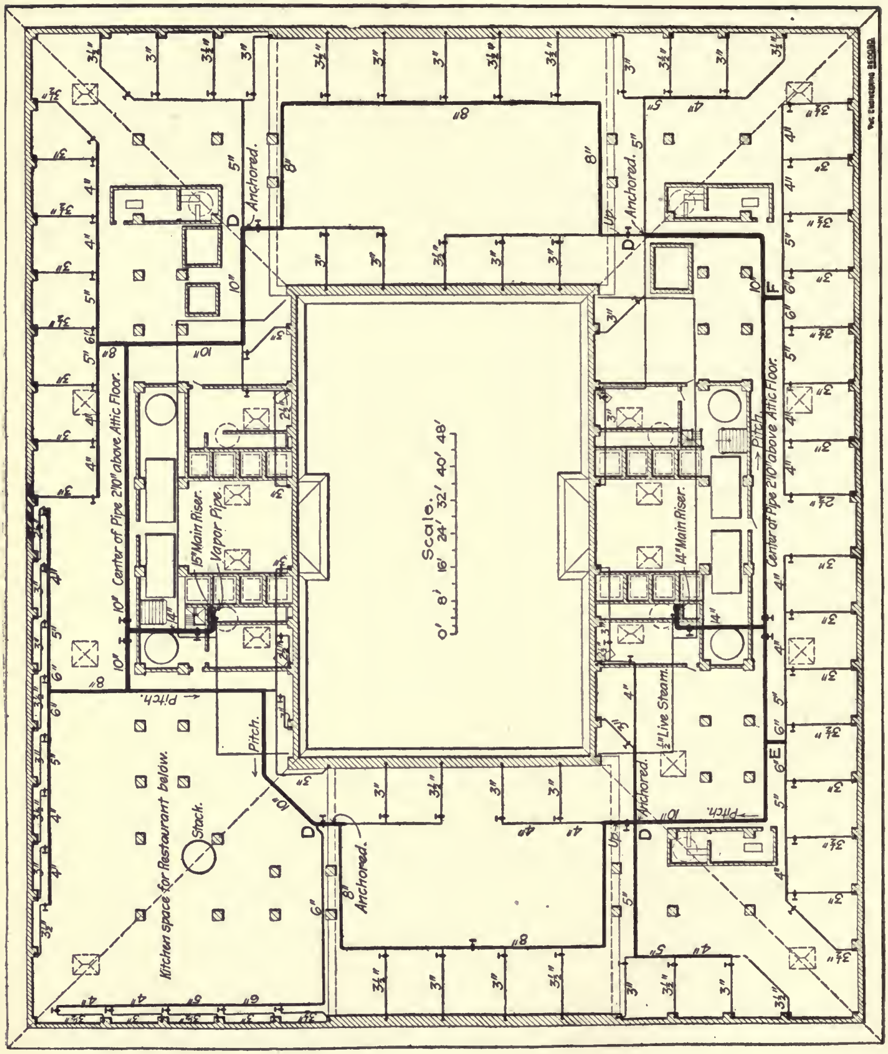

Figure 36.—Piping in Attic of Ellicott Square Building, Buffalo.

this expansion, and on the first floor they were connected as in Figure 33. If the radiator connections were very short, two joints would have been put on each of these risers.

In laying out large systems, valves should be placed on each riser so that each one can be shut off independently of the others in case of leaks or in case of repairs or changes to be made on any of the radiators. Gate valves should be used preferably on account of the fact that they interpose infinitely less resistance to the flow of steam or water than do globe valves. Furthermore, in such cases provision should be made for changes in the arrangement of rooms and consequent changes in the location of radiators. It is a very good practice to put tees on each riser at each floor whether or not, in the first instance, a radiator connection is required, as subsequent changes in the arrangement of rooms may make it desirable to change the radiators.

Figure 36 shows the arrangement of piping in the attic of the Ellicott Square, a large 10-story building in Buffalo, N. Y., which is heated by direct radiation on the overhead system. The figure illustrates the method of connecting the overhead mains to the risers, and also the way in which expansion of the mains is provided for by bends and offsets. In this instance the piping was rigidly anchored at four points marked D, and the expansion allowed in all directions from these four points. It may be noted here that branch mains were taken off at points marked E and F, instead of connecting each riser to the main 10-inch pipe at these points. This was done for the purpose of saving the expense and the delay to the work of connecting each riser into the 10-inch pipe.

Valves.—Much care should be used in placing valves on a piping system. Gate valves should always be used on mains. If globe valves are used anywhere, the stems must be placed horizontally, as otherwise they form a water pocket. Thermostatic valves, so-called, are often used on radiators, being connected with an automatic device which opens the valve when the temperature falls, and closes when it rises.

Location of risers.—In laying out the floor plans for the heating system of a large office building it is a mistake to try to reduce the number of risers to a minimum. It is much better to put in risers enough so that a radiator can be placed under any window in the building without too long a connection from the riser, for in such buildings one can never know what changes in the arrangement of rooms or in the location of radiators may ultimately be desired. Figure 37 shows the typical floor plan of the heating diagrams for a fourteen-story building in Chicago, showing the location of risers and radiators. This building is exceptional on account of the large number of bay windows and large amount of glass surface. Furthermore, the risers were all concealed in the columns in the manner shown in Figures 38 and 39, the building being framed with Gray columns, built as indicated. An expansion joint was placed on each riser, above the radiator connection at the eighth floor, with flange unions above and below the joint. At these joints a removable wooden panel was placed over each riser, as indicated at Figure 38, but otherwise they were enclosed by the wire-lath and plaster forming the ordinary finish of the columns. Figure 39 shows a section of the column at the fourteenth floor. The radiator connections were exposed above the floor and run about as indicated on the floor plan. This building is heated on the one-pipe overhead system. It contains 11,000 square feet of radiation, supplied by an 8-inch main to the attic. The typical floor has 1,055 square feet of glass surface, 2,025

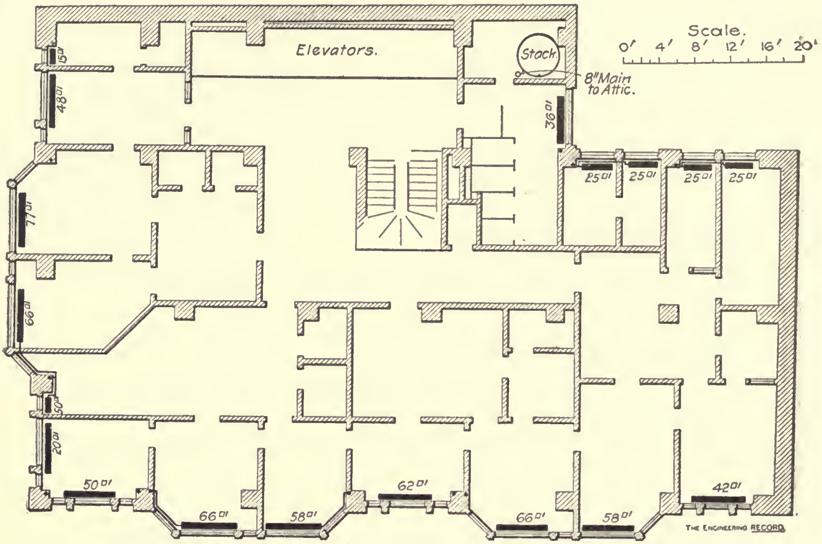

Figure 37.—Plan Showing Location of Risers and Radiators.

square feet of wall surface and 47,400 cubic feet of space, including corridors, and is heated by 18 radiators containing 787 square feet of surface. By the author's formula given on page 68 the amount of surface required amounts to 730 square feet, but the exposure of the upper stories of this building is unusually severe.

It is frequently a very difficult matter to conceal risers in fireproof buildings on account of the floor plates of the columns and the beams, which frequently interfere with placing the risers very close to them. Figure 40, however, represents the manner in which they were enclosed in a building which was framed with box columns. In this case the tile fireproofing was put on over both column and riser. In concealing risers in the walls of wooden buildings it is necessary to protect the pipes carefully from immediate contact with the woodwork. In hanging risers in buildings great care must be taken that the pipe be cut to the proper lengths so that the fittings for the radiator connections will come exactly in the proper place.

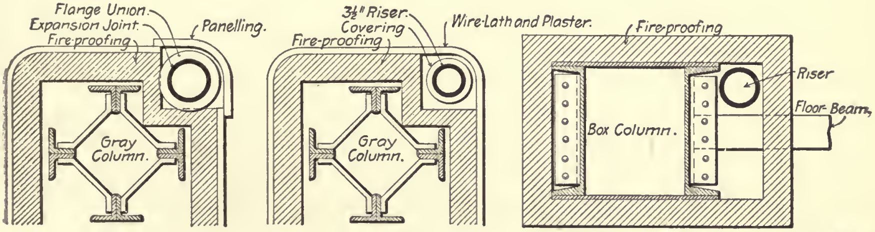

FIG. 38 FIG. 39 FIG. 40

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Methods of Running Risers in Columns.

Riser anchors.—As previously stated, risers are usually, especially in large buildings, anchored rigidly at certain points so that expansion shall be in both directions from these points. This should be carefully done so that the pipe will not slip, and the method to be employed to accomplish this depends largely upon the local conditions. Figures 41 and 42 show two methods of accomplishing this, the latter being especially adaptable where the riser can be run close to the floor beam, but to make it perfectly rigid it should be made strong and shrunk in place. The method indicated by Figure 41 can be adapted to anchoring the pipe to a column instead of to the floor beams. In some cases risers are also secured at the other floors so as to allow expansion, but at the same time maintain proper alignment; but this is not generally necessary, as the rigidity of the piping and connections is generally sufficient to keep the pipes properly in line.

Protecting pipes.—Where risers or other pipes run through the floors or walls they are generally protected by floor sleeves with floor and ceiling plates. These are usually made of galvanized iron in a telescopic form so as to fit any thickness of floor. In buildings with wooden floors they are necessary so as to give an air space around the pipe and prevent immediate contact of the steam pipe with the woodwork. In fireproof buildings they are frequently omitted, but it is preferable to use them, as they make a better finish around the pipe at the ceiling and prevent the expansion of the pipe from disturbing the flooring or plaster. Floor and ceiling plates should be used in any case.

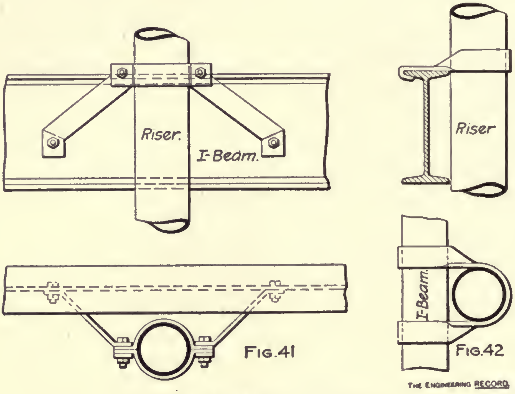

Fig. 41 Fig. 42

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Types of Riser Anchors.

Radiator connections are frequently encased in the floor, but it is generally difficult to accomplish this in fireproof buildings, as the space between the floor level and the top of the iron beams is not generally sufficient to box in the connections and make proper allowance for the vertical movement of these connections due to riser expansion. It can be done in some cases, however, but the connections should always be enclosed in a galvanized-iron box and the flooring should be so laid that a strip over the pipes can be easily removed.

Supporting pipes.—Horizontal pipes are almost invariably supported from the ceiling above by means of some kind of an expansion hanger, two common types of which are shown in Figures 43 and 44, the two shown in each case being, one for wooden beams and the other for iron. The rods can be cut to the length desired after the pipe is in place. There is sufficient movement of the rod at the top to allow for the small play of the pipe due to expansion. A simple and cheap form of hanger frequently used for small pipes in buildings with wooden floors is made of a piece of light chain looped under the pipe and hung from the nails in the floor beams. The chain can be cut to length with wire nippers. In case of very large pipes in the basement of buildings, they are sometimes supported by some kind of a standard erected from the floor.

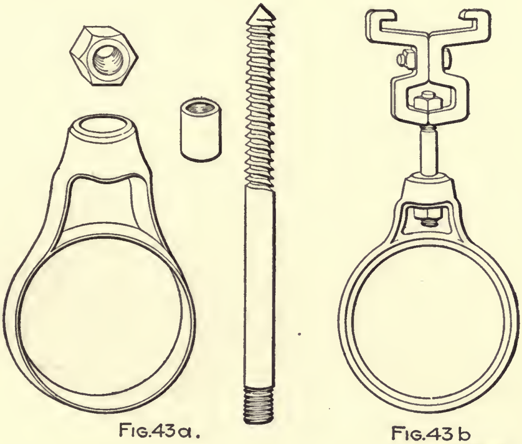
Fig. 43a.
Fig. 43 b
The Engineering Record.

Expansion Pipe Hangers.

Arrangement of pipes.—In laying out the main piping connections of the power plant of a large building great care must be taken to arrange the pipes as systematically as possible so that they take up no more room than necessary, and also to properly provide for the drainage of all pipes into proper receptacles. This is frequently a difficult matter, but one can hardly give too much consideration to the subject, as the successful operation of a plant depends largely upon the way piping connections are arranged. It is impossible to give any detailed rules, as each plant is a prob-

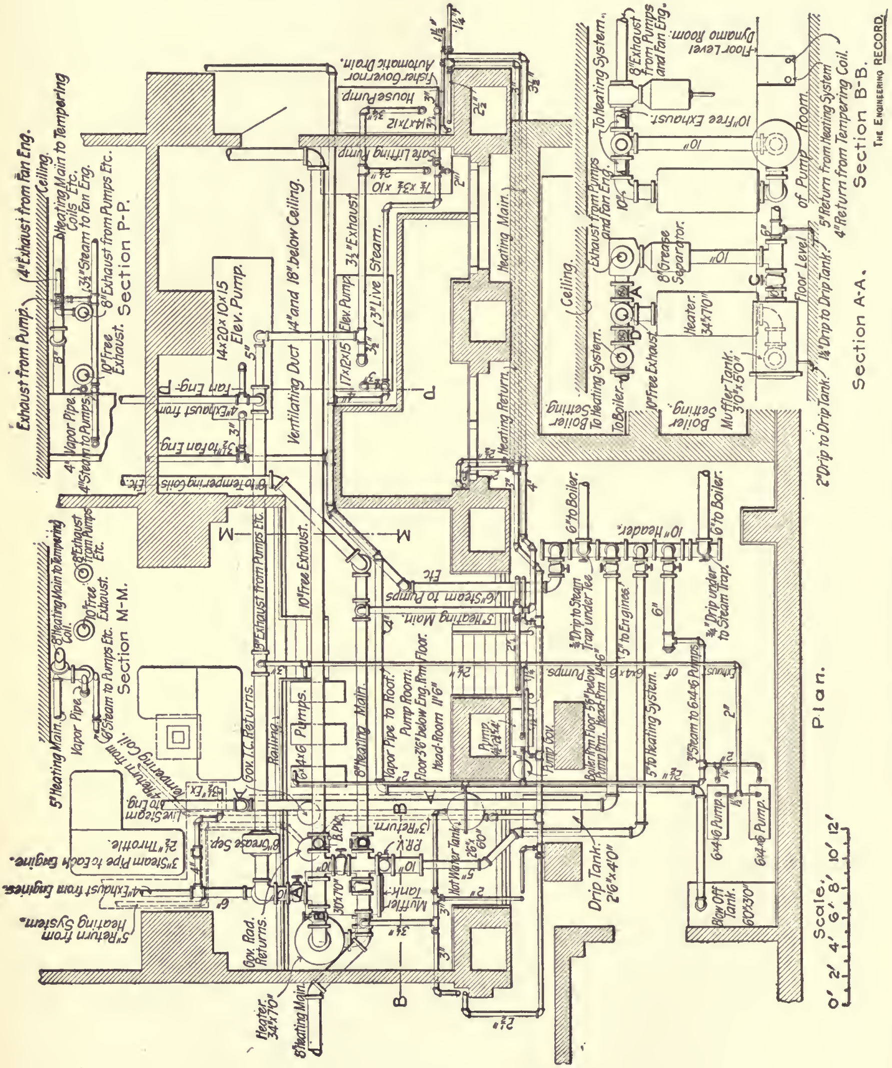

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Figure 45.—Piping in an Office Building Plant.

lem in itself, and is entirely subject to local conditions. The main connections to the heating system must be laid out in connection with the exhaust and live-steam pipes of the power plant, according to the principles established in Chapter II. Simplicity in a piping system is always primarily desirable, but sufficient valves and by-passes should be installed, so that if any accident occurs to one part of the system that part can be shut off without crippling more than a small section.

Figure 45 shows the arrangement of the main piping connections in a large office building in Syracuse, N. Y., in which, on account of the extreme difference in floor levels and the crowded condition of the machinery, a really systematic arrangement of piping it was impossible to obtain. (The Engineering Record of November 5, 1898.) The main valves controlling the heating system are indicated at A, B, C and D. During the heating season the valve, D, is opened and the back-pressure and reducing-pressure valves put into service, while during the summer months the valve, D, is closed entirely, shutting off the heating mains, and the 10-inch back-pressure valve is opened wide. Ordinarily, both in winter and summer, the valve, A, is closed, so that all exhaust steam from the pumps and engines goes through the muffler tank and heater; but in case it is necessary to open these for cleaning, the valves B and C are closed and the valve, A, opened, so that the exhaust steam may go directly either into the free exhaust or the heating system, as the case may be. The building in question contains about 15,000 square feet of radiators and is heated on a two-pipe system with basement mains. The returns come back to the two automatic governors which control the 6 x 4 x 6-

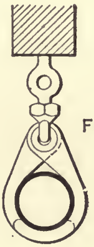

FIG.44a.

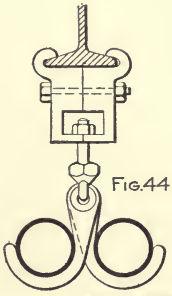

FIG.44 b.

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inch pumps. These deliver the return water through the closed heater into the boilers. There are three pumps used for this purpose, and so connected that any one can be used on the governors separately or together, and any one can be used to pump cold water through the heater. The feed pipe has a by-pass around the heater, to be used when the heater is being cleaned.

Return pipes should be given as much pitch as possible except where they are below the water-line of the system. In running these below basement floors they should be put in trenches, preferably of brick or concrete, and with movable covers. If there is danger of water underground the trenches must be arranged so that they can be kept dry, and no better trench can be made than one of good concrete.

Pipe coverings.—All the piping connections should, as far as possible, be covered with some kind of non-conducting pipe covering, of which there are innumerable varieties made. In some cases risers and other pipes are left uncovered so as to utilize the heating effect, but the disadvantage of this is that heat is given out from such pipes whether it is wanted or not, and it is much better practice to cover the risers and depend on the radiators for heating. One of the greatest sources of fuel waste is found in uncovered mains in basements of buildings where heat is nothing but an inconvenience, and in order to dispel it in moderate weather windows are opened, which greatly increase the wasteful condensation. A good pipe covering will save from 65 to 80 per cent. of the heat which would ordinarily be wasted from the pipes. Coverings of which 85 per cent. is carbonate of magnesia, certain molded forms of pure asbestos fiber, and molded forms of mineral wool are the best kinds of protection for steam pipes to reduce condensation. Some coverings which show very good results when new, deteriorate rapidly, due to the charring effect of the pipes and to disintegration.

Pipes and flues for indirect radiators.—We come now to the consideration of certain details of construction which are especially requisite in indirect heating. In this class of steam heating the piping connections are subject to much the same rules for running pipes as those for direct radiators, but indirects are almost invariably located in the basement of buildings and the pipes running to them are horizontal. Furthermore, the condensation per square foot of indirect radiator is from 25 to 50 per cent. more than that per square foot of direct radiator, so that the piping connections are generally made about a size larger, and, except in rare cases, connected on two-pipe systems. Indirect radiators are usually hung from the beams of the first floor, and various methods, which are dependent upon the local conditions, are adopted for supporting them. A frequent form of support is indicated in Figure 46, the radiator resting on short pieces of pipe which are hung by rods bolted to the floor joists, or hung from a pipe over them. Indirect radiators are always encased in some kind of a metal box, either of galvanized iron or tin, or of wood lined with tin. These boxes connect directly with the hot-air flues which run to the rooms above and which are of heavy tin or sheet iron. Both the flues and boxes should, of course, be as nearly air tight as possible. In regard to sizes of hot-air flues, an old rule gives 1 square inch of flue area to 1 square foot of radiator. This is very satisfactory in most cases, but the following table, which gives the sizes recommended by Prof. J. H. Kinealy, is to be preferred, as the size of flue should depend upon its height:

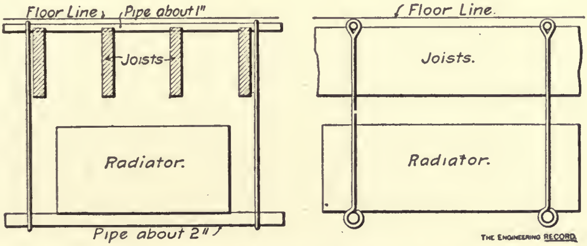

Figure 46.—Indirect Radiator Support.

SIZES OF FLUES FOR INDIRECT RADIATORS.

Height in feet from center of radiator to center of register	5	10	15	20	25
Sq. in. of flue area for 1 sq. ft. radiation	1.7	1.2	1.0	0.85	0.75

The indirect-radiator boxes must, of course, have a fresh-air inlet. This should always be run from the outside and from a location removed from the possibility of contamination to the incoming air; and it is preferable that the cold-air inlet be located at least a few feet above the ground. Cold-air supply connections from the outside to indirect boxes should be made as short as possible; 1 square inch area per 1 square foot is generally sufficient, although if the flues are of considerable length or are winding, a larger ratio should be given. If a number of radiators receive air from the same cold-air flue, the flue may be somewhat smaller. In buildings in which there are a considerable number of indirect radiators there are two general methods of connecting the fresh-air flues, which are illustrated in Figures 47 and 48. Figure 47 represents the cellar plan of a large Massachusetts residence (The Engineering Record, August 5, 1893; Mr. A. A. Sanborn, Boston, heating contractor), in which there are seven large clusters of indirect radiators which supply about 30 hot-air flues rising to the rooms above, the hot-air pipes running horizontally from the radiator boxes, in some cases for 50 feet, to the vertical flues. (The radiators in this building are all Gold's Pin in 16-foot sections.) In the Philadelphia residence shown in Figure 48 (The Engineering Record, December 15, 1894), there is, on the contrary, a long main cold-air duct which supplies a large number of indirect radiators, one for each of the vertical flues, the radiator in all cases being located directly under the vertical flues. In the opinion of the author this is much the preferable method,

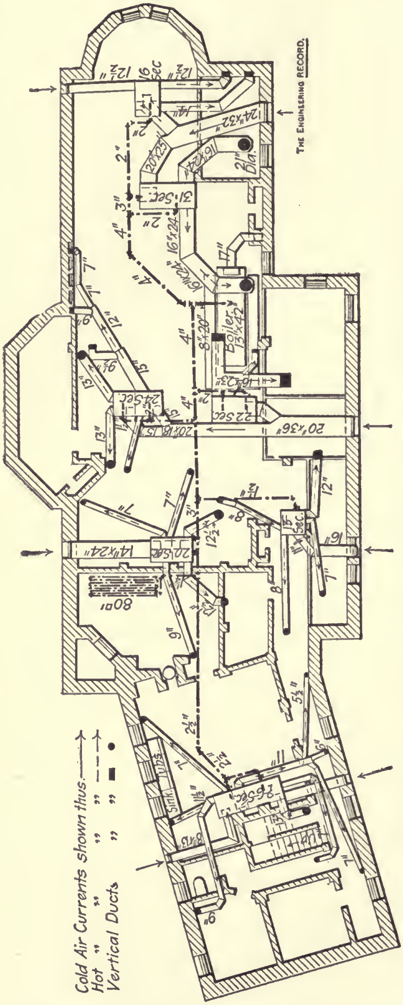

Figure 47.—The Indirect System in a Massachusetts Residence.

as a much more positive circulation of air to the separate rooms can be secured than by the other method.

The system shown in Figure 48 is interesting also on account of the construction of the main cold-air duct and the connections from it to the radiator boxes. These are well illustrated in Figure 49, the main duct, it will be noted, being of brick, and underground. In the author's opinion there is one particular in which the system shown in Figure 48 might have been much improved. The cold-air duct is long and winding, and had it been more uniform in size and supplied with another cold-air connection on the side of the house opposite the existing one, it would have insured a more positive circulation to all the radiators. The reason of this is that in cases, such as shown in Figure 48, where there is only one cold-air connection for a number of radiators, when there is a strong wind blowing against the side of the house opposite the fresh-air inlet it is sometimes very difficult to get a good draft in the flues, especially in those most removed from the cold-air inlet, as the force of the wind (which, with the best constructed houses, blows through the walls to a great extent), seriously opposes the current.

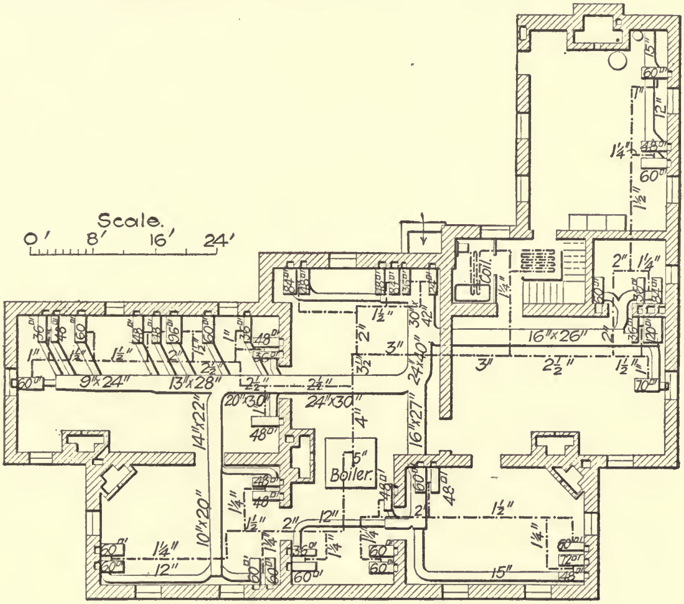

Figure 48.—The Indirect System in a Philadelphia Residence.

of air in the ducts. If there are two fresh-air connections, each provided with dampers, the one on the leeward side of the building can be closed and the one on the windward side opened to give a proper amount of cold air. It is, moreover, desirable to put a tight damper in the duct to each radiator.

Setting direct-indirect radiators.—In regard to the setting of direct-indirect radiators, the piping connections are made according to precisely the same rule as for directs, although in cases of large radiators of this kind it may be desirable to increase slightly the pipe sizes on account of the somewhat increased condensation. A frequent form of fresh-air connection for this kind of radiator is indicated in Figure 50, and the connection to the outside air should in all cases be provided with an easily adjusted damper. One trouble with direct-indirect radiators is that when a strong wind is blowing against the outside wall it is difficult to prevent objectionable drafts, due to sudden gusts of wind, which, in cold weather, will make frequent cold waves across a room notwithstanding the average temperature may be about right. Figure 51 represents a special form of setting for large radiators of this kind adopted by Mr. Alfred R. Wolff, in the Singer Building, New York City. (The Engineering Record, September 3, 1898.) It will be seen that the effect mentioned is here avoided by making the cold-air

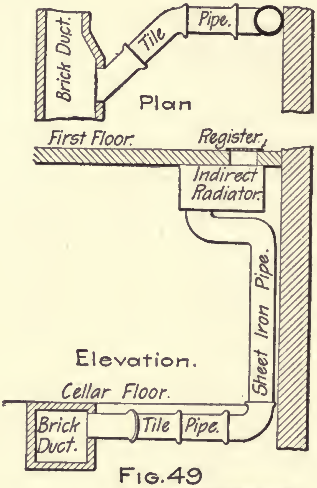

FIG. 49

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inlet to the radiator somewhat tortuous, so that, as far as possible, the draft is due only to the hot air from the radiator. The same effect is accomplished in the United States Government method

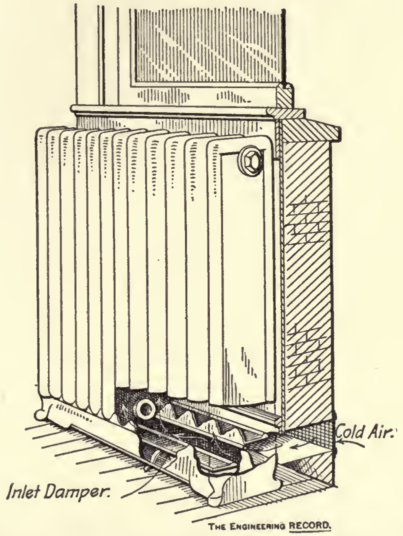


Figure 50.—A Direct-Indirect Radiator.

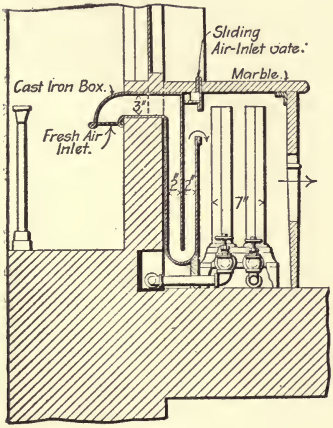


FIG. 51

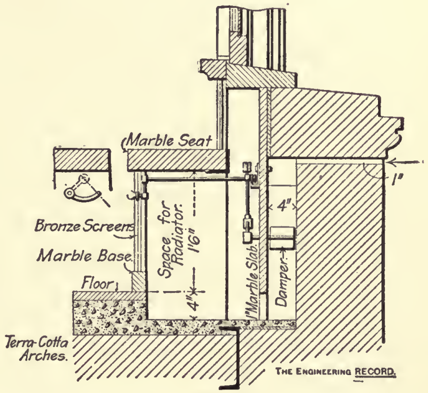


FIG. 52

Types of Direct-Indirect Radiator Casings.

of setting indirects in the Detroit Post Office, which is shown in Figure 52. Mr. Henry Adams, of Baltimore, Md., was the engineer for this work. (The Engineering Record, August 7, 1897.)

CHAPTER VII.—MECHANICAL VENTILATION— GENERAL PRINCIPLES.

Need of proper ventilation.—It may be stated as an undeniable truth that no system of ventilation is adequate to give proper results at all times and in all kinds of weather, unless it is a mechanical system. As has been seen in a previous chapter, the air discharge of an ordinary ventilating flue with the gravity system depends upon the difference in temperature between the air in the flue and the outside air, so that its discharge is very different in moderate from what it is in very cold weather. Very satisfactory results are in many cases obtained from indirect radiators, but the same is true of these as of an ordinary ventilating flue. And every one now knows of the precarious nature of ventilation by open doors and windows, since in cold weather the occupants of rooms invariably prefer warm and bad air to that which is cold and fresh. Yet those who have been interested in the subject, for as long as a decade, can readily recall the days when such means of ventilation were considered entirely sufficient even for schools, churches and other densely-peopled buildings. It is part of the marvelous scientific development of the close of the nineteenth century that there has been such an advance in the popular appreciation of the necessity and value of good ventilation, that a very fair percentage of school-houses now erected, even in the smaller communities, boasts of a complete ventilating plant.

There are, however, many such plants that are in reality not the perfect ones they are made to appear, and the problems connected with the proper distribution of an adequate volume of air to and through buildings and rooms of various kinds are more varied and complicated than is ordinarily supposed. Only those who have had much experience with them and who have met with failures in some of their cherished schemes of ventilation, realize that air is a very subtle medium of control. It is a comparatively simple matter to obtain a large blower and connect it by a system of ducts to the rooms to be ventilated, but to admit the air into the rooms in sufficient volume without drafts and make it circulate where it is needed is a different proposition. The air currents have an exasperating way of going around the ceiling instead of across the breathing line; or of running down walls and out of doorways instead of across the room and out of properly-prepared vent openings. Another source of tribulation is the fact that in winter the temperature of the fresh air blown in is in most cases warmer than the average temperature of the room; while in summer it is somewhat cooler, so that in the former case the incoming air tends to go to the ceiling, and in the latter to the floor.

There are a few old-time fallacies, vestiges of which still linger to a surprising degree in the minds of many who appreciate the necessity of good ventilation. Among these are the ideas that fresh air must be cold and that it must be admitted through windows, and the foul air be drawn off through vent flues. But the worst of all is one of the carbonic-acid theories, which is to the effect that exhaled air is laden with carbonic-acid gas (CO_2), which, being heavier than pure air, sinks to the floor, and may be tapped off by putting an outlet anywhere at the floor-level. This notion seems to be firmly grounded into the minds of many, who cling to it steadfastly. It is difficult to explain to these unfortunates that the air exhaled by man contains ordinarily less than 5 per cent. of carbonic acid, which would not affect the specific gravity to an appreciable degree; and that furthermore there is an indisputable natural law known as the diffusion of gases, in accordance with which two gases in contact tend to form a perfect mechanical mixture.

The carbonic-acid gas in the air of rooms is, however, an important consideration, as it serves as an accurate index of the degree of vitiation. It must be understood, of course, that the carbonic-acid gas in itself is not injurious and is merely an index. The air of the stuffiest lecture room that one ever goes into does not contain more than 50 parts in 10,000, and air that contains as much as 15 parts in 10,000, due to being repeatedly breathed, is of a very unhealthy quality. Notwithstanding this, in soda-water factories the air frequently contains as much as 150 or 200 parts of CO_2 to 10,000, and is in no way injurious. In air that contains as much as 10 or 15 parts of CO_2 in 10,000, due entirely to exhalations from the body, it is not so much the CO_2 that constitutes the obnoxious element, as it is the organic matter and the germ-laden moisture that accompanies it—not necessarily disease germs, but all kinds of natural germs, which are more or less injurious, and which, together with the organic matter given off in the moisture of the breath, gives to confined air that oppressive and stuffy effest which is at once disagreeable and exceedingly unhealthful.

It is not intended here to go into detail in regard to the ill effects of breathing vitiated air and the hygienic value of good ventilation. The absurdity of expecting to develop bright and healthy children by sending them day after day to shut-up school rooms, or of expecting inspiring results from sermons or lectures delivered in close and stuffy halls, or of having popular reading rooms or theaters where the air is laden with the peculiar aroma of a mixed and varied populace, is rapidly being better and better understood, and more and more widely appreciated.

There is no doubt but that in a large room which is occupied for some length of time by a crowded assembly it is impossible to secure air of the same purity as that outside, as the breath from the occupants vitiates the incoming air as well as that which is already in the rooms. In other words, it is impossible for the occupants of a room to inhale pure incoming air and exhale it so that it will pass out by a vent shaft without a portion of it coming in contact with any one else. If this were the case it would only be necessary to supply from 12 to 15 cubic feet of air per person per hour, which is about the rate of breathing of adults, in order to insure perfect ventilation. As a matter of fact, however, the best we can do is to dilute the vitiated air as much as possible, and it has been found that to accomplish this to a satisfactory degree requires from 100 to 200 times the amount of air above mentioned per person per hour.

Pure air is found by investigation to contain very close to 4 parts of CO_2 in 10,000. The opinions of many able hygienists agree that when the proportion of CO_2 exceeds 6 parts in 10,000 the bad effects of poor ventilation begin to be noticeable, and when 8 parts in 10,000 are found, the characteristic odor of an ill-ventilated room is apparent; and to those who remain in such an atmosphere for any length of time there comes a feeling of closeness, lassitude and dullness. It is therefore universally agreed that when the carbonic acid is formed entirely by the breathing of the occupants, the quantity should not exceed 6 parts in 10,000, though 8 parts may in some cases be permitted for short periods, and that anything in excess of this figure indicates poor ventilation.

Air required for ventilation.—The amount of fresh air required depends upon the number of people and the amount of carbonic-acid gas given off by each individual in breathing. This last factor is exceedingly variable, depending upon the weight, age and physical, as well as mental, condition of the person. Pettenkofer, a very painstaking scientist, gives the following figures for the average amount of carbonic-acid gas given off per hour by adults per pound of weight:

In repose	0.00424 cubic feet.
In general exercise	0.00591 cubic feet.
In hard work	0.0122 cubic feet.
In sleep, about	0.00320 cubic feet.

He also adds that the amount given off by young children is nearly twice as much per pound of weight as for adults. Some diseases, such as fever, increase the amount, and others decrease it. Pettenkofer's figures would make the average for persons in repose about as follows:

Males (160 pounds weight)	0.68 cu. ft. per hr.
Females (120 pounds weight)	0.51 cu. ft. per hr.
Children (80 pounds weight)	0.68 cu. ft. per hr.

Parkes, in his work on hygiene, gives as the amount of carbonic-acid gas given off during repose the following:

Males (160 pounds weight)	0.72 cu. ft. per hr.
Females (120 pounds weight)	0.60 cu. ft. per hr.
Children (80 pounds weight)	0.40 cu. ft. per hr.
Average mixed community	0.6 cu. ft. per hr.

These figures show some variation from Pettenkofer's; but certainly for adults the variation is not more than might be found in two sets of individuals. It is very generally accepted by hygienists that 0.6 cubic foot per hour represents a very fair average for such mixed assemblies as are found in theaters, lecture rooms, churches, etc.

The amount of air required per person per hour to maintain the air of a room at a certain standard of purity may be worked out by a simple algebraic calculation, as follows:

Let V be the volume of air required per person per hour for continuous occupation:

N, the number of persons in the room;

R, the number of parts of CO_2 gas to be allowed per 10,000, the number of parts in the fresh incoming air being 4;

C, the total number of cubic feet of CO_2 acquired by the air of the room per hour;

$$\text{Then } R = \frac{10{,}000\ C}{VN},$$

$$\text{But } C = \frac{VN \times 4}{10{,}000} + 0.6\ N,$$

$$\text{So that } R = \frac{VN \times 4 + 6{,}000\ N}{V\ N}.$$

Solving this equation with $N = 1$, we find $V = 6{,}000 \div (R - 4)$. For $R = 6$, we have $V = 3{,}000$; for $R = 7$, $V = 2{,}000$; while if we allow $R = 8$, we have $V = 1{,}500$.

Now if the room is of large volume and is only to be occupied for a short period, and before occupancy the air is brought to the same standard of purity as the outside air, then a less amount of air is required. For example, if the room contains 500 cubic feet of space per person and is to be occupied but one hour, then obviously $3{,}000 - 500 = 2{,}500$ cubic feet will have to be supplied the first hour to have the air within the standard of 6 parts of carbonic acid gas per 10,000.

We may reduce this to algebraic form as follows:

Let V be as already given;

v, the volume per person per hour for a short occupancy,

H, the number of hours to be occupied,

and Y, the cubic feet of space in the room per person.

$$\text{Then } v = V - \frac{Y}{H}.$$

From this formula Table No. 1 is calculated.

TABLE NO. 1.—THE VOLUME OF AIR TO BE SUPPLIED PER PERSON PER HOUR THAT THE PURITY OF THE AIR AT THE END OF THE OCCUPANCY WILL NOT EXCEED THE AMOUNT GIVEN.

Cu. ft. space in room per person.	Number of hours to be occupied.								
	1			2			3		
	Parts of CO_2 in 10,000 not to be exceeded at end of occupancy.								
	6	7	8	6	7	8	6	7	8
	Cubic feet to be supplied per person per hour.								
100	2,900	1,900	1,400	2,950	1,950	1,450	2,970	1,970	1,470
200	2,800	1,800	1,300	2,900	1,900	1,400	2,935	1,935	1,435
300	2,700	1,700	1,200	2,850	1,850	1,350	2,900	1,900	1,400
400	2,600	1,600	1,100	2,800	1,800	1,300	2,870	1,870	1,370
600	2,400	1,400	900	2,700	1,750	1,250	2,800	1,800	1,300
900	2,100	1,100	800	2,550	1,550	1,050	2,700	1,700	1,200

From the figures given it will be seen that the quantity of air to be supplied per person depends upon the size of the room and the length of time it is occupied as well as the standard of purity demanded.

The standard of purity to be required depends somewhat upon the nature of the room. Some rooms, such as churches, lecture rooms, theaters, libraries, and some reading rooms, are occupied by widely varying numbers of people, being sometimes very crowded and sometimes but partially filled; while others, school rooms and hospitals in particular, are occupied almost always by about the same number. Of the former class, if the cubic feet of air required is based upon the maximum crowded capacity, we may allow between 7 and 8 parts carbonic acid gas per 10,000 at the end of the period of occupancy, inasmuch as they are crowded only on rare occasions, and are also assumed to be thoroughly ventilated before occupancy, as of course should be the case, the proportion of carbonic acid gas reaching the maximum only toward the end of the occupancy period. In schools and hospitals we should never allow over 6 parts in 10,000, and as these are occupied for long periods fully 3,000 cubic feet of air should be allowed per person per hour, and in many hospitals, on account of the condition of the occupants, much more. Churches, theaters and lecture rooms, besides being occupied by a variable number, are occupied for from one to three hours at a time, while libraries and reading rooms may be said to be occupied continuously.

An inspection of the table and formulas already given, with proper allowance for the considerations here cited, will warrant the use of Table No. 2.

TABLE NO. 2.—AMOUNT OF AIR TO BE SUPPLIED PER PERSON PER HOUR IN BUILDINGS OF VARIOUS KINDS.

Hospitals	3,600 to 5,000 cu. ft. per hour
Barracks	3,000 cu. ft. per hour
Schools	2,500 to 3,000 cu. ft. per hour
Libraries based on crowded capacity	2,000 cu. ft. per nour
Reading rooms based on crowded capacity	2,200 cu. ft. per hour
Churches based on crowded capacity	1,400 cu. ft. per hour
Lecture rooms based on crowded capacity	1,500 cu. ft. per hour
Theaters based on crowded capacity	1,400 cu. ft. per hour

For the latter, based on maximum seating capacity:

Churches	1,400 cu. ft. per hour
Lecture rooms	1,800 cu. ft. per hour
Theaters	1,600 to 1,800 cu. ft. per hour

No room which is occupied for more than five hours continuously by a definite number of adults is adequately ventilated with a less allowance than 2,400 cubic feet per hour per individual, and 3,000 should be given.

CHAPTER VIII.—SYSTEMS OF MECHANICAL VENTILATION.

In the last chapter were discussed the general principles on which depend the volume of air necessary to give good ventilation; the next point for consideration is the method by which this air is to be supplied and distributed. In the earlier days of mechanical ventilation two general systems of air distribution were considered, the plenum or pressure system, and the exhaust system. In the former the fresh air is drawn from the outside and forced by the fans into the rooms to be ventilated, and finds its way out again through flues provided for the purpose. In the exhaust system, flues or ducts are provided for the inlet of the air, but the fans are connected to the outlets and the circulation of air is maintained by drawing out the vitiated air and allowing the fresh air to take its place.

The plenum system is generally considered more direct and positive, but this idea arises largely from the fact that when the exhaust system has been used alone the fans are connected to flues in the top of the room, and the inlets, if provided at all, are small and poorly located, so that most of the incoming air comes from doors and windows and passes out of the flue without coming much in contact with the occupants. Theoretically, either system is efficient if it is properly designed and arranged, but the best results are generally obtained in practice, especially for large halls or rooms, by a combination of both systems. Some years ago many rooms were ventilated on the principle that if a sufficient quantity of fresh air were forced into a room, it could find its way out through doors and windows. This was soon found to be a mistake, as in winter all windows and doors would be closed on account of cold and the outside winds; and it is impossible to force air into a room unless an adequate outlet is provided.

In the opinion of the author, the distribution of the air supply is even more important to the success of a ventilating system than the volume, and there is much that might be written on what not to do. It is difficult to lay down general rules, as each separate case requires careful study, with proper consideration of the local conditions. The use to which the room is to be put, the arrangement of the occupants (whether the seats are fixed or movable), the duration of occupancy, the method of heating, the kind and extent of the outside exposure and the height of the room must all be taken carefully into account in determining the location of inlets and outlets. The point that must be borne constantly in mind is that the most perfect ventilation is desired not at the top of the room, or along the floor, but at the breathing line, which, as a rule, is about 4 feet above the floor level. There are very many rooms, unfortunately, which are much better ventilated at the ceiling than at the breathing line.

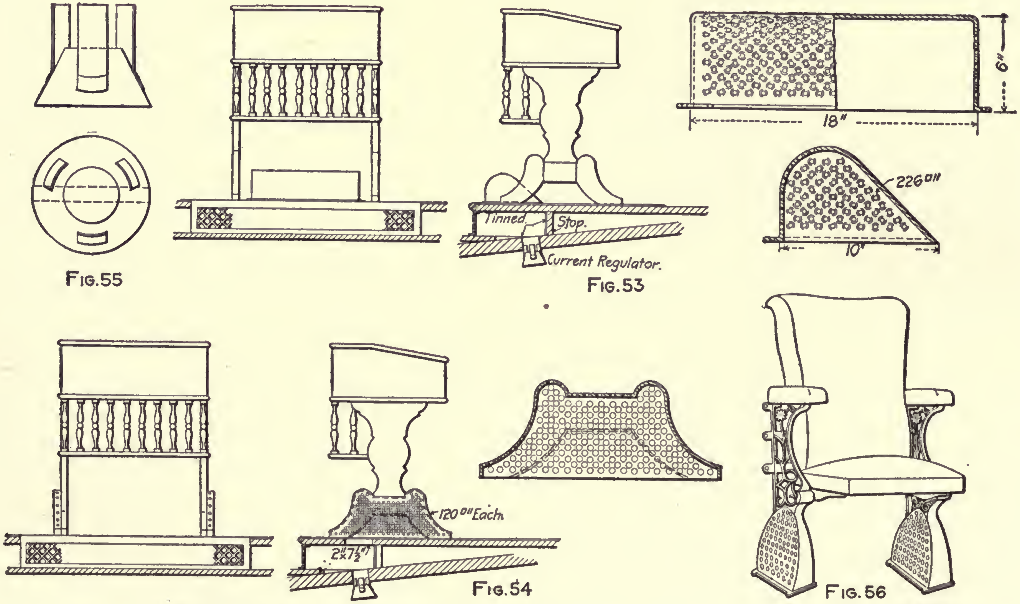
Upward versus downward ventilation.—There is one question which enters more or less into every problem of ventilation, but especially into that of theaters, churches and other large halls, which is a source of continual and arduous discussion among architects and ventilating engineers—that is, the respective value and merits of upward and downward ventilation, the former referring to supplying the fresh air at the floor and drawing the vitiated air out at the top, and the latter to the reverse of this method. The upward method is decidedly the natural one, as the temperature of the air is normally about 30 degrees lower than the temperature of the body, and the latter gives off enough heat when in repose to raise the temperature of 1,800 cubic feet of air per hour 10 degrees. A person, therefore, standing in an open space, creates an upward current which naturally carries the exhalations from the body away from it. The downward method of ventilation must necessarily be opposed to the tendency of the individual currents from the bodies of the occupants of the room, and carries the breath back upon them, requiring a larger volume of incoming air to effect proper dilution than the upward method.

In rooms which are heated entirely by the incoming air, the temperature of the latter is frequently much higher than the average temperature near the occupants, and in cold weather is frequently higher than that of the body. In this case the air loses its heat, as the air descends, and to a large extent the natural circulation is downward. But in such cases the chief loss of heat is due to outside walls and windows, and the consequence is that there is a strong current downward at the windows, and along the floor to the outlets, while a large part of the breathing line escapes with what ventilation comes from a meager degree of diffusion. Prof. S. H. Woodbridge, in his admirable report to the Committee on Rules of the United States Senate (rendered December 14, 1895), on the Heating and Ventilation of the Senate Wing of the United States Capitol at Washington, has an interesting discussion of this subject, especially in reference to large halls, and contains the following summary of his views upon the subject:

"Especially when the walls of the auditorium are inside walls and warm, the air supply does not then have to carry surplus heat to compensate for loss through cold outer walls and windows. It must generally enter the room cooler than the air of the room because of the animal furnaces within it, each occupied chair representing approximately the heating effect of a burning candle. In legislative halls the temperature of the air supplied is generally from 2 to 5 degrees lower than the air of the room. In crowded auditoriums, as theaters, the temperature of the supply has been known to have been held for hours from 10 to 15 degrees lower than the auditorium temperature, the per capita hourly supply being in excess of 1,200 cubic feet.

"When air cooler than the air of a room enters it in large quantities, the most rational, as also the safest, way of admitting it is in a quiet and well-diffused manner through the floor. It then finds itself in its natural position of stable equilibrium. Because cooler, it is also heavier than the air of the warmer room, and it is at once in its normal position at the floor, where it envelops the breather, or is ready for easy, short and direct movement to the user. The warmer and polluted air is above, and in its own natural position or stable equilibrium, and ready for the shortest and easiest escape through the ceiling vent.

"Ventilation by removal is the most perfect of all methods, both in the completeness of its work and in the economy of its operation. The nearest possible approach in practice to ventilation of occupied rooms by the removal method is found when one is surrounded by cool, pure, quiet and abundant air which the heat of the body can freely move in an approaching and enveloping and ascending current about and from the body. That is upward ventilation. If the conditions are reversed, the fresh air entering at the ceiling and the spent being withdrawn at the floor, the following results seem inevitable:



THE ENGINEERING RECORD.

Diffusers Recommended by Prof. Woodbridge for Senate Chamber.

"First, the entering air being cooler and more dense than that within the room, it must be entered in greatly diffused form to escape the production of drafts, since its weight must cause its precipitation; and if it falls either by the swooping down en masse, now here and now there, or by continuous flow from large and scattered wall or ceiling inlets, the effects will vary from the annoying to the intolerable, according to the momentary or continuous action of such down-flowing drafts. The condition of stable equilibrium is reversed by such a procedure, and nature's effort to restore that equilibrium must necessarily result in disturbance.

"Second, the mass movement of air being downward, is in direct conflict with the individual currents, which are upward. The individual currents rise, as may be shown by experiment, and as may be also seen by the ascent of smoke entangled in the breath, with a movement varying from 20 to 40 feet per minute. To turn these individual currents downward, and to insure their moving from the nostrils and body floorward would require a mass downward movement of the air over the entire area of the Chamber of about 30 feet per minute, which would be equivalent to a per-minute supply for the floor alone of 129,000 cubic feet of air. The ascending individual currents average from 40 to 50 cubic feet per minute, under favorable conditions of supply of fresh air to the body, and of rise of vitiating air from it. To completely reverse this air flow, about twenty-five times such quantities in mass movement would be required.

"Unless such a complete reversal is effected, the occupant must, in downward ventilation, breathe air which contains his own and others exhaled breath and dermal vapors turned back upon him. He is in the position of a candle burning at the bottom of an open pipe through which the air current is being unnaturally forced downward. He is at the discharge end of the ventilating system rather than at the supply end. He is breathing a dilution of composite eliminations. The effect on gas flames distributed and burning at the floor of a chamber, to which the controlled air supply was admitted in diffused form, showed that by the downward method of supply the luminosity of flame is less than 5 per cent. of that obtained when the same air quantity is used with upward ventilation, the quantity of air used being a little more than sufficient to bring the flames to a maximum luminosity by upward ventilation. The life of the flame seemed even then to depend on the local down drafts of fresh and cool air, which was denied admission at the bottom of the Chamber, the place of its natural entrance.

"Upward movement makes necessary the use of only enough air to supply the individual upward currents, in order to envelop the occupant in the purest air it is possible to provide by artificial ventilation methods. In crowded theaters it has recently been found that with a well-diffused air supply of 1,200 cubic feet per capita per hour the air below the breathing line can be kept within 1 part in 10,000 of carbonic-acid increment.

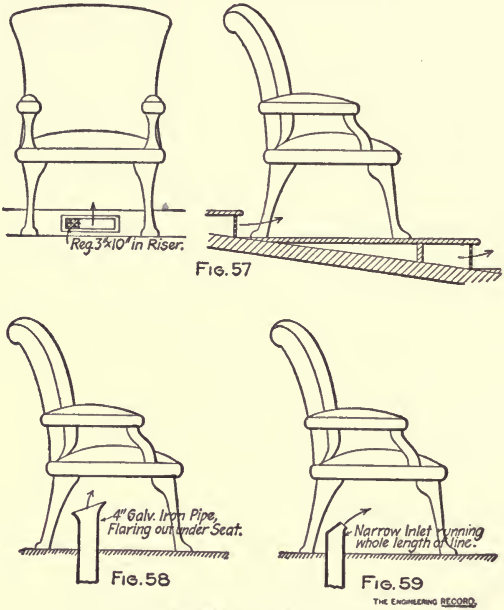


Fig. 57

Fig. 58

Fig. 59

THE ENGINEERING RECORD.

Types of Diffusers for Theaters.

"The contrast between results of upward and downward auditorium ventilation with equal air quantities can perhaps be best imagined by considering the effects on a theater floor crowded with smokers.

"Third. In the case of the Senate Chamber, the galleries, frequently occupied with persons of varying degrees of cleanliness, become an important factor. To so ventilate as to carry the gallery air downward through the Chamber floor would be a piece of professional malpractice.

"The only logical reason to be advanced in favor of downward ventilation is cleanliness; that is, if the air passages of the floor are foul, then downward ventilation does not bring a contamination due to that foulness into the Chamber. Practically, however, it is exchanging a seen and relatively harmless offense for the unseen menaces of vitiated airs. Moreover, the only vestige of a reason for downward ventilation disappears when air is draftlessly moved through the floor and through channels and chambers so constructed and cared for as to insure cleanliness. In this connection it should be said that a thorough investigation of the supply chambers made at the close of the last Congress and before any cleaning had been done, revealed a condition of cleanliness which was as gratifying as it was surprising, because of much that has been said and also because of my own preconceptions to the contrary."

This is a strong argument in behalf of the upward system for ventilating halls of such a character. In the writer's opinion, the argument is unassailable and the success of Prof. Woodbridge's work in the Senate Chamber makes it especially forceful. The argument that is frequently made against the upward method is that it is difficult to secure a proper distribution of the incoming air without causing disagreeable drafts on the feet and legs of the occupants. With the upward system the inlets must be distributed among the seats, since, if the air is admitted through large registers in the aisles, it ascends straight to the ceiling with but little effect on the occupants.

Air inlets and outlets.—When the air is admitted by small openings under the seats the creation of drafts is difficult to avoid. Difficult it is, but by no means impossible. The inlets must be so large that the incoming air has a low velocity (not over 150 feet, or at the most 200 feet per minute) and so arranged that the air does not strike directly against the legs of the occupants. The trouble in most cases of the kind is that the inlets are not nearly large enough. If in a theater, for example, we are going to have 1,800 cubic feet per person per hour, and this is to come in at a velocity of 150 feet per minute, it will be seen that a register about 6 inches by 5 inches or 2¾ inches by 48 inches will be required under every seat in the house. Furthermore, this inlet should not be right in the floor, but should be raised up a few inches. Figures 53, 54, 55 and 56 show some forms of "diffusers" recommended by Prof. Woodbridge for the Senate Chamber, and Figures 57, 58 and 59 some other practical forms for theaters. For churches it is easy to contrive simple forms for long narrow inlets along the pews. It will be seen that all of these arrangements requires that the inlets be connected to a large plenum chamber underneath or that the arrangement of ducts be such as to give a perfectly uniform distribution of the air to the numerous inlets.

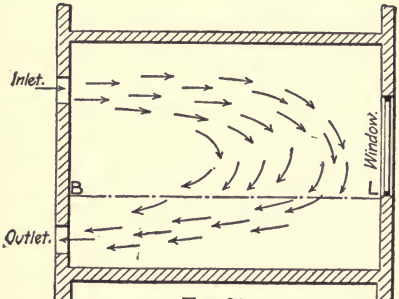


FIG. 60

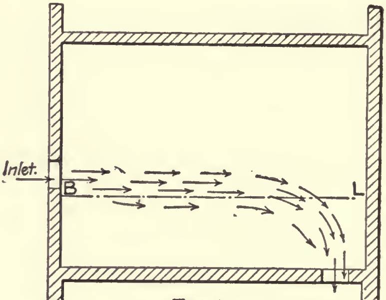


FIG. 61

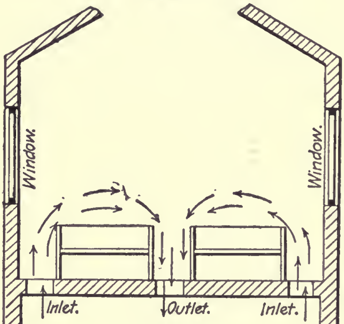


FIG. 62

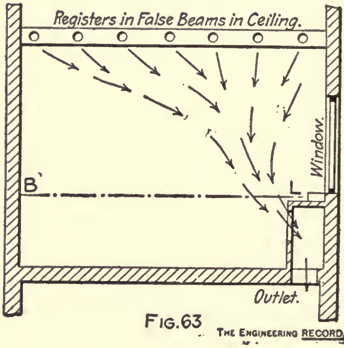


FIG. 63

THE ENGINEERING RECORD.

A little reflection will show that in a large theater, for example, if the downward ventilation is employed, it is quite as necessary to have the outlets well distributed as with the reverse method. The Chicago Auditorium, a very large theater, is ventilated on this scheme. The outlets are under the seats, but are small and not frequent. The consequence is that most of the air, coming down from above, goes out the exits, which are numerous, and the large outlets back of the boxes, leaving a pocket in the middle of the house which frequently becomes very close.

For smaller rooms, such as school rooms, small churches, lecture and reading rooms, there are many methods of air distribution which have proved successful in accomplishing the desired result of ventilating along the breathing line. Figure 60 shows a method which is much used in schoolhouses, and in rooms not over 30 feet wide it is very successful. If the rooms are of much greater width there should be inlets and outlets on both sides. Figure 61 is another method much used in school houses. Figure 62 is a very practical arrangement for small churches, but it obviously requires that, especially in winter, the roof and windows be very tight. These three figures show vertical sections through the rooms.

Figure 63 shows a very wasteful method of ventilation which is employed in the reading rooms of a large library. Most of the air in this case (especially in mild weather) goes down the walls and out without affecting the breathing line. An improvement could be effected by putting inlets at the point A. There is always a tendency of air currents to cling to wall surfaces and this should always be taken into consideration.

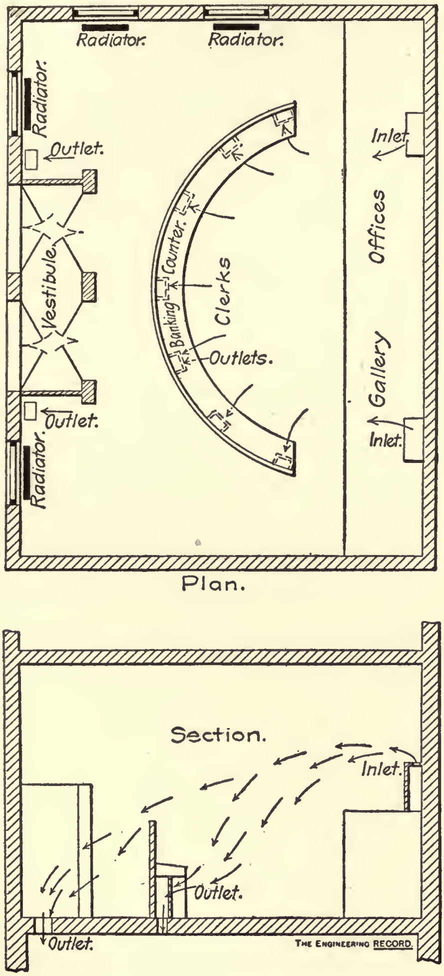


Figure 64.—Ventilation in a Syracuse Bank.

Figure 64 shows a diagram of the ventilation of the large banking room of the Onondaga County Savings Bank at Syracuse, N. Y. The arrangement is very successful, and, on account of the fact that the clerks are employed at the windows all day long, may be preferable to a reversed arrangement of inlets and outlets; but with the system employed, the air supply is very ample in proportion to the number of regular occupants.

Air velocities through inlets and outlets.—As to the size of inlets and outlets for large registers for ventilating schemes of this kind, standard practice allows a velocity of about 300 feet per minute through the gross area of the register. Naturally a rule of this kind is dependent upon circumstances, and if an inlet has to be where air will blow directly on any of the occupants, the velocity should be slower. Mr. Wolff states that when air enters at or near the floor, the velocity should not exceed 120 feet per minute. The author has taken 180 feet per minute as a maximum in such cases. This figure may be used if diffusers are arranged so that the air will not blow directly on the feet and ankles of the occupants. Where the inlets are removed from the danger of direct drafts on the occupants, a velocity of 300 feet per minute may be used with safety. In hospitals and similar institutions, the inlets and outlets should be very carefully placed to meet the requirements of the particular arrangement of beds, and velocities should be low. The velocities through outlets may range from 400 to 600 feet per minute.

There is another consideration which should be discussed at this point, as it seriously affects the question of air distribution. That is the question of heating by means of the ventilating air. In the opinion of the author, this is never desirable in a room of what we have called the densely peopled character. Especially where there is any considerable amount of glass or exposed wall surface, there should be heating coils in the room sufficient at least to counteract the loss of heat from such surfaces; otherwise the incoming air must in cold weather have a temperature of about 130 degrees or more and is very hard and dry. In such cases the inlets must be very high, so as not to be near the occupants. Besides this, such a great difference in temperature between the incoming air and the average of the room creates currents which interfere with the uniform circulation desired, in addition to making it very difficult to maintain a uniform temperature throughout the room.

CHAPTER IX.—VENTILATING DUCTS.

Theory of the flow of air in ducts.—Any flow of air is created only by an inequality in the pressure of the air at two different points, and it follows that the primary requisites for a ventilating system are a means for creating the required difference in pressure and a means for distributing the flow of air to required points. As accessory to the first of these there is generally required some means for heating the air and frequently for washing it.

The theoretical laws which govern the flow of air are very difficult of direct application to ventilating conditions, and yet a clear understanding of the principles governing the air flow is necessary to the successful understanding of the way in which air can be handled in a ventilating system.

FIG. 65

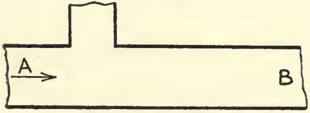


FIG. 66

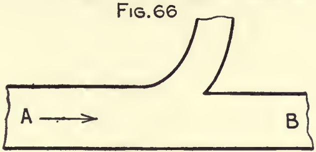


FIG. 67

Consider the simplest case: a pipe or duct, AB, Figure 65, of indefinite length, in which a flow of air is created from A to B. This flow can only be kept up by maintaining the air pressure at A in excess of that at B; and the greater this excess, the greater will be the velocity of air in the duct. Let us denote this excess, or difference, of pressure by p. It can be measured in pounds per square inch, ounces per square inch or in the height of the water column which it will balance. In ventilating work, since p is generally small, it is measured in one of the two latter units; and a column of water 1 inch high is equivalent to 0.579 ounce per square inch. The pressure p has two functions to perform; it must create the velocity (v) of air in the duct and it must overcome the frictional resistance to the passage of the air. Now, if it were not for the friction of the air in the pipes, the velocity could be expressed by the familiar formula

$$v = \sqrt{2\,g\,h}$$

in which v is given in feet per second and h is the height in feet of a column of air, the weight of which would give the pressure p which creates the flow. If p is expressed in inches of water column, $h = [67.7 + (t \div 520)]\,p$, where t is the temperature of the air; and as $g = 32$ (approximately) in the foot-pound-second system of units, the formula becomes:

$$v = 8\sqrt{\left(67.7 + \frac{t}{520}\right)p} \;\ldots\ldots\;\ldots\ldots(1)$$

As already stated, this represents the theoretical velocity that would be attained if there were no frictional resistance to be overcome. This formula is not absolutely accurate even for the theoretical velocity without friction, on account of the compressibility of air, but with the pressures attained in ventilating plants, the factor of correction would amount to a very small fraction of 1 per cent. But as it is, the actual velocity (v^1) may be anything from 0.2 v to 0.7 v, and under the conditions of most ventilating plants it is from 0.3 v to 0.6 v. Or, v^1 being the actual velocity, we may put

$$v^1 = c\sqrt{\left(67.7 + \frac{t}{520}\right)p} \ldots\ldots\ldots\ldots\ldots(2)$$

where c is a coefficient which will vary from 2.4 to 5 according to the nature of the resistance to be overcome, its maximum value being 8 for the theoretical velocity without friction.

Prof. Unwin gives a formula for the flow of air in round pipes which is as follows:

$$v = \sqrt{\frac{g\,k\,T\,d\,(p_0 + p_1)\,(p_0 \quad p_1)}{4\,m\,l \qquad\qquad p_0^{\,2}}} \ldots\ldots\ldots(3)$$

in which $k = 53.15$; $T =$ absolute temperature of air; $g = 32.2$;

d = diameter in feet; l = length in feet; m = a coefficient of friction; p_0 = the greater absolute pressure and p_1 = the lesser pressure. The difficulty, however, with any such formula as this is that in any ventilating system with a complicated arrangement of ducts, containing, as it must, bends and branches, dampers, rectangular pipes and round, registers, heating coils, etc., it is beyond the possibility of theoretical calculation to obtain any adequate value for a coefficient of friction.

The pressures employed in ventilating systems do not usually exceed 1 ounce per square inch, nor the velocity 50 feet per second, or 3,000 feet per minute.

The accompanying table gives the velocity v^1 as obtained by formula (2), already stated, for air at 60 degrees Fahr. and various values of c and different pressures, p. This table is rather difficult to apply practically, but it is the writer's experience that in a well-proportioned system a coefficient of 5 can be used. If the ducts are very long or tortuous, or contain many dampers, a smaller one should be used.

TABLE OF AIR VELOCITIES—TEMPERATURE 60 DEGREES FAHR.

p		v^1 in feet per second			
Inches water.	Oz. per sq. in.	c = 2.4	c = 3.	c = 4.	c = 5.
0.01	.006	2.0	2.5	3.3	4.1
0.05	.030	4.4	5.6	7.4	9.2
0.10	.058	6.2	7.8	10.4	13.0
0.20	.116	8.8	11.0	14.6	18.4
0.40	.232	12.5	15.6	20.8	26.0
0.60	.347	15.1	18.8	25.2	31.5
0.80	.463	17.4	21.8	29.2	36.4
1.00	.579	20.0	25.0	33.	41.2
2.00	1.158	28.2	34.8	46.4	57.8
3.00	1.737	34.6	42.7	56.9	71.2
4.00	2.316	40.	49.5	66.2	82.5

It will be seen from this table, as well as from formulas (1), (2) and (3) that p is proportional to v^2. (In formula (3), $p_0 - p_1$ is equivalent to the p of the table and of the other formulas, and for small values of p, $p_0 + p_1$ would be practically a constant.) On this account, in a given system of ventilating ducts, any increase in velocity can be obtained only by increasing the pressure created by the fan, proportionally to the square of the velocities. And as the power required to move the air is practically proportional to the product of the pressure, area and velocity, the power required, exclusive of that used by the friction of fan and engine or motor, is proportional to the cube of the velocity. These laws should be thoroughly understood by all who have anything to do with ventilating systems. They would be still more important were it not that the pressures employed in ventilating systems are always small, rarely exceeding 1 inch of water column, equal to 0.579 ounce per square inch.

Velocity of air in ducts.—From what has been said it may be gathered that the design of a system of ventilating ducts is largely a matter of velocities. The velocity in the main ducts may vary from 30 to 65 feet per second, the latter figure being somewhat excessive if the ducts are of any considerable length. For branch ducts the velocities must be lower—the smaller the duct the lower the velocity—in order to maintain the proper distribution throughout the system. This seems rather indefinite, and so it is, but there is no branch of engineering which is more strictly dependent upon empirical rules and the experience and study of the designer, than the design of a ventilating system. We may take 35 to 40 feet per second as a standard velocity for air in the main ducts, from a fan delivering from 20,000 to 40,000 cubic feet of air per minute. In the branch ducts the velocity should be reduced, according to the size of the ducts, as low as 20, or even 15 feet per second in small ducts (8 x 10-inch or 6 x 12-inch) supplying individual registers in small rooms.

The velocity through the registers should not exceed 5 feet per second through the gross area, except through large ones so located that there is no possibility of a direct draft on the occupants of the room. If these proportions are carried out, the necessary pressure at the fan to force air through the ducts will not generally exceed 0.3 ounce per square inch, but it must be borne in mind that additional pressure is required for heating coils and other similar obstructions. This will be more particularly considered in a subsequent chapter. The pressure necessary will increase rapidly as velocities are increased, and must be made up by increased capacity of fans and increased power.

Branch ducts.—In laying out ducts the utmost ingenuity should be exercised in arranging the branches, dampers, etc. All short bends and T-branches should be carefully avoided, as they greatly reduce the flow of air. A frequent specification in regard to bends is that the inside radius of the bend must be equal to the diameter, or equivalent, of the pipe. This should certainly be a minimum and twice that radius would be a preferable minimum. The air will frequently pass right by a right-angle branch, as in Figure 66. The velocity in the branch being but a small percentage of that in the main, such connections should be made as in Figure 67.

Dampers.—Dampers are a necessary evil, as they certainly impede the flow. They should be used with caution, and the duct system should be laid out in the first place with as few dampers as possible, and in the second place with the idea that under normal conditions the system should be run with all dampers wide open.

There is a common practice when laying out a complicated system of ducts with numerous branches and sub-branches of putting a damper on every branch, the idea being that if one branch gets more than its share of air it can be "throttled down" by means of its damper, so that the other branches will get more. The author has hardly found a case in practice where dampers were used in this way but that, in the course of practical experiment on the part of an ignorant attendant to proportion the air supply, most, if not all, of the dampers were more or less closed, thus diminishing the air supply and throwing a greater load on the fan. It is not alone the velocity in the ducts that we must look after, but also that at the dampers; a few half-closed dampers will have a decided effect upon the pressure required at the fan.

Dampers should only be put in at or near the registers, and in many cases the system is better off without them even there. The branches must be systematically laid out, and with reasonable care they can be properly proportioned without adding dampers to act as a safeguard on the designer.

The ordinary butterfly damper, hung by the rod in the middle, is the type most employed. They should be firmly attached to the rod, so that they cannot work loose. The damper should fit loose in its duct and should always be provided with a substantial attachment by which its position can be set and secured from the outside.

Arrangement of ducts.—In large plants the ducts usually radiate from the fan to the registers in a tree-like pattern; but in the opinion of the author, although apparently the simplest, this is in reality the most complicated possible way to lay out a ventilating system; and it is his firm opinion that much better results can be obtained by a system of mains and feeders, to borrow electrical phraseology. The idea of the first system is indicated in Figure 68, and that of the second in Figure 69. The diagram in each case represents the basement of a building, VVV being vertical flues which it is necessary to supply with air. In Figure 69 M may be called the mains and F the feeders. In the "tree" system of Figure 68 it is difficult indeed to prevent the ducts nearest the fan from taking most of the air, and a much more uniform distribution is obtained by the other system, especially if the mains are made large so that the velocity is low. The feeders can then be proportioned for a comparatively high velocity (45 to 60 feet per second for large systems) without loss. The connection to the vertical flues should, of course, be curved upward from the mains, or the connection made very free. In this system the object is to make the mains something of a plenum chamber in which the velocity is slow and the pressure uniform throughout.

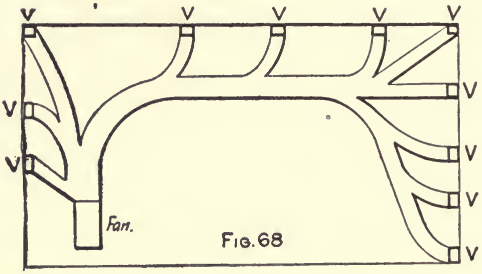


Fig. 68

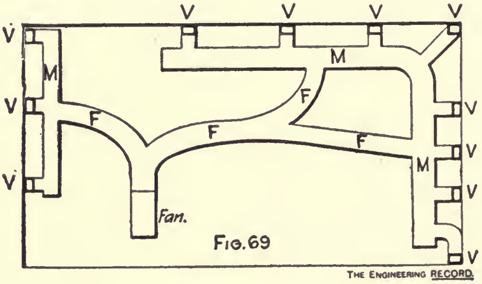


Fig. 69

THE ENGINEERING RECORD

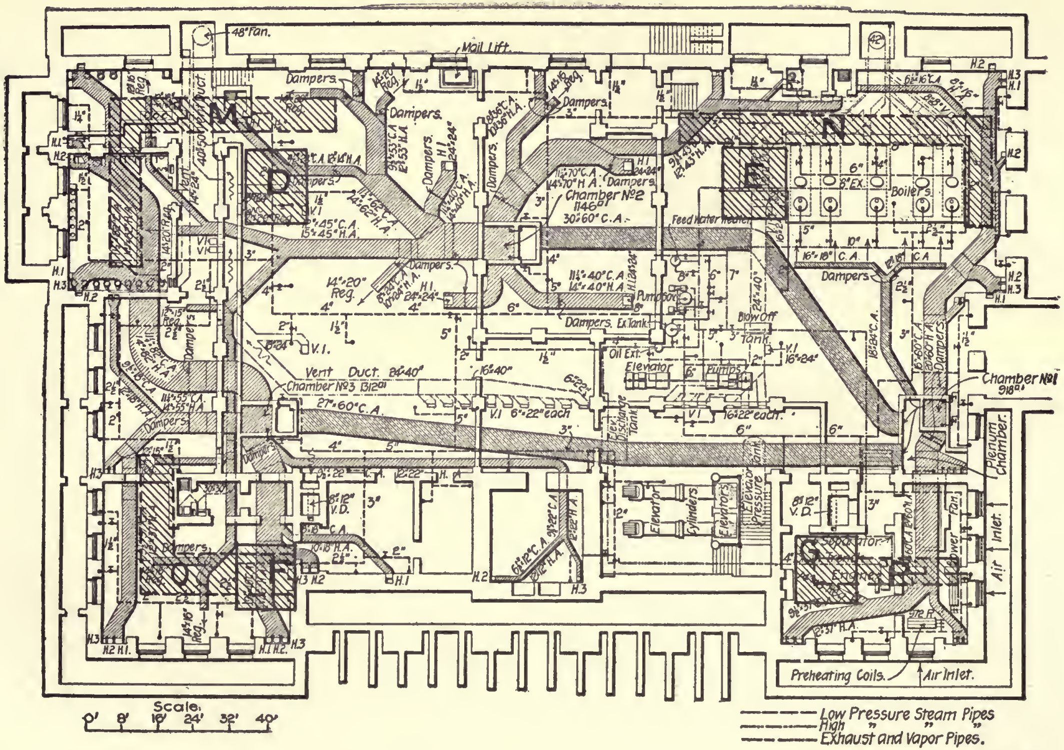
Types of Duct Arrangement.

In a large system, where several fans are used, the best results will be obtained by locating two or three plenum chambers, as mains or as centers of distribution, at central points, from which the ducts can radiate, and to each of which feeders from the fans can be conducted.

A large library building in the Middle West is a case in point. It is ventilated by an elaborate system with five large supply fans and as many exhaust fans. The ducts radiate from the fans on the "tree" system, each fan connecting to its own independent system of ducts. The ducts are large and long and ramify through the basement so as to render useless a large amount of valuable space. As the system stands, it is very difficult to adjust the air supply to the different ducts and the pressures on the different fans are very unequal. If two plenum chambers had been located in the center of each end of the building and each of the supply fans connected into one or the other, it would have greatly simplified the air distribution, taken up much less space and equalized the pressure and the load on the different fans, some of which at present are considerably overloaded, while others are the reverse.

Figure 70 shows the basement plan of a building taken from The Engineering Record. The following description of the arrangement of ducts accompanied the plan: Fresh air enters through windows at the northeast corner of the basement, where the fan is located. In cold weather the air passes through the windows of a tempering chamber provided with tempering coils, but in moderate weather this chamber is shut off and windows in the fan room adjoining are opened to allow the air to pass directly to the fan. By means of an 8-foot blower the air is delivered into a plenum chamber about 10 x 17 feet in size adjoining the fan room. From this the air is forced to three indirect heating chambers, constructed of brick, located at convenient points in the basement, from which both heated and tempered air may be uniformly distributed by the double duct system to the base of the heat flues. One of these heating chambers is built within the plenum chamber, while the other two are located at distant points and connected with it by galvanized-iron ducts. The heating chambers are numbered 1, 2 and 3 in the drawing. Number 1 is located inside of the main plenum, while the other two are located at distant points of the basement, as shown.

It will be seen that in this plant the vertical ducts are supplied from the three chambers, which are practically three centers of distribution, but, in the opinion of the author, the system could have been improved by locating four main ducts at M, N, O, P, and



THE ENGINEERING RECORD.

Figure 70.—Plan of a Ventilating Plant, Showing Possible Mains and Centers of Distribution.

supplying these by feeders from the fan at points about at the middle of the mains. The four mains would supply the vertical flues in the four sections of the building and they could be connected together by a small equalizing duct forming a sort of ring system around the building. Of course there may be objections to such a system on account of the constructional features of the building, or the special use of certain rooms, and in the case under consideration the engineer wished to place a heating coil in each of his centers of distribution; but this being the case, it would have been better to locate four centers of distribution; for example, at D, E, F and G, the object being to make the connections from them to the vertical flues as short and direct as possible. In this case they should each have a feeder from the fan and could be profitably connected by an equalizing duct from which the stray vertical ducts between them could be connected. The question of the distribution of heating coils in ducts will be further considered in a subsequent chapter. Figure 72 represents another building in which three centers could have been very advantageously located at A, B and C. The ducts shown, it may be pointed out, form the exhaust system of a downward ventilating apparatus installed in this building.

FIG. 71

In regard to vertical flues, they should, if possible, be separate for each outlet; and the longer the duct, the slower the velocity to be allowed. The author is familiar with one building in which some of the vertical flues supply three registers. Each outlet is provided with an adjustable swing damper, as indicated in Figure 71, and it is exceedingly difficult to adjust them so as to give anything like a uniform distribution to the three outlets.

Materials for ducts.—As to the material for the construction of ducts, they are usually made of galvanized iron, in which case they should be soldered at the joints, as it is very essential that they be made air tight. Large ducts are frequently made of sheet iron, and these should be close riveted; and when they are painted, the joints should be thoroughly doped with an asphalt or other similar paint.

Underground ducts should be made of brick. Wood is objectionable in any case, and especially so unless the ground is very

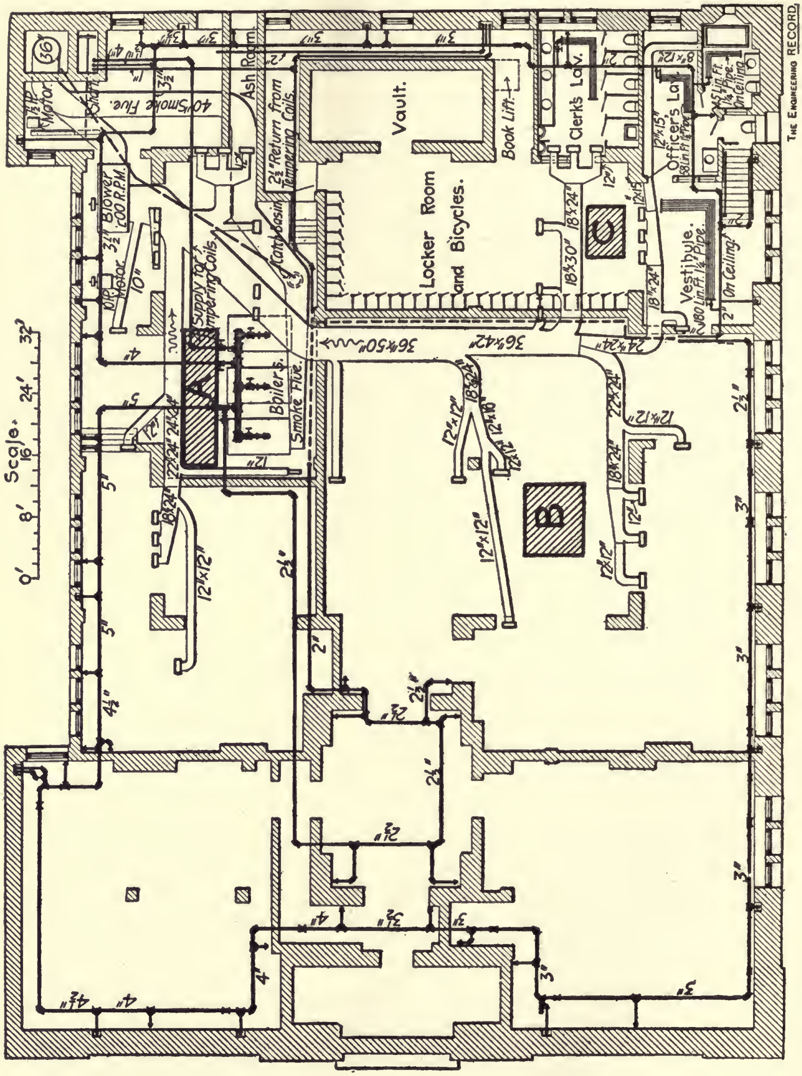


Figure 72.—Plan of a Basement Duct System, Showing Flues and Possible Centers of Distribution.

dry, and they should be lined with tin or galvanized iron to make them tight. Brick ducts should be plastered inside and out all around with a ½-inch coat of rich cement mortar, or, preferably, asphalt. There is, among some engineers, but more particularly among ventilating contractors, an opposition to underground ducts. The author has thought this originated with the latter largely from the fact that there is less profit for the ordinary ventilating contractor in building brick ducts than there is in iron. The objection is raised that they are liable to become damp and dirty. This is not at all the case if they are properly made. In fact, from the standpoint of cleanliness, they are preferable to iron, as any duct will become very dirty in time, and brick ones can be easily arranged so as to be washed out with a water stream from a hose. Underground ducts must, of course, as a rule, be laid out before the building is built, and it is not generally practicable to put very small ones underground; but with a system designed with centers of distribution and feeder ducts, as suggested, the latter could, in most cases, be put underground with great advantage. In the building first referred to, not only the feeder ducts, but the centers of distribution as well, might have been put underground, and at less expense than the existing system, if the work had been laid out at the proper time. There is an objection to blowing heated air through underground ducts, but this will be considered in the following chapter.

CHAPTER X.—VENTILATING FANS AND OTHER APPARATUS.

Types of fans.—There are but two kinds of fans commonly used in ventilating plants. These are the centrifugal fan, or blower, and the propeller, or disk fan. The distinctive characteristics of the two types are well shown in Figures 73 and 74.

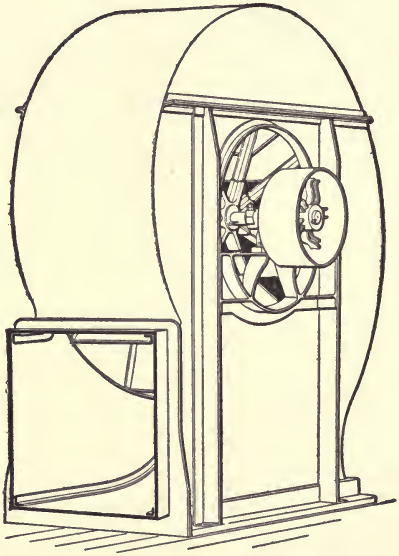


Figure 73.—The Centrifugal Fan.

The centrifugal fan consists of a wheel with several vanes mounted on a horizontal shaft, as shown in Figure 75, where the covering or casing is removed. It is always mounted in this casing, which may be of wood, brick or iron, but usually the last, although for large fans the bottom part is generally of brickwork and the top of iron. The air enters through an opening in the center and is forced to the outlet by the centrifugal action due to the rapid revolution of the fan wheel.

The disk fan is mounted in an opening in a wall, or in the end of a pipe, and drives air by means of its screw-like action. The disk fan is only used against very light pressures, and consequently, when ducts are very short and openings large and few, the disk fan loses in efficiency rapidly as the pressure rises.

Centrifugal fan capacities.—There is no manufactured machine about which there are so many varying data as there is in connection with ventilating fans. The makers' claims as to capacity are generally too high.

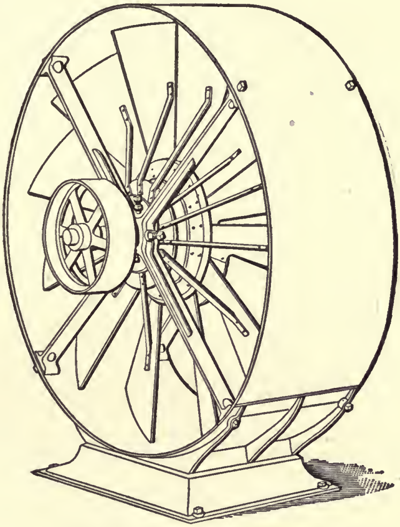


Figure 74.—The Disk Fan.

Mr. Alfred R. Wolff, in his very excellent pamphlet on "The Ventilation of Buildings," publishes the accompanying table, Table I, for centrifugal fans. This table, like everything else from Mr. Wolff's pen on the subject, is very valuable, although the experience of the author in testing some large fans would indicate that even the capacities here given are somewhat too liberal.

Mr. M. C. Huyett, an ex-fan manufacturer of extended experience, has published a valuable table of centrifugal fan capacities which is given in Table II. Mr. Huyett's table is based on the

TABLE II.—THE HUYETT TABLE OF CENTRIFUGAL FAN-WHEEL CAPACITY COEFFICIENTS.

Width of Wheel at Periphery (in Inches).

Outside diam. of wheel in inches.	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**40**	**42**	**44**	**46**	**48**	**50**	**52**	**54**	**56**	**58**	**60**
36	14.1	15.7	17.3	18.8	20.4	22.0	23.6	25.1	26.7	28.2												
38	15.7	17.5	19.2	21.0	22.8	24.5	26.3	28.0	29.8	31.5	33.2	**40**										
40	17.5	19.4	21.4	23.3	25.2	27.2	29.1	31.0	33.0	34.9	36.9	38.8	**42**									
42	19.3	21.4	23.6	25.7	27.8	30.0	32.1	34.2	36.4	38.5	40.7	42.8	45.0	**44**								
44	21.1	23.4	25.8	28.2	30.5	32.8	35.2	37.5	39.9	42.2	44.6	47.0	49.3	51.6	**46**							
46	23.0	25.6	28.2	30.7	33.3	35.8	38.4	41.0	43.5	46.1	48.6	51.2	53.8	56.4	59.0	**48**						
48	25.2	28.0	30.8	33.5	36.3	39.1	41.9	44.7	47.5	50.2	53.1	55.9	58.7	61.5	64.2	67.0	**50**					
50	27.3	30.3	33.3	36.4	39.4	42.4	45.5	48.5	51.5	54.5	57.5	60.6	63.6	66.6	69.6	72.7	75.7	**52**				
52	29.5	32.8	36.1	39.3	42.6	45.9	49.2	52.5	55.8	59.0	62.3	65.6	68.9	72.2	75.4	78.7	82.0	85.2	**54**			
54	31.8	35.3	38.8	42.3	45.8	49.4	53.0	56.5	60.0	63.5	67.1	70.6	74.2	77.7	81.2	84.7	88.2	91.8	95.4	**56**		
56	**18**	38.0	41.7	45.6	49.4	53.2	57.0	60.7	64.5	68.3	72.1	76.0	79.8	83.5	87.3	91.1	95.0	98.7	102.6	106.5	**58**	
58		40.8	44.9	48.9	53.0	57.1	61.2	65.2	69.3	73.4	77.5	81.6	85.6	89.7	93.8	97.9	102.0	106.0	110.1	114.1	118.2	**60**
60		43.6	48.0	52.3	56.6	61.0	65.4	69.8	74.1	78.5	82.8	87.2	91.5	96.0	100.0	104.6	109.0	113.3	117.8	122.0	126.5	131.0
62		**20**	51.3	55.9	60.6	65.2	69.9	74.5	79.2	83.9	88.5	93.1	97.7	102.5	107.1	111.8	116.4	121.0	125.8	130.4	135.0	139.6
64			54.5	59.5	64.5	69.5	74.5	79.5	84.5	89.4	94.3	99.2	104.2	109.1	114.0	119.0	124.0	129.0	134.0	139.0	144.0	149.0
66			58.2	63.4	68.6	73.9	79.2	84.5	89.7	95.0	100.0	105.5	111.0	116.2	121.3	126.6	132.0	137.2	142.5	147.6	153.0	158.3
68			**22**	67.2	72.9	78.5	84.0	89.6	95.2	100.8	106.4	112.0	117.6	123.2	128.7	134.4	140.0	145.5	151.1	156.8	162.4	168.0
70				71.3	77.2	83.2	89.2	95.0	101.0	106.9	112.9	118.8	124.7	130.6	136.5	142.5	148.5	154.5	160.4	166.3	172.1	178.1
72				75.3	81.6	87.9	94.2	100.5	106.7	113.0	119.3	125.6	131.9	138.1	144.4	150.6	157.0	163.3	169.5	175.8	182.1	188.4
74				**24**	86.2	92.8	99.5	106.0	112.6	119.3	126.0	132.5	139.1	145.8	152.5	159.0	165.7	172.3	179.0	185.6	192.3	199.0
76					91.0	98.0	105.0	112.0	119.0	126.0	133.0	140.0	147.0	154.0	161.0	168.0	175.0	182.0	189.0	196.0	203.0	210.0
78					96.0	103.1	110.6	118.0	125.3	132.8	140.1	147.5	155.0	162.3	169.6	177.0	184.3	191.6	199.0	206.4	214.0	221.4
80					**26**	108.6	116.4	124.1	132.0	139.6	147.5	155.2	163.0	170.7	178.5	186.2	194.0	202.0	209.6	217.3	225.0	233.0
82						114.2	122.4	130.5	138.6	146.8	155.0	163.2	171.4	179.5	187.8	196.0	204.0	212.2	220.2	228.4	236.6	245.0
84						119.8	128.3	136.8	145.5	154.0	162.6	171.1	179.7	188.2	196.8	205.3	214.0	222.5	231.0	239.5	248.0	256.5
86						**28**	134.3	143.2	152.1	161.1	170.1	179.0	188.0	197.0	206.0	215.0	224.0	233.0	242.0	251.0	260.0	269.0
88							140.5	150.0	159.3	168.7	178.1	187.5	196.8	206.1	215.5	225.0	234.3	243.6	253.0	262.2	272.0	281.0
90							147.0	156.6	166.5	176.5	186.3	196.0	206.0	215.8	225.8	235.5	245.0	255.0	264.6	274.3	284.0	294.0
92							**30**	164.1	174.5	184.6	195.0	205.0	215.5	225.8	236.0	246.2	256.3	266.4	277.0	287.0	297.5	308.0
94								171.0	182.0	192.5	203.5	214.0	224.4	235.4	246.0	256.6	267.5	278.0	289.0	299.5	310.0	321.0
96								178.8	190.0	201.0	212.3	223.6	234.6	246.0	257.0	268.2	279.6	290.3	302.0	313.0	324.0	335.0
98								**32**	198.3	210.0	222.0	233.5	245.0	256.5	268.0	280.0	292.0	303.5	315.0	327.0	338.0	350.0
100									206.0	218.0	230.0	242.5	254.5	266.6	278.8	291.0	303.0	315.0	327.0	339.5	351.5	364.0
102									214.4	227.0	240.0	253.0	265.0	277.5	290.0	303.0	315.5	328.0	341.0	353.0	366.0	378.5
104									**34**	236.0	249.2	262.4	275.5	288.6	302.0	315.0	328.0	341.0	354.0	367.0	380.0	394.0
106										247.5	259.0	272.5	286.5	300.0	313.5	327.0	341.0	354.5	368.0	382.0	395.0	408.0
108										255.0	269.0	283.0	297.5	311.5	326.0	340.0	354.0	368.0	382.0	396.5	411.0	425.0

Given size of fan wheel and revolutions per minute to find capacity.

Rule.—Find number from table for wheel of given diameter and width. Multiply this tabular number by the given number of revolutions per minute. The product is the "free" capacity of fan wheel in cubic feet per minute.

velocity of the fan-wheel periphery multiplied by the "blast area" of the fan. The blast area being practically the area of the blade, is taken as the width of the wheel multiplied by one-third of the diameter. As Mr. Huyett points out, it will be seen that this represents a maximum velocity for the air, as it is impossible to give to it a velocity greater than that of the wheel rim. The table may, therefore, be taken as representing practically a free air discharge, and checks very close with the author's tests made on fans working under low velocities or free delivery in the ducts.

TABLE I.—QUANTITY OF AIR SUPPLIED BY BLOWERS OF VARIOUS SIZES AGAINST A PRESSURE OF ONE OUNCE PER SQUARE INCH. (ALFRED R. WOLFF.)

Diam. wheel, ft.	Revs. per minute.	H.-P. to drive blower.	Cubic ft. per minute.
4	350	6.	10,635
5	325	9.4	17,000
6	275	13.5	29,618
7	230	18.4	42,700
8	200	24.	46,000
9	175	29.	56,800
10	160	35.5	70,340
12	130	49.5	102,000
14	110	66.	139,000
15	100	77.	160,000

The theoretical calculation of fan discharge is very complicated, and, so far as the author's experience goes, is very unreliable on account of the difficulty of obtaining accurate values for the coefficients.

In a paper in the "Transactions" of the American Society of Heating & Ventilating Engineers, for 1899, Prof. R. C. Carpenter deduces a formula in which the fan "capacity is equal to the product of three constants multiplied by the width of wheel, diameter of inlet, and by diameter of fan wheel into the number of revolutions." He states also that since, by common practice the three first factors are now always made proportional to one another, the formula becomes

$$q = c\ n\ d^3,$$

by which q is obtained as cubic feet per minute, d being the diameter in feet of the fan wheel, n the number of revolutions per minute, and c a coefficient, the value of which Prof. Carpenter gives as 0.6 for single-inlet fans under free discharge, 0.5 with a pressure of 1 inch of water, and 0.4 with a pressure of 1 ounce per square inch. "For fans with double inlets the coefficient should be increased 50 per cent." For practical work on ventilating plants Prof. Carpenter recommends $c = 0.4$. This coefficient gives capacities which are about 10 per cent. less than those of Mr. Wolff's table, and is very reliable where duct velocities are employed such as the author recommends in the preceding chapter, with 45 to 55 feet per second in the main duct; but where heating coils and other similar resistance are interposed in the air passages, as is generally the case, a coefficient of $c = 0.35$ is much safer.

Prof. Carpenter also gives a formula for the power required to drive centrifugal fans ("Transactions" Am. Soc. Htg. & Vent. Engrs., Vol. V., p. 237), which is:

$$HP = b\,d^5\,n^3 \div 10^6,$$

in which H P is horse-power delivered to the fan; d, the diameter in feet; n, the number of revolutions per second, and b a coefficient, which should be taken as 30 for free delivery and 20 for delivery against 1 ounce pressure. This formula, with a coefficient of 20, gives results almost identical with those of Mr. Wolff's table, and may be taken as very reliable for practical work. It is interesting to note that according to Prof. Carpenter's coefficient, the power required for free delivery is 50 per cent. greater than when working against a pressure of 1 ounce. This is in accordance with experience, as well as theory, but is, of course, due to the fact that the volume of air delivered under free discharge is much greater than under 1 ounce pressure.

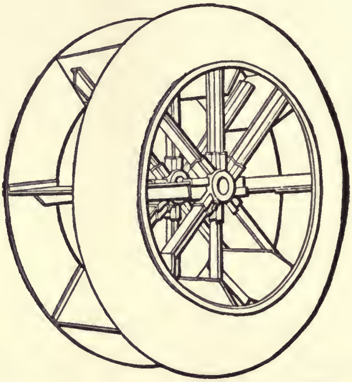


Figure 75.—Centrifugal Blast Wheel.

Disk fans.—Disk fans, as stated above, are not generally used where large capacity is required, except where the delivery is very free. They are usually employed where exhaust fans are required on roofs, or in other elevated positions where it is impracticable to set the large foundation which the centrifugal fan requires. It is the opinion of the author that the field of usefulness of the disk fan is larger than is generally considered, and that its delivery is not as much reduced by increasing the resistance under which it works as is usually supposed. The disk fan seems to be used much more in Europe than it is in America. Mr. Wolff gives some valuable data upon disk fans in Table III.

TABLE III.—QUANTITY OF AIR MOVED BY APPROVED FORMS OF EXHAUST FAN DISCHARGING DIRECTLY INTO ATMOSPHERE. (ALFRED R. WOLFF.)

Diam. wheel, ft.	Revs. per minute.	H.-P. to drive fan.	Cubic ft. per minute.
2.0	600	0.50	5,000
2.5	550	0.75	8,000
3.0	500	1.00	12,000
3.5	500	2.50	20,000
4.0	475	3.50	28,000
5.0	350	4.50	35,000
6.0	300	7.00	50,000
7.0	250	9.00	80,000

In an article in the "Transactions" of the American Society of Heating & Ventilating Engineers, 1899 (See Vol. V, p. 128), Prof. J. H. Kinealy gives the following formula for disk fans with straight vanes set at an angle of 40 or 45 degrees:

$$Q = d^3 n \div 3{,}050,$$

where d is the diameter in inches; n, the revolutions per minute, and Q, the number of cubic feet per minute. He also gives for the Blackman fan (which has a blade constructed with a peculiar curve):

$$Q = d^3 n \div 1{,}880.$$

Prof. Kinealy states that the proper velocity for a fan is given by the formula

$$n = 21{,}000 \div d,$$

where d is again the diameter in inches. The formula is based on a velocity at the rim of 90 feet per second. Prof. Kinealy's formula for the Blackman fan corresponds quite closely with the figures given in Mr. Wolff's table, and may undoubtedly be accepted as reliable for free delivery. If the disk fan is used on a complicated system of ducts the author would favor multiplying Prof. Kinealy's formulas by a coefficient of 0.65; and if heating coils and other similar resistances are added, this coefficient should be made not greater than 0.5.

Ventilation by gravity.—There is one method of creating a circulation of air which may properly be discussed in connection with other apparatus for the purpose, and which is frequently of great value. This is the heated flue. In Chapter IV the author discussed the effect produced by heating the column of air in an open flue, and the formula

$$v = \sqrt{2\,g\,H\,\frac{T - t}{t + 460}}$$

was derived for the theoretical velocity in feet per second (without friction) obtained in the flue, where T is the temperature to which the air in the duct is heated, and t is external temperature, H being the height of the flue, and g the acceleration of gravity = 32.2.

Mr. Alfred R. Wolff is of the opinion that 50 per cent. must be deducted from the formula for friction of air in ducts, etc., in order to get the actual velocity that can be attained, and he reduces the formula to the following form:

$$V = 240\sqrt{\frac{H\,(T - t)}{492}}$$

in which V is the velocity in feet per minute. Mr. Wolff also gives the following table calculated from this formula:

TABLE IV.—VELOCITY OF AIR, IN FEET PER MINUTE, THROUGH A VENTILATING DUCT (THE EXTERNAL TEMPERATURE OF THE AIR BEING 32 DEGREES FAHR.

Height of Vent-Duct in ft.	Excess of Temperature of Air in Vent Duct Above that of External Air, Degrees Fahr.								
	5	10	15	20	25	30	50	100	150
10	77	108	133	153	171	188	242	342	419
15	94	133	162	188	210	230	297	419	514
20	108	153	188	217	242	265	342	484	593
25	121	171	210	242	271	297	383	541	663
30	133	188	230	265	297	325	419	593	726
35	143	203	248	286	320	351	453	640	784
40	153	217	265	306	342	375	484	656	838
45	162	230	282	325	363	398	514	726	889
50	171	242	297	342	383	419	541	766	937

It will be seen from this table that the velocities obtained are small, and as V is proportional to the square root of (T — t) and also to the square root of H, it is necessary to multiply one of these factors by four in order to double the velocity. It is, therefore, necessary to have a very considerable difference in temperature, or a great height of flue, or a large area, in order to produce the volume of flow that would be required in a moderate ventilating plant. The cost of heating a large volume of air to the required temperature is excessive in comparison with the cost of fan power.

There are many special cases, such as the ventilation of the toilet rooms, where continual circulation is desired, and especially where cheap gas is available, in which the heated flue is a valuable means to be employed. In many cases a vent shaft can conveniently be located around a metal chimney, from which sufficient heat is obtained to produce a decided draft.

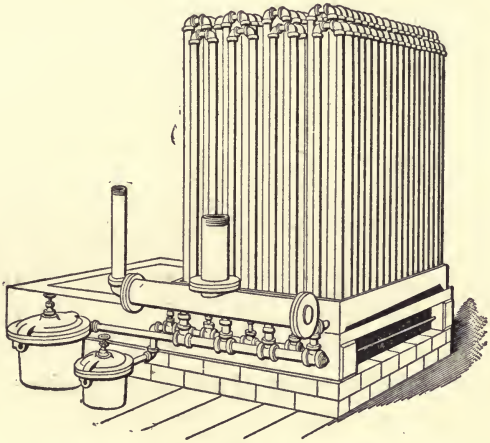


Figure 76.—A Type of Heating Coil.

Heating coils.—In the latitudes of most of the United States it is necessary to provide heating coils for all fans which take air from the outside and blow it into buildings for ventilating purposes. These coils are of many kinds and forms. They are usually located either between the air intake and the fan, or just at the outlet of the fan, but frequently separate coils are placed at the base of the vertical flues to each room; and often, indeed, a temporary coil for use in very cold weather is placed at the fan and additional ones at the separate vertical flues. Figure 76 shows one form of heating coil for a fan, the casing being removed. Figures

77 and 78 show fan and coil together, in the former the heater being on the suction side, and in the latter on the blast side.

The heating coils are generally made of loops of 1-inch pipe, and the rules for proportioning them are very conflicting. The same general theories apply to them as to indirect radiators, as given in a preceding chapter of this series.

In a brief article in the issue of May 13, 1899, The Engineering Record gives some valuable data from the authorship of Mr. W. S. Blessed of the American Blower Company. The data refers to coils similar to that shown in Figure 76, each section of which contains four rows of 1-inch pipes set 2¾ inches center to center, and give the final temperature attained by the air under different "mean velocities" through the coil. With air at an initial "temperature of 30 degrees Fahr. passing through the coils at a mean velocity of 1,600 feet per minute, a common velocity with a centrifugal fan, the air will be raised to the temperature shown in the following table, with the steam pressures and number of coils in use as mentioned:

Steam, 5 lbs. Pressure.		Steam, 75 lbs. Pressure.	
Number of Sections.	Final Temp. of Air. Deg. Fahr.	Number of Sections.	Final Temp. of Air. Deg. Fahr.
4	74	4	92
5	88	5	117
6	100	6	137
7	110	7	143
8	117	8	156

"With a mean velocity of air of 900 feet per minute the rise in temperature of the air will be:

Steam, 5 lbs. Pressure.		Steam, 75 lbs. Pressure.	
Number of Sections.	Final Temp. of Air. Deg. Fahr.	Number of Sections.	Final Temp. of Air. Deg. Fahr.
4	85	4	125
5	110	5	158
6	130	6	186
7	147	7	210
8	160	8	230

"With 5 pounds pressure about 1,720 B. T. U. are given off per hour per square foot of heating surface, and with 70 pounds pressure about 2,520 B. T. U."

Commenting further on this subject, in response to an inquiry, The Engineering Record of June 3, 1899, says:

"It may be well to describe how the manufacturers of this apparatus usually determine the size of hot-blast coils necessary to do a certain amount of work. It is manifest that the amount of heat which can be transferred from one substance to another, as from the steam-heated pipes of a hot-blast coil to the air which is being blown past them, is proportional, in a measure, to the time that the air is subject to the heating influence of the steam pipes. Consequently, hot-blast coils must be large enough in a plane perpendicular to the direction of the moving air; or, in other words, they must be a sufficient number of pipes wide, and the pipes must be of such a length that the combined area of the openings between the pipes will be sufficient in size to insure the proper velocity of the air to be forced through them.

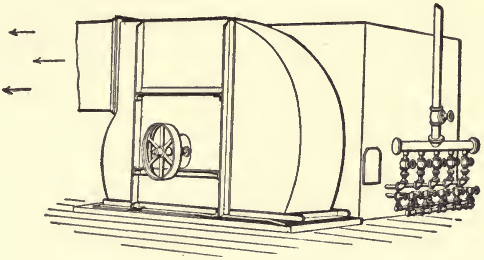


Figure 77.—Heater on Suction Side.

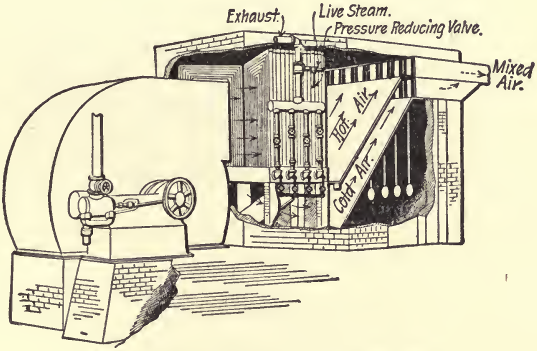


Figure 78.—Heater on Blast Side.

"For instance, if the mean velocity of air through the coils is to be 1,600 feet per minute, which is not an uncommon one with centrifugal blowers, and it is desired to put 16,000 cubic feet of air per minute through the coils, the area of the openings between the pipes should be 16,000 ÷ 1,600 = 10 square feet. Makers of hot-blast coils know the area of the openings between the pipes of coils of various sizes, and select the size which will give them the clear opening needed. With the data given in the note referred to, it is possible to calculate the rise in temperature of the air which will occur with various rows of pipes and with steam of 5 and 75 pounds pressure.

"The mean velocity of air should be explained. If 16,000 cubic feet of air at a temperature of say 120 degrees are to pass through the registers of a ventilating plant in a minute, this air, when at zero degrees, will have a volume of about 12,800 cubic feet. Consequently, as the air expands as it is heated in passing through the coils, its velocity must increase, and its mean velocity is the one upon which most calculations are based. If the 12,800 cubic feet is expanded to 16,000 cubic feet its mean volume is (12,800 + 16,000) ÷ 2 = 14,400 cubic feet. Then 14,400 ÷ 1,600 (the mean velocity assumed) = 9 square feet, the area of the clear opening between the coils that would be needed."

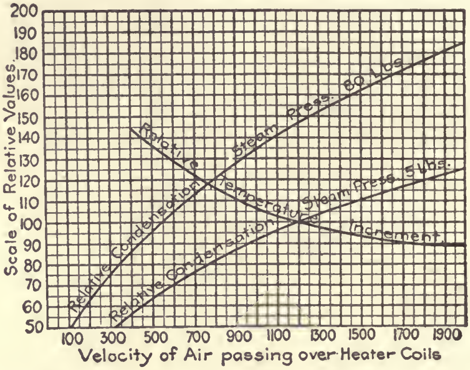


Figure 79.—Influence of Velocity of Air in Heaters.

Mr. Walter B. Snow, of the B. F. Sturtevant Company, in a lecture delivered before various technical colleges, gives some diagrams which, taken in connection with the data given above, are of great value in proportioning heating coils. These diagrams give only the relative effects of varying velocities through the free area of the coils, as well as the relative effect of different depths of coils. The diagrams are given in Figures 79 and 80, and as quoted from The Engineering Record of April 21, 1900, Mr. Snow gives the following explanation:

"The effect of varying velocities and of different steam pressures is shown in the accompanying curves drawn from the results of tests of Sturtevant heaters used in connection with fans. The relative condensation increases with both of these factors, but, as indicated by the third curve, the relative temperature increment with a given steam pressure decreases with the velocity. This is the natural result of moving a larger volume of air across the heating surface, and decreasing the time of contact. Disregarding the expansion by heat, the volume is proportional to the velocity; therefore the relative heat transmission may be determined by multiplying the given velocity by the relative condensation.

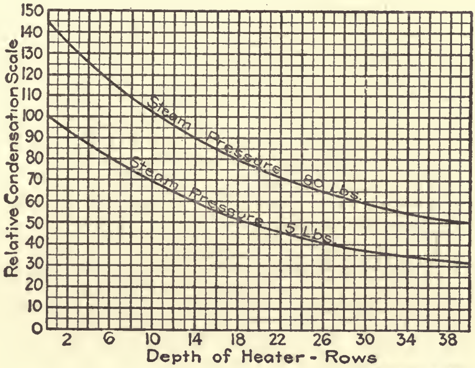


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Figure 80.—Influence of Depth in Heaters.

"The rate of condensation is naturally dependent upon the temperature difference between the air and steam, and is therefore greatest with the maximum difference. Hence, the less the depth of the heater, the less the total temperature increment of the air, but the more rapid the rate of transmission from steam to air. With increasing depth of heater there is a corresponding decrease in the average condensation per square foot. The surface first exposed to the air, of course, continues to maintain the same efficiency, but the surfaces subsequently passed over are progressively exposed to smaller and smaller temperature differences.

"The exact conditions in a Sturtevant heater operated in connection with a fan which produces a mean air-velocity flow of 1,200 feet per minute through the free area of the heater, are presented in the accompanying curves. From these and the preceding curves it is evident that the greatest surface efficiency is secured with the highest velocity of air and the least depth of heater. Practically, however, it is necessary to limit the velocity of the air, and to make the heater of sufficient depth to give the required temperature increment to the air."

Heating coils should always be provided with a by-pass around the coil, with a damper that can be opened in warm weather, when the heating coil is not in use; and also in moderate weather, to regulate the temperature of the entering air.

Heating coils, although an absolute necessity, in almost every case form a resistance to the movement of air which invariably reduces the output of the fan; and few, even among those familiar with ventilating plants, realize the full extent of the resistance offered by such coils. The author, in a paper in the "Transactions" of the American Society of Heating & Ventilating Engineers, for 1899 (Vol. V, p. 117), presented some tests made on some large fans in the Chicago Public Library. In the accompanying tables, V and VI, are given the principal results of the tests:

TABLE V.—Test of Fan E. Diam. wheel, 78 inches; width of blade, 45 inches; diam. inlet, 54 inches; net area, 13.1 sq. ft. Main duct, 45 x 45 inches; area, 14.1 sq. ft. Gross area heating coil, 34.7 sq. ft.; surface, 7,200 sq. ft.

Revs. per min. Fan.	Pressure of Air in oz. per sq. in.			Velocity of Air. Ft. per min.		Cu. ft. air per min.	Net amperes at 225 volts.	Approx. Temp. of air through fan.
	Suction.	Blast.	Total.	Inlet.	Main Duct.			
				By-pass Open.				
102	...	.086	.173	1,230	....	.....	6.2	65
110	.144	.086	.230	1,430	1,330	18,700	8.6	65
137	...	.115	.302	1,700	1,580	22,300	13	65
152	.259	.144	.403	1,870	1,740	24,500	17.3	65
157	...	.144	.403	1,920	1,780	25,100	20.6	65
				By-pass Closed.				
77	.151	.029	.180	621	580	8,180	2.9	65
77	.165	.007	.172	650	605	9,500	3	130
77	+.180	—.015	.165	690	640	9,010	2.9	160
144	...	.072	.310	1,120	1,040	14,650	12	65
164	.334	.086	.420	1,420	1,320	18,670	19.2	65

TABLE VI.—Test of Fan F. Diam. wheel, 78 inches; width blades, 45 inches; diam. inlet, 54 inches; net area, 13.1 sq. ft. Main duct, 45 x 45 inches; area, 14.1 sq. ft. Gross area heating coil, 40 sq. ft.; surface, 7,200 sq. ft.

Revs. per min. Fan.	Pressure of Air in oz. per sq. in. Suction.	Blast.	Total.	Velocity of Air. Ft. per min. Inlet.	Main Duct.	Cu. ft. air per min.	Net amperes at 225 volts.
		By-pass Open.		(No steam on coil.)			
73	.040	.026	.065	788	730	10,320	...
86	.054	.032	.086	945	830	12,380	3.36
100	.068	.040	.108	1,093	1,020	14,320	5.16
114	.123	.053	.176	1,240	1,150	16,250	7.11
123	...	.061	...	1,350	1,255	17,680	8.88
139	...	.075	...	1,520	1,415	19,900	12.1
143	...	.075	...	1,580	1,470	20,650	13.5
		By-pass Closed.		(No steam on coil.)			
76	.071	.011	.072	554	....	7,260	3.05
141	...	.043	.257	1,075	....	14,080	11.

A comparison is also given between the air deliveries and power required for both open and closed by-pass in Table VII. It should be noted here that the values in columns (2), (3), (5) and (6) were obtained from Tables V and VI, but in some cases by interpolation, so as to obtain for comparison the values corresponding to the same number of revolutions per minute of the fan for open and closed by-pass.

TABLE VII.—EFFECT ON AIR DELIVERY AND POWER OF CLOSING BY-PASS.

(1) Revs. per min., fan.	(2) Vel., air in inlet, by-pass open.	(3) Vel. Air, by-pass closed.	(4) (3) ÷ (2), per cent.	(5) Current, by-pass open.	(6) Current, by-pass closed.	(7) (6) ÷ (5), per cent.	(8) Amperes for vel. in (3), by-pass open.	(9) (6) ÷ (8).	(10) Air thro' fan, by-pass closed, deg.
				Fan E.					
77	935	621	66.3	3.2	2.9	91.	..	...	65
77	935	650	69.5	3.2	3.0	94.	..	...	130
77	935	690	74.0	3.2	2.9	91.	..	...	160
144	1,800	1,120	64.0	15.5	12.0	77.5	4.9	2.44	70
164	2,050	1,420	69.1	23.8	19.2	80.6	8.4	2.3	70
				Fan F.					
76	850	554	65.1	2.9	...	...	..	...	..
141	1,550	1,075	69.0	12.5	11.0	88.0	4.7	2.35	70

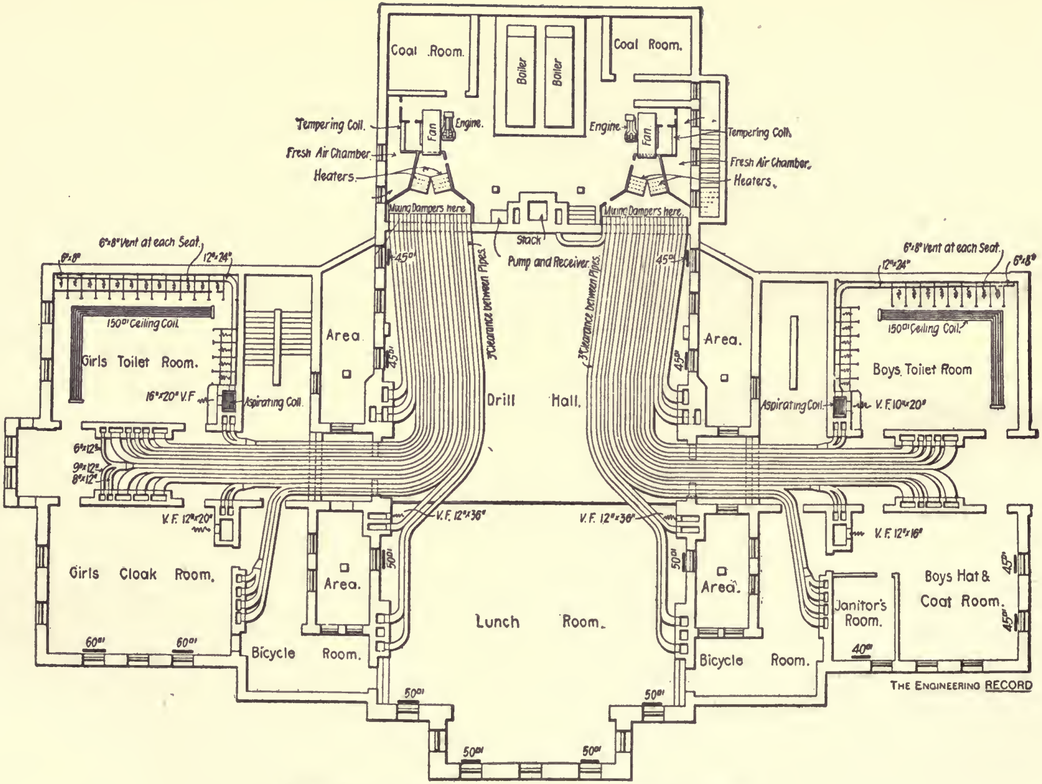


Figure 81.—Basement Plan of a Schoolhouse.

The following comments on the results of these tests were made, and they have a valuable bearing on practical installations:

"It will be seen that the air delivery was decreased from 21 to 36 per cent. merely by closing the by-pass. Two tests on fan E, with part of the heater turned on, and a high temperature through the fan, gave a somewhat less reduction. But even with the by-pass closed, and as high a temperature as 160 degrees, the

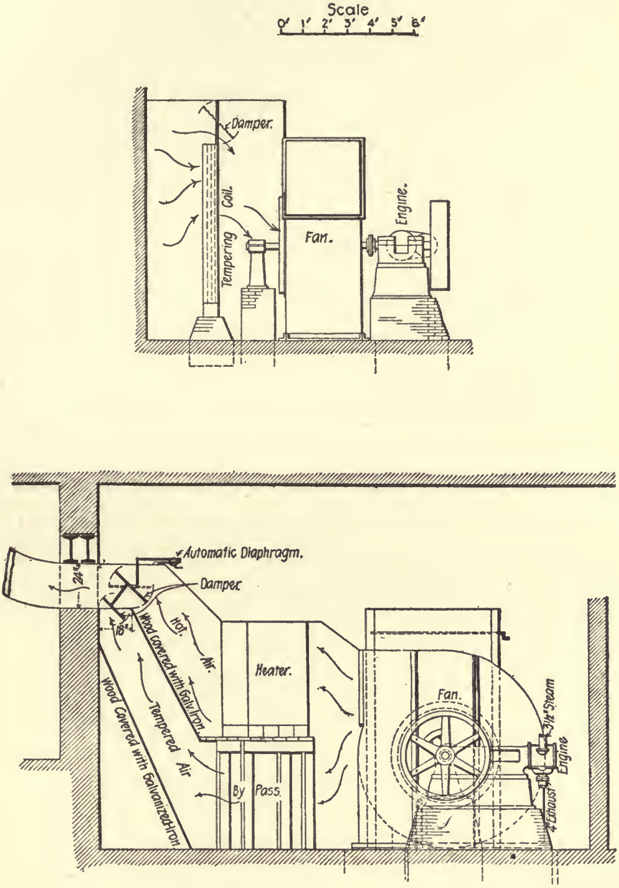


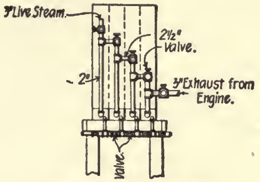
Figure 82.—Elevations of the Hot-Blast Unit.

delivery was 20 per cent. less than with the by-pass open. The only tests at these high temperatures were made with very low fan speeds, and the test of 160 degrees showed a negative pressure on the blast side of the fan, due to the draft of the hot air in the vertical ducts. The author regrets that it was impossible to repeat these temperature tests at higher fan speeds, but they do not have much bearing on practical results, as temperature in air ducts of much over 100 degrees would not be good practice anywhere. It will be noted also that whereas the delivery of air is reduced about 24 per cent. by closing the by-pass, the power required (for same speed of fan) is reduced only from 9 to 22 per cent., while it will be seen that for equal air deliveries the power was increased from 2.3 to 2.44 times by closing the by-pass.

"Attention should also be called at this point to the fact, as shown by the pressure observations in Tables V and VI, that even with the by-pass wide open the resistance due to intake and passages through and around the heater—or, in other words, the total resistance on the inlet of the fans—was in all cases quite considerably more than the total resistance of the delivery ducts, dampers and registers. This was a matter of considerable surprise, as the intake seemed to be of ample size, and area of the by-pass large. It was probably due, however, to the height of intake [about 40 feet], and as such resistances are very often but little considered, it will be valuable to note their importance in this case."

In regard to the fan capacities obtained by these tests it will be interesting to note that those on fan E, with by-pass open, correspond very closely with those given by Mr. Huyett's table, and also correspond with Prof. Carpenter's formula ($Q = cnd^3$) using a coefficient $c = 0.57$, while with by-pass closed the coefficient for Prof. Carpenter's formula is $c = 0.43$. The velocities in the delivery duct, however, even the highest attained, were rather low, the maximum being about 30 feet per second (1,780 per minute), which would indicate a very free delivery.

Arrangement of heating coils in air ducts.—The possible arrangements of heating coils in ducts are limitless, but thoroughly satisfactory ones, which operate with perfect success in all kinds of weather, are by no means easy to obtain. Figure 81 shows the arrangement of air ducts, fan and heating coils adopted for a schoolhouse in a large city, and Figures 82 and 83 show a detail of the arrangement of fan and heaters. It will be seen that there is a separate duct for each room in the building, each emanating from the central distributing point, and each provided with a mixing damper.



Front Elevation of Heater Showing Steam Connections.

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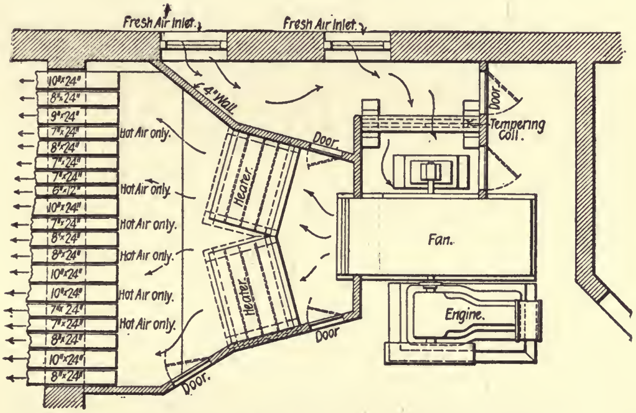

Figure 83.—Plan of One of the Hot-Blast Units.

The system shown is a good example of a method sometimes used to distribute air through long ducts of small size. The author believes, however, that it is open to criticism, as the large number of long, small ducts cannot fail to greatly increase the frictional resistance to the flow of air, thus either diminishing the fan capacity or, for a given capacity, greatly increasing the power required to run the fan. Besides this, the air in the ducts opposite the center of the fan will unquestionably have a higher velocity than those at the sides. It would have been much better to locate centers of distribution convenient to the vertical ducts at each end of the building and at each bicycle room, and locate the heating coils with mixing dampers at these points with "feeder" ducts (underground, perhaps) from the fans to the centers of distribution.

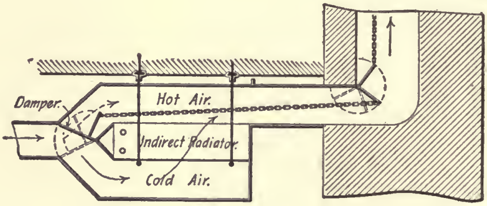

Figure 84.

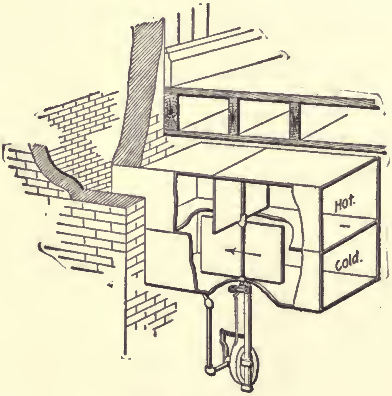

Figure 85.

In this connection it is well to state that it is not advisable to run heated air through underground ducts, for the reason that they rapidly absorb heat in cold weather. Where mixing dampers are employed, however, with coils located at a distance from the fan, it is not generally necessary to temper the air with a coil at the fan; but all the required heating surface can be placed at the centers of distribution.

Mixing Dampers.—There are innumerable arrangements for constructing mixing dampers, the idea being to provide a cold-air and a hot-air connection to the vertical flue to each room, the temperature of the air to the room being regulated by the position of the mixing damper. They usually consist of a double damper, one in the cold-air connection and one in the hot-air connection, fastened together so that when one is entirely closed the other is entirely open, and vice versa. Three types of mixing dampers, selected at random, are shown in Figures 84, 85 and 86.

Thermostats.—Mixing dampers are frequently arranged to be operated by automatic thermostats, which regulate their position by the temperature of the room being heated. The principal difficulty is that they frequently throw the dampers to the extreme "cold-air position" when the temperature rises, and to the extreme "hot-air position" when it falls again. It is very difficult to obtain a thermostat which will move a mixing damper gradually through its arc by means of a small range of temperature at the thermostat, and this is the most important requirement.

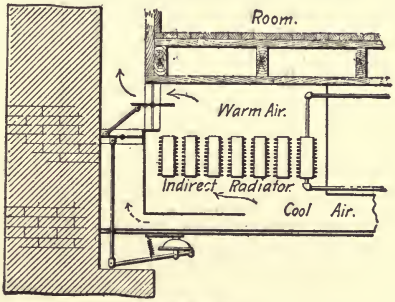

Figure 86.

Air purification.—There is much auxiliary apparatus employed in ventilating systems besides the heating coils, and among these may be mentioned especially means for cleaning and purifying the air. In our large cities, especially for hospitals, something of this kind is very essential. The air is frequently blown through loose cloth screens. The most effective way of cleaning the air, however, is to blow it through a spray of water or through wire screens over which water is kept running, or over shallow trays of water. Care must be taken to provide against the annoyance due to freezing, and the formation of icicles in winter. In summer the water will lower the temperature of the air somewhat, but the danger from the washing process lies in making the air too damp.

Mr. R. H. Thomas, of Chicago, a ventilating contractor of wide experience, has recently patented a dirt "eliminator," represented in the accompanying cuts, Figures 87 and 88, which has proved very effective in several large ventilating plants. The air is blown through a special form of spray and the eliminator proper collects the dirt and removes the excess of moisture from the air.

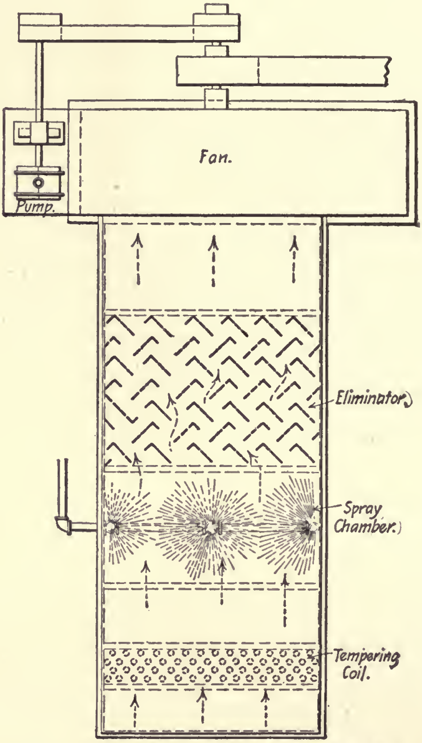

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Figure 87.—Plan of Air-Washing Apparatus.

Air cooling.—Trays of ice are sometimes used, and refrigerating coils also, for cooling the air in summer for theaters; but this is a luxury which has not as yet been employed to a large extent. It must always be remembered that any apparatus of the kind described will add to the resistance through which the fan has to force its air, and will therefore lessen its capacity, or must be made up by increased speed and power.

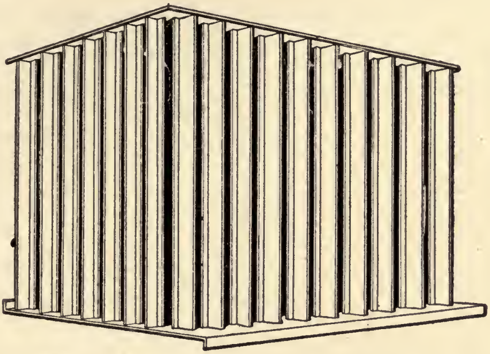

Figure 88.—The Eliminator of the Air-Washing Apparatus.

Measuring air currents.—Before closing a chapter on the apparatus of ventilating systems it seems necessary to say a few words about the instrument most always used for testing purposes. It is not the author's intention to treat of the many methods to be employed in testing ventilating apparatus for different objects, but the anemometer, which is used to measure air velocities, is so generally employed, and so necessary in inspecting plants, that a brief description seems advisable. There are many forms, but they all consist of a set of vanes attached to a

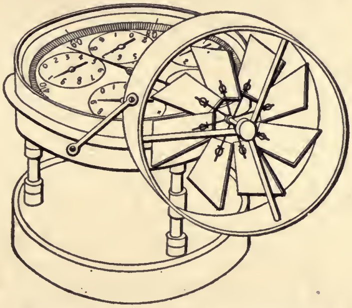

Figure 89.—The Anemometer.

revolving shaft like a small windmill or disk fan and a registering device as shown in Figure 89. They are rarely accurate, and should not be used without being calibrated. This is usually accomplished by attaching the instrument to the end of a stick about 8 or 10 feet long, and revolving in a circle at different uniform speeds in still air and plotting a diagram showing the relation between the actual velocities and the reading of the instrument. This will give data for correcting the indications of the instrument obtained during a test.

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Ventilation and Heating.

By JOHN S. BILLINGS, A. M., M. D.,

LL.D., Edinb. and Harvard. D. C. L. Oxon. Member of the
National Academy of Sciences. Surgeon, U. S. Army, etc.

FROM THE PREFACE.

IN preparing this volume my object has been to produce a book which will not only be useful to students of architecture and engineering, and be convenient for reference by those engaged in the practice of these professions, but which can also be understood by non-professional men who may be interested in the important subjects of which it treats; and hence technical expressions have been avoided as much as possible, and only the simplest formulæ have been employed. It includes all that is practically important of my book on the Principles of Ventilation and Heating, the last edition of which appeared in 1889; but it is substantially a new work, with numerous illustrations of recent practice. For many of these I am indebted to THE ENGINEERING RECORD, in which the descriptions first appeared.

JOHN S. BILLINGS.

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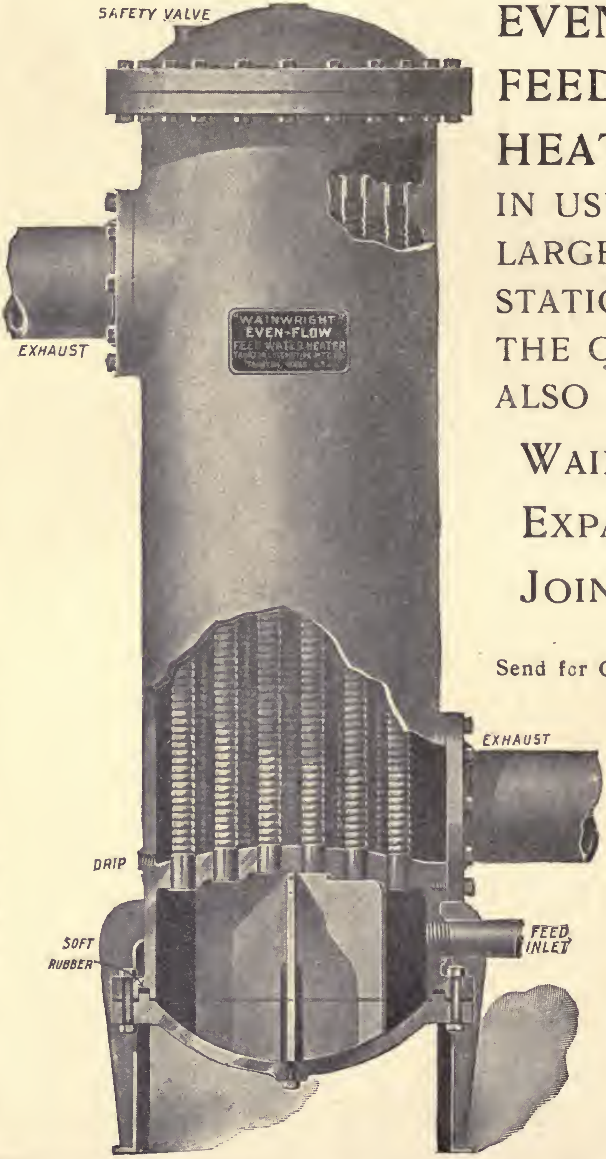
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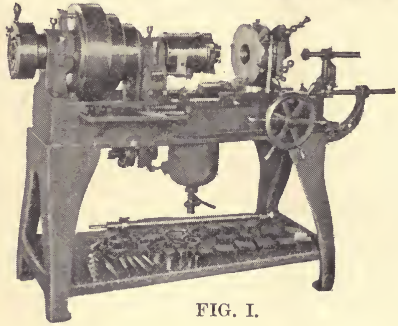

FIG. I.

Apex Nipple and Pipe Mill Machine

IS SHOWN BY FIG. I.

The gearing is entirely protected from dust; six different speeds possible with but a three-step cone. Pump is out of way of operator; vise open or closed while machine is in motion. Nipple grips may be closed on threaded ends of pipe without injury to thread, thus avoiding the necessity of screwing nipple into grips after they are closed; this feature possessed by no other machine. With this machine we furnish an automatic threading gauge. Both left and right-hand threads may be made. A description in more detail will be found in our catalogue.

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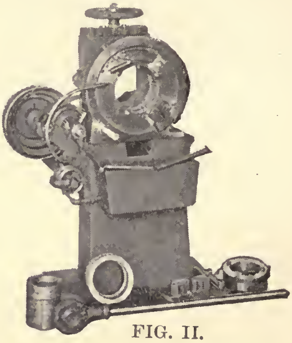

FIG. II.

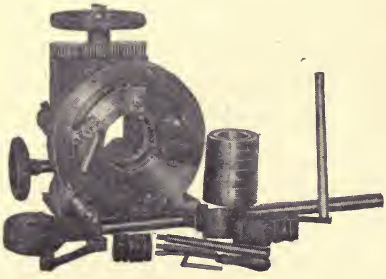

FIG. III.

Our Portable Machine

IS SHOWN BY FIG. III.

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THIS book is a description of the methods of construction of the various portions of a water-works plant, outside of a few features, like pumps, which are now left, in a large measure, to the manufacturers of standard specialties. Even in respect to these specialties enough general information is given to enable anyone with ordinary intelligence to understand the technical descriptions in manufacturers' catalogues and the statements of their agents.

The theory of the flow of water, the strength of materials entering into a water-works plant, of the wind pressure on stand-pipes and similar matters are mentioned as briefly as possible because they are thoroughly taught in technical schools and explained in numerous text books. On the other hand, there is no book giving a general account of the methods of building and maintaining works, dams, pipe lines, reservoirs, stand pipes and other features in sufficient detail to enable an engineering student to understand properly the application of the theories he learns in school.

There is another class to whom it is believed the book will be particularly valuable, and that is superintendents of works and engineers who may have occasion to require the compilation of the best information of any feature of such a plant. Even if a superintendent is thoroughly acquainted with the subject on which he must prepare a report, it often happens that from lack of experience in writing he may have difficulty in preparing it. In such a case, it is confidently believed, this book will prove of assistance, particularly as it has been written very largely with the idea of proving serviceable to men without technical education called upon to act as members of a water commission.

In view of the fact that the information presented has been acquired by correspondence with water-works officials in many parts of the country and a review of all the published information of value on the subject, it is believed that even engineers and water-works managers of experience in their specialty will find the book of interest in a number of particulars.

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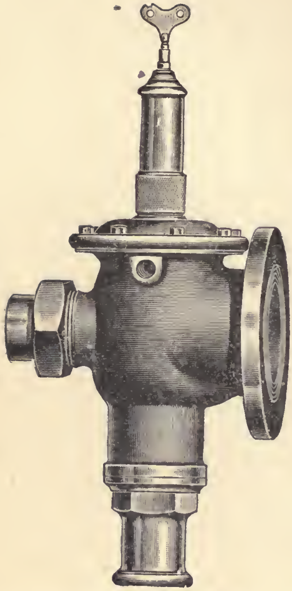

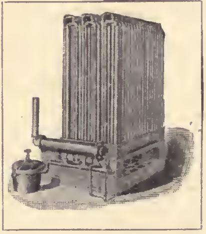

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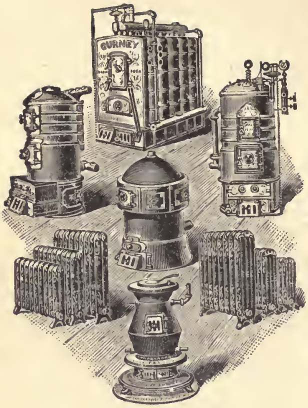
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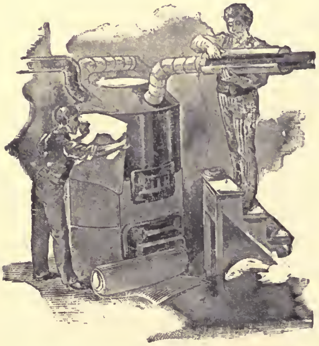

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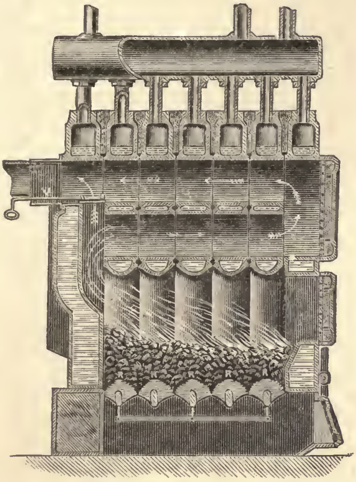

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