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A HISTORICAL REVIEW OF THE ART OF HEATING AND VENTILATING

By

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A HISTORICAL REVIEW OF THE ART OF HEATING AND VENTILATING*

By NEVILLE S. BILLINGTON,† M.Sc., M.I.H.V.E.

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"In God is all our hope" (*Worshipful Company of Plumbers*).

Introduction.

IT has been remarked by several authors that there appears to be some connection between civilisation and climate. Markham, for instance, has suggested that it is no accident that the early civilisations arose in the subtropical parts of the world, where the temperature and humidity are such as not to require artificial modification to enable life and work to continue. Only when artificial heating became possible did the northward march of civilisation to the temperate parts of the earth take place. Bernan, in his remarkable *History*, also suggests that the quality of heating is not without its effect upon civilised peoples. He says, "Anciently, Buckinghamshire was overgrown with wood until it was cut down to prevent its harbouring the robbers with which the district had become infested. But the remote effect of denuding the land has been to dwarf its people, if not somewhat to dull their wit. In the county of Lancashire, says Sir Gilbert Blane, the great abundance and cheapness of fuel is extremely favourable to life, health and comfort ; and he thinks it is owing to this advantage that the inhabitants of this district, particularly the females, have become noted for their well-formed persons and comely countenances—forming a contrast with those of Bucks, where fuel was exceedingly scanty and high-priced before the extension of inland navigation. . . . By skilful management of their scanty supply, the people of Bucks would have been as tall as the inhabitants of Lancashire ; and their maidens would have been as distinguished for their shape, symmetry and pleasing faces, as the northern beauties, whose personal attractions were developed and preserved by burning five times more coal." However that may be, the art of heating and ventilating is important in our present civilisation, and the story of its development is a fascinating and, at times, amusing study.

Heat emitted from the bodies of animals was perhaps the basis of the first form of artificial climate. It was still in use in 1845, for Bernan writes, "In Normandy, where the cold is severe, and the firing expensive, the lace-makers, to keep themselves warm and save fuel, agree with some farmer who has cows in winter quarters, to be allowed to carry on their operation in the society of the milky mothers. The cows are tethered in a row, on one side of the apartment, and the lace-makers sit cross-legged on the ground on the other side, with their feet buried in straw. The cattle being out a-field by day, the women work all night, and numbers of young men of their own rank resort to these cowhouses, and sit or lie down on the straw besides their sweethearts, and sing, tell stories or say soft things to cheer them in their labours." It is interesting to note that quite recently a Swedish farmer installed a heat pump to warm his house, the heat from the cows in the adjacent cowshed serving as the source of heat.

* Manuscript received April 6th, 1955.

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The Open Fire.

The vast majority of man's attempts to keep warm rely upon the fire, the origin of which is lost in antiquity. Legendary accounts of its discovery appear in the mythologies of many primitive peoples. According to the Ancient Greeks, fire was first brought to the earth by the god Prometheus, who stole a flame from the sun. It is probable that in fact fire was first produced by natural agencies—a lightning stroke, a volcanic eruption, or the heat of the sun's rays.

In the earliest times the making of fire was not understood, and very great efforts were made to keep alight any natural blaze which might occur. Members of the tribe (often the virgins) were appointed as keepers of the fire, and they suffered disgrace if the flame became extinguished. The making of fire by friction soon became known to some peoples, and variants of the fire-stick are still used by the more backward races (Fig. 1). The use of flint and steel was not known until the Iron Age ; but it was the best method of producing fire until the modern frictional method (the match) was invented a few centuries ago.

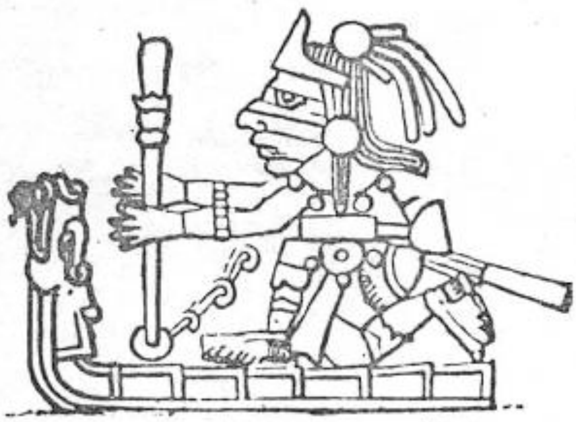


Fig. 1.—Drill in Old Mexican Picture Writing.

Both the Neanderthal man and the true man of the Mesolithic and Neolithic periods (6000–3000 B.C.) made use of fire for cooking, pottery-making and cremation. The first fires for providing warmth were probably those of the cave dwellers ; while nomadic peoples also made camp-fires for warmth at night. The development of permanent dwellings led to the fire being brought indoors : houses at Corinth of 2500 B.C. had fixed hearths. Such hearths placed in the centre of the main room have been found in houses at Troy (2000 B.C.) and Thebes (1400–1100 B.C.), while they persisted in Britain until the fifteenth century A.D. (Fig. 2). No outlets for the escape of smoke were originally provided, but at a later stage an aperture was formed in the roof above the hearthstone (Fig. 3). This had curious consequences in the Tartar cottage, which was "seldom above the surface. The top is covered with beams of wood, branches of trees, and over these with a coat of earth, which makes it level with the ground. The inmates of the pit are frequently disturbed, when sitting round the fire, by the leg of some unfortunate cow or camel making its appearance down the chimney ; and it is not uncommon for lambs to fall through and spoil whatever may be cooking" (*Bernan*).

The hearth, then, remained in the centre of the main room of the dwelling, be it cave or Great Hall, until the development of two-storey buildings made this position inconvenient. The Norman keep accordingly had wall fireplaces, and several examples are still extant. This development brought with it the need to provide some means for the escape of

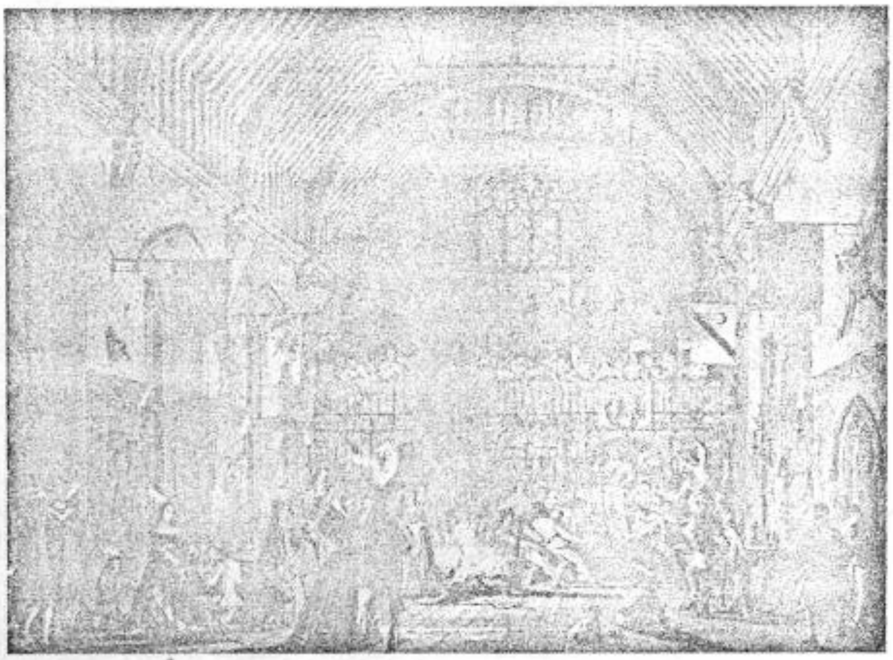


Fig. 2.—The Hall, Penshurst, Kent.

Fig. 3.—Turreted Roof, Glastonbury.

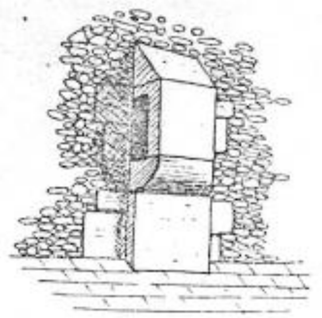


Fig. 4.—Chimney Vent, Abingdon Abbey. (Thirteenth century.)

smoke ; and in the earliest instances this was simply a short flue in the wall leading directly to outside. The origin of the chimney properly so-called is somewhat obscure. There is little doubt that the Romans made use of smoke-flues in the walls of houses, but the purpose here was primarily that of heating. It has been claimed that the first chimneys were erected in Italy: the earliest account was given in 1347. Nevertheless the distinction between the flues in Norman castles and at Abingdon Abbey (thirteenth century) and the chimney as we know it is slight; and perhaps we may say that the idea was born in Britain (Fig. 4).

Early chimneys were of large size—this was a consequence of the large fireplaces required for burning logs—but the dimensions have been progressively reduced in the succeeding centuries by the efforts of Savot, Rumford and Teale. The chimney was not common in small dwellings in Britain until the sixteenth century, when the increasing use of coal made the absence of a chimney disagreeable, while the greater use of bricks made it easier to build them. Yet they did not appear to everyone to be an unmixed blessing. Harrison, in the time of the first Queen Elizabeth, wrote, "Now we have manie chimnies, and yet our tenderlings complaine of rheumes, catarhs and poses. Then we had none but reredoses (that is, braziers in the centre of the hall) and our heads did never ache. For as the smoke of those daies was supposed to be a sufficient hardning of the timber of the houses, so it was reputed to be a far better medicine to keep the good man and his family." It may be noted, in passing, that the importance of the position of the chimney and fireplace was realised by some architects over a hundred years ago. Brown condemned the practice of placing them on outside walls. Yet it was felt necessary to make the point again in the Egerton Report of 1945.

The fires on the central hearth and in the early wall fireplaces were simply heaps of fuel. It was Savot who introduced the grate, in 1600. In due course, fire baskets were made; and the manufacture of iron firebacks was an important part of the work of the Sussex forges in the late sixteenth century. About this time conscious effort was made to improve the performance of the open fire. One of the first to attempt this was Savot in France in 1624. His grate in the Louvre in Paris supplemented the radiation by air-warming. He introduced room air to the jacket of the fire, and the warmed air was then discharged to the room through

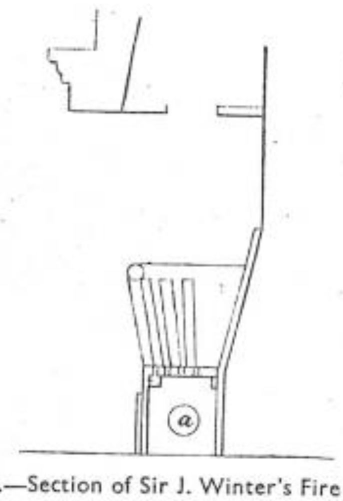


Fig. 5.—Section of Sir J. Winter's Fire Cage.
a, Pipe to supply external air to fire.

openings below the mantel. Sir John Winter, in 1658, introduced primary air for combustion direct from outside by means of a duct beneath the floor (Fig. 5).

There followed a period of intense activity in this direction, due chiefly to Gauger, Franklin and Rumford. Rumford's work was perhaps remarkable in that it was the result of a scientific investigation into the performance of fires; and his "Rules" for the construction of fireplaces, published in 1796, have not been bettered to this day. During the century which followed, a very large number of inventions relating to open fires was made, including revolving grates, back-to-back grates, and grates with "mechanical" stoking. Hardly any survived, and the chief fruits of the work of the nineteenth-century inventors were the use of firebrick rather than iron as the principal material, and an understanding of the importance of close control of primary air. Little further was done until comparatively recently, when the use of machined surfaces, accurate control of primary air and the provision of a greater volume of firebed, surrounded by refractory, enabled overnight burning and continuous operation to be achieved with economy and efficiency. But we may note that downward combustion to reduce the production of smoke, the use of large ash-pits, the back-to-back grate, and convected warm air—all of which can be recognised in modern grates—were described by Bernan over a hundred years ago.

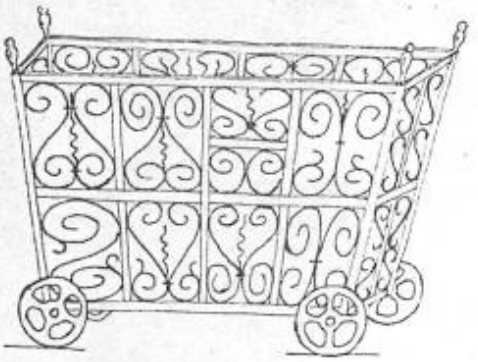


Fig. 6.—Spanish Brazier.

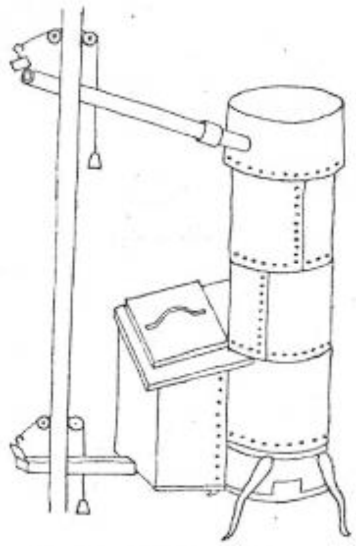


Fig. 7.—Old German Stove. (c. 1600.)

The Stove.

The Greeks and Romans made use of braziers and altar hearths as well as the simple hearthstone. The Roman brazier was an elegant affair of bronze, on a tripod, in which was placed a round dish containing the fuel, and a small vase below to hold perfume to mask the smell of burning charcoal. Similar devices, used in Spain, were illustrated by Edwards as late as 1870 (Fig. 6). The Persian *kourcy* consisted of a jar containing fuel sunk into the earth in the centre of the room, and the mouth of the jar was covered with a board to serve as a table. A cloth was placed over all, and the occupants sat or lay on the floor with their legs beneath the cloth. It is said that some would creep right under the cover, and were occasionally suffocated.

These braziers and kindred appliances were the forerunners of the closed stove. Stages in the development include the lengthening of the sides of the brazier, the fitting of a lid and of a flue-pipe. Sheet-metal stoves were in use in Europe in the sixteenth century (Fig. 7). Early in the following century Kesslar in Germany and Savot in France made efforts to improve the stove. Kesslar introduced the zigzag flueway, thus making more effective use of the heat in the flue gases. He also fitted primary-air and flue-dampers. An interesting innovation was contained in a metal stove of the Dutch or German type designed by a M. Dalesme in 1680. The flue from this stove left at the base, and the fuel burned from the top downwards—a principle now known to assist smoke consumption. The idea, however, was not widely adopted. The Dutch stove suffered from three main defects—the high temperature of the surface, the high temperature of the flue gases, and the lack of proper control, with large consequent variations in output. Subsequent improvements consisted in the use of fins and ribs attached to the body of the stove, and an air jacket around it, lining the stove with refractory material, and the provision of a magazine for fuel. There was thus a trend towards the design of the Swedish type of stove—greater weight, tortuous flue passages, greater fuel capacity and continuous, slow combustion.*

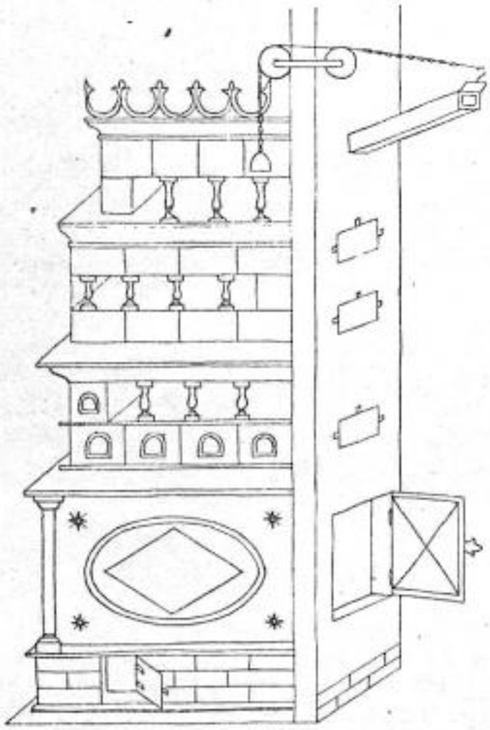


Fig. 8.—Swedish Stove. (c. 1614.)

The massive Swedish brick-and-tile stove (Fig. 8) was also described by Kesslar. The distinguishing feature of this type was the enormous weight of material used in its construction, which served to make the heat output more uniform and to reduce the surface temperature. The stove was, and is, " a common article of furniture in Northern Europe " (*Tomlinson*) ;

* A stove designed by Dr. Arnott in the nineteenth century had air tubes through the fuel bed, and also a " rotary blowing apparatus " in the flue (i.e. induced draught) to ensure easy starting.

and was often arranged to heat two rooms and to incorporate a boiler and an oven.

In Britain the closed stove has never been in popular favour. Long and acrimonious arguments took place over the alleged overheating of the air resulting from the use of metal stoves ; and the lack of ventilation afforded by a stove of either type was an additional reason for it to be discouraged, although this was not considered a demerit in Russia. Bernan comments, "It is essential for the economical effect of a stove that the room be nearly airtight. . . . In apartments with ill-fitted rickety doors and windows, and a large extent of ill-glazed surface, and thin heat-absorbing walls, abounding in wind-chinks—or in general in all cases where the apartment approximates to the exposure of a field, as many English rooms do—an open fire is to be preferred." As a result, the compromise of an openable stove has been developed. Although we tend to think of this as a modern development, such stoves were in fact in use in this country in the early 1800s. Sir G. O. Paul fitted folding doors to an ordinary Bath grate, and provided a lid to cover the fuel bed ; and de Chabannes devised a free-standing openable stove early in the century (Fig. 9). Perkins, about 1830, designed a ventilating stove in which air was warmed by passing round the body and fluepipe of the

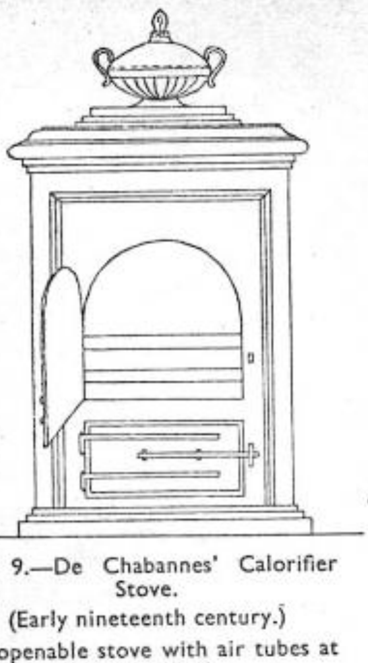


Fig. 9.—De Chabannes' Calorifier Stove.
(Early nineteenth century.)
An openable stove with air tubes at sides and back.

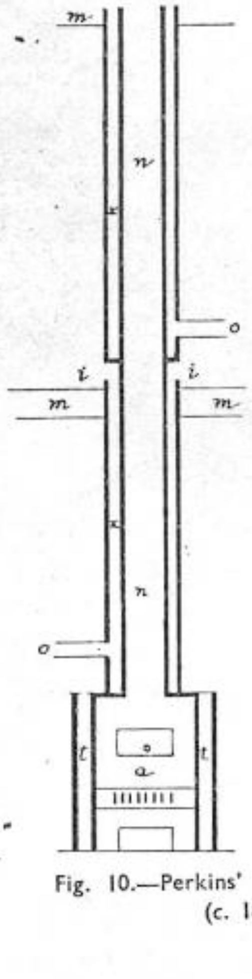


Fig. 10.—Perkins' Ventilating Stove.
(c. 1830.)

stove and was then discharged to upper rooms (Fig. 10). We can recognise these ideas in present-day appliances.

Other methods of heating had been used by the Romans and the Chinese. The hypocaust will probably be familiar: it consists of a chamber beneath the floor of a house, through which combustion products were suffered to pass. In some instances the products were then taken through flueways in the walls and discharged to outside (during the day) or into the room (at night). By this means a warm floor and warm walls were obtained ; and one is reminded of the present development of perimeter warm-air heating in the U.S.A. The hypocaust was clearly the first floor-panel heating system.

The Chinese *kao-kang* was essentially similar ; and is still in use to-day. A massive stove placed in the centre of the house is used for both heating and cooking. The combustion products are taken beneath a raised portion of the floor and thence discharged. The inhabitants sit on this raised part by day and sleep upon it by night. A *tong-kang* (a very similar arrangement) was used in 1761 to heat the Orangery at Kew.

Warm-air Heating.

The stove gave rise to gravity warm-air heating. A classic example is that installed by Strutt in Derby Hospital in 1792 (Fig. 11). A stove was constructed within a brick chamber, to which fresh air could be supplied through an underground duct some 40 ft long. The air, warmed by its passage through the chamber, was led by ducts to heat various parts of the hospital. Further airways were provided for the escape of the vitiated

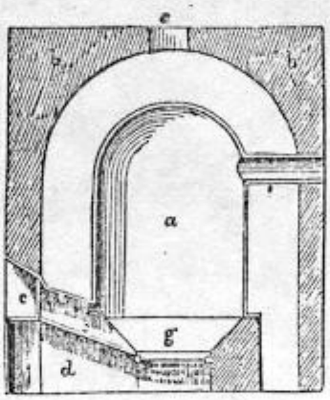


Fig. 11a.—Strutt's Cockle Stove.

a, the cockle.
b, brickwork.
c, fuel door.
d, ash pit and draught hole.
e, aperture to room.
f, fire bars.

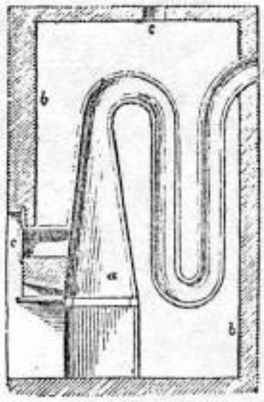


Fig. 11b.—Variation of the Cockle Stove.

a, serpentine iron pipe.
b, brickwork.
c, fuel door.
d, to chimney.
e, aperture to room.

air. De Chabannes also devised a ducted warm-air system, which is perhaps more akin to the later models, being based on the lighter Dutch stove (Fig. 12). Although these examples were not immediately followed, we find a good deal of emphasis on warm-air heating in both English and American books of the late nineteenth century ; though the application seems to have been restricted largely to dwellings. In the U.S.A. warm-air heating continued in favour, and its use has extended following the introduction of electrically driven fans. In Britain, on the other hand, the method fell into desuetude about 1900, and has only recently been revived, on a small scale, as a forced circulation system, with either direct heating or heating by means of hot-water calorifiers. The continued use of warm-air heating in the U.S.A. probably led to the introduction of the unit heater for factories.

Hot-water Heating.

Many of the developments I have been describing took place during the sixteenth and seventeenth centuries. Hot-water heating was first suggested about 1610, though substantial development was delayed until the period 1800–1840. The arts of war gave the initial impetus, when Sir Hugh Platt proposed to use hot water to dry gunpowder (*c.* 1610). In 1716 Sir Martin Triewald successfully used hot water to warm a greenhouse ; and in 1777 a M. Bonnemain heated an incubator by this means. (A bi-metallic thermostat was also fitted to Bonnemain's incubator.) But not until Chabannes' time (*c.* 1816) was hot water used to heat ordinary buildings ; and in 1830 Bramah heated Westminster Hospital in this way (Fig. 13). For many years, however, the principal use appears to have been for horticulture : pineries, vineries, palm houses and forcing-houses all figure largely in engineers' tables of the mid-Victorian era. For this class of work large cast-iron pipes (usually 4 in. in diameter) were used, with complete satisfaction (and indeed a better form of heating surface would be hard to devise). The engineer became familiar with 4-in pipe ; and all heating surfaces were expressed in terms of this. Boiler power, too, and heat requirements were specified in the same terms. For dwellings, the pipes were concealed in decorated openwork cases, called *calorifères*, which were in effect convectors. One such appliance, described by Walker in 1850, was devised by Mr. Haden,

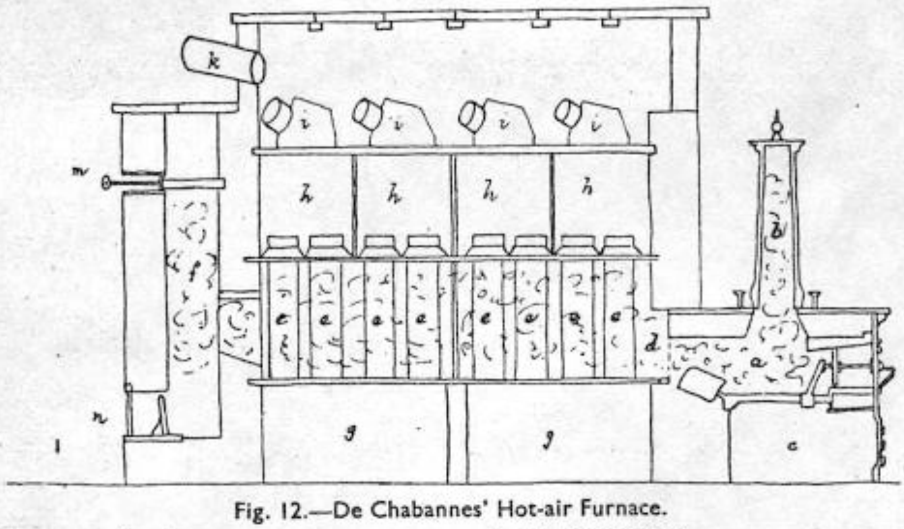


Fig. 12.—De Chabannes' Hot-air Furnace.

a, fireplace.
b, fuel hopper.
c, ash pit.
e, air tubes.
f, flue.
h, hot-air chamber.
i, warm-air outlet connections.
k, warm-air pipe.
m, damper.
n, soot door.

who added fins to the water-backed surface ; and this can have been very little different from a modern convector. The use of these *calorifères* seems to have been consequent upon the rather earlier development of steam heating, in which the higher temperatures made exposed piping undesirable.

Only fifteen years after de Chabannes' introduction of hot water as a heating medium Perkins invented the high-pressure system. The earliest of these were crude in the extreme : they consisted of a closed circuit of $\frac{1}{2}$-in wrought-iron pipe, between one-third and one-tenth of which was in the furnace, and the rest in the room to be heated. No safety valve was fitted. The pipe was tested to a pressure of 2800 lb/sq in, but even so bursts were comparatively frequent, due to the lack of control. Calorifiers were used as the heating surface. The Perkins system, improved by the addition of safety valves, the restriction of the portion of the pipe within the furnace, and the use of $\frac{7}{8}$-in pipe, was used for a number of important buildings during the period 1835–1910, including the British Museum, the Soane Museum, and the Guildhall, from which the system has just been removed. Each coil had a heating surface of between 300 and 500 sq ft, and 20 ft of pipe was allowed for every 1000 cu ft of room volume. In residences the pipe was usually hidden in the skirting, which was perforated ; and in other instances the pipe was led through the base of an ordinary radiator filled with water. It then appears to have fallen into disuse ; and although interest in high-pressure systems is now waxing, this is thought to be due to the requirements of process work involving temperatures above the normal boiling point of water.

I have mentioned that the usual form of heating surface was, at first, pipes or calorifiers. These were followed by box-end and siphon-end coils. The first radiator was invented in 1858 by a Mr. Tasker, of Philadelphia ; and in it the wrought-iron tubes were fitted together with flanged joints, and held in place by long bolts passing through the sections.

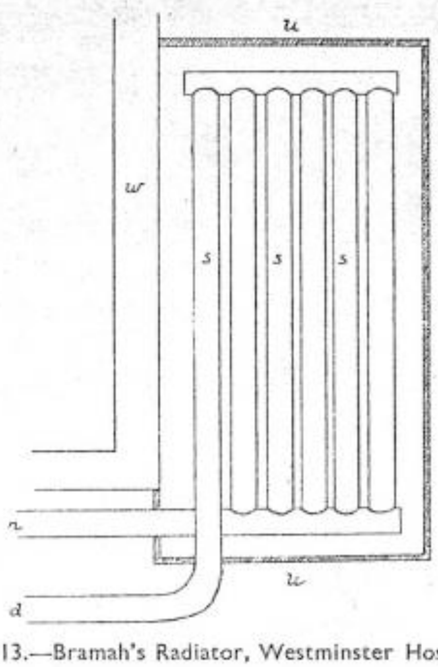


Fig. 13.—Bramah's Radiator, Westminster Hospital.

s, heating pipes.
u, *u*, case perforated top and bottom.

A cast-iron radiator was patented in the U.S.A. by Bundy in 1874, and three years later Gillespie (also of the U.S.A.) produced a cast-iron sectional radiator. James Keith took out the first English patent in 1882 : his " Universal " radiator was cast in one piece. The British designs were plain, whereas the American ones were ornate. Dye illustrates one which " was the work of a first-class Italian artist ". He adds that he " once bought some hot-water radiators from seeing some steam samples, and the result was quite disappointing. In this case, the most important and telling detail in the ornamentation, a very finely moulded lion's head, came just where the top connection was needed, and consequently did not appear at all on the water radiators. It was an experience." The early English radiators closely resembled present-day hospital radiators. Four-column radiators were coming into use during 1917 ; but the present thin-section, multi-column radiator did not appear till much later. During the past thirty years other forms of heating surface have appeared—the cast-iron wall-panel radiator, gilled convectors and cast-iron skirting or baseboard heating sections—although they are in some instances revivals of earlier ideas.

Steam Heating.

Steam heating actually pre-dates hot-water heating in established fact, although it was not even suggested until 1745, when it was mooted by a Col. William Cook. Watt made some attempt in 1784 to warm his house and office by steam, not altogether successfully ; but later, in association with Boulton, several workable schemes were installed in various premises. In one of these the steam was conveyed through cast-iron pipes which also served as supports for the floor (Fig. 14). Tredgold gives descriptions

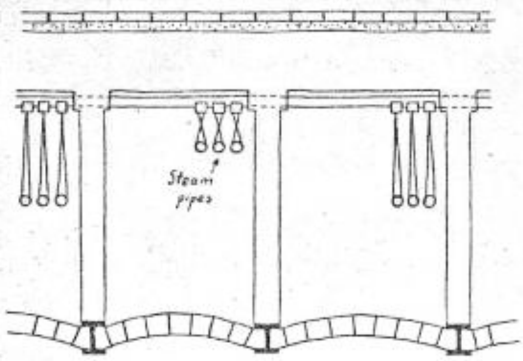
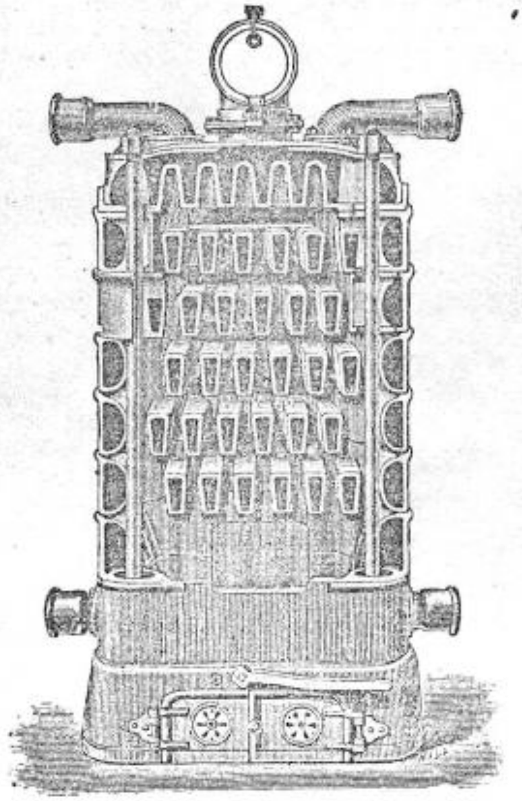


Fig. 14.—Steam-heated Floor Heating.
(Germany, c. 1900.)

of steam installations in a silk mill, a chapel and a group of horticultural houses. These were all installed by Mr. Bailey between 1817 and 1821. In each case the steam pipe itself formed the heating surface. Steam pressures of from 2 to 10 lb/sq in were commonly employed ; and although Dye, writing in 1897, mentions both high-pressure and vacuum steam systems, neither seems to have been used to any great extent at that time.

Boilers.

Early boilers for either steam or hot water were invariably of the saddle type, but later, cylindrical and even spherical steam boilers were used. Count Rumford experimented on this subject, and concluded that boilers should be as large as possible (minimum heat loss per lb of water), and he also recommended the use of thin materials in their construction, preferring wrought to cast iron. In his boiler setting the flue gases leaving the combustion chamber were returned to the front end of the boiler by means of flues beneath, and then led back again to the smoke-stack through flues alongside the fire chamber. Neville patented the use of side flues and return flueways in the water space in the early 1800s. Preheating of secondary air was first suggested by a Mr. Chapman, of Whitby, to reduce smoke and soot formation. He also made use of a hopper feed. In 1870 Edwards illustrated a cylindrical independent boiler, and by the end of the century these were gaining ground, except for glasshouse heating. For residence work a vertical independent boiler was con-



15.—Keith's Cast-iron Sectional "Challenge" Boiler.

sidered the best, as it could be charged with sufficient coke to last the night through, and "whenever the fire is attended to, it does not require more than ordinary care. This is of much advantage, for in so many houses, it is only a maid-servant or a page-boy that attends to the fire." The cast-iron hot-water boiler, both independent and sectional, was pioneered in Britain by James Keith, about 1890. His "Challenge" boiler (Fig. 15) was a vertical sectional model.

Both Jones (1904) and Carpenter (1910) emphasised the risk of boiler explosions. Jones initiated tests to show that the admission of water to a red-hot boiler would not cause an explosion. "I was away during these experiments," he writes, "and left them to the care and superintendence of a trustworthy manager, who did the test three times without a burst." Clearly, Jones was a man of discretion !

Only as recently as 1905 was the output of a boiler given in B.t.u./h. The earliest estimates, taken from steam-engine practice, were in horsepower, and these were followed by a specification in terms of the length of 4-in pipe and then of the area of heating surface which could be served. Coal and coke were the usual fuels ; but by 1917 gas-fired boilers were becoming more popular for heating, although the cost of useful heat was about four times that given by solid-fuel boilers. (Gas circulators for hot-water supply systems and greenhouse work had appeared some ten years before.)

Heat Requirements.

The earliest experiments bearing on heat emission and heat loss seem to have been those of Tredgold, about 1820, who determined the rate of cooling of water in cylinders of iron and glass. The experiments were repeated by Hood some twenty years later, and he concluded that 1 ft of 4-in pipe at 180°F emits enough heat to warm 222 cu ft of air at the rate of 1 deg. F/min. Hood was also able to make a rough estimate of the heat loss through a window : he found that 1 sq ft of glass would cool 1·28 cu ft of air at the rate of 1 deg. F/min with a temperature difference of 1 deg. F. (This corresponds to a *U*-value of 1·54 B.t.u./sq ft. h. deg. F.) The design procedure was thus to compute the cooling effect of the windows, add the ventilation and so arrive at a total heating load : the necessary length of pipe could then be deduced. The design outdoor temperature was chosen in relation to the usage of the building : 25°F was recommended for buildings used only in the daytime ; but for those to be heated, both by night and by day, "10°F will not be too low to calculate from".

Box, writing in 1875, was aware that heat was lost also through the solid parts of the structure. By drawing upon Dulong and Petit's work on radiation and convection, he was able to arrive at the surface conductance ; and in conjunction with Péclet's data on thermal conductivity Box calculated the *U*-values for some walls, obtaining figures which were not very different from those in use to-day. (Incidentally, this was the first use of the symbol *U* in this connection, and yet it was not widely adopted until about 1935.) He was aware of the influence of radiation transfer between the walls and showed that the transmittance of the *only* external wall of a room was appreciably greater on this account than the transmittance of the walls of a room which is exposed on all sides. This fact, long forgotten, is attaining greater importance with the increase in radiant heating.

Box neglected the losses through the floor ; and those through ceilings were felt to be too difficult to calculate. In 1910 Carpenter adopted an empirical rule that ceilings were to be treated as walls of one-third their area ; he, too, ignored floors. Barker, in his famous book, speaks of a resistance to the flow of heat—probably the first explicit use of the term—although he did not attach to it any quantitative significance. The more accurate method of computing heat losses, proposed by Box, and supported by Carpenter and Barker, was still not universally accepted. Dye gave the idea cautious approval in 1917 : " Until recent years it was the practice to . . . allow a certain quantity of radiating surface per 1000 cu ft of space. . . . The simple rule can seldom work out correctly. The coefficient method is now almost universally employed, and while this aims at meeting all varying conditions, there is a feeling that some improvement on this will presently be possible. For those who have not a suitable office staff, the method is distinctly tiresome, if not impossible in some cases." By this time, some figures were available for the heat loss through floors and roofs, though even now there is some uncertainty.

District Heating.

The genesis of the concept of district heating is not easy to discern. Walker (1850) suggested the possibility of a district plenum-heating system for a row of cottages near a factory. The factory engine was to drive a fan, screw or pump to force warm air along an underground trunk, to which were to be connected vertical shafts to each cottage, the air finally being discharged through apertures in the skirtings. Hot-water heating was proposed by Edwards (1870) : " It may be well worthy of consideration whether a number of houses, say twenty or fifty, might not be heated from a single source, and not merely heated but supplied constantly with hot water for all household purposes. . . . At one end of a line of houses, boilers and furnaces would be fixed, and from the boilers hot-water circulating pipes could pass in proximity to the houses. From such main circulating pipes, branch pipes could enter each house. That there would be any insuperable difficulty does not appear for a moment. Competent persons could be as readily found to manage such a system as to make gas or drive a railway train."

The first plant to be put into operation was that of the New York Steam Company in 1879, and the U.S.A. has generally remained in the fore in the practice of district heating. Vicissitudes were not unknown, for Carpenter remarks that steam heating was not financially successful in cities, all but one plant having closed down (*c.* 1895). The tide turned, however, and from 1909 onwards (when the N.D.H.A. was formed) expansion has been continuous. In line with the common American heating practice, steam distribution was largely employed, though there is now a tendency to develop thermal-electric working. In Europe a thermal-electric plant designed by Rietschel and Henneberg was erected in Dresden (1885–1901), but further development on the Continent was slow until after the first world war. Manchester, too, was early in the field, with a thermal-electric plant which began operation in 1911. No further plants were erected in Britain until after the first war, when the Dundee scheme was opened (1922). The situation then was very similar to that in 1945. Raynes' words, written in 1921, would have been equally applicable in our time. He said, " Time may come when in order to conserve fuel, less consideration will be given to the cost of accomplishing it than at present ; but so long as fuel is fairly plentiful, the £. *s*. *d*. side of the problem will remain the most important one. . . . From a national and communal standpoint, its [district heating's] value lies in the possibility it offers for conserving fuel, and the aid it would afford in reducing the smoke nuisance of towns. . . . The National Housing Schemes at the present time offer an exceptional opportunity for the introduction of district heating on a large scale." He estimated that district heating would be cheaper than open-fire heating.

Ventilation.

The need for ventilation was probably first realised when the use of a central hearth resulted in smoke-filled rooms. The only remedy then was the aperture provided for the escape of smoke. Although windows were in use they were permanently closed, being " glazed " with horn, mica, cloth and, only exceptionally, glass. The development of the flue must have eased the situation somewhat, until the sash window was designed. It first appeared in 1300, but not until 1700 was it fairly common. The window tax, imposed in that year, militated against large windows ; and since it was not finally repealed until 1851, it has left its legacy in the small windows of dwellings and tenements almost to this day. The sash window was prone to cause draughts, when open, and many attempts were made to overcome this difficulty. A crude form of hopper window was installed in St. Thomas's Hospital in 1784 ; and this was followed by the use of perforated metal, louvred glass, and windmill ventilators. None was entirely satisfactory, chiefly on account of the loss of light.

During the Victorian era the ventilation of working-class dwellings became a social scandal. " Ventilation is easy, and badly understood ; that is, it is easy to ventilate a room, but the necessity for doing so is not generally admitted by the great mass of the people, nor even by those whose duty it is to teach them, and to provide for the practice. . . . But not only are our dwelling-houses badly ventilated, but those buildings on which the architect has lavished all his art and skill are, for the most part, entirely destitute of special means for ventilating and are so constructed as to render the application of such means extremely difficult or even impossible " (*Tomlinson*). A great deal of attention was accorded to it by the engineers and physicians of the period, and it was also the subject of a Governmental inquiry. Compare this with modern texts, where natural ventilation of dwellings is hardly mentioned—a *volte face* which cannot be commended. The fundamentals of natural ventilation were given by Walker in 1850 :

(*i*) windows were to admit light and not air ; ventilation should be catered for separately,
(*ii*) both inlets and outlets were necessary,
(*iii*) incoming air should be warmed to avoid draughts,
(*iv*) inlets and outlets should be well distributed,
(*v*) ventilating openings should be permanent, realising that once closed, they will remain closed.

It is doubtful whether these principles could be improved upon to-day. Walker himself proposed to use the wall cavity as an intake shaft, thus ensuring some warming of the air, while the later Tobin tubes had the same purpose. The ubiquitous air-brick has displaced them all, but it cannot be said to function better. Its only virtue perhaps is its small free area, which restricts the quantity of air admitted. Although Walker's principles were largely ignored in his time, recent attempts to improve the ventilation of dwellings have been based upon them, perhaps unconsciously, and upon the teachings of Dr. Neil Arnott.

Quite early in the practice of ventilation it was realised that it was unsatisfactory to rely solely upon wind forces, and accordingly other methods were tried. In the sixteenth century Agricola ventilated a mine by lighting a fire at the base of the shaft. The idea was not applied to buildings until 1723, when Desaguliers used a fire to assist the ventilation of the House of Commons. Although mechanical fanners were used in the interim, Dr. Reid again used thermal means in his scheme for the House when it was rebuilt in 1836. De Chabannes utilised the heat from the gas chandeliers to ventilate Covent Garden Theatre. But with the perfection of the electrically driven fan, all other means of assisted ventilation have vanished.

The first estimates of fresh-air requirements were made in the late eighteenth century, and were based on measurements by Prout, Davy, Pettenkoffer and others, who determined the CO_2 content of respired air and the water vapour evolved in the breath and through the skin. Hood used the latter data to estimate the quantity of air needed to carry off the water vapour, arriving at a figure of 3½ to 5 cu ft/min. Péclet made some observations of the odour in a school and in the Prison Mazas in France. As a result, he recommended 300 cu ft/h per person for ordinary rooms and 212 cu ft/h for schools. Morin asked for three times as much fresh air for schools. Box (1875) estimated the fresh air requirements as follows :

for life	22 cu ft/h
for removal of water vapour	237 cu ft/h
for removal of heat (including fuel and light)	220–500 cu ft/h
for removal of odours (after Péclet) ..	250–300 cu ft/h

He realised that all of these functions could be fulfilled by 250 cu ft/h per person, rising to 500 cu ft/h in crowded rooms.

Rather earlier than this Dr. Reid had formed the opinion that 10 cu ft/min per person was required, on the basis of " an extreme variety of experiments made on hundreds of different constitutions, and also in numerous assemblies and meetings ". He recounts that about fifty members of one of the Royal Society clubs in Edinburgh " dined in an apartment I had constructed, where though illuminated by gas, the products of its combustion were essentially excluded, as they were all removed by a ventilating tube connected with, but concealed in, the drop of the gothic pendant in which the central lights were placed. Large quantities of a mild atmosphere were constantly supplied and passed in quick succession through the apartment throughout the whole evening, the effect being varied from time to time by infusing odoriferous materials, so that the air should imitate successively that of a lavender field, of an orange grove, etc. Nothing very special was noticed during the time of the dinner by the members ; but Mr. Barry, of the British Hotel, who provided the dinner, and who, from the members of the club being frequently in the habit of dining at his rooms, was familiar with their constitutions, showed the committee that three times the amount of wines had been taken that were usually consumed by the same party in a room lighted by gas but not ventilated—that he had been surprised to observe that gentlemen whose usual allowance was two glasses took, without hesitation, as much as half a bottle—that those who were in the habit of taking half a bottle, took a bottle and a half, and that, in short, he had been compelled twice to send hackney-coaches for additional supplies during dinner, though he had provided a larger supply than usual, considering the circumstances under which the members met."

At the turn of the century much attention was directed to CO_2 as an index of ventilation. The experiments of Haldane and Leonard Hill are noteworthy, showing as they did that wide variations of carbon dioxide content were possible without ill-effect. Nevertheless as a general working rule a limit of 0·1 per cent. CO_2 was fairly widely accepted. No substantial advance was made until about 1925, when Yaglou and his colleagues followed up Péclet's work and studied ventilation in relation to odours. It has remained the basis of ventilation practice ever since.

Nowadays, the ventilation of many classes of buildings is governed by legislation. The growth of this has been extremely rapid ; for in 1921 Raynes wrote, " In Great Britain there has been no legislation to enforce a given standard of ventilation for public buildings. This is most unfortunate : for the heating and ventilation of these places is often notoriously bad . . . [it is] high time a certain standard of purity was enforced by law " for theatres and cinemas.

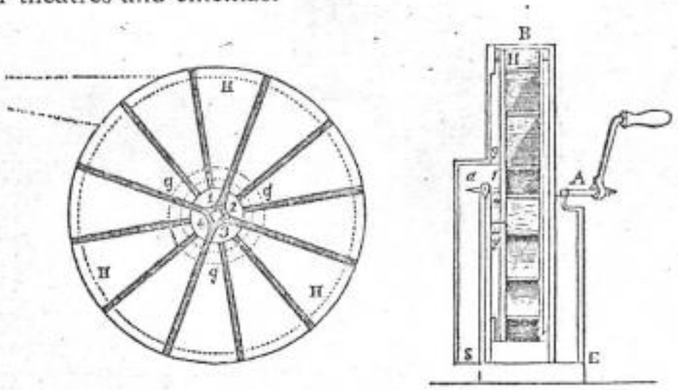


Fig. 16.—Desaguliers' Fanning Wheel.
gg, *HH*, blanketing sealing casing.
B, air exit.
S, air inlet.

The Fan.

The fan itself was devised by Desaguliers in 1734. His original model was no more than a paddle wheel 7 ft *in* diameter with radial blades 1 ft wide rotating in a concentric casing (Fig. 16). This operated in the House of Commons for many years (till 1791). Little development took place during the next hundred years. But in 1844 Ure illustrated a scroll casing ; and in 1860 Guibal introduced his *chimney*—an expander section attached to the delivery port of the fan (Fig. 17). It is not known when curved blades were first introduced ; but they were occasionally employed by 1844 : their use is ascribed to Combes. Both forward- and backward-curved blades were tried ; but Péclet reported that they showed little if any improvement over radial-bladed fans. An early rule of fan design was to provide one blade for each foot of diameter ; but this was abandoned when Ser devised the multi-blade fan. Tests of fans were carried out by Buckle as early as 1847 and reported to the I.Mech.E. As a result he was able to formulate dimensional rules for fan construction which still held good sixty or seventy years later.

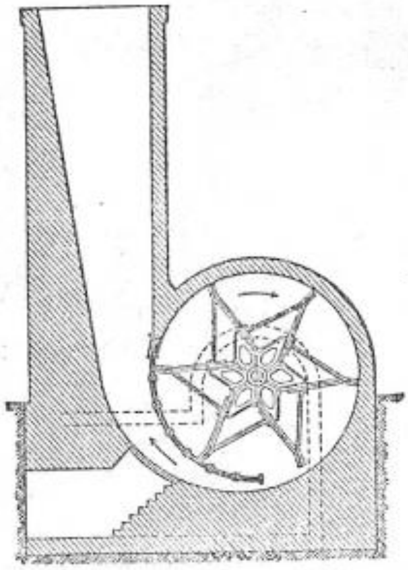


Fig. 17.—The Guibal Fan and Chimney.

He recommended :

Diameter of outlet	D
Diameter of inlet eye	$\frac{1}{2} D$
Width of wheel at outlet circumference	$\frac{1}{4} D$
Width of wheel at inlet circumference	$\frac{1}{2} D$
Radial length of blade	$\frac{1}{4} D$

Murgues, a colliery engineer, developed a theory of fan operation (1872) and proved that plane radial blades were incompatible with high efficiency. He showed that the blade should be radial at the tip and tangential to air flow at inlet edge. This was, however, in marked contrast to the position in 1904, when Kinealy reported that all curved-blade fans had backward blades. One fan carried this idea to such an extent that the blades extended round one-quarter of the fan-wheel.

By 1912, when Barker wrote on *Heating*, the fan laws were known ; and Barker worked out the manometric, dynamic and total efficiencies of a fan, using the concept of "equivalent orifice". There seems to have been no important development in centrifugal fans (apart from detailed improvements, such as in manufacturing tolerances) since Ser's original multi-vane fan.

In 1834 a M. Motte received a prize for the application of the Archimedean screw in place of a fanner : and this was used for a time in Belgium and elsewhere. Some years later Mr. Combe, of Leeds, used a double-threaded screw, which can perhaps be regarded as the first axial-flow impeller. The screw soon fell into disuse ; and interest in this form of impeller did not revive until the 1930s.

The noise production by fans has always been a problem. Walker felt that fans were more suited to manufactories than for ventilating buildings, and he preferred a screw. He described a screw 4 ft in diameter running at 500 rev/min, which was stated to deliver 5000 cu ft/min. Reid noted that the noise from small fanners running at high speed (1000–2000 rev/min) was "penetrating and oppressive". For ordinary ventilating work he found it most economical to use large fans, up to 20 ft diameter, running at low speed. This is still the practice to-day where extreme quiet is essential.

Air Conditioning.

Air conditioning has grown up from warm-air heating, the provisions for cooling, cleaning and altering the humidity being additional refinements. As far as cooling is concerned, the use of *punkahs* and *tatties* has long been known in hot countries. The *punkah* maintained a satisfactory air movement ; while the *tattie*, a form of moistened matting over the doorways and window openings, served to cool the air by evaporation of the water. Bernan records that indoor temperatures were often 20 deg. below the outdoor temperature, but he adds that even lower ground temperatures were available, and better results might have been possible by the use of underground tunnels to supply the ventilating air. Such a scheme was used in Venice in 1661, by Strutt at Derby, and in one of the House of Commons schemes.

Vallance is said to have devised a plenum scheme in which either heating or cooling could be provided. Air was supplied to the room by a mechanical pump, passing on its way through a coil immersed in warm or cold water, according to season. The air was allowed to escape from the room through a pipe carried through the ceiling and roof and inserted to the depth of an inch or so into a cistern of water. The level of the water in the cistern served to regulate the pressure of the air within the room. Dr. Reid, in 1848, proposed to circulate cool well-water through the steam heating pipes of the Commons chamber. About the same time, ice was also used for cooling air, one of the first applications being by Dr. Gorrie in a hospital in the U.S.A.

Artificial humidification of ventilating air was first attempted by Reid in the House of Commons in 1836. " Perhaps no buildings have been subjected to such numerous experiments as the Houses of Parliament, to which Sir Christopher Wren, the Marquis of Chabannes, Mr. Davies

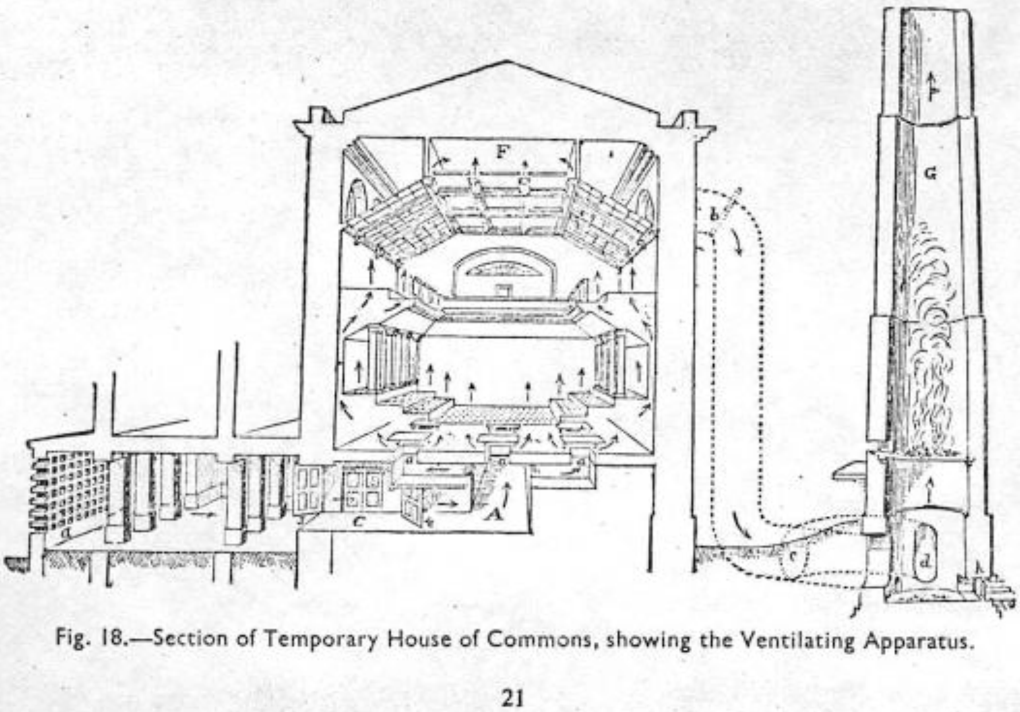


Fig. 18.—Section of Temporary House of Commons, showing the Ventilating Apparatus.

Gilbert, Sir Humphry Davy and many others directed their attention; and it may afford some clue to the diversity of practice if it be remembered that the area of discharge provided by Sir Humphry Davy in the present House of Commons [at that time the House of Lords] was one foot, whereas at present it is fifty feet." Reid goes on to describe the scheme of 1836: "A chamber was provided for moistening, drying, cooling, and producing other alterations in the air, besides those effected by the hot-water apparatus". The air was filtered through a veil, 42 ft long and 18 ft 6 in deep; and it was introduced into the chamber through nearly a million holes in the floor (Fig. 18). This was similar to the arrangement made by Davy, and about which it was said

"For boring twenty thousand holes,
The lords gave nothing—damn their souls".

With the growth of the textile industry, direct water or steam injection was tried, and these three methods have remained substantially unaltered for a century.

Dehumidification was more of a problem, and, apart from that resulting when ice was used for cooling, no progress was made until Willis Carrier developed his dew-point control system in 1902, when a paper mill in Brooklyn was so equipped. Carrier's system was, of course, dependent upon the availability of mechanical refrigeration. The alternative method of dehumidification, by solid absorbers, was first suggested as recently as 1925, the inventor proposing the use of silica gel.

Recent air-conditioning and ventilation research and practice has seen the introduction of chemical additives for deodorising or as bactericides. It is perhaps not so well known that Reid was first here also. For air purification in large cities he adopted the following measures:

(*i*) exclusion of soot by filtration,
(*ii*) washing,
(*iii*) washing with lime water, and the addition of ammonia (to neutralise acids),
(*iv*) addition of chlorine or nitrous oxides to decompose animal or vegetable matter,
(*v*) warming by steam or other means.

For special purposes he proposed further treatment of the air: "By constructing a few chambers in every hospital, where the quality of the air that passes the zone of respiration might be entirely under control and medicated, dried, heated, moistened, cooled and applied in any quantity as circumstances might dictate, a more specific power would be obtained capable of being applied advantageously in numerous cases of disease". Among the additives suggested were nitrous oxide, nitrous and nitric acid fumes, chlorine, sulphurous fumes, acetic acid, arsenical, prussic, mercurial, alcoholic, ethereal and benzoic fumes, and various aromatics like camphor, creosote, and oils of lavender, orange and cinnamon.

Mechanical refrigeration developed rapidly after Vallance's patent in 1824 for a sulphuric-acid absorption process and Perkins' sulphuric-ether machine (1834). A patent was granted in 1871 to Andrew Muhl, who proposed to blow the ventilating air over refrigerated coils near the ceiling of each room. Further similar inventions followed, and about 1890 Vollman and the Linde Canadian Refrigeration Co. installed an air-cooling plant with brine-washed coils in the palace of an Indian rajah.

A 10-ton machine had been installed two years previously in an American factory to cool air for the process. As far as air conditioning was concerned, ice was still the popular cooling agent ; but several industrial cooling plants were put in during the next ten to fifteen years. A large comfort cooling system was installed in the New York Stock Exchange in 1904 (300 ton) and in a German theatre about the same time ; and no important ice-using systems were employed thereafter. Chilled brine coils seem to have been the most usual method since then, although the first direct-expansion cooler was introduced in 1905.

In presenting this short and very incomplete survey of the development of heating and ventilating, it has been my endeavour to select a few of the more important advances for notice. The story illustrates (though it does not always confirm) the adage that " There is nothing new under the sun ". Although we have been able to see some humour in the older texts, there is nevertheless a lot of good sense which we ignore only to our cost. It may well be that in another century our present ideas may provoke mirth ; though it is to be hoped that the transition from an art to a science has enabled us to ensure a sound basis for modern techniques.