# A Historical Review of the Art of Heating and Ventilating

BY

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

**Introduction**

A verse in *Ecclesiastes* runs:

"The thing that hath been, it is that which shall be; and that which is done is that which shall be done; and there is no new thing under the sun.

"Is there any thing whereof it may be said, See, this is new? It hath been already of old time, which was before us."

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 quotes Sir Gilbert Blane:

"In the county of Lancashire, 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.

Referring once again to *Ecclesiastes,*
"Again, if two lie together, then they have heat; but how can one be warm alone?"

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.

**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. 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.

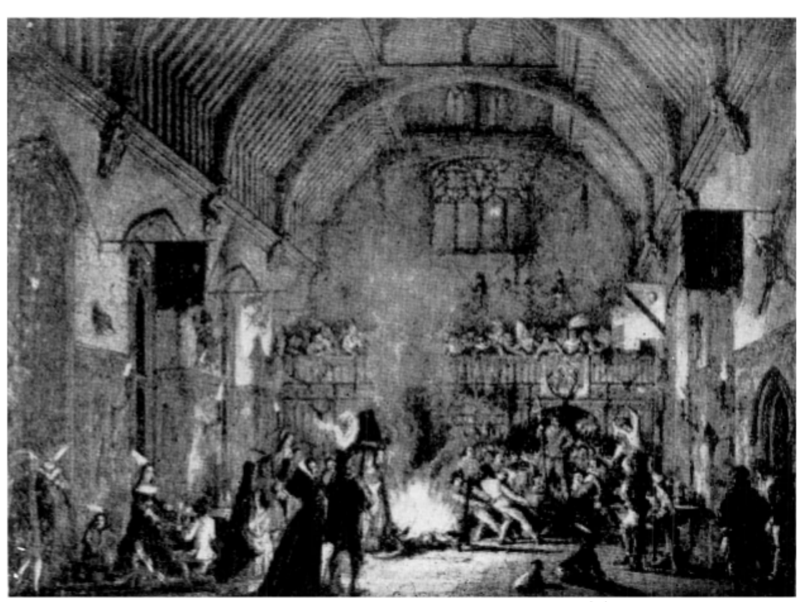
In the earliest times the making of fire was not understood, and very great efforts were made to keep alight any natural blaze which might occur. The making of fire by friction soon became known to some peoples, and variants of the fire-stick are still used by the more backward races. The use of flint 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.

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. 1). 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. 2). 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"

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. This development brought with it the need to provide some means for the escape of 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. 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. 3).

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

Fig. 1. *The Hall, Penshurst, Kent. (England)*



of the first Queen Elizabeth, wrote, "Now we have manie chimnies, and yet our tenderlings complain of rheumes, catarhs and poses. Then we had none but reredoses, i.e., 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 far better medicine to keep the good man and his family."

So deeply rooted was the prejudice against coal that it was not until the commencement of the 17th century that its use became more general. Ladies had an idea that a coal fire injured their complexions, and they would not enter a house or room where the obnoxious fuel was used; nor would they even partake of meat which had been roasted at a coal fire.

Fig. 2. *Turreted Roof, Galstonbury*

We have heard, during the last decade or so, of the Shunt flue — a common flue serving a number of solid fuel appliances on different floors of a building. This was a Belgian patent. Yet in 1857, the Board of Health's report on the Warming and Ventilation of Dwellings suggested precisely this arrangement. In addition, the Board proposed to make a ventilating shaft round the smoke flue, to provide warmed air to each room.

The fires on the central hearth and in the early wall fire places 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 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. 4).

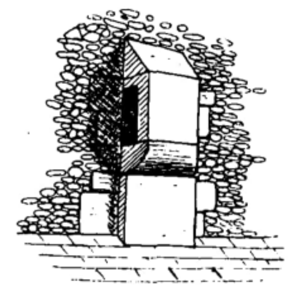


Fig. 3. *Chimney vent, Abingdon Abbey (13th. cent.).*

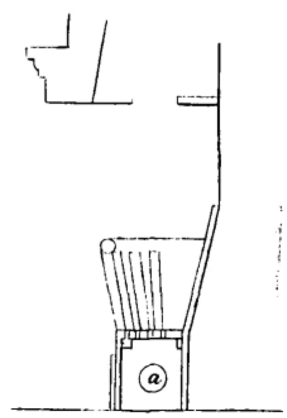


Fig. 4. *Sir John Winter's Firecage. a. pipe to supply external air to fire.*

There followed a period of intense activity in this direction, due chiefly to Gauger, Franklin and Rumford. During the century which followed, a very large number of inventions relating to open fires was made, including revolving grates, and grates with "mechanical" stoking. Hardly any survived and little further was done until 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.

Atmospheric pollution, too, was a problem: we read:—

"The gloom of the winter of 1879-80 was so disheartening, so dangerous, or in each sense of the ward, so appalling, that on a recurrence of fog just recently, some have asked whether nothing can be done to relieve our Metropolis from the pernicious smoke . . . .

"One scheme for getting rid of smoke is to warm our houses entirely by gas, but this scheme is met by exceedingly strong objections. The cost is very great . . .

"A second scheme is to burn coke or anthracite coal, but these are unfit for open fire places . . .

"A third scheme is to levy a tax on all open fire places . . .

"A fourth scheme is to heat a large number of houses, say 20, 50 or 100 from a single source . . ."

An alternative was to use the sewers, with "powerful chimney shafts at suitable intervals, the smoke to be consumed as far as possible in powerful furnaces burning perpetually at the bottom of each shaft, the unconsumed smoke and other products to be discharged in the open air at a great elevation." But Edwards demonstrated the impracticability of the notion on account of the size and frequency of the shafts and sewers required.

According to Constantine, an anti-fog bill (a private member's effort) of about 1880 proposed, "by means of a pipe fixed to the highest part of our principal buildings, and with the aid of a fan, to bring down the pure air from above and force it into buildings such as St. Paul's and the Houses of Parliament, thus displacing fogs and smoke and all impure air."

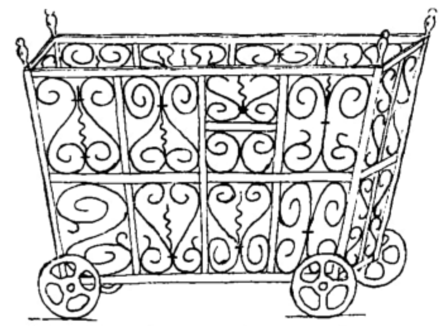


Fig. 5. *Spanish Brazier.*

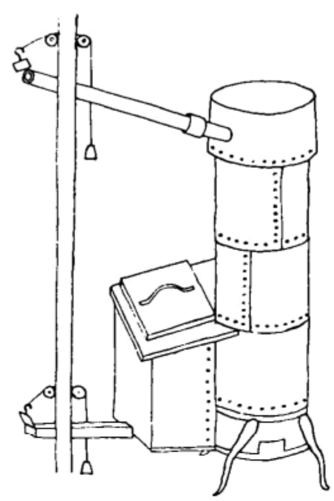


Fig. 6. *Old German stove. (in 1600).*

**The Stove**

The Greeks and Romans made use of braziers and altar hearths as well as the simple hearthstones. 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. 5). 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.

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. 6). Kesslar introduced the zig-zag flueway. 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 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. According to Constantine, "a cockle stove weighing 14 cwt. was taken out of a church which had an area of 180,000 cu. ft.; it was replaced by a Convoluted stove of 50 cwt. The difference in weight gives the difference in heating power. Every pound of metal has a certain capacity to radiating heat and no more, and the heating power of an apparatus may be readily ascertained in this manner."

Constantine also gives some costs — for the Free Trade Hall in Manchester, a hot water system of pipes round the floor was tried at a cost of £700; but it was expensive in repairs, etc. It was replaced by two of Constantine's Convoluted stoves for £270. The coke consumption on these was 4½ tons a year, costing £2/10/-.

The massive Swedish brick-and-tile stove (Fig. 7) 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.

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 1800's.

## 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. 8). A stove was constructed within a brick chamber, to which fresh air could be supplied through an underground duct some 40 feet 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 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. Although these examples were not immediately followed, a warm air system was installed in Pentonville prison by Major Jebb, Surveyor-General of Prisons, in 1844; and a similar system was employed at Glasgow University. We are told that in this case, the volume to be heated was two million cu. ft., that the plant cost £17,000, the maintenance was £500 p.a., and the fuel usage was 2.2 tons per day.

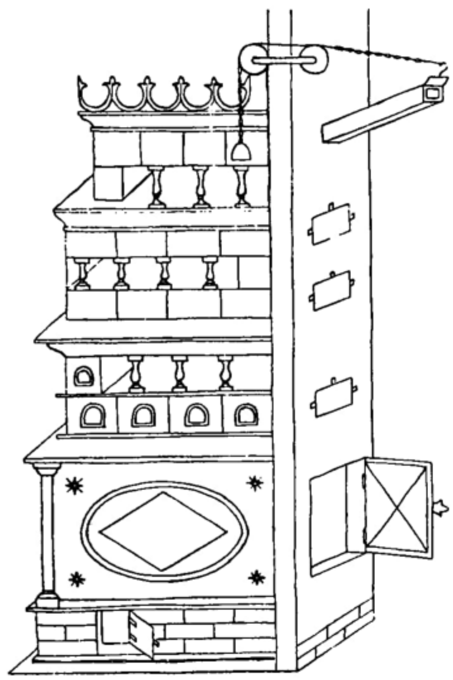


Fig. 7. *Swedish stove. (1614).*

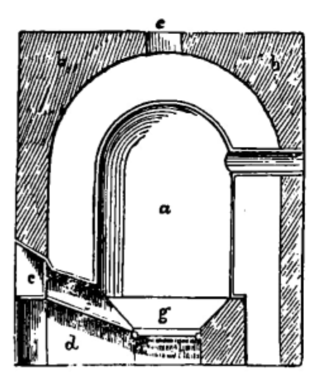



Fig. 8. *Strutt's cockle stove*

## Hot Water Heating

Hot water heating was first suggested about 1610 when Sir Hugh Platt proposed to use hot water to dry gunpowder. 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. 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. 9). 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-Victoria 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.

"Of late years (ca. 1880) the makers of boilers, pipes, bends and other fittings for the circulating system, have exercised considerable ingenuity in providing everything necessary for reducing or enlarging the flow pipes, turning corners dipping or ascending, so that the execution of this class of work has been greatly simplified, and now almost any respectable plumber can do hot water fittings, and they all know that one foot of four inch pipe

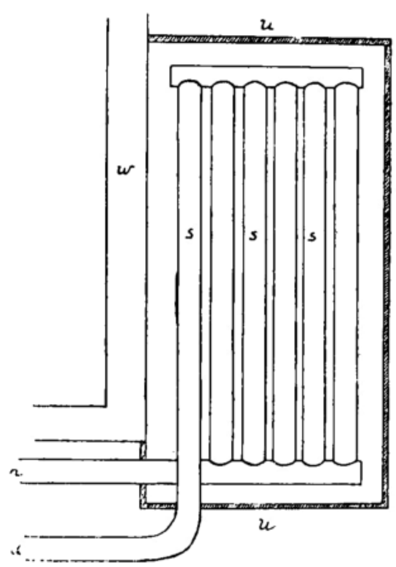



Fig. 9. *Bramah's radiator, Westminster Hospital s, s, heating pipes; u, u, casing, perforated.*

warms 100 ft. of air; there is therefore no necessity for giving elaborate tables, as was the custom in works written twenty years ago. Another simple rule should never be lost sight of, that is *always have a good margin of heating power both in boiler and pipes.*" (Constantine).

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 ½ 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 2,800 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 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.

When the high pressure system was first introduced, many fires occurred in consequence of the hot pipes (which frequently attained a temperature of 600-700°) not being a sufficient distance from timber and inflammable material. This was investigated by the Manchester Assurance Office in 1841. During the course of these experiments, wood shavings placed on the pipes were found to ignite, and lead could be melted on the flow pipes. The expansion pipe was observed to be in a state of considerable agitation. A further test was carried out for the express purpose of an explosion. The system was filled at 3 o' clock and heated up. At 5 o' clock, the sheet lead affixed to the upright pipe freely melted; steam issued violently from the bend in one of the upper horizontal pipes and in three minutes afterwards the explosion occurred in the furnace pipe at the top of the seventh coil.

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; in it the wrought iron tubes were fitted together with flanged joints, and held in place by long bolts passing through the sections. 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. The British designs were plain, whereas the American ones were ornate. 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. Edwards in 1881, wrote "For domestic use, it is common to use hot water pipes fixed behind the skirting board, with gratings to admit air from an external source into the main channel containing the pipes and thence through other gratings into the room."

**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. 10). Tredgold gives descriptions 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.

**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. For residence work a vertical independent boiler was considered the best, as it could be charged with

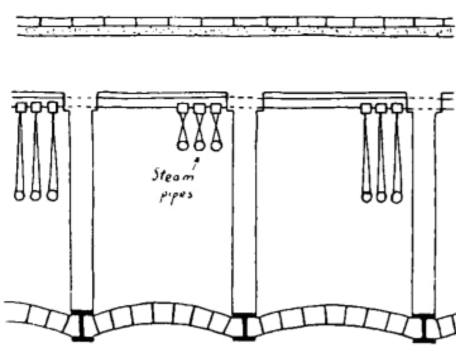



Fig. 10. *Steamheated floor warming system (Germany in 1900).*

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 section, was pioneered in Britain by James Keith, about 1890. His "Challenge" boiler (Fig. 11) was a vertical sectional model.

**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 per 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 per min. with a temperature difference of 1 deg. F. (This corresponds to a *U* value of 1.54 B.t.u. per 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. Box calculated the *U* values for some walls, obtaining figures which were not very different from those in use today. 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 1,000 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."

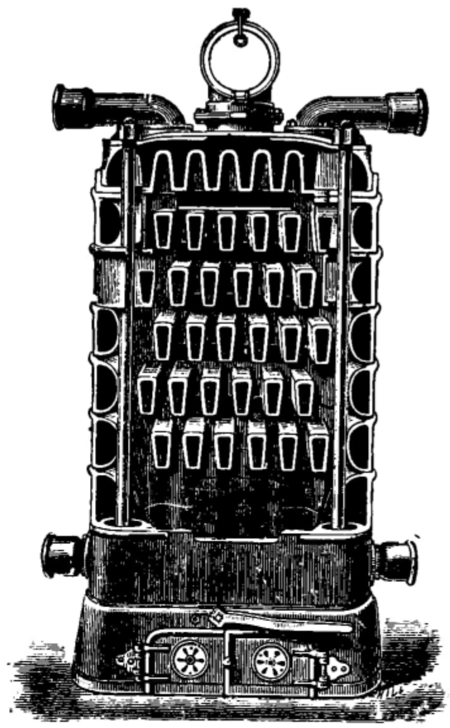


Fig. 11. *Keith's vertical sectional boiler.*

**District Heating**

The genesis of district heating is not easy to discern. Walker in 1850, suggested the possibility of a district plenum-heating system for a row of cottages near a factory. Hot water heating was proposed by Edwards in 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 at Lockport, N.Y., in 1877, and the U.S.A. has generally remained in the fore in the practice of district heating. 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 in 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. 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. 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 Government 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. Although his 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. Peclet 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. per h. for schools. Box, in 1875 estimated the fresh air requirements for life, for removal of water vapour, for removal of heat (including fuel and light), for removal of odours (after Peclet) and realised that all of these functions could be fulfilled by 250 cu. ft. per h. per person, rising to 500 cu. ft. per h. in crowded rooms.

Rather earlier than this Dr. Reid had formed the opinion that 10 cu. ft. per 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.

## The Fan

The fan itself was devised by Desaguliers in 1734. His original model was no more than a paddle wheel 7 ft. diameter with radial blades 1 ft. wide rotating in a concentric casing (Fig. 12). This operated in the House of Commons for many years.

Desaguliers tried to interest the Admiralty in using his fan to ventilate men-o'-war, instead of the earlier wind-sock. Although a trial was arranged on a vessel at Greenwich, the fan was not adopted, because of the obstruction offered by Sir Jacob Ackworth, surveyor to the Navy. According to Edwards, Sir Jacob "avoided witnessing an experiment when Desaguliers was present. When he did attend, he chose a time when plenty of wind was blowing. He had his favourite wind-sails hoisted and 'Now', he said to the doctor's representative, 'I would have you work the engine and see whether that will throw out so much air as our wind-sails you see do.' The man pointed out that the blowing wheel was to be used when the wind-sails were useless. But Sir Jacob would not stay any longer. He told Dr. Desaguliers afterwards that 'he was sorry it succeeded no better, but he thought it might be a very pretty thing in a house'."

In 1739, a brewer, Mr. Samuel Sutton, also patented a device for ventilating ships. The normal air supply to the furnaces was cut off, and air was drawn to the ash pit below the fire by tubes leading from the spaces to be ventilated. He too tried to interest Ackworth, and fared little better than Desaguliers. "Sir Jacob made an appointment for Mr. Sutton to call on him on a future day at seven in the morning, when, being engaged, he allowed him to wait about till the evening. He then told him that no experiment should be made if he could hinder it." At length, in 1741, an official trial was made, and Sutton was asked to fit out a vessel going to the Guinea coast. He received the sum of £100 for loss of time and expenses over the invention The device soon fell out of use again.

In 1744, Dr. Hales made an enormous bellows for ventilating purposes, and this too was tried on board ship. A constant objection to the bellows was the necessity for frequent manual labour to work them. Hales sought to stimulate the men who worked the bellows by the sight of a little twirling windmill or the sound of a tinkling bell, occasioned by the rapid passage of the air, that they might thereby be amused, and have some evidence of their labour not being in vain.

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. 13). 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 Peclet 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 Institution of Mechanical Engineers, London. As a result he was able to formulate dimensional rules for fan construction which still held good sixty or seventy years later.

Murgues, a colliery engineer, developed a theory of fan operation in 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. One fan carried this idea to such an extent that the blades extended round one-quarter of the fan-wheel.

In 1834, a M. Motte received a prize for the application of the Archimedean screw in a 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 1930's.

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 5,000 cu. ft. per min. Reid noted that the noise from small fanners running at high speed (1,000-2,000 rev. per 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 today 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.

We read, too, that the Emperor Varius Avitus had large mounds of snow built in his gardens, to cool the breezes blowing around his house in summer. A thousand years later (775 A.D.), one of the followers of the Caliph Mahdi had snow packed between double walls of his summer residence. Such schemes were hardly practicable for widespread use; and further progress had to await the development of mechanical refrigeration.

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. He constructed a room without windows, but with an opening at floor level in one wall. A block of ice was suspended in a bowl from the ceiling, and surmounted by a cone-shaped hood with a vent pipe passing through the ceiling into a shaft. Downward movement of air over the ice was thus ensured, the cool air descending to the floor and out through the

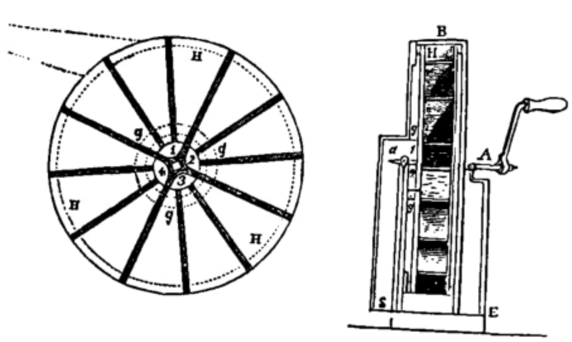



Fig. 12. (left). *Desagulier's Fanning wheel.*
*gg. HH casing.*
*B air exit.*
*S air inlet.*

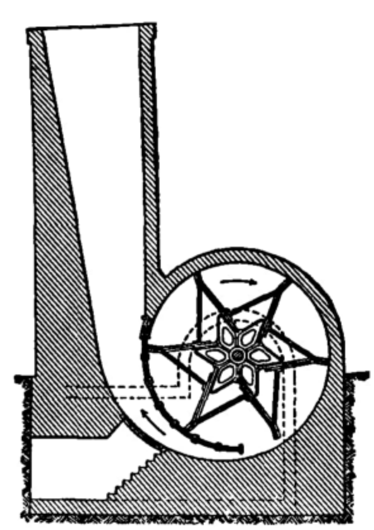


Fig. 13. (right). *Guibal fan and "chimney".*

opening. Gorrie eventually gave up medicine and devoted his energies to the perfection of a cold air ice-making machine, which he patented in 1851.

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 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."

### The Houses of Parliament

Prior to 1791, the House of Commons was heated by charcoal braziers, while the House of Lords (almost from time immemorial) used hot air or smoke flues beneath the floor. The ventilation had been effected by Desaguliers, who employed first his fire (1723) and then his fan (1734). The attempt to employ fires in the ventilating shafts was defeated by Mrs. Smith, the housekeeper, who objected to the passage of the shafts through her rooms. She neglected to light the fires until the House was crowded and too hot — too late. Desaguliers' fan was said to be able to discharge air at 60 m.p.h. through an opening 7 in. in diameter. It was used for about 80 years all told.

In 1791, a Committee enquired into the arrangements for heating and ventilating the Chambers. The ventilation was placed in the hands of Mr. Henry Holland, architect, whose estimate for the scheme was £45. The Committee also recommended that a hot air stove be used to inject warm air into the House through the floor. The stove — an Empyreal, by Jackson and Moser — was 6 ft. square and 14 ft. high. It was placed in the crypt, and an opening 3 ft. 6 in. diameter admitted air through the floor of the House. The stove cost £120, and two thermometers £14/14/-.

In 1811, Sir Humphry Davy proposed the use of Desaguliers' fires to assist the ventilation of the House of Lords, and this was apparently done. A further Committee was set up in 1813 to deal with the heating and ventilation of the Lords. Adam Lee, who superintended the ventilation of the House of Lords from 1806 onwards, reported that Davy's one ft. diameter extract opening was insufficient, and he proposed a 3 ft. diameter pipe, without assistance from a fire. This was also proved to be inadequate, and in 1817, Lee further recommended an air pump or machine to extract the vitiated air.

At about this time, De Chabannes was called upon to treat the House of Commons. He removed Desaguliers' fan and Wren's air tubes. He applied a number of coils of iron pipe beneath the members' seats, the coils being heated by steam in winter. Air entered the House at various points after being warmed by steam coils. To remove the vitiated air, he placed steam coils over the ceilings and galleries, and by rarefying the air, created upward currents through apertures in the ceiling, past the coils into exhaust ducts terminating in a 4 ft. diameter cowl. The scheme was not entirely successful, and the control of temperature was poor.

The Chamber was destroyed by fire in 1834, and Dr. Reid was asked to advise upon the arrangements for the temporary chamber in 1836. His scheme provided temperature control by mixing warmed and fresh air in appropriate quantities. Reid was also invited to advise upon the ventilation of the new building, and he proposed to use a tower as the air intake, with a fan driven by a steam engine. The exhaust was to be fire-assisted. The scheme was not too successful, due to the division of responsibility and control between Reid and Sir Charles Barry. Reid's mechanical intake was removed by Gurney, and by 1880, the scheme had reverted to that of the temporary chamber.

A new Committee was set up in 1854. Mr. Goldsworthy Gurney advised steam heating and downward ventilation, with a steam jet to assist the extraction. It appears that these suggestions were not in fact adopted; and Gurney used steam heating with gilled tubes (Gurney's batteries), upward ventilation (as Reid had done) and did not employ the steam jet.

In 1866, Constantine wrote "The system adopted is very complicaated and expensive, and it is to be regretted that so much public money was spent, and that the nation generally derives so little benefit from it."

Would he have made the same comment today?

**Conditioning**

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.

The story of mechanical refrigeration would require an article in itself. Apart from Gorrie's cold air machine, the early years of the 19th century saw Vallance's patent for a sulphuric acid absorption process and Perkins' vapour compression machine using ether. Development was fairly rapid, owing to the work of Harrison in Australia, Carré in France, and Linde in Germany. $SO_2$, $O_2$ and $NH_3$ were the common refrigerants. Carrier, among others, introduced the centrifugal compressor, but its full development was not possible until refrigerants of high molecular weight, like the halogenated hydrocarbons, were readily available. 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.

From 1930 onwards, the development of light refrigerating equipment, automatic controls and direct expansion cooling gave a considerable impetus to the use of air conditioning in buildings. Without these developments, the modern unit conditioner would have been impracticable.

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.