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THE ROYAL SOCIETY OF HEALTH

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VENTILATION, HEATING, AND LIGHTING.

BY

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PREFACE.

THE object of the present volume is to briefly consider, mainly from a Sanitary Engineer's point of view, a few of the more important matters connected with the practical side of the important subjects of Ventilation, Heating and Lighting.

It is, of course, not intended to deal in anything like an exhaustive manner with the subjects mentioned, but principally to give, as briefly as possible, such useful information in connection therewith as will be of practical interest and assistance to those whose duties or interests lie in this connection.

A large part of the notes from which the book has been written were originally prepared by the Author, from time to time, during the course of his own experience and studies, and, at the request of the publishers, have since been revised, amplified, and illustrated throughout, and are here given with the special hope that they may be of service to Sanitary and Ventilating Engineers, Surveyors, Architects, and also to candidates preparing for professional examinations, such, for example, as those of the Association of Municipal and County Engineers, the Royal Sanitary Institute, and the Surveyors' Institution.

Some of the chief sources of information are indicated in the foot-notes, so that should the present volume prove an incentive to a more exhaustive study, the reader is confidently referred to the standard works there mentioned.

For the convenience of those who may desire to obtain more detailed information, prices, &c. in regard to the numerous descriptions of Ventilating, Heating, and other fittings and apparatus now on the market, a list of manufacturers and engineers is provided at the end of this volume—the Author having found this feature to be very greatly appreciated by practical readers of his previous technical publications.

WILLIAM H. MAXWELL.

TUNBRIDGE WELLS.
1907.

VENTILATION.

CHAPTER I.

Air: Its Composition and Sources of Impurity.

The term "ventilation" is of wide application, applying as it does to buildings, sewers and drains, streets and courts, mines, tunnels, &c.; in the present volume, however, its application is confined to inhabited rooms or buildings, where the air is rendered impure mainly from two causes, viz, *respiration* and *combustion;* also to the ventilation of sewers and drains, the air of which becomes vitiated by gaseous emanations from the sewage flow, mainly due to its fermentation and decomposition.

Ventilation is defined by Dr. Parkes[1] as the "removal or dilution, by a supply of pure air, of the pulmonary and cutaneous exhalations of men, and of the products of combustion of lights in ordinary dwellings, to which must be added, in hospitals, the additional effluvia which proceed from the persons and discharges of the sick. All other causes of impurity of air ought to be excluded by cleanliness, proper removal of solid and liquid excreta, and attention to the conditions surrounding dwellings." The ventilation of rooms may also be described as that gradual and imperceptible

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[1] "Practical Hygiene."

change of air which prevents the carbonic acid (carbon dioxide CO_2) from exceeding six parts per 10,000, *i.e.*, two parts above the normal.

The great necessity for ventilation, or the supply of pure air, must have come within the experience of all. The pollution of the atmosphere is constantly taking place wherever there are human beings or animals, or wherever there is combustion of lights. The air is constantly being deprived of constituents (oxygen, for example) which are essential to life and health, and impurities such as CO_2 and organic matter are given off in the breath. The general effects of breathing impure air are "quickened respiration (an involuntary effort is thus made to supply the blood with more oxygen by taking more air), this is followed by decreased pulse, languor, sighing, sleepiness, headache, sickness, faintness, stupor, and even death, if relief is not obtained in the form of purer air." Continued breathing of impure air lowers the tone of health, and produces a general predisposition to disease. Those diseases which affect the lungs (*e.g.*, consumption and scrofula) are attributable to the breathing of vitiated air.[1] The instance of the confinement of 146 Englishmen in the Black Hole of Calcutta, in the year 1756, is illustrative of the fatal effects of vitiated air. The cell was 18 ft. long by 14 ft. wide, and had only two small holes on one side to admit air. Ten hours after imprisonment only twenty-three persons were alive.

"The purity of the atmosphere habitually respired is essential to the maintenance of that power of resisting disease which, even more than the ordinary state of health, is a measure of the real vigour of the system."[2]

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[1] Dr. Pilley's "Hygiene."

[2] Dr. Carpenter's "Human Physiology."

The great natural purifiers of the atmosphere are briefly—the fall of rain, the diffusion of gases (due to variations of temperature), dilution by winds, and oxidation; also the CO_2 of the atmosphere is kept within certain limits through its absorption by the vegetable world.

The Composition of Atmospheric Air.—Pure air is a mechanical mixture of gases, the two chief of which are—

Nitrogen	..	79 parts (approx.) in 100 of air.
Oxygen	..	21 " " "

Other substances usually present in small amounts are—

Carbon dioxide (carbonic acid gas) ·04 per cent., or four parts in 10,000 of air; watery vapour; ozone; ammonia; suspended matter (organic and inorganic).

Nitrogen serves to dilute or weaken the strength of the oxygen, and thereby prevents its rapid action. Animal life is sustained only for a short time in pure oxygen.

Oxygen is essential for all forms of animal life, and for the combustion of fires, gas, lamps, candles, &c.

Carbonic Acid Gas (CO_2) is produced when carbon combines with oxygen—the combustion being always accompanied by the evolution of heat. The carbon may be derived from candles, coal, coke, paraffin of lamps, or the heat-producing foods of the bodies of animals. CO_2 also results from the breath of animals; whilst *plants*, on the contrary, under the influence of sunlight, take up CO_2 and set free oxygen, thereby purifying the air. Plants in the dark take in oxygen.

Watery vapour is derived from the breath of animals; is exhaled by plants, and evaporated from the earth's surface. The amount of watery vapour given off by an individual in ordinary health from the skin and lungs together is enough to saturate about 90 cubic feet of air per hour, at a temperature of 63 deg. Fah.

"A *gas light* affording one candle power of light (*i.e.*, giving light equal to a sperm candle burning 120 grains per hour) will emit ·025 lb. of watery vapour. A *sperm candle* would for the same amount of light give out ·02 lb. of watery vapour, and an *oil lamp* ·018 lb. Thus we shall not be far wrong in considering the effect on the air of each gas or candle light burned in the room as equivalent to that of a human body."[1]

Ozone is a condensed form of oxygen—is a powerful oxidising agent and is produced when an electric discharge takes place in air.

Ammonia is given off from all decaying nitrogenous matter. It is the substance known as spirit of hartshorn. Ammonia gives the peculiar smell to rotten fish, decomposing urine, &c., and forms the most valuable part of most manures.

The *suspended matters* usually found in air may be classed under two heads, viz., organic and inorganic.

Organic.—Bacteria, disease germs, spores of fungi, pollen grains, small seeds, fatty particles, starch cells.

Inorganic.—Dust, sand, clay, chalk, common salt, carbon, coal, phosphate of lime, oxide of iron.

Also, in rooms inhabited by healthy persons, in addition to the above, may be found scales of skin, bits of hair, wood and coal; small fragments of flax, wool, cotton, and silk. In sick rooms, hospitals, &c., the amount of organic matter is found to be especially large.

In addition to the above sources of impurity, air may also be vitiated by effluvia from sewage matter, by sewer air or gases, and by air from churchyards or vaults.

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[1] Galton's "Hospital Construction."

Town air is rendered impure mainly by respiration, combustion, effluvia from soil, sewers, and trades. A few of the most important *Trades* which give off gases and vapours which pollute the atmosphere are :—

Alkali works, giving off hydrochloric acid gas.
Chemical works—various—especially ammonia works.
Brickfields and cement works, giving off carbonic acid, carbonic oxide, and hydrogen sulphide.
Glue refiners, Bone burners, Slaughterhouses, Knackeries — All give off offensive organic vapours.
Match factories give off phosphoric fumes.

Changes in the Composition of Air by Respiration.— In the act of respiration the air received into the lungs is not only deprived of oxygen, but takes up carbon dioxide (CO_2) and organic matter. The presence of oxygen in proper proportion is absolutely essential to health and life, so that anything tending to reduce the amount of this gas must result in a harmful effect, as the air we breathe is brought into contact with the blood, which takes up any impurities which may be present, and carries them into the system.

"An adult man on an average breathes about sixteen times in a minute, and at every respiration takes in about 30 cubic inches of air, and at every expiration exhales about the same amount. Hence it follows that about 16·6 cubic feet of air are passed through the lungs of an adult man every hour, and is deprived of oxygen and charged with CO_2 to the amount of nearly 5 per cent."[1]

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[1] Dr. R. V. Pierce, "Medical Work."

An average adult gives off about ·6 cubic feet of CO_2 per hour.[1]

The changes the air undergoes in the lungs, therefore, are as follows:[2]—

1. *Oxygen* diminished about one-fourth.
2. *Carbonic acid* gas increased about 100 times.
3. *Watery vapour* increased.
4. *Ammonia and organic* matter increased.

The air of inhabited rooms is rendered impure and injurious to health chiefly by:—

1. Respiration, overcrowding.
2. Combustion of gas and other forms of light, open coke and other fires.
3. Want of efficient ventilation.
4. Defective and unventilated drains, and untrapped wastes.
5. Dirt and dust on furniture.
6. General dirtiness of persons, clothes, and houses.
7. Injurious matters given off from factories as previously mentioned.

The two chief impurities given out in *respiration* are *carbonic acid* and *organic matter*, the latter being by far the most important.

Organic matter.—The exact composition of organic matter is not thoroughly understood, but is considered to consist of "epithelium and molecular and cellular matter."[3]

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[1] ·56 during sleep, ·78 when awake (Pettenkofer).

	Nitrogen.	Oxygen.	Carbonic acid, per cent.
Inspired or atmospheric air......	79	21	·04
Expired air	79	16	3 to 4.

[2] Dr. Pilley's "Hygiene."

[3] Galton's "Hospital Construction."

"It is extremely poisonous, and is the cause of the lassitude or feeling of sickness and faintness, and of the smell we always experience in close rooms. It is given out from the lungs and also from the skin (transpiration). It is not diffusible, but tends to hang around our bodies. It rapidly decomposes, and is intimately associated with the presence of bacteria in the air and dirt of all kinds. It readily attaches itself to woollen and other articles of a similar nature in a room; hence the necessity for thoroughly airing and cleansing such things regularly. The amount of organic matter exhaled varies in different states of the body, and also varies in offensiveness in health and disease. Some fevers are accompanied by peculiarly offensive smells and exhalations, which, if not freely diluted with fresh air, are certain to cause further spread of the disease."[1]

The influence of heat and moisture increases the amount of organic matter in air. Dryness diminishes it. Rain in hot weather has a very decided influence in removing organic particles from the atmosphere.

"The exhalations of unwashed persons are more offensive, and are said to contain more organic matter than those of the cleanly. Those of the sick are more fetid than those of the healthy."

The relation existing between the amounts of organic matter and carbonic acid in air, is well put by Dr. Willoughby in his "Health Officer's Pocket-book" as follows:—"The poisonous effects of 'rebreathed' air are due not to the CO_2, except under extraordinary circumstances, but to the effete organic matter exhaled partly from the lungs and partly from the skins of the occupants of the room, to which may be added the CO_2 and other gases given off in the combustion of

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[1] Dr. Littlejohn, M.B., "Ventilation, Warming, and Lighting."

lamps of all kinds " (excepting, of course, electricity). " But *since the organic matters cannot be easily or accurately estimated, while the CO_2 can, and moreover bears a fairly constant ratio to the former*, it is usual to distinguish the proportion present in excess of that in the outer air as 'respiratory' or 'organic' carbonic acid. The normal amount of CO_2 in pure air may be taken at ·4 per 1000. Any further addition of organic carbonic acid not exceeding ·2 per 1000 is imperceptible to the smell, and may be considered innocent and unavoidable."

Therefore, a total of ·6 per 1000 is called the " *limit of permissible impurity*." When it exceeds this the smell becomes evident to a person coming in direct from the open air, the ventilation is imperfect, and the air cannot be breathed with impunity.

" The sense of smell is a very fair test of the purity of the air of a room if proper precautions are used. The sense is blunted by prolonged exposure to foul air, so that the observer must enter the room straight from the open air, or re-enter after at least a quarter of an hour's free respiration out of doors."

In the process of *combustion* the oxygen of the air is reduced, carbon dioxide (CO_2) is increased, and carbon monoxide (CO, an extremely deadly gas), watery vapours, and sulphurous acid ($H_2 SO_3$) are also given off.

In the combustion of a cubic foot of gas, 2 of CO_2 and ·2 to ·5 grains of sulphur dioxide (SO_2) are given off, and about 1800 cubic feet of fresh air must be introduced to properly dilute the products of combustion.

The combustion of gas vitiates air to an amount equal to *one adult per cubic foot of gas burnt per hour*, and, as an ordinary burner consumes from 3 to 5 cubic feet of gas per hour, a supply of 5400 to 9000 cubic feet of air is required, that is, as much as would suffice for three men per hour.

There being no organic matter added to the air through the impurities given off by *combustion*, as is the case with *respiration*, there is, therefore, no foul, nauseous smell, although the percentage of CO_2 may be quite as great. *Carbon monoxide*, or carbonic oxide gas (CO), is formed when carbon burns with a limited supply of oxygen. In an ordinary red-hot coal fire the production of this gas may often be observed; "oxygen of the air, which enters at the bottom of the grate, combines with the carbon of the coal, forming carbon dioxide; this substance then passing upwards over the red-hot coals, parts with half its oxygen to the red-hot carbon. The carbon monoxide, on coming out at the top of the fire, meets with atmospheric oxygen, with which it at once combines, burning with a lambent blue flame, and re-forming carbon dioxide."[1]

CO is a strong poison, and is fatal when inhaled even in small quantities.

The combustion of a cubic foot of good coal gas produces about two cubic feet of carbon dioxide. (Parkes.)

The Effect of the Combustion of Lights on Ventilation.—Pure wax candles, when compared with 13-candle power gas, generate nearly double the amount of CO_2 *in producing the same amount of light.* But, as a rule, a brilliant light is expected from gas, whilst a dim light usually suffices from candles; hence it is that complaints respecting the excessive heat and oppressiveness of gas are so general.[2] Such complaints, however, could, no doubt, be minimised if consumers could be more readily induced to appreciate the

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[1] Roscoe's "Chemistry."

[2] Modern improvements in the methods of gas illumination have very substantially improved the condition of the atmosphere and ventilation of rooms lighted by this form of illuminant.

absolute necessity (that is, if anything like a pure atmosphere in a room is to be maintained) of making suitable provision for carrying off the many impurities created by combustion, with which the atmosphere of so many of our dwelling-rooms, shops, warehouses, &c. is constantly being poisoned.

Where gas is made use of, it is essential, in order to ensure a satisfactory atmosphere in the room, that a separate *outlet* should be provided for the noxious gases produced imme-

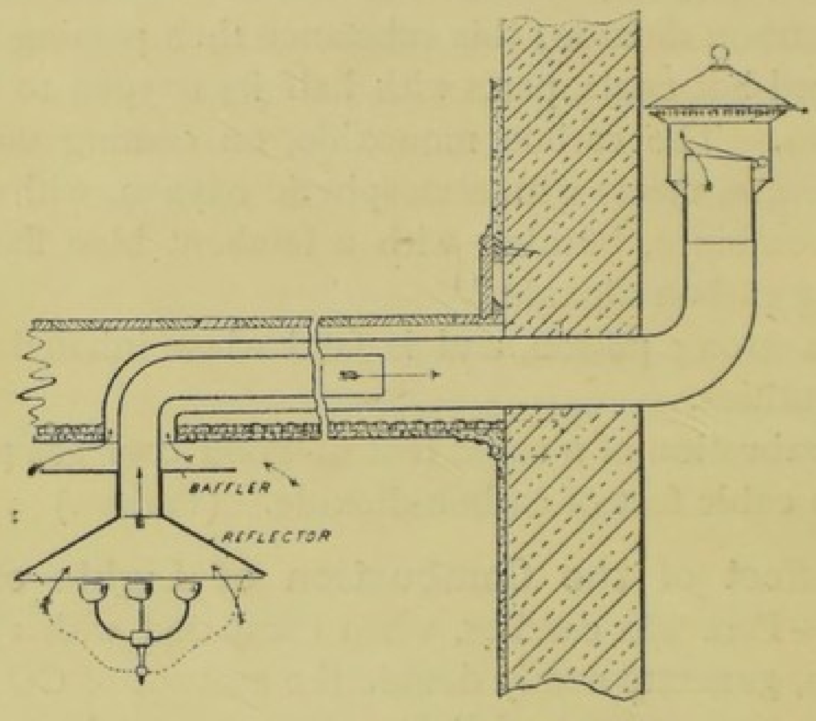

FIG. 1.

diately over the light. This outlet may either communicate with a chimney or with the external air, as shown in Fig. 1. There are several ventilating gas burners in the market, *e.g.*, "The Wenham" and the "Regenerative" burners of Siemens and Clarke. A good arrangement is to have a number of Sugg's, or other good maker, vertical flames from burners of steatite placed beneath the mouth of an extracting shaft passing perpendicularly or horizontally from the ceiling to the outer air. This tube is surrounded by a larger one, and the space between the two acts as an extraction shaft for foul air from the room, being heated by the inner tube. The outer tube should be surrounded with asbestos for safety, and to retain the heat.

The fumes of gas may, therefore, thus be utilised to assist the ventilation, but unless some motive power in the flue, independent of the heat of the gas, is provided, the fumes are at times liable to return into the room.

For a given amount of illumination the degree of vitiation of the atmosphere is very greatly reduced in the case of the Welsbach incandescent "C" pattern, the Welsbach-Kern, and the "Block" light types of gas burners, as compared with forms preceding these latest improvements.

The electric incandescent light, contained, as it is, within an enclosed vessel, is the most hygienic form of light conceivable. The arc electric light, however, being open to the atmosphere, is said to probably be injurious to health if used in enclosed spaces, owing to the nitric acid developed.

CHAPTER II.

The Movement of Air.

The Movement of Air and Means by which it is Set in Motion.—Air is set in motion chiefly by:—

(a) **Diffusion.**—Gases diffuse inversely as the square root of their density, thereby affording a constant escape of any foreign gas into the atmosphere.

(b) **Winds—Perflation.**—The air of a room is most effectually changed by perflation; that is, opening doors and windows, and allowing air to blow through.

(c) **Variations in Temperature**—that is, by the difference in weight of masses of air of unequal temperature.

Movements Produced by Unequal Weights of Air.—The *movement* of inside air, with its temperature higher than that of outside air, depends upon—

(a) The difference of temperature of inside air and outside air.

(b) The area of aperture through which the air passes.

(c) The height of the column of ascending air of the higher temperature.

The calculation of the constant stream of cold air ventilating a room by entering at the inlet orifices, and escaping as hot vitiated air at the outlets, is based on the following laws, known as Montgolfier's law of falling bodies—

1. "The velocity in feet per second of falling bodies is equal to eight times (about) the square root of the height through which they have fallen."

2. "Fluids pass through an orifice in a partition with a velocity equal to that which a body would attain in falling through a height equal to the difference in depth of the fluid on the two sides of the partition."

Putting this in the shape of a formula, we have—

$$v = \sqrt{2\,g\,H}$$
$$= 8{\cdot}02\sqrt{H}$$
$$\text{and } H = \frac{v^2}{2g}$$

where v = theoretical velocity in feet per second,

g = the acceleration of velocity in each second of time, = 32·2. (The force of gravity.)

H = vertical height or head in feet.

The ordinary atmospheric pressure is about 15 lbs. per square inch, which is the weight of a column of air about five miles in height, so that air rushes into a vacuum with a velocity equal to that which a body would acquire in falling from that height, that is v = 1,304 ft. per second.

Suppose, however, the air passes into a room containing air of a lower pressure than that outside, its velocity in this case will be that produced by a height representing the difference of *pressure* outside and inside.

This difference is inferred from the difference of *temperature* of the outer and inner air; and the height to produce velocity of the inflowing current is therefore equal to "the height (H) from the aperture at which the air enters to that from which it escapes, multiplied by the difference of temperature between outside and inside, and divided by 491."[1]

[*Note*.—Air expands with heat to the extent of one part in 491 of its volume for every degree Fahrenheit (or one in 273

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[1] Dr. Parkes' "Hygiene."

for every degree Centigrade). Hence the coefficient of dilatation of air (for 1 deg. Fah.) is $\frac{1}{491} = \cdot 00203.$]

The difference of pressure outside and inside, or *the height producing velocity of inflowing current*, therefore

$$= \frac{H \times (t^1 - t)}{491},$$

where t^1 = inside temperature,

t = outside temperature.

Hence, *the theoretical velocity of inflowing air*, from the fundamental equation $v = 8 \cdot 02 \sqrt{H}$ given above, is

$$v = 8 \cdot 02 \sqrt{\frac{H \times (t^1 - t)}{491}},$$

or, using c for coefficient of dilatation—

$$v = 8 \cdot 02 \sqrt{H c \times (t^1 - t)}.$$

Hence we see that—

(a) The velocity of the escaping current is proportional to the square root of the excess of the temperature of the warm air in ventilation shaft over the external air.

(b) Also, to the square root of the height of the shaft or chimney.

(c) The volume of air extracted is, of course, proportional to the sectional area of the flue.

The *actual velocity* is, however, reduced from one-fourth to one-half of the above theoretical velocity by the *friction* or *resistance* offered by the air flue.

The resistance increases directly with the length (L), and inversely with the area (A) of the flue; and also increases with the square of the velocity (V^2) of the current, that is as $\frac{V^2 L}{A}$.

Circular openings offer less resistance than square or rectangular ones, the circle being the figure which includes the greatest area within the smallest periphery.

Angles in the air flue afford a very serious resistance, and it is shown by experiment that a right angle diminishes the current by one-half; two right angles would reduce it to one-fourth. If they cannot be avoided altogether, all angles should be rounded off as much as possible.

The resistance is also influenced by the roughness or otherwise of the sides of the air flue, and the actual velocity in practice is diminished by the inadequate supply of fresh air to the room.

In practice the velocity is usually ascertained by the use of the anemometer, or it may be obtained by small hydrogen balloons weighted to the specific gravity of the air. On testing results obtained by Montgolfier's formula with the anemometer, it has been found to give too much when the tubes are long, on account of the great friction, and a further deduction of one-sixth should be made when the tube is long and of small diameter.[1]

Of course the *movement* of air *increases with the difference of temperature*, and is very considerable in winter (when rooms are heated), and practically nil in summer, when the inside and outside temperature are about the same.

The actual velocity in feet per second having been arrived at, this number multiplied by the sectional area of the opening in square feet gives the volume passed through in cubic feet per second.

Quantity of Air and Cubic Space Required.—An average adult gives off ·6 cubic feet of CO_2 per hour, and in order that the expired impurities may be properly diluted, requires 3,000 cubic feet of fresh air per hour, so that the "standard of purity" (viz., six parts of CO_2 per 10,000 of air) may not be

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[1] Dr. Parkes' "Hygiene."

exceeded. The art of ventilation consists in so admitting this amount of air that no current is perceptible, and that it may be endured without feeling draughts or other discomfort. The above standard amount applies to people at rest; a much larger supply is required in workshops, &c., as more impurity is given out by people at work.

"It is found experimentally that with ordinary appliances, and under the average atmospheric conditions of the climate of England, the air of a room cannot be changed more than about three times per hour without causing an inconvenient amount of draught. Hence, in order to supply 3,000 cubic feet of fresh air per hour, we should have an air-space for each person of at least 1,000 cubic feet."[1] This would be represented by a room 10 ft. square and 10 ft. high, the air of which should be changed three times per hour.

Comparing the above figures with the conditions usually found in practice, it is at once evident that either our rooms are too small or are insufficiently supplied with air.

An opening (into a room) with a sectional area of 24 square inches (say 6 in. by 4 in.), admitting air at a velocity of 5 ft. per second, would supply in one hour,—

$$\frac{24}{144} \times 5 \times 60 \times 60 = 3{,}000 \text{ cubic feet of air,}$$

which is the amount required by one adult.

It is usually preferable, however, to adopt a lower velocity than above stated, in which case the inlets would require to be more numerous. Several small inlets are preferable to one or two large ones, as the air is more uniformly distributed, and not so likely to cause unpleasant draughts.

As to the rate of movement of air 55 deg. to 65 deg. Fah., Dr. Willoughby[2] gives the following:—

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[1] Dr. Whitelegge, "Hygiene and Public Health."

[2] "Health Officer's Pocket Book."

1½ ft.	per second	is felt	by none		
2-2½ ft.	,,	,,	,,	,,	only by a few sensitive persons
3 ft.	,,	,,	,,	,,	by most
3½ ft.	,,	,,	,,	,,	by all
4 ft.	,,	,,	,,	a distinct draught.	

About 2½ ft. per second is a suitable rate for cool air entering rooms, and about 3 ft. per second when the air is warm.

It may here be convenient to mention that "a sheet of light tracing paper, moved through the air at 2 ft. per second, takes up an angle of 45 deg., and affords a ready means of measuring that velocity; and for smaller velocities, the angle of inclination with the horizon assumed by the flame of a candle affords a fairly accurate index,"[1] *e.g.*, the velocity of flow is 1·6 ft. per second when the flame makes an angle of 30 deg. with the horizon; 1·0 ft. per second, when flame makes an angle of 40 deg. with the horizon; and ·50 ft. per second, when flame inclines 60 deg. with the horizon.

In calculating cubic space, take account of available air-space only, and deduct for furniture, large projections, &c. No height over 12 ft. should be reckoned. Air stagnates in nooks and corners, and the useful part of the air space is limited to that in which the air moves freely.

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[1] Galton's "Hospital Construction."

CHAPTER III.

Statutory and other Amounts of Cubic Air Space, Floor Space, &c.

Dwelling-houses, cubic space necessary per head, 1,000 cubic feet.

Common Lodging-houses, Local Government Board recommendation, 300 cubic feet.

Common Lodging-houses (London), 350 cubic feet air space; 30 square feet floor space.

Metropolitan Lodging-houses, 30 ft. floor space, and 240 cubic feet air space per head.

Lodging-house, Vauxhall (erected by Lord Rowton), the cubic air space per head is from 380 to 455 cubic feet.

Salford Corporation Lodging-house, 600 cubic feet air space per head.

Glasgow Municipal Lodging-houses, 400 cubic feet air space per bed.

Poor Law Boards, 300 cubic feet for healthy person in dormitory, and 850 to 1,200 cubic feet for sick person.

Registered Lodging-house (Dublin), 300 cubic feet per head.

Factory and Workshops Act, 1895, Section 1 (1), 250 cubic feet minimum per head, and 400 cubic feet during overtime.

Canal Boats Act, 1877 (irrespective of number of occupants), after cabin, 180 cubic feet; fore cabin, 80 cubic feet.

Metropolitan Police Section-houses, 50 ft. super floor space, and 450 cubic feet air space.

Army regulation space, 600 cubic feet per head.

London Building Act, requires habitable rooms to be not less than 8 ft. 6 in. in height.

Public Elementary Schools, minimum *floor space* 10 square feet per child. The walls of every school-room, *if ceiled at wall-plate level*, to be at least 12 ft. high from floor to ceiling; if *ceiled to rafters and collar beam* the minimum is 11 ft. from floor to wall-plate, and 14 ft. to the ceiling across collar beam.

London School Board :—

(a) 10 square feet floor space in general school-room.

(b) 9 square feet floor space in graded schools. 13 ft. to be the minimum *height*, thus giving 130 cubic feet air space per head in case (a); 117 cubic feet air space per head in case (b).

Hospitals.—The Local Government Board requirements are :—Ward space per patient, 2,000 cubic feet; floor space per patient, 144 square feet; wall space per patient, 12 ft. (lineal); wall space for children never to be less than three-fourths adult ditto; height of wards, 13 ft. to 14 ft.

Amount of *window surface* as compared with *cubic space* about 1 square foot to every 70 cubic feet.

Animals.—"Horses and cows require for health 10,000 to 20,000 cubic feet of air per hour, and for the minimum cubic space 1,200 to 1,800, but if the cowsheds are practically open 1,000 may suffice."[1]

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[1] Dr. Willoughby's "Health Officer's Pocket Book."

Floor Space.—It is by no means sufficient to merely obtain a certain specified amount of *cubic space;* a room cannot be considered of good proportion for securing efficient ventilation unless a suitable amount of *floor space* is also provided. The minimum amount of floor space allowable is an amount equal to one-twelfth of the cubic space. The hygienic conditions of a room with 60 square feet floor space and 20 ft. high would obviously be much less favourable than those of a room of the same cubic capacity, but say 100 square feet floor space and 12 ft. high. The height of ordinary rooms should be something between 12 ft. and 9 ft. Where the height is excessive, if special and ample outlets in the roof are not provided, the vitiated and heated air rises and accumulates at the ceiling, becomes stagnant, gradually cools, and then falls again into the room to be re-breathed by the occupants. Rooms of large cubic capacity are as a rule more readily ventilated, without causing discomfort, draughts, &c., than small ones. The change of temperature is more gradual, the inlets may be further from the occupants, and the room space being greater, windows may be more numerous. Cubic space, however, must not be considered a satisfactory substitute for *change of air*, for whatever may be the capacity of the room, it is only a question of time, and the atmosphere will eventually reach the limit of permissible impurity, when the previously mentioned standard amount of fresh air per occupant must be supplied hourly as usual.

Window Surface as Affecting Ventilation and Warming in Hospitals.—With respect to the amount of window surface as affecting the question of ventilation and warming, the following remarks of Dr. Thorne in an official report of his on Isolation Hospitals may be of interest:—
"Having regard to cheerfulness, to adequate means of lighting and ventilation, as also to the maintenance of an equable

and sufficient ward temperature, it has appeared to me that in a well-constructed and efficiently warmed building the amount of window surface to cubic space should not vary much beyond the limits of 1 square foot to from 60 to 80 cubic feet; a proportion of about 1 square foot to every 70 cubic feet being, as a rule, most advantageous. The experience obtained in the Children's Hospital at Pendlebury in this connection deserves special consideration, for, due regard being had to ventilation, the failure to maintain the ward air equably warm, and at the same time sweet, was to a great extent due to the excessive window surface, which there amounts to 1 square foot for every 35 cubic feet."

The minimum amount of *window area* prescribed by the Local Government Board Model By-laws is one-tenth of the floor area of the room; at least one half of the window must open, and the opening extend to the top of the window.

CHAPTER IV.

The Practical Ventilation of Buildings.

The application of arrangements and appliances to a building for the purpose of ventilating it may be very conveniently considered under the two heads of "*natural ventilation*" and "*artificial ventilation*."

Natural Ventilation includes those cases where the change of air is effected by natural forces; it is dependent upon the difference of temperature externally and internally, upon the diffusion of gases, and upon the wind.

Artificial Ventilation is that where some mechanical force, such as rapidly revolving fans or other motors, are used to assist the natural forces, and change the air of the building either by the *extraction* of the vitiated air or by the *propulsion* of fresh air into the building.

NATURAL VENTILATION.

The Diffusion of Gases is one of the forces assisting in "natural ventilation." All gases have a tendency to expand and mix with each other, and the rate of this diffusion is inversely as the square root of the density of the gas. This is known as Graham's Law. It is a source of great benefit, as gaseous impurities given off into the atmosphere are constantly being diluted and mixed with fresh air, and thus rendered less harmful. It has been shown by Pettenkofer and Roscoe that diffusion takes place even through the walls of a room; but in ordinary cases, with walls of plastered and papered surfaces, it is insufficient to be of any practical use as regards ventilation; also, organic matter is not affected by it.

The Action of the Wind.—This is a most powerful and efficient ventilating agent. No method will change the air of a room so rapidly and effectually as "*perflation*," *i.e.*, by opening the doors or windows on opposite sides of the room, and allowing the air to freely blow through. If inhabited rooms, schools, &c., could be vacated at short intervals to allow of this thorough change of air, it would greatly assist in maintaining the purity of the atmosphere. The windows and doors of bedrooms should be regularly thrown open during the day to admit of this through ventilation.

The practical drawbacks in trusting to the perflation of the wind for ventilation are:—

(1.) The air may become stagnant.

(2.) The uncertainty of the movement, and the difficulty of regulation, so as to properly distribute the air without causing draughts.

The Aspirating Power of the Wind causing a movement of air up a tube is an important action assisting in ventilation, *e.g.*, as is caused by the wind *blowing over the tops of chimneys*. This produces a strong up-current, and the chimney thus becomes an important extraction shaft for foul air. By the fixing of suitable cowls to air shafts and outlets, the aspiratory power of the wind is secured and down draughts prevented.

In what was known as Sylvester's plan (in use many years ago) the power of the wind was made use of by allowing it to blow down a large cowl with an opening a little above ground level placed near the building, and then passing the air along an underground channel to the basement of the house, where it was warmed and then allowed to ascend in tubes to the respective rooms above, and finally out through outlets in the roof, assisted by the aspiratory power of the wind. In the method of Van Hecke a fan is placed in the tunnel to move the air in times of calm.

The Difference of Temperature between Two Volumes of Air is an important aid in effecting natural ventilation. The laws upon which this depends, and the calculation of the velocity of air under such conditions, have already been given. It is manifest that the heating and cooling of air must be constantly going on; such changes of temperature and movements of air in rooms are produced by the heat of the sun's rays, by fires, gas, animal heat, &c., and by the cooling effects of windows, walls, &c. The greater the difference of temperature between two bodies of air the greater their mutual action, and consequently the greater the velocity through inlets and outlets. The velocity and quantity passed through inlets is also greater for increased difference of level between inlets and outlets, as is apparent from the formula (*ante*).

The usual conditions and movements of air prevailing in ordinary dwelling-houses are as follows:—The air is warmed by some or all of the sources indicated above, its density is reduced, and the air is relatively lighter, and therefore ascends. If there is no proper outlet provided in the ceiling or apex of the roof it soon cools by contact with cold surfaces, as windows, &c., and falls again into the room in its vitiated state to be re-breathed by the occupants, and oftentimes causing unpleasant draughts. A draught experienced near a window may be due to the falling of the air cooled by the window surface, and not, as may be imagined, to air passing through badly fitted joinery. If the internal temperature of a room is higher than the external, the warmer air will have an outward tendency, whilst the cold air, being heavier, will naturally force its way in to take the place of the warm air discharged through the outlets.

The ventilating action of the ordinary fire in dwelling-houses is as follows :—The heat raises the temperature of the air in the chimney, and thus creates a rapid upward draught, causing more air to enter the room to take the place of that discharged. If suitable inlets are not provided, the required air, which is absolutely essential for combustion, is drawn from every available source, through spaces round windows and doors, cracks, &c.; and when these and other sources fail, air is sometimes drawn down the chimney, causing it to smoke by setting up a double current in the shaft. The ordinary fireplace extracts air from a room so powerfully that, if proper provision in the shape of an air "inlet" is not provided, it will draw the necessary air for combustion into the room from all sorts of sources, whether good or bad. It may be drawn from cellars or basements, untrapped drains, unventilated water-closets, and through badly fitting doors or windows; so that in this way, and under the conditions indicated, a fire may become a source of danger in drawing impure air into a room, or a cause of draught by attracting air through small spaces at a high velocity.

Every room should, therefore, be adequately provided with "*inlets*" for fresh air, and "*outlets*" for foul air; and no room intended for human habitation should be constructed without a fireplace with a properly built flue.

For the *ventilation of rooms without fireplaces and flues*, the model by-laws of the Local Government Board prescribe that such room must be provided with "special and adequate means of ventilation by a sufficient aperture or air shaft, which shall provide an unobstructed sectional area of 100 square inches at the least." To this clause "Knight's

Annotated Model By-laws" gives the following note:—"A room without a fireplace and chimney flue is always to be regarded as less wholesome than one in which a proper fireplace is provided, for even though a fire be rarely lighted, the draught up the chimney flue will usually be such as to draw a considerable quantity of vitiated air out of the room, and the chimney will thus afford most valuable ventilation to the room. . . . . Hence this clause is intended to apply to habitable rooms unprovided with any fireplace and chimney; and accordingly it prescribes that any such room is to be provided with some special ventilator having a sectional area somewhat approximating to that of an ordinary chimney flue. The latter usually measures 14 in. by 9 in., thus giving a sectional area of 126 square inches, and the clause prescribes at least 100 square inches, which would be met by a grating in a wall or chimney stack 10 in. by 10 in.; or 12 in. by 9 in."

THE DOWNWARD PRINCIPLE OF VENTILATION.

In this system, which generally combines both natural and artificial processes, the inlets for pure air are placed at or near the ceiling, and foul air is extracted near the floor level. In respect to this method, the following remarks of Dr. Parkes, in his "Practical Hygiene," will be of interest:—"By some it has been argued that it is better that the foul air should pass off below the level of the person, so that the products of respiration may be immediately drawn down below the mouth, and be replaced by descending pure air. But the resistance to be overcome in drawing down the hot air of respiration is so great that there is a considerable waste of power, and the obstacle to the discharge is sometimes sufficient, if the extracting force be at all lessened, to reverse the movement, and the fresh air forces its way in through the pipes intended for discharge. *This plan, in fact, must be considered a mistake.*

. . . . In the case of vapours or gases, the proper place of discharge is above; but heavy powders, arising in certain arts or trades, which from their weight rapidly fall, are best drawn out from below." The downward principle of ventilation was also unfavourably reported on by the Board of Investigation, which was composed of experts appointed by the United States Government to examine into the various systems of ventilation for the purpose of recommending the most suitable method for the ventilation of the Capitol at Washington, in the following terms:—"The relative merits of the upward *versus* the downward systems of ventilation may be estimated from the following considerations:—

"1. The direction of the currents of air from the human body is, under ordinary conditions, upwards, owing to the heat of the body. This current is an assistance to upward, and an obstacle to downward, ventilation.

"2. The heat from all gas-flames used for lighting tends to assist upward ventilation, but elaborate arrangements must be made to prevent contamination of the air by the lights if the downward method be adopted.

"3. In large rooms an enormous quantity of air must be introduced in the downward method if the occupants are to breathe pure fresh air, or about three times the amount which is found to give satisfactory results with the upward method.

"4. In halls arranged with galleries, the difficulty of so arranging downward currents that, on the one hand, the air rendered impure in the galleries shall not contaminate that which is descending to supply the main floor below, and, on the other hand, the supply for the floor shall not be drawn aside to the galleries, is so great that it is almost an impossibility to effect it.

"For these and other reasons the Board are of opinion that the *upward method* should be preferred."

The ventilation of the French Chamber of Deputies, which is on the *downward principle*, is also apparently (according to an official report made by M. Trélat) in a very unsatisfactory condition: "The fresh air is delivered at the top of the room, and the currents of air are strong and varied,

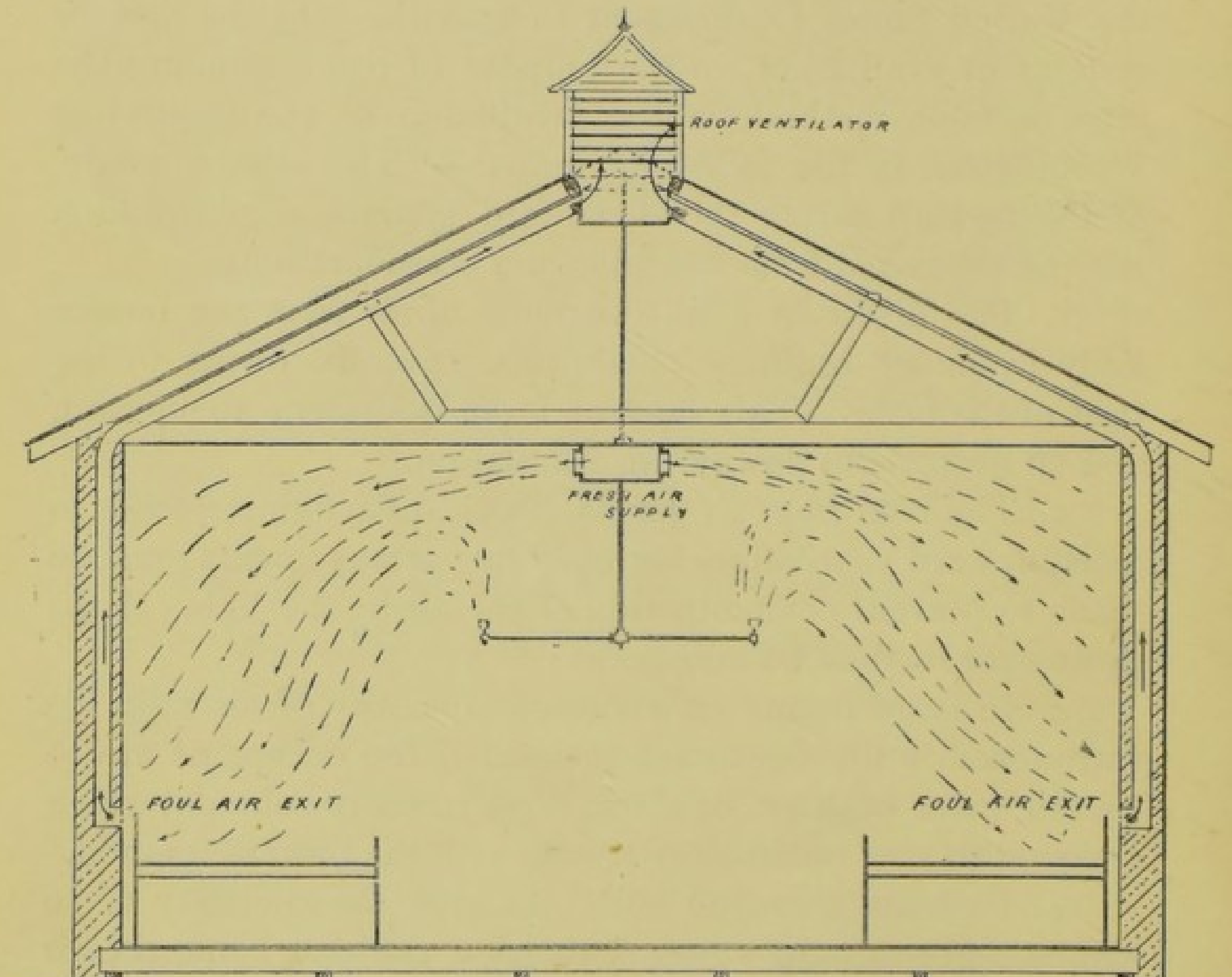

FIG. 2.

causing great discomfort. The air is delivered by fan propulsion at the ceiling, and is taken out at the floor, giving *a downward system of ventilation*. The apparatus is powerful enough to change the air in the chamber every six minutes; but it can only be worked slowly, owing to the draughts produced, and the *air vitiated by respiration is brought back to be re-inhaled.* M. Trélat, as the result of his observations, emphatically condemns downward ventilation."[1]

The accompanying cross-section (Fig. 2) illustrates an instance carried out, I believe, in Birmingham, of the application of mechanical *ventilation on the down draught principle* by impulsion, or the plenum system, to a hospital ward. The fresh air is mechanically propelled into the room through ducts carried along the centre of the ceiling, from which it is projected, and descends on to the patients, passing away through the foul air exits placed at the head of each bed.

These are, as is obvious from the diagram, most undesirable conditions under any circumstances, but in the case of rooms for the treatment of the sick no system could be much more dangerous and insanitary. The whole of the vitiated air, both from combustion and respiration, and including the organic matter and exhalation of the sick, is drawn towards the heads of the unfortunate patients to be re-breathed by them instead of pure air, which they in particular need. If the foul air outlets are placed at the side of the bed, or just above or below, the results are practically the same, as also is the case when the fresh air supply is introduced at the upper parts of the side or end walls.

The air of a room, vitiated as it usually is chiefly by respiration and combustion, is rendered warm, and naturally ascends to the ceiling, which is without doubt the proper place for extracting foul air by means of suitable outlets; and these, combined with the admission of fresh air at the lower parts of the room, at a low velocity, seem to give the only natural and satisfactory method of ventilation.

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[1] "Ventilation and Heating," J. S. Billings, M.D. (Washington); and Report (1891) of M. Trélat to French Chamber of Deputies.

CHAPTER V.

Inlets, Outlets, and Cowls.

FRESH AIR INLETS.

Inlets, whether in the shape of window openings, ventilating fireplaces or stoves, or special ventilator openings, require to be introduced in such positions and in such a manner as not to cause draughts or discomfort of any kind. If the cold incoming air flows against the body moisture is evaporated, and a sensation of cold is felt, which generally results before very long in the inlet being closed, and ventilation thereby suspended. Again, if the inlet be at the floor level, it may give rise to cold feet, and, in addition, is liable to become fouled by dust and sweepings from the floor; although, theoretically, this is the proper place, but for the practical reasons mentioned, it is not advisable to place it here, at any rate, unless the inlet air be first warmed.

The best position for the fresh air inlet, the air entering without being warmed, is at a height of about 7 ft. from the floor line, *i.e.*, just above the heads of the occupants—the inflowing current being directed upwards in a slanting direction towards the centre of the room, and well distributed and diffused by sub-dividing it into many small currents, or by enlarging the mouth of the inlet, so that the air sinks gently without causing draughts or discomfort.

In order to secure uniform distribution the total inlet space provided is better not confined to one opening, but should be divided into smaller inlets placed at different parts of the room. All corners and recesses should be provided with inlets to prevent the air stagnating. By this means a satisfactory result may be expected. Of course, inlets must not be placed too near outlets, or a mere direct current may be set up from one to the other without ventilating the rest of the room. An instance of this has been pointed out by the late Mr. Ernest Turner, F.R.I.B.A., at the Reform Club, London. If the inlet air be warmed it may with advantage be introduced at a much lower level than above mentioned, and a good plan, where the additional expense is no objection, is to provide both warm air inlets at the lower level and cold air inlets at the higher level.

It is, of course, impossible to fix upon any uniform size for the ventilating sectional area of inlets and outlets which will be suitable under all the varying conditions of temperature, wind, weather, &c., but in England an area of about 24 square inches per head for inlet and the same amount for outlet is about the proportion to adopt. Owing to the expansion of the heated foul air it has been suggested that the outlet area should be larger than the inlet, but this is not of much practical importance, and may be neglected, so that an outlet area equal to the inlet will give good results. Arrangements should always be made to admit of the ventilating openings being closed or reduced according to the weather or velocity of the outside air.

The area of individual inlets should not exceed about 50 square inches, or enough for two persons, and that of outlets about 1 square foot, or enough for six persons. The inlet should be trumpet-shaped where discharging into the room, as this assists in the distribution of the air.

The air admitted through inlets should always be from the external atmosphere, and never, if it possibly can be avoided, from a staircase or passage. Town air is generally loaded with numerous particles, "blacks," &c., and should, therefore, be filtered by means of porous flannel, muslin, or canvas spread over the inlet opening, which will then require to be a little larger in proportion. This screen, however, should be very frequently removed and cleansed, or it will soon get blocked, foul the air, and impede the ventilation.

The velocity of inlet air may be from 3 ft. to 5 ft. per second, provided its distribution and delivery is satisfactorily accomplished without draughts. In designing or arranging inlets the aim should be to make the air channels as short as possible, to prevent the collection of dust, &c., and to so construct them as to admit of easy and frequent cleansing; they should also be straight, and should have smooth sides to prevent loss of velocity by friction. *Movable* gratings will be necessary at the ends.

FOUL AIR OUTLETS.

The best position for the foul air outlets will be at the highest point of the room, at or near the ceiling level, but the arrangement of the inlets must be taken into consideration in determining their exact position. The outlet tubes should be as straight as possible without angles, and are best circular in shape, with smooth internal surfaces to reduce the friction to a minimum. Their action will be more uniform and certain if they can be enclosed within walls, so as to prevent the exit air from being cooled in the shaft. The discharge end of the outlet may be covered with some suitable form of cowl, which will aid the aspiratory power of the wind, prevent a blow down the shaft, and exclude rain. A down draught may arise from any of the following causes:—Wind forcing its way down the shaft into the room; rain entering and lowering the temperature of the air in the shaft, thus making it heavier than the air of the room; also the air may be cooled by passing through an exposed tube; and sometimes a more powerful outlet may reverse the current. The unpleasant effects of down draughts may be mitigated by fixing baffle plates (see Fig. 1), or valves may be inserted in the outlets.

All outlets in the same room should, as far as possible, be under similar conditions. They should commence at the same level and be of the same height, and if possible have about the same amount of exposure to sun, wind, and rain, so that their action may be uniform and the discharge approximately equal. The application of artificial heat will greatly increase the certainty of action and the discharge of outlets. The ordinary chimney flue is itself an excellent extraction shaft, and its heat may be further utilised by surrounding it with foul air tubes built in the chimney breasts, and opening into the room near the ceiling. With a moderate fire, the velocity of the up current in a chimney flue is from 3 ft. to 6 ft. per second, and with a large fire is often increased to 9 ft. per second and over. With a common-sized flue, 14 in. by 9 in., and a velocity of 6 ft. per second, a volume of nearly 19,000 cubic feet of air is extracted per hour, provided the flue is straight and the friction small. This rapid extractive force may at times reverse the current in the other and less powerful outlets, and down draughts may occur unless ample inlet provision is made.

Where the supply of air to the fire is deficient, a double current is set up in the flue, as previously referred to, and a down draught and smoky chimney results. Such may, however, be cured by the liberal provision of suitable inlets.

The Building Rules issued by the Board of Education,* for the guidance of Architects in planning and fitting up

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* July 7th, 1905. (Extracted by permission of the Controller of His Majesty's Stationery Office.)

Public Elementary Schools, recommend as follows :—"The chief point in all ventilation is to prevent stagnant air; particular expedients are only subsidiary to this main principle.

"There must be ample provision for the continuous inflow of fresh air, and also for the outflow of foul air. The best way of providing the latter is to build to each room a separate air chimney, carried up in the same stack with smoke flues. An *outlet* should be by a warm flue or exhaust, otherwise it will frequently act as a cold inlet. *Inlets* are best placed in corners of rooms furthest from doors and fireplaces, and should be arranged to discharge upwards into the room. Gratings in floors should never be provided. Outlets in ceilings must not open into a false roof, but must be properly connected with some form of extract ventilator.

"The *size* of the *inlets and outlets* must be carefully adapted to the method of ventilation proposed. A much larger area is required when no motive force is provided.

"It is as well that the *windows* should have both the top and bottom panes arranged to open inwards as hoppers.

"Besides being continuously ventilated by the means above described, rooms should, as often as possible, be flushed with fresh air admitted through open windows and doors. *Sunshine* is of particular importance in its effects on ventilation and also on the health of children.

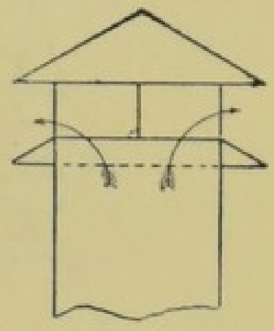
"Although lighting from the left hand is considered so important, ventilation demands also the provision of a small swing window as far from the lighting as possible, and near the ceiling."

COWLS.

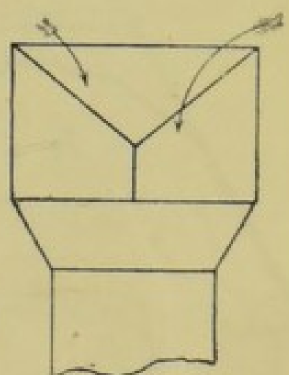
The real object and function of a cowl is merely to prevent the entrance of gusts and eddies of wind down the tube or shaft to which it may be fixed, and to assist or tend to maintain the aspiratory power of the wind. The investigations, however, of a committee of the Sanitary Institute indicate that the majority of cowls possess no practical advantages over the simple open tube. A simple flat, horizontal plate, fixed over the mouth of the shaft or pipe, seems to be almost the extent of elaboration required, the object being to keep out the gusts of wind that may be deflected downward from the adjoining roofs and walls.

Fixed Upcast Cowl.

FIG. 3.



Cowls will not prevent *downward suction*, neither will the familiar revolving mechanisms effect *upward suction*. As to moving arrangements in general, they require constant attention, often make a disagreeable noise, and are liable to get out of order, and then do more mischief than good.

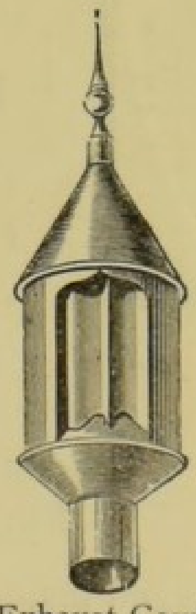


Fixed Downcast Cowl.

FIG. 4.

Whatever may be the external form of cowls, the general principle upon which they are all based is indicated by the accompanying sketches (Figs. 3 and 4). The "downcast" has a trumpet mouth and inverted conical cap.

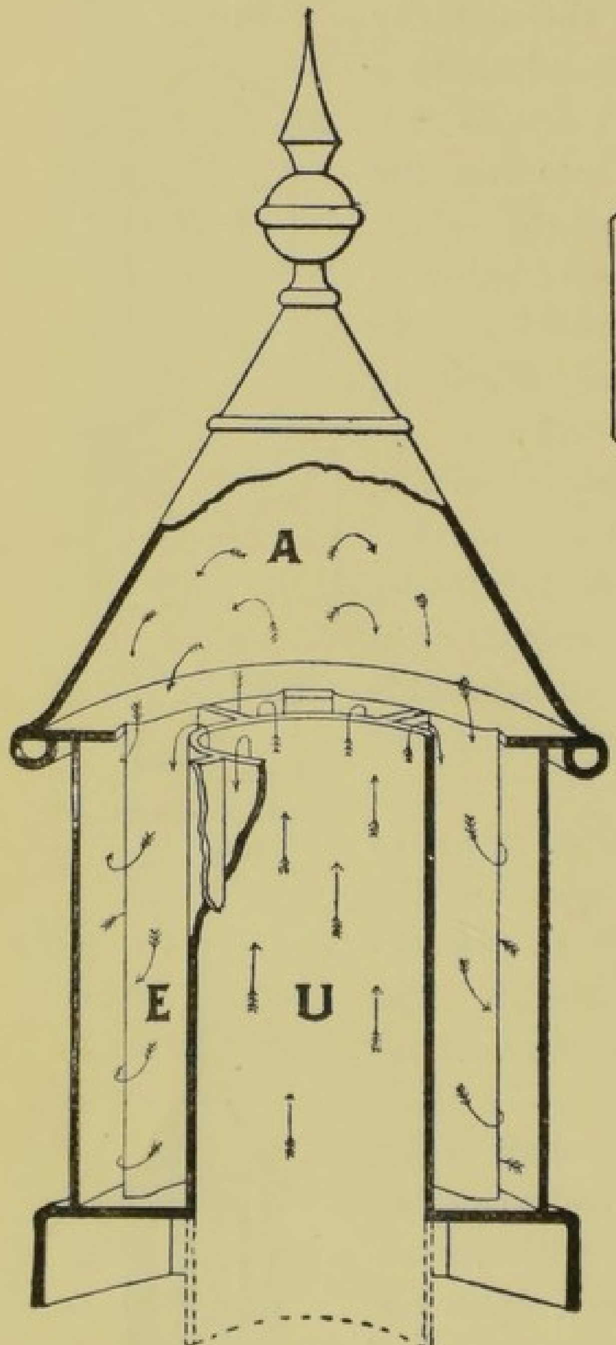
The extracting efficiency of a shaft is dependent upon the size of its head or outlet, across which the wind blows with its aspiratory action, and not so much upon the diameter of the tube itself. If the cowl afford a larger outlet area than the cross-section of the shaft to which it is fixed, the current in the shaft will be increased. This, it will be noticed, is the case in Mr. Robert



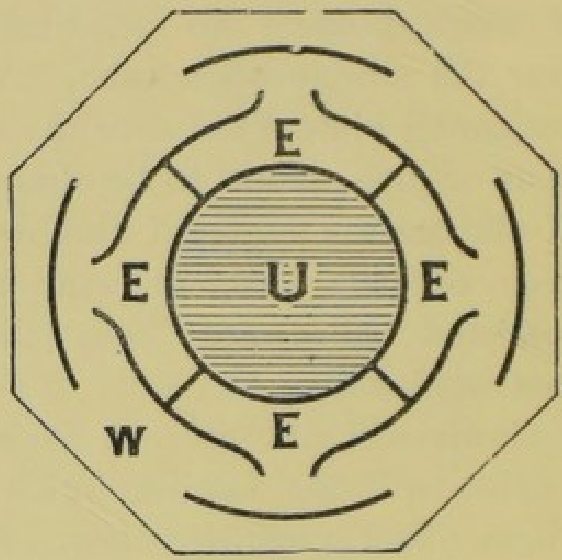
Exhaust Cowl.

FIG. 5.

Boyle's cowls (Fig. 5), where the area of exhaust is much larger than the area of the tube. These cowls are also



Vertical Section.
FIG. 6A.



Plan.
FIG. 6.

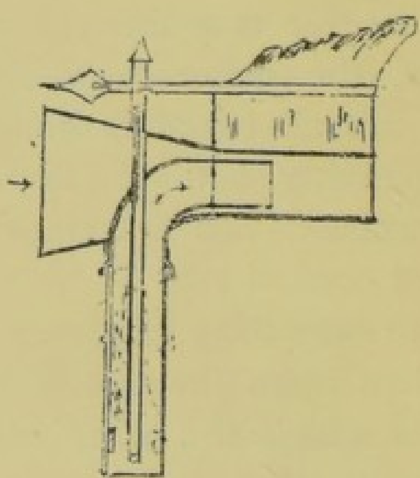


FIG. 7.

arranged inside with fixed blades, diverting the direct action of the wind and assisting the exhaust.

Barker's Automatic Air-extracting Ventilator is designed for the extraction of vitiated air from the apex of a roof. Its construction, and the direction of the exit air current, is well illustrated by the accompanying vertical section and plan (Fig. 6 and Fig. 6A). The ventilating action of the apparatus is described as follows:—

External air currents enter the opening W (Fig. 6), and passing across the outlet openings of extracting chambers E, exhaust the air from same. These draw their supply downwards from the air chamber A (Fig. 6A), and this chamber in turn draws its supply upwards from the central shaft U, which is connected to the apartment to be ventilated. This ventilator is said to give a high extraction duty, with a minimum amount of external air current to actuate it. The ventilator is manufactured of galvanised annealed steel enamel painted by Mr. F. W. Barker.

A cowl with a curved head and trumpet oval-shaped mouth (Fig. 7), moving so as to always present its back to the wind, is well adapted to assist extraction, but there is the general objection to moving arrangements of the uncertainty of action without constant attention.

CHAPTER VI.

Practical Applications.

Some simple arrangements and appliances for admitting fresh air into rooms will now be briefly described and illustrated:—

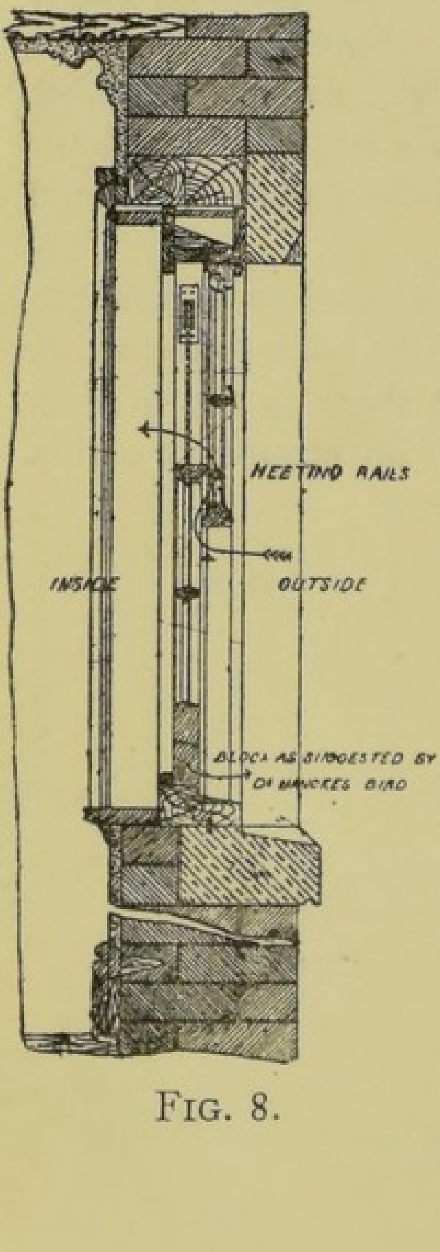


Fig. 8.

APPLIANCES OR ARRANGEMENTS IN CONNECTION WITH WINDOWS.

All windows should be so constructed as to open *easily* both top and bottom to the external air, so that the room may be thoroughly flushed through with air when required. The Local Government Board Model Bye-laws, as previously referred to, provide that at least one half shall be made to open, such opening to extend to the top of the window.

Dr. Hinckes Bird has suggested a simple arrangement, as illustrated in Fig. 8, of admitting fresh air between the meeting rails of the window sash. The lower sash is simply raised some few inches, and a block of wood is inserted. The air enters, as shown by the arrow in the figure, and is directed upwards. This arrangement is very simple, easily adopted, and is well suited for bedrooms and small class property, where nothing but some such inexpensive and simple expedient is likely to be used.

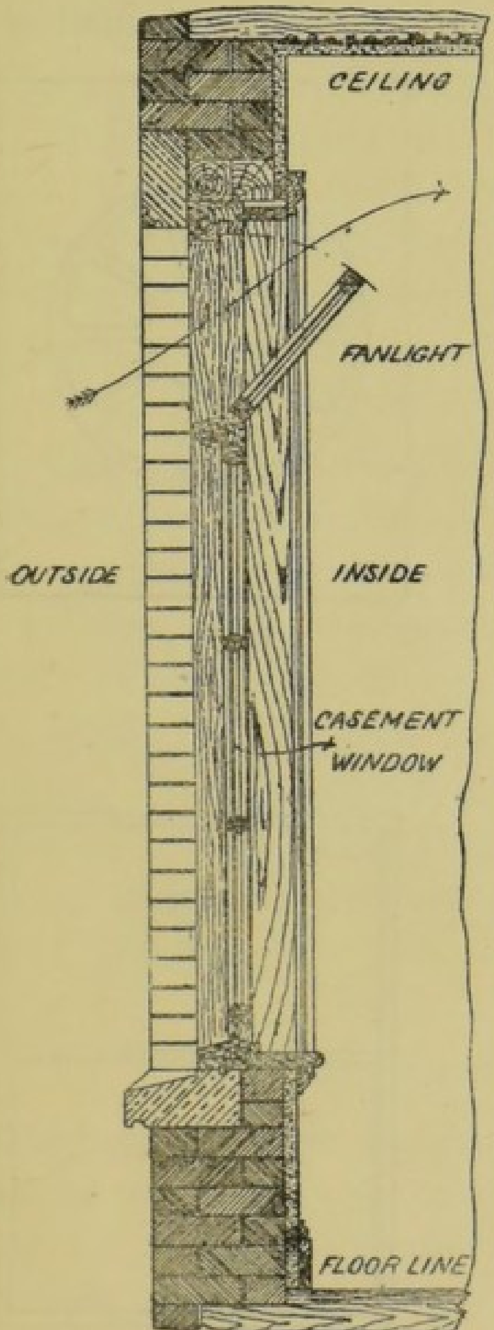


FIG. 9.

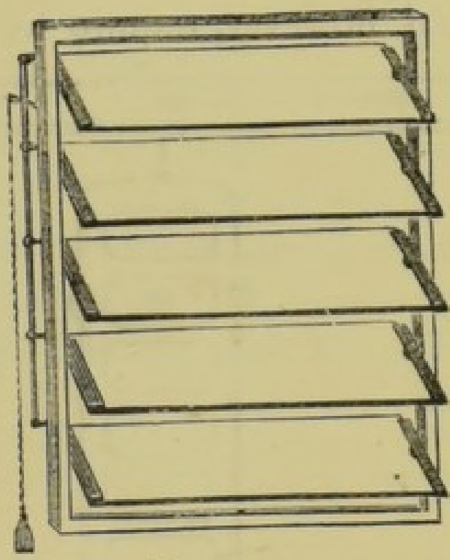


FIG. 10.

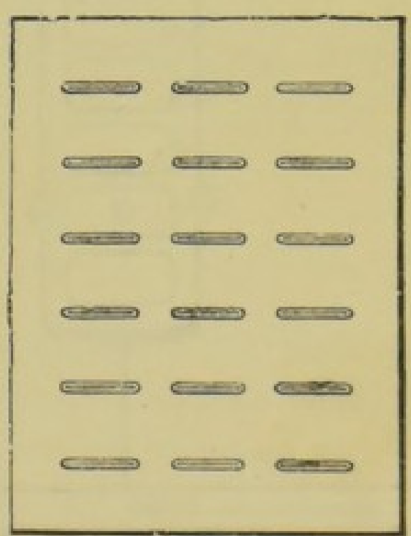
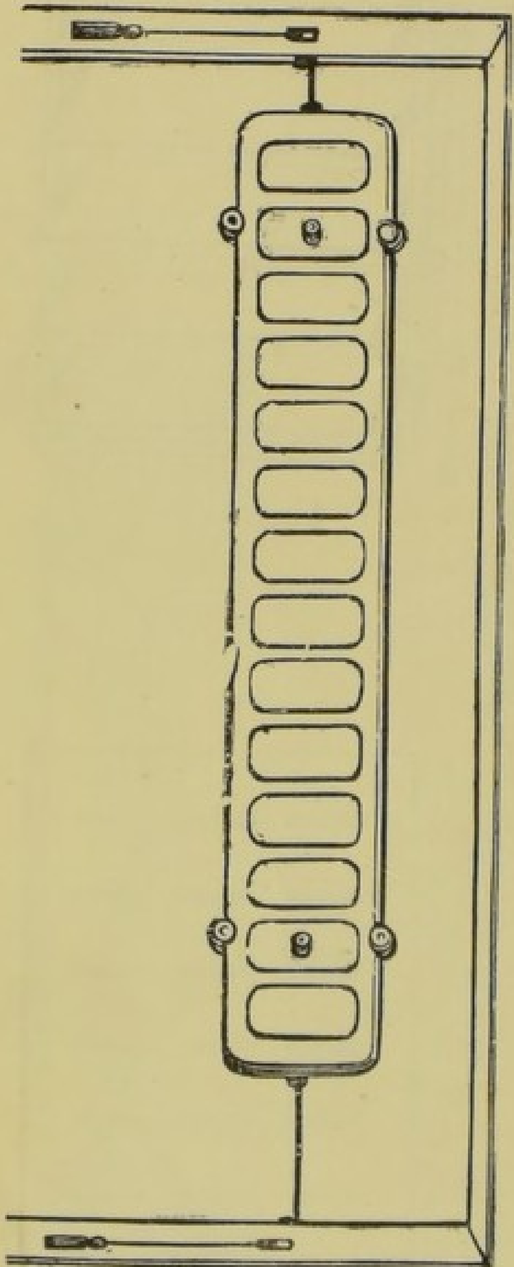


FIG. 11.

Mr. Tobin has suggested a plan, which consists in cutting slits between the two sashes, or piercing them with auger holes, so that a current may enter when the window is shut;

cotton wool may be placed in these openings, if required, to filter the air and prevent the admission of "blacks." This would, however, require to be very frequently cleaned or re-



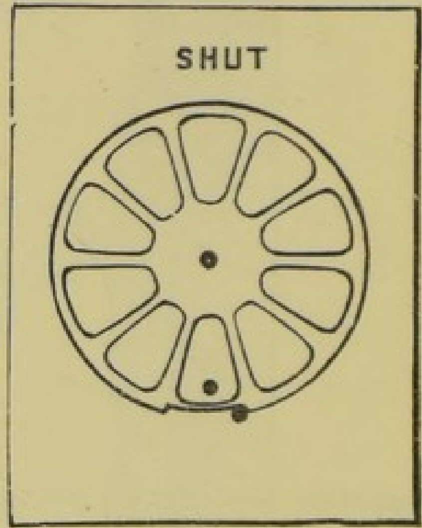


FIG. 13.

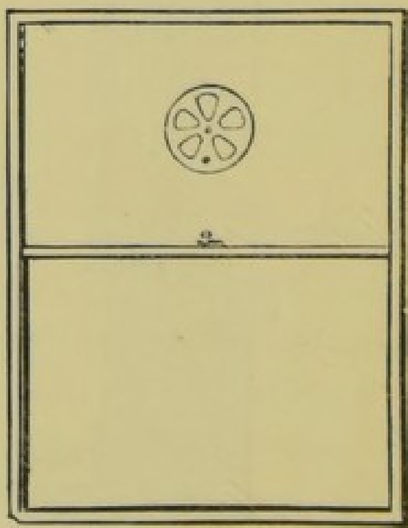


FIG. 12.

FIG. 14.

newed. Air may also be admitted without draught by having double windows, or one or more double panes, provided with an opening at the bottom of the outer and at the top of the inner one, thus admitting the fresh air in an upward direction.

Windows may also be constructed to admit of the top portion opening inwards, as in Fig. 9, directing the incoming air towards the ceiling.

The glass louvre ventilator (Fig. 10)[1] is constructed of slips of glass mounted in a metal frame, and is opened or closed by pulling a string. Where *Venetian blinds* are in use, these may also be utilised to direct the inflowing air upwards.

Small slits are sometimes cut in window panes to admit air (Fig. 11), and may be closed by a suitable slide when found necessary. These are often seen in hospitals.

A "hit and miss" opening may be made, or an arrangement as illustrated in Fig. 12.

Another simple plan is to let down the upper sash, and fill the opening with wire-gauze or canvas, to prevent the admission of soot, dust, &c.

Cooper's Ventilator (Figs. 13, 14) may be fixed to windows. It consists of a circular plate of glass, which moves on a pivot passing through its centre, and through a sheet of glass in which holes are made, corresponding with those in the moveable disc.

OPENINGS IN THE WALLS.

Ellison's Conical Bricks are sometimes let into walls. They are perforated with conical holes of about ¼ in. diameter externally, and 1¼ in. internally, the depth being 4½ in. The usual size is 9 in. by 3 in., and the total area of the several openings is about twelve square inches. They produce little draught, and diffuse the air passing through them.

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[1] This class of ventilator, together with Figs. 11, 12, 13, and 14, is manufactured by Messrs. H. W. Cooper & Co., London.

The Sherringham Valve (Fig. 15) is a convenient means of ventilating rooms through the wall. It consists of an iron box with a valve, and is fitted into an opening made in an

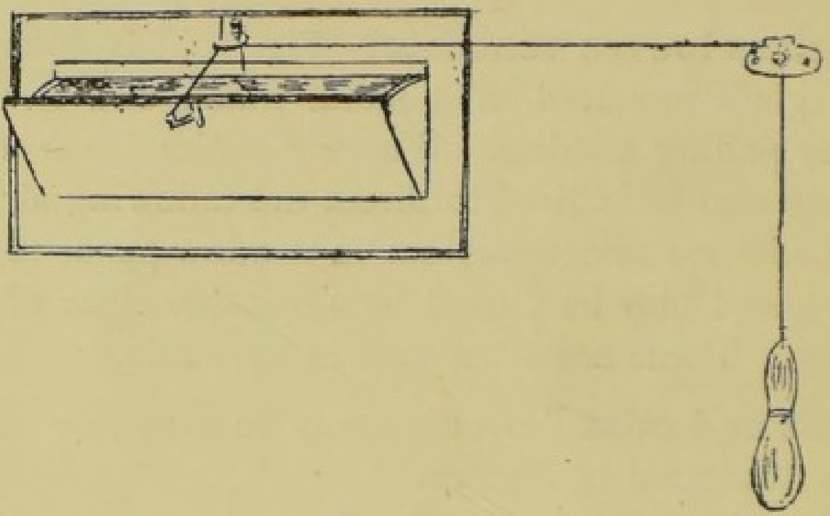
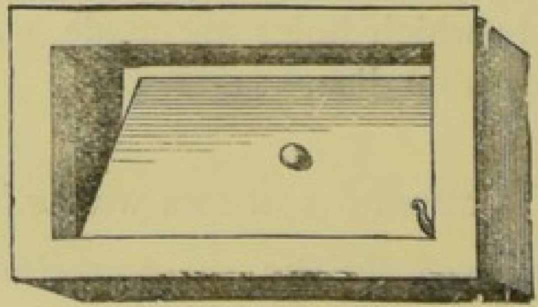


FIG. 15.

external wall. The valve is balanced by a counterpoise, is hinged to swing into the room, and can be regulated by a cord. These valves act as inlets, and the air is directed towards the ceiling, thus preventing a direct draught.

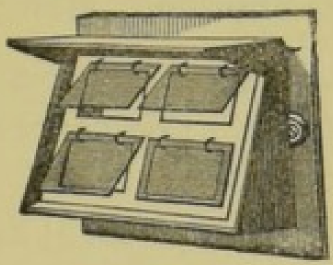


Arnott Valve.

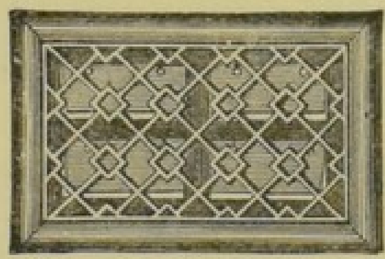
FIG. 16.

Several of such valves in different parts of the room (but not opposite each other) should be fixed in preference to one large one. The area of the internal opening is about twenty-seven square inches, the usual size being 9 in. by 3 in.

Dr. Neil Arnott devised the valve (Fig. 16) which bears his name, by which the warm vitiated air accumulated at the ceiling is passed off into the chimney flue. An opening is made through the chimney breast, near the ceiling, and an iron box inserted, in which is a light metal valve, fitted to

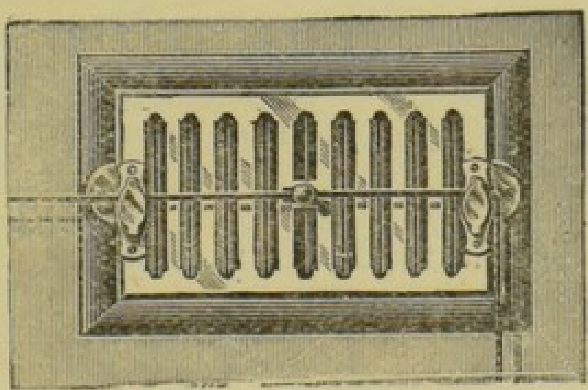


Back View.
FIG. 17.



Front View.
FIG. 18.

swing towards the flue, to allow the passage of air from the room to the chimney. Whenever the pressure in the chimney exceeds that in the room, the valve shuts to prevent a reflux. Unless these valves are well made and padded, they are apt



Chimney Breast Valve, with brass hit and miss front.
FIG. 19.

to make a noise, and when they get out of order they often admit "blacks" and air from the chimney. In the more modern form of this valve, several small flaps of talc or mica (Figs. 17, 18, and 19), which hang in front of holes in the plate, are substituted for the one metal flap in Arnott's valve.

These valves are light, rigid, incorrodible, and are so sensitive that they open with the slightest up-current and close against down-draughts, preventing the passage of smoke into the room. The sketches given (Figs. 17, 18, and 19) illustrate the valves as manufactured by Messrs. Shorland, Manchester.

Kite's Counterpoise Valve Ventilator (Figs. 20 and 21), for fixing in chimney breasts, is a good one. The counterpoise automatic valve, which guards against a "blow back," is very sensitive in its action, and does not make the usual flapping noise so common with these ventilators. The projecting

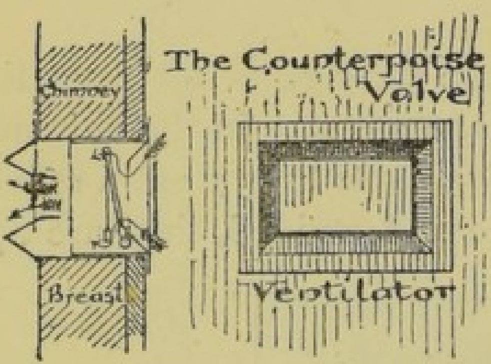
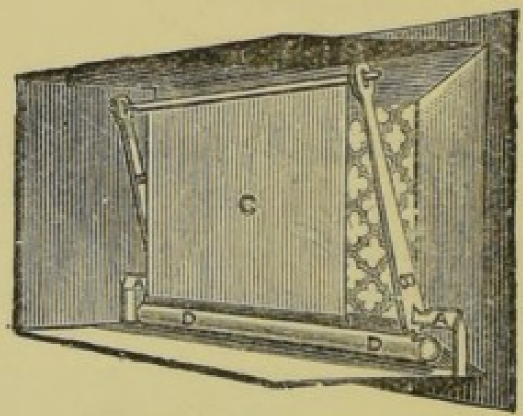


FIG. 20.



Kite's Counterpoise Valve.
Back view, showing valve open.
FIG. 21.

V pieces are intended to direct the smoke and heated air away from the opening.

Before ventilating into a chimney breast it is important to first ascertain whether the chimney has a *good up-draught;* if not, a chimney breast ventilator should never be fixed in it, as a "smoky chimney" will thereby be made worse.

Shafts by Side of Chimney.—A separate ventilating shaft leading from an opening into each room, near the ceiling level, acts well, and the heat of the chimney assists the up-current. These shafts, of course, must be constructed when the house is being built.

An arrangement for cold air inlet, which has been adopted in the army, is illustrated in Fig. 22,[1] and is placed about 9 ft. from the floor. The ventilation of the barracks is based on

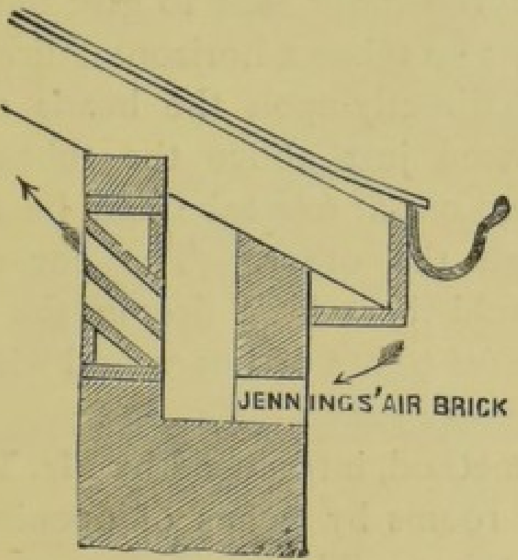
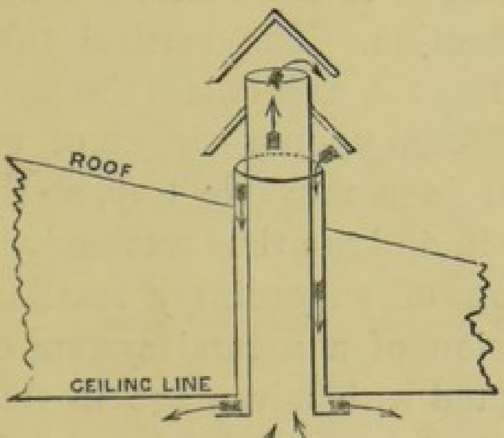
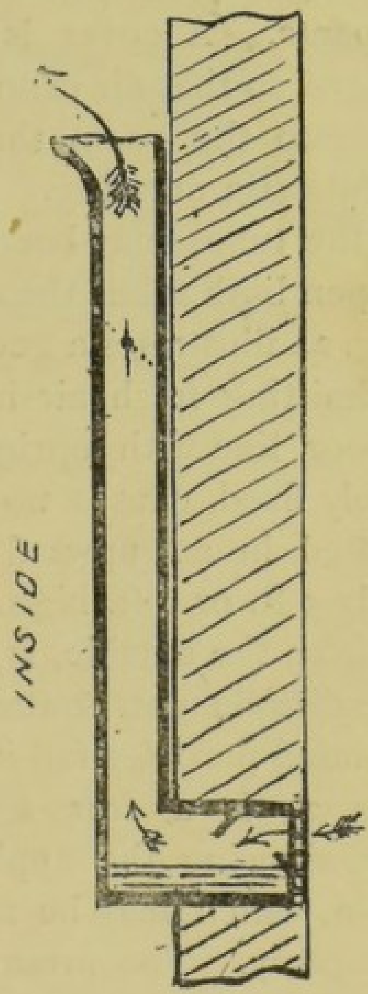


FIG. 22.



McKinnell Ventilator.
FIG. 23.



Tobin Tube.
FIG. 24.

the plan of *natural ventilation*, with outlet shafts from the highest point of the room.

The McKinnell ventilator (Fig. 23)[2] is well adapted for

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[1] Dr. Parkes' "Hygiene."

[2] Professor Corfield's "Laws of Health."

small rooms with no rooms over. The arrangement consists of two tubes, one inside the other, which pass through the ceiling and roof into the outer air. A rim or "baffler" is fixed round the lower end of the inner tube to give the fresh air which enters between the two tubes a horizontal direction, in order that it may not fall directly upon the heads of the occupants. A cover is placed just above the tubes, and arranged so that air cannot go out at one tube and be blown back into the room through the other. The cover also prevents rain entering. Should there be a fire in the room both the tubes may become *inlets*, but if doors and windows are open both tubes then become *outlets*.

Fig. 24 illustrates a good method, introduced by Mr. Tobin, of admitting fresh air into rooms by means of openings at the floor line with upright tubes. This arrangement, when suitably fixed, causes no draught in the room, the air being admitted in an upward direction. The vertical tubes are usually 5 ft. or 6 ft. high. The air, as it enters the horizontal tube from the outside, is deflected upon a surface of water or dilute disinfectant contained in a movable tray, so that the suspended particles fall into it, and are thus retained.

Fig. 25 is a cross-section of an ordinary small terrace house, showing the application of a natural system of ventilation, which may be adopted with advantage in this class of property. The arrangement is very simple, and if constructed as the house is being built the additional expense would be very trifling, whilst the wholesomeness of the atmosphere of the rooms would be greatly enhanced. The diagram explains itself.

The whole of the appliances in the system as shown, including a roof ventilator, piping, junctions, knees, inlet bracket, &c., can be obtained in strong galvanised iron at a cost of from £4 to £5, exclusive of fixing.

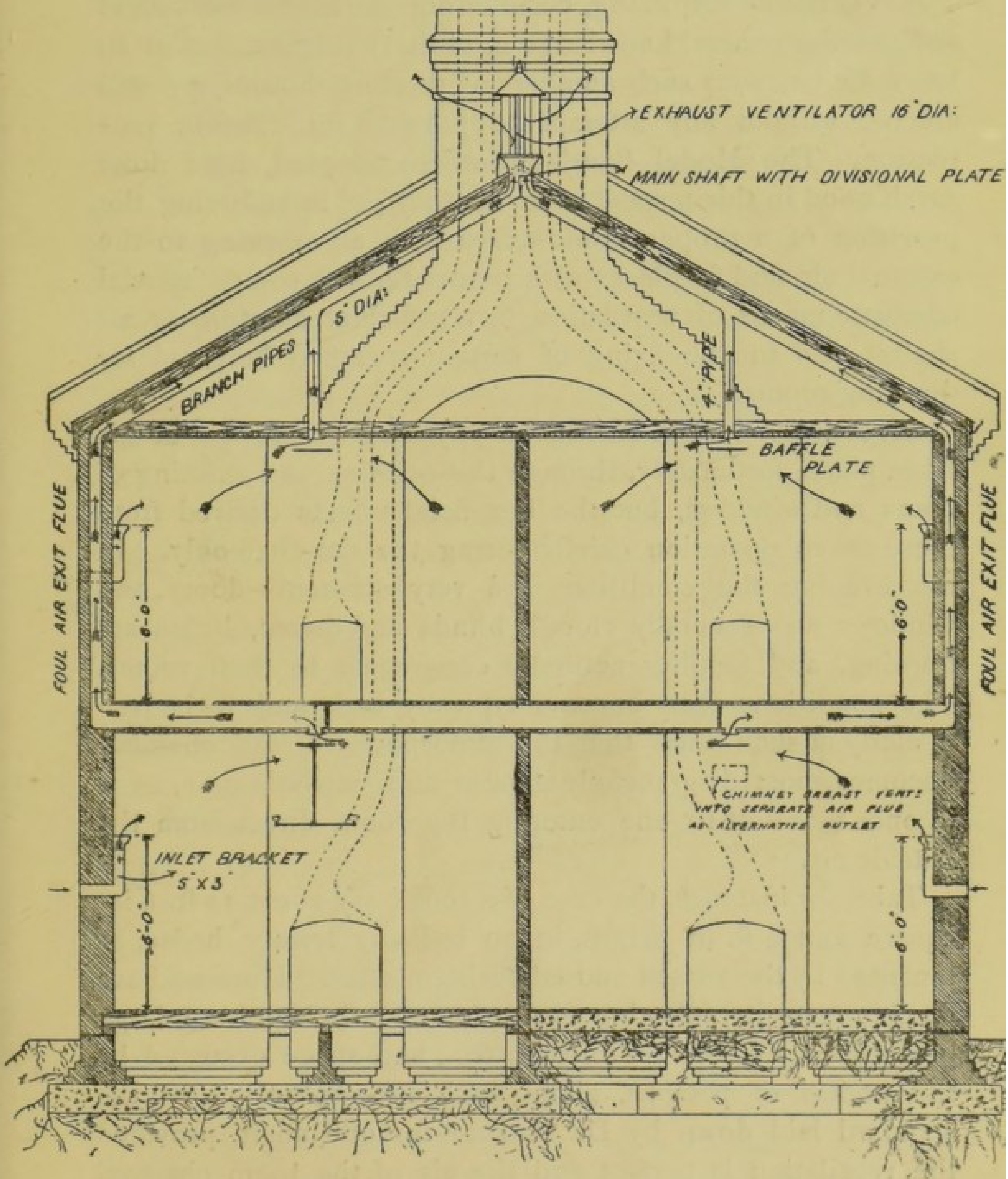
EXHAUST VENTILATOR 16" DIA:
MAIN SHAFT WITH DIVISIONAL PLATE
5" DIA:
BRANCH PIPES
4" PIPE
BAFFLE PLATE
FOUL AIR EXIT FLUE
FOUL AIR EXIT FLUE
6'-0"
6'-0"
INLET BRACKET
5"X3"
6'-0"
6'-0"
CHIMNEY BREAST VENTS
INTO SEPARATE AIR FLUE
AS ALTERNATIVE OUTLET

FIG. 25.

It is certainly surprising, considering the modern advances and popular general knowledge in sanitary science, that at so late a date as 1907 such numbers of dwelling-houses are still erected without any attempt to provide for efficient ventilation. The Model Bye-laws, where adopted, have done much good in this respect as far as they go, in enforcing the provision of a proper window area with an opening to the external air, and fireplaces with proper flues or some "special adequate means of ventilation by a sufficient aperture or air shaft," also in the fixing of certain specified heights[1] for dwelling rooms.

Of course a certain amount of *perflation* or change of air takes place, fortunately, through the opening and shutting of doors and windows, but the beneficial effects derived from these are in operation chiefly during the day-time only. In the evening the conditions are very different—doors and windows are generally closed, blinds are drawn, lights are burning, and families naturally congregate to their rooms. The conditions then become typically bad, and it is particularly at such times that the atmosphere of the chamber becomes most disgracefully impure and unwholesome, as is at once manifest to one entering the room direct from the outside air.

Take, for instance, the case of a room, say about 12 ft. 6 in. square and 9 ft. in height, in an ordinary terrace house, as tenanted by the artisan and labouring classes. Here we have a cubic capacity, allowing for deductions for furniture, large projections, as chimney breasts, &c., and space occupied by the bodies of persons, about sufficient—according to the standard laid down by Dr. Parkes—for one adult, provided the ventilation is perfect and the air of the room changed

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[1] Bye-laws under Public Health Acts Amendment Act, 1890, s. 23.

three times per hour. But what are the actual conditions prevailing in numbers of such rooms? Doors, windows, and blinds, all closed or drawn, *and no provision whatever for ventilation;* often there may be five or six occupants in the room, which, as we have already seen, is only sufficient for one adult, even with perfect ventilation; the air strikes one on entering as being manifestly impure and much too hot for health or comfort; it is also over-saturated with moisture, highly charged with organic matter from the breaths and bodies of the occupants, and the carbonic acid derived from the breath and combustion of lights is found to be much in excess of the prescribed limit of permissible impurity. To these may oftentimes be added the stale smell left by previous tobacco smokers, and similar fumes also being given off by one or two of the present occupants. In addition to all this, in not a few cases are we likely to find the whole atmosphere of the house pervaded with some such smell as that derived from the cooking of kippers, or some equally odoriferous dainty!

The proper ventilation of bedrooms is also a matter of very serious neglect; the cubic space of the room is often over-monopolised with furniture and hangings from bedsteads, window curtains, &c., thereby blocking out the light and air essential for health; and, in addition to there being no proper "inlet" and "outlet," the windows and doors are frequently kept quite closed, as also sometimes is the register to the fire-place flue, should there happen to be one. In England bedroom windows can usually be kept open at the top a few inches all the year round.

All these conditions described naturally result in an intensely unwholesome atmosphere, which cannot be inspired for any length of time with impunity. It is a matter of common knowledge that from the nature of the constitution of the human system (and the same principle applies to all animal life), to maintain health we require to breathe *pure air*, just as pure food and drink are essential. In proportion as the artificial conditions under which we live deviate from those directly provided by nature, so will our health and strength wane. The aim and object of all ventilation is, as far as possible, to maintain the air in our houses and buildings in a condition of purity equal to that of the outside air.

The insanitary conditions described are by no means confined to the small class of dwelling referred to above. They, unfortunately, often obtain in many better class houses, only in these the rooms are usually larger, the cubic space per head is greater, and they are, therefore, less quickly vitiated, whilst the changes from room to room, as for meals, &c., afford a great help towards renewing the wholesomeness of the air.

CHAPTER VII.

Arrangements for Warming Inlet Air.

The arrangements hitherto described have been for the admission of cold air, unaided by any special application of artificial heat or other force, and dependent entirely upon the natural differences of temperature between the inside and outside air, and upon wind, &c.

These act well, and are oftentimes the only provision made, but it is always desirable, wherever possible, to have some arrangement for warming the inlet air when the temperature outside is sufficiently low to require it before discharging into the room; otherwise draughts are experienced, and ventilators then soon get closed and the ventilation consequently suspended.

The *warming of inlet air* must merely be considered as an auxiliary to *heating*, which latter should be carried out independently of the warm air supply. Air supplied for the combined purpose of ventilation and warming usually requires to be of such a high temperature as is not fit for healthy and comfortable respiration.

There are various methods and arrangements for the purpose of warming the fresh air supply, most of which are based on one of the following principles:—

1. Air is passed through boxes or chambers containing coils of *hot water* pipes. This is the best method, and is much preferable to steam. Mr. Saxon Snell's thermhydric stove is on this principle.

2. Air is passed into chambers behind or round iron grates

and stoves, as in Sir Douglas Galton's grate, or through air ducts in close proximity to and warmed by the heat from an ordinary fireplace constructed wholly of firebrick, the air having no contact with heated iron, which is a considerable advantage.

3. The air is sometimes warmed in a tube passing through a stove, as in George's calorigen.

A few of the arrangements for effecting the above purpose will now be briefly described:—

In **Mr. Saxon Snell's Thermhydric Stove,** a small boiler is fixed behind the grate, and communicates with a series of iron pipes alongside it, in which hot water circulates. The pipes are so arranged as to afford a large heating area, over and through which air is admitted to the room. The grate is fixed in the centre of the room, and the products of combustion are conveyed away by a smoke flue underneath the floor.

Mr. George's Calorigen is a form of gas stove consisting of two compartments, an inner and an outer, by which the fresh air current is conveyed from the exterior through a coiled tube placed in the outer compartment, and warmed by the gas which is burnt in the inner compartment, and then delivered into the room.

Dr. Bond's Euthermic Ventilating Gas Stove consists of four concentric vertical cylinders. Fresh air is admitted into the central and second annular chamber, and escapes at the top heated into the room. A ring-burner of atmospheric gas is placed at the bottom end of the first annular chamber, and the gaseous products pass off through the outer chamber to a flue.

The Manchester Stove is largely used for schools, hospitals, infirmaries, &c. Fig. 26 illustrates the general arrangement, the supply of fresh inlet air to the stove, and its exit in a warmed state into the room; also the arrangements of the flue for carrying off the smoke. Fig. 27 gives a detail

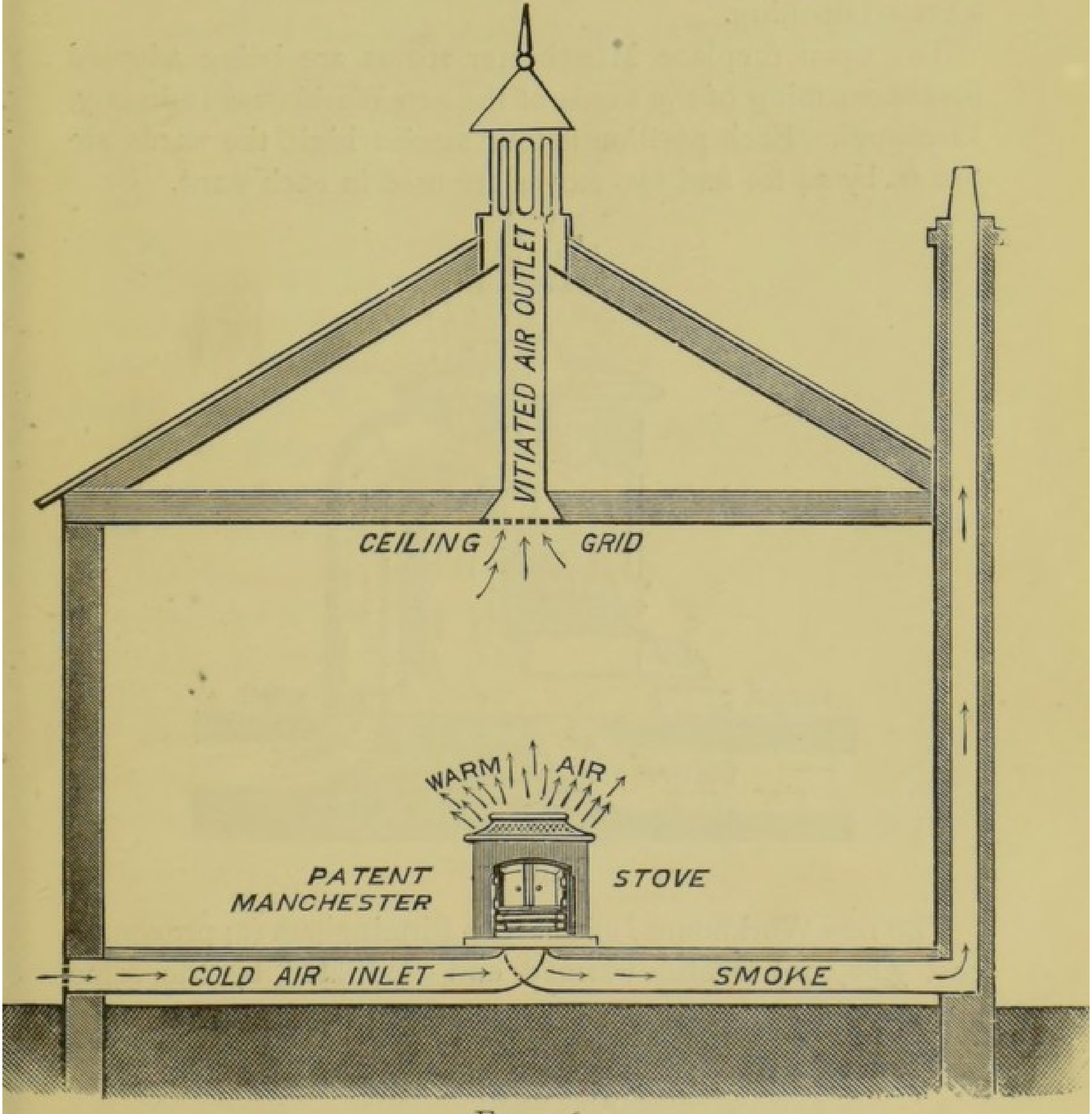


Fig. 26.

of the stove itself, showing the cold air supply brought along between the joists of the flooring, taken into the chamber at the rear of the grate with a firebrick back, carried through tubes round the mouth or hottest part of the smoke flue, and then discharged into the room at the top of the stove through a grated opening.

The open fireplace Manchester stoves are being adopted for the warming of the wards of the new Workhouse Infirmary, Liverpool. Each pavilion is four stories high, the wards are 110 ft. by 24 ft., and two stoves are used in each ward.

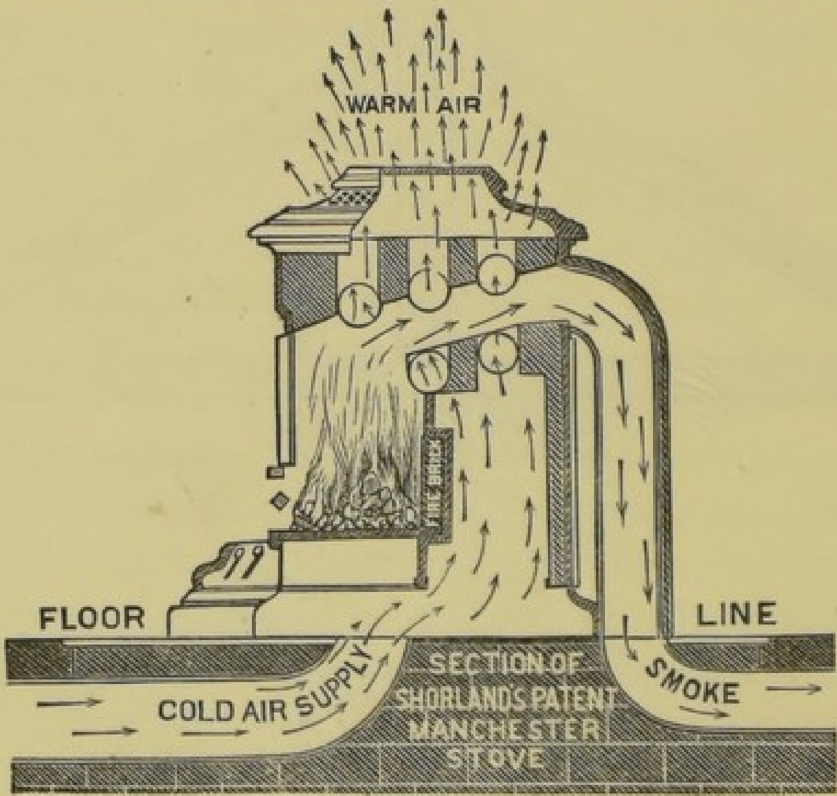


FIG. 27.

The new Workhouse Infirmary at Birmingham (approximate cost £60,000) is also warmed and ventilated by the same means.

OPEN FIREPLACES.

The ordinary open fireplace is the most universal and orthodox method of warming a room, but in all its forms there is a large amount of heat evolved from the fuel which is not radiated into the room. A large part of this heat is, however, usefully applied, in many fireplaces of modern design (a few of which will presently be described), to the warming of inlet air admitted at the back or sides of the grate.

In regard to the successful design of the open fireplace, Mr. T. Pridgen Teale has pointed out the following practical considerations:—

(1) Use as much firebrick and as little iron as possible.

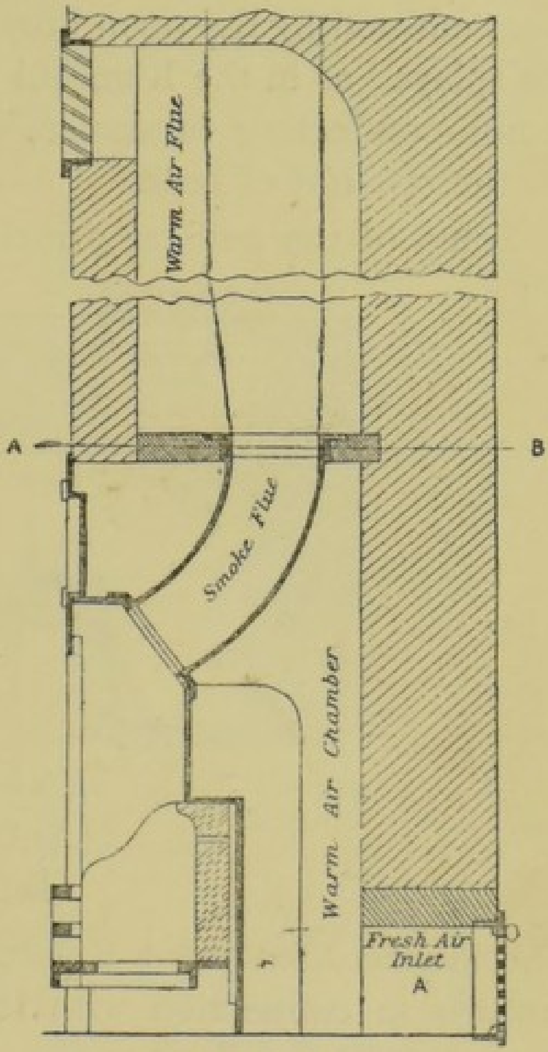
(2) Back and sides of grate should be of firebrick.

(3) The back should lean forward over the fire.

(4) The "throat" of the flue should be constructed to improve the draught.

(5) The spaces in the bottom grating and bars in front should be narrow.

(6) The usual space under the fire should be closed in front by a close-fitting "economiser."



SECTION

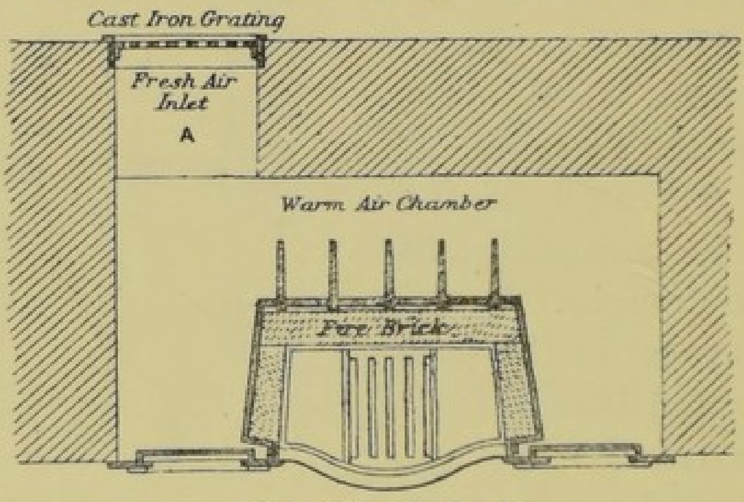
FIG. 28.

The effect of the "economiser" is to exclude air from the bottom of the fire, causing the fuel to be entirely consumed, a fine ash being the only residuum, and thus effecting "economy." The same object is achieved in the "slow combustion grates" with a solid bottom of fireclay.

The advantages of considerations Nos. 1, 2, and 3, and the splaying of the sides of the fireplace, were suggested by Count Rumford, an American scientist, as far back as 1796, when he reduced the large square fireplaces then in use by adopting splayed firebrick sides and backs, and this system has since been in general use.

In order to derive the maximum benefit from the radiant heat emitted by the open fireplace the sides and back should be splayed as in the Rumford grate, and should be formed of a non-conducting substance, with a glazed surface favourable to the *reflection* of heat.

Some of the general principles which guided the jurors at



(*See* FIG. 28.)

FIG. 29.

the Smoke Abatement Exhibition (1881) in the granting of awards in connection with the stoves, grates, &c., exhibited were briefly as follows :—

(1) No noxious fumes to be given off into the apartment.

(2) To emit an abundance of radiant heat in the case of open fireplaces.

(3) To show a favourable ratio of heating power to the amount of smoke produced.

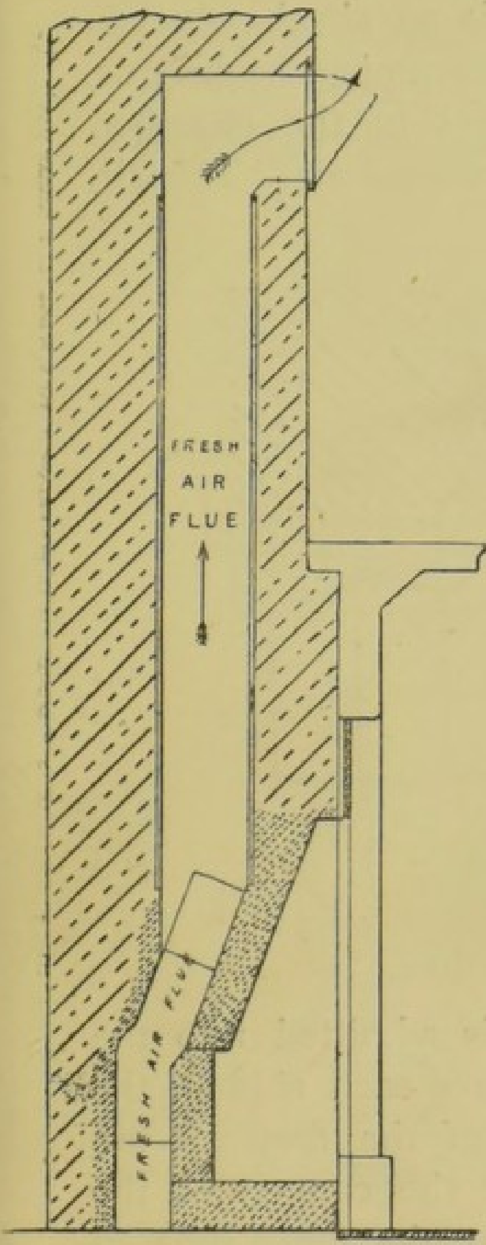
(4) Combination of heating with ventilation.

(5) Economy of fuel and labour.

(6) Simplicity of construction and working.

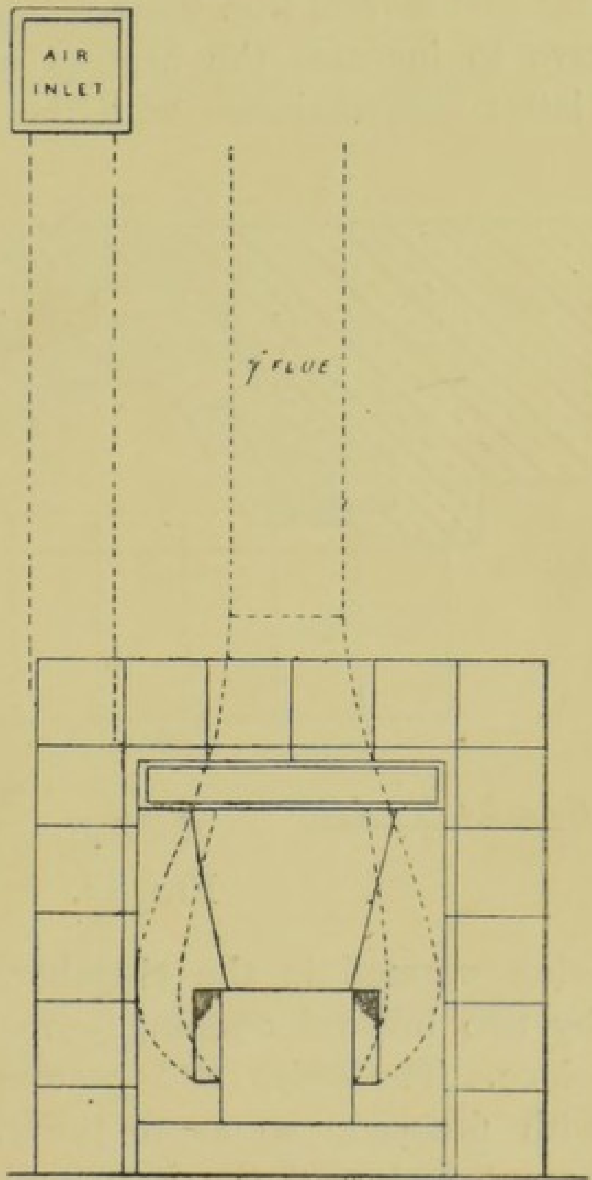
— IMPROVED FIREPLACE BY A. S. GOODRIDGE ESQ —

WHOLLY OF BURRS, NO VERTICAL FLUE OVER FIRE
AND THEREFORE NO WASTE OF HEAT UP THE CHIMNEY



SECTION
SHEWING FRESH AIR FLUE

FIG. 30.

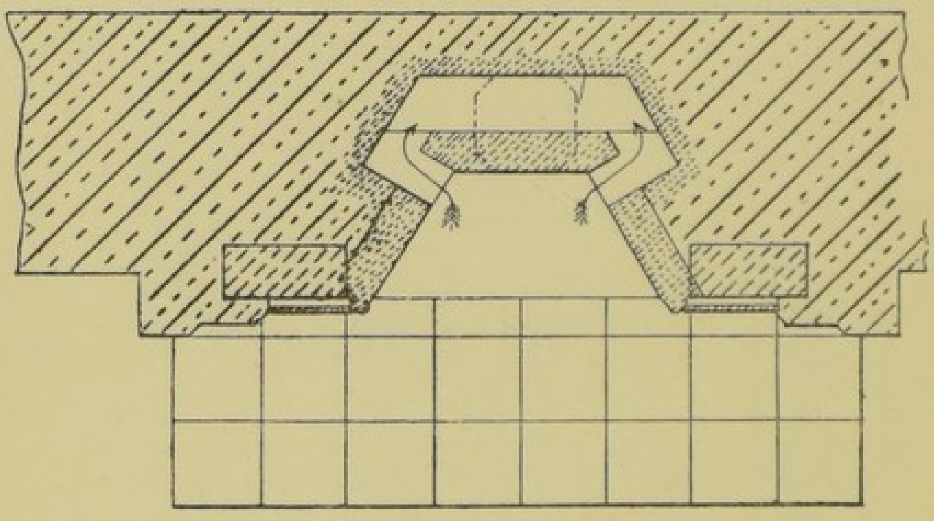


ELEVATION

FIG. 31.

For the admission of warm pure air into a room, one of the best grates in general use is that of Sir Douglas Galton, which he designed for the War Office. The construction and arrangement is illustrated in Figs. 28 and 29.[1]

In this grate, behind the fireplace, is an air-chamber, in which are cast several iron flanges, which project backwards, and serve to increase the heating effect of the chamber, which latter communicates with the external air. The air,



Scale ½ · 1ft PLAN

FIG. 33.

after being warmed in the chamber, is admitted into the room by two louvred openings—one on each side of the mantelpiece. The sides and bottom of the fireplace are lined with firebrick, so as to prevent the contact of the incandescent fuel with the iron, and at the same time to preserve a high uniform temperature to assist the combustion. A current of air passing up between the fireclay back and

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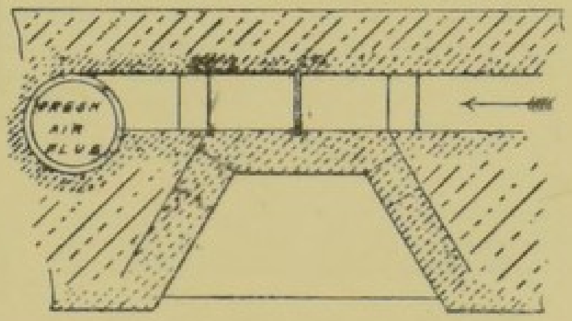
[1] From drawings kindly lent by the Falkirk Iron Company.

the iron back is thus heated, and is made to impinge upon the upper part of the fire and mix with smoke and gases. The formation of smoke is thus reduced, the combustion is rendered more perfect, and a larger percentage of the heat produced by the fuel is utilised.

Another form of "*improved fireplace*" for increase of heat and economy of fuel, providing also a supply of warmed

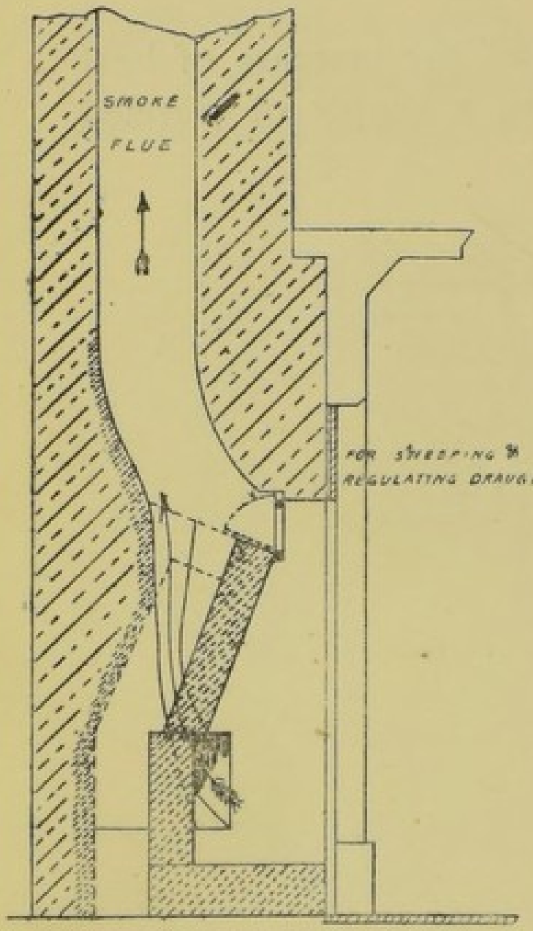


PLAN

SHEWING FRESH AIR FLUE

FIG. 34.

fresh air, is that designed and used for some years past by Alfred S. Goodridge, Esq., Member of the Royal Institute of British Architects, of Bath. This fireplace is constructed wholly of firebrick burrs, and having no vertical flue over the fire, there is no waste of heat up the chimney. The heat radiated into the room from the burrs is considerable, and is given out so equally and continuously, that should the fire go down or out the heat is retained for some time, and is perceptibly more pleasantly and equally diffused than from the ordinary iron grate. The fire will last from twelve to fifteen hours without attention if properly regulated by the register fixed above.



SECTION SHOWING SMOKE FLUE.
(Goodridge's "Improved Fire-place.")

FIG. 32.

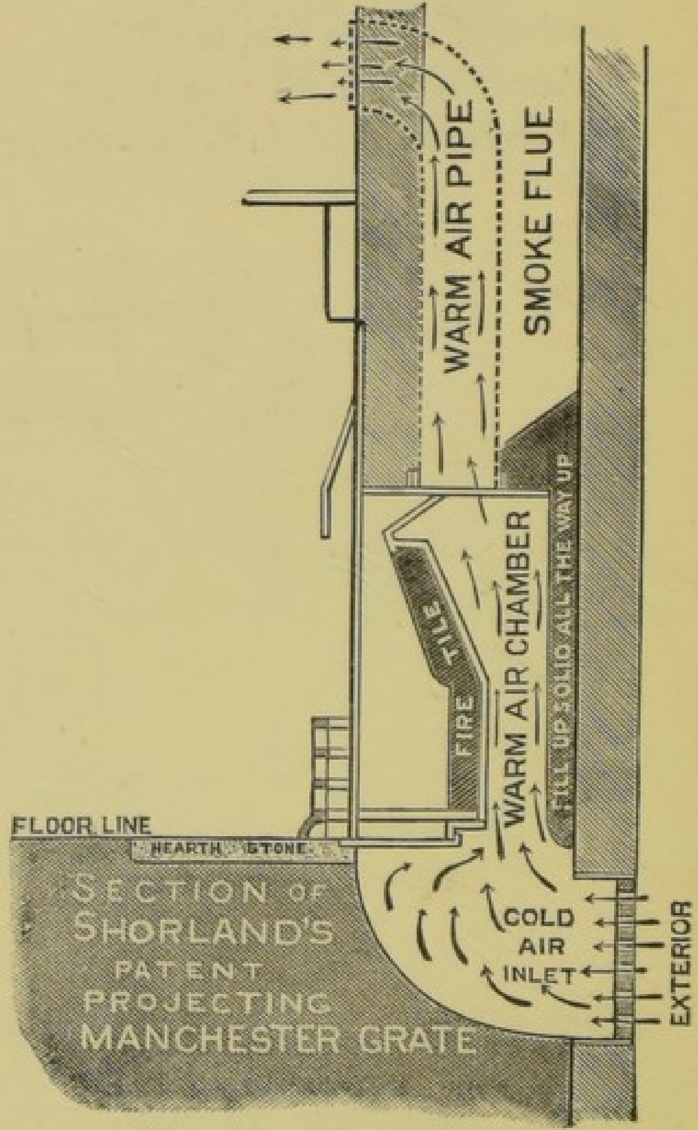


FIG. 35.

The detailed construction, and also the arrangement for the admission of fresh warmed air, is well shown—far better than could be given by any written description—in the accompanying figures 30 to 34, which have been prepared from drawings kindly supplied to me by Mr. Goodridge.

Other good forms of grates for the admission of fresh air are the "London Grate,"[1] "Lloyd's Patent Ventilating Grate,"[2] and the "Hygiastic Grate," by D. O. Boyd.

Shorland's Patent Warm Air Ventilating Manchester Grate, with improved projecting back and fire-box lined with fire tiles, is illustrated in section (Fig. 35); it claims to give an increased radiation, economy of fuel, and a large consumption of smoke.

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[1] Manufactured by Mr. G. Jennings.
[2] Manufactured by Mr. T. Elsley.

CHAPTER VIII.

Artificial Ventilation.

Artificial Ventilation is carried out on one of the following plans, or, in some cases, both methods may be combined :—

(a) By *extraction*, *aspiration*, or *vacuum*, as it is called, in which the foul air is drawn out of the building by machinery, and fresh air is allowed to come in and take its place after having been warmed, if necessary.

(b) By *propulsion*, *impulsion*, or *plenum*, the fresh air is forced into the building by means of rotary fans, &c., and the foul air is allowed to escape by shafts or flues.

Artificial ventilation is applied almost exclusively to large buildings, where sudden assemblages of people take place, such as, for example, theatres, large public halls, churches, houses of parliament, law courts, and large hospitals.

A system of natural ventilation is, of course, much less costly as regards the initial outlay, and particularly so as regards the cost of maintenance, but its efficient action is inconveniently dependent upon the most variable atmospheric conditions in this country, and it is therefore found to be inadequate for the proper maintaining of a pure atmosphere in large buildings of the kind above mentioned.

Speaking generally, mechanical ventilation may perhaps be said to have met with a considerable amount of comparative non-success, and this, no doubt, has been taken advantage of to the utmost, especially by biassed minds, in condemning the *principle*. Ventilation, however, is a difficult and somewhat complicated science, and requires the individual attention of a specialist in the design and arrangement of shafts, tubes, inlets, outlets, &c., for, as has been well pointed out by Mr. J. Keith, A.M.I.C.E., in his "Report (1894) on the Ventilation of the Houses of Parliament," it is quite possible to force large columns of air through a building without properly ventilating it—the fresh air admitted not being sufficiently distributed and diffused by means of suitably placed extract shafts, &c. The want of such *distribution* has perhaps been one of the chief causes of complaint of lack of ventilation at certain points in rooms served by mechanical systems, although the *volume* of air supplied is generally in excess of that supplied by natural means. The more numerous and scattered the inlets and outlets, provided their positions are judiciously fixed, the better will be the result.

What must ever recommend the *principle* of mechanical ventilation is that it can be made constant under all conditions, it affords facilities for regulating the source and volume of the fresh air supplied, also for effecting any needful preparatory treatment modifying its temperature, humidity, or purity.

Very frequently the question of mechanical *versus* natural ventilation, and even sometimes the consideration as to whether a building shall be ventilated at all, is purely a financial one, but it should be remembered that no habitable structure can really justify its existence in the present age, however elaborate it may be in other details, unless it is constructed throughout on sound sanitary principles, particularly as regards its ventilation, drainage, &c. The growing use of electricity as a motive power will no doubt greatly economise the working of mechanical systems, ridding them to a great extent of the oftentimes fatal objection of requiring a special engine of some kind and skilled attendance with its consequent expense. Of course, where steam or other power is already in use for other purposes this does not apply.

EXTRACTION.

Extraction by Heat.—The ordinary fireplace is the principle usually employed in most systems of artificial extraction. The extractive force of the common chimney flue, as has been previously described, is very considerable indeed. The air movements are from the inlets gradually towards the fireplace, and should the inlet provision be deficient, the action of outlets may be thereby reversed.

The ventilation of the workings of mines is carried out on this same principle of the extractive force of a heated air column, and for this purpose two shafts are provided at opposite ends of the mine, or else a single shaft may be divided if there should be only one. At the bottom of the upcast shaft a large fire is kept burning to create a powerful up-draught. Fresh air descends the downcast shaft, and is made to traverse throughout the workings, being directed through the various passages or galleries by means of doors, partitions, &c., until it reaches and ascends the upcast shaft.

At the basis of the main towers of the Houses of Parliament coke fires are kept burning throughout the year, thus forming powerful aspirating shafts for the extraction of the vitiated air which is drawn considerable distances from the ceilings of the various rooms, corridors, &c. Also the vitiated air from a part of the drainage system of the Houses of Parliament is liberated into the upcast shaft in the Clock Tower, which draws off the foul air from the Debating Chamber, whilst the remaining portion of the sewer gas is liberated into the lower part of the upright aspirating shaft in the Victoria Tower, which also ventilates most of the committee rooms and the House of Lords.

Many French and English hospitals are also ventilated by means of the plan of hot air extraction shafts.

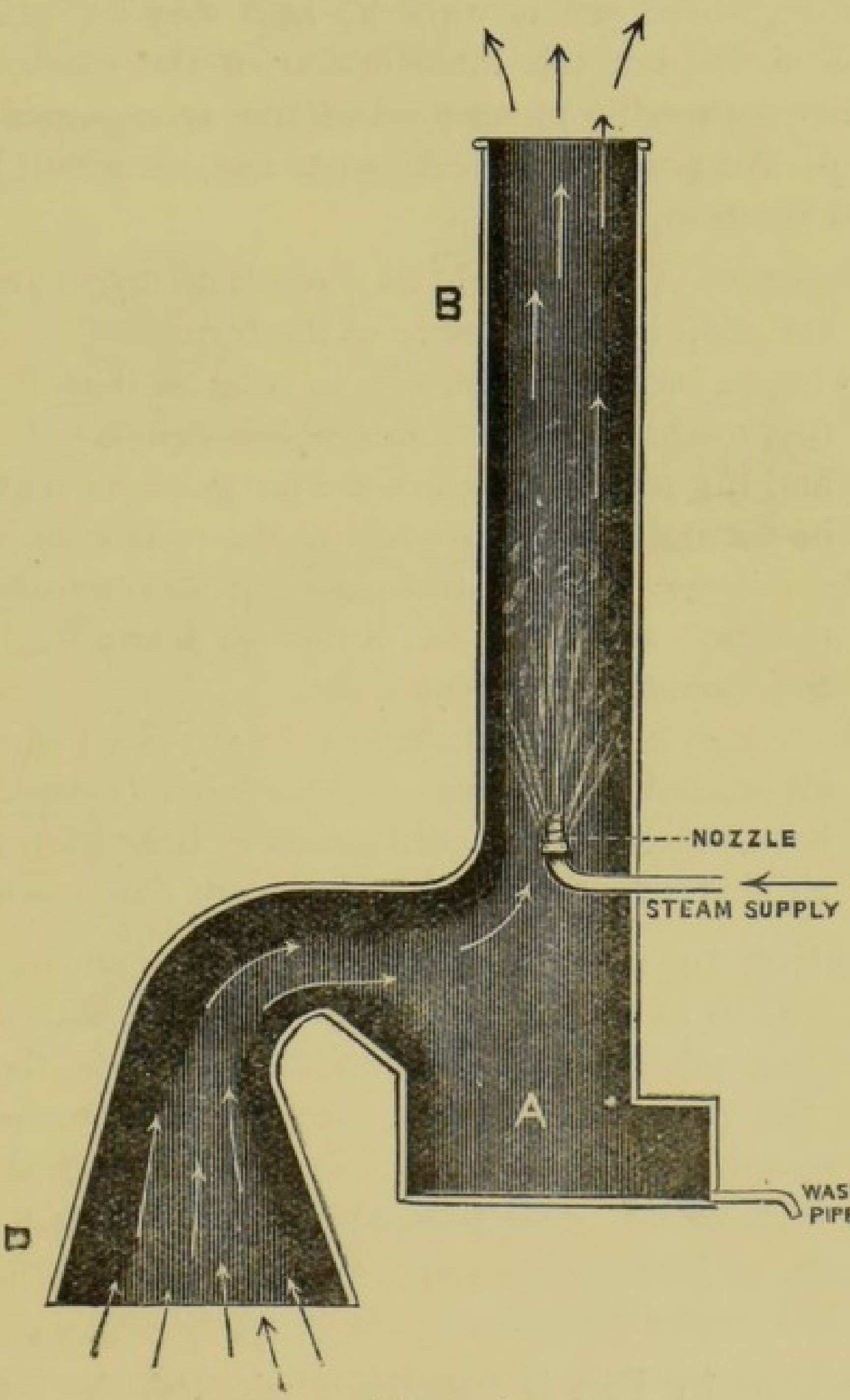

FIG. 36.

In addition to, or instead of, a fire, the heat in the shaft is sometimes derived from hot water or steam pipes, hot water pipes being preferable, as the steam pipes are liable to scorch the air.

Of course, where gas is used its heat may be utilised in extraction shafts, but the introduction of the electric light must somewhat modify present ventilating arrangements.

Some of the practical objections to the extraction by fires in central shafts are—

(1) Inequality of up-draught as a result of the unavoidable variation in temperature of the furnace.

(2) Owing to increase of friction in long air flues from distant rooms there is considerable inequality of current, and the sectional area of the air passages requires to be accurately proportioned to the resistance.

(3) There is very little control over the source from which the fresh air is derived; it may be drawn from defective drains, water-closets, &c.

(4) There may be a down draught in the shaft of vitiated air or smoke into the room. Such has "occasionally" been experienced in connection with the main vitiated air shafts ventilating the Houses of Parliament.

Extraction by Steam Jet.—An upward current is produced in a shaft by the force of the steam jet, as shown in the diagram (Fig. 36),[1] which illustrates the principle, the steam being in this case delivered by a patent duplex nozzle. The cone of steam sets in motion a volume of air equal to 217 times its own bulk.[2] This plan may be used in places with spare steam, as in factories, ships, &c., also for work rooms in general, and smoke rooms.

Extraction by Fan is sometimes adopted, the fan being

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[1] From block kindly lent by the Banner Sanitation Company.

[2] Dr. Parkes' "Practical Hygiene."

driven either by steam, gas, or electricity. An objection to this method is that the source of air supply, not being under control, may be drawn by suction from undesirable sources. Fans of this kind are largely used in mines, workshops, &c.

Extraction by Water Spray is illustrated in Fig. 37. The arrangement consists of a nozzle which delivers a jet of

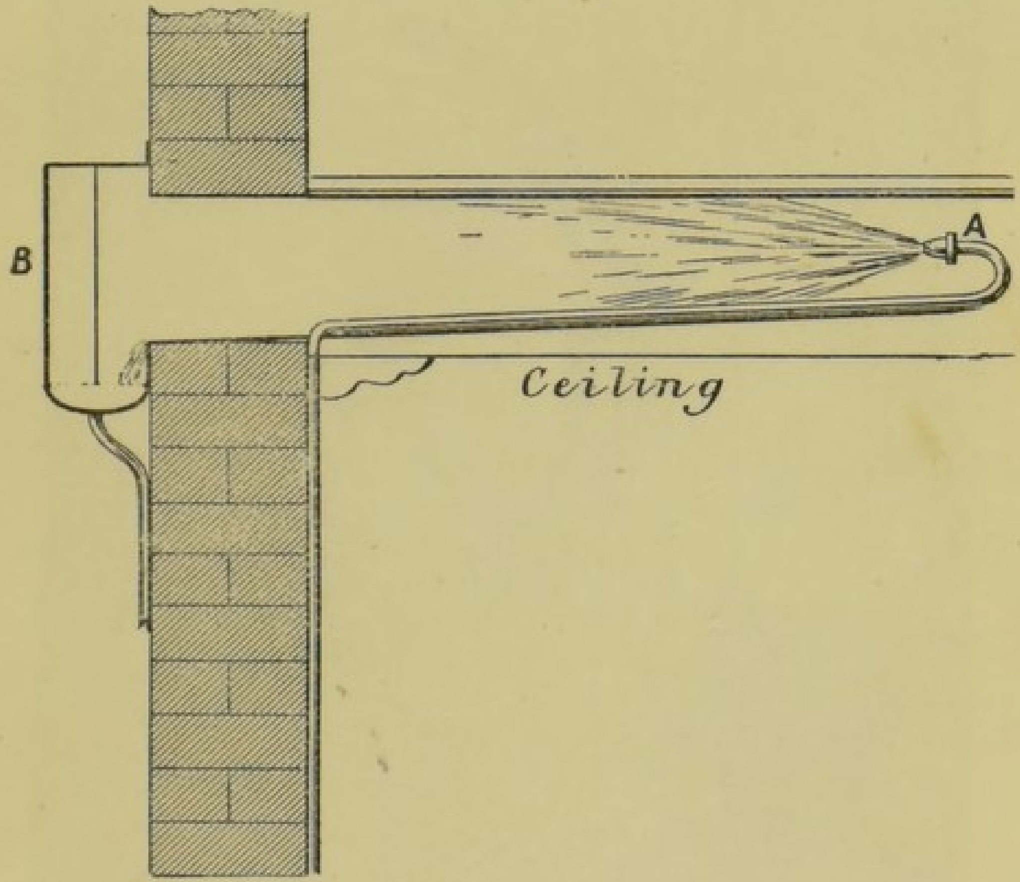

FIG. 37.

water under pressure, thus inducing an air current along the extract tube at a velocity somewhat under that of the water. The average consumption of water used by a Kite's patent simplex water-jet air propeller is about one gallon per 1,000 cubic feet of air extracted. This method is rather expensive comparatively, but is useful for ventilating smoke and billiard rooms, basements, wine cellars, &c., and may be seen in operation in the underground conveniences at Regent Circus, Portland Road, and Tottenham Court Road, London.

PROPULSION.

In systems of propulsion it is assumed that air will come in at definite inlets, and will also find an exit at defined outlets,

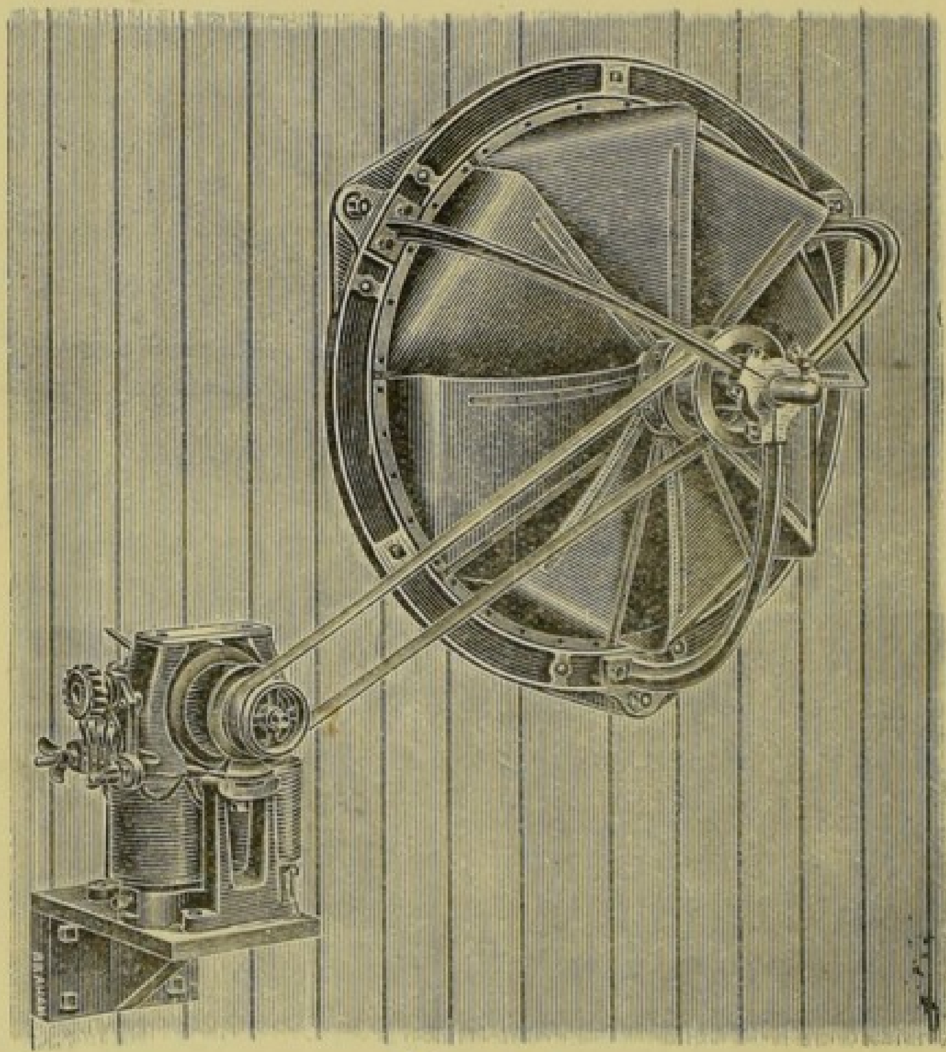

FIG. 38.

so that the opening of windows would upset the proper working of the system.

The air is usually forced in by means of fans (Fig. 38), with six or eight rays carrying vanes, sometimes enclosed within a box. The fans of Verity Brothers and of Blackman are well known, and are powerful machines. "The best propellers have produced a useful effect of from 70 to 75 per cent. in proportion to the power employed." [1]

"The amount of air delivered can be told by timing the speed of revolution of the extremities of the fan per second or per minute; the effective velocity is equal to three-fourths of this, and this is the rate of movement of the air. If the sectional area of the conduit be known, the number of cubic feet discharged per second, minute, or hour can be at once calculated." [2]

The friction of the air in the channels along which it is driven is considerable, and varies as the square of the velocity multiplied by the pressure against the sides. The total pressure is proportional to the total surface, *i.e.*, the length of passage × the perimeter of cross section.

The force required to propel air through any passage is equal to the square of the velocity into the total surface × by the coefficient of friction.

A practical formula of general application given by Mr. D. P. Morrison [3] is as follows:—

H = Head in feet of pressure of air of same density as the flowing air.
D = Diameter of tunnel or air passage in feet.
L = Length of pipe or passage in feet.
P = Perimeter of cross section in feet.
A = Area of pipe or passage in feet.
V = Velocity in thousands of feet per minute.
K = Coefficient or friction = ·03.

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[1] Sir Douglas Galton, in "Our Homes."
[2] Dr. Parkes, "Practical Hygiene."
[3] Min. Inst. Civ. Eng., vol. xliv.

$$H = \frac{K\,V^2\,P\,L}{A};$$

$$= \frac{K\,V^2\,4\,L}{D} \text{ for circular section.}$$

In respect to the method of ventilation by propulsion, Sir Douglas Galton remarks as follows:[1]—"In practice . . . the system of propulsion, *i.e.*, forcing the fresh air into the room and allowing the vitiated air to find its way out, has not been generally found successful as a means of purifying the air. The air forced in seems to seek the first place of escape, and unless the system is combined with an efficient system of extraction, much of the *vitiated air may remain in corners and dead angles*. It is therefore generally advisable to combine with a system of propulsion for the inflowing air some method of extraction for vitiated air."

General Morin, also of great experience in ventilation, preferred the system of "extraction" to that of "propulsion."

Propulsion, though not suitable for continuous ventilation, is useful under certain conditions, such as, for example, when a large building requires to be provided with special means of ventilation on some temporary occasion, such as the assembly of large numbers of people for comparatively short periods.

The general advantage of the system is the completeness with which the supply of air is brought under control, that is, as regards its source, purity, washing, heating, or cooling, &c.; but there are important disadvantages, *e.g.*, its excessive cost, likelihood of machinery breaking down, and the difficulty of effecting a *thorough distribution* of the air supplied—air may be forced in at one opening and out at another

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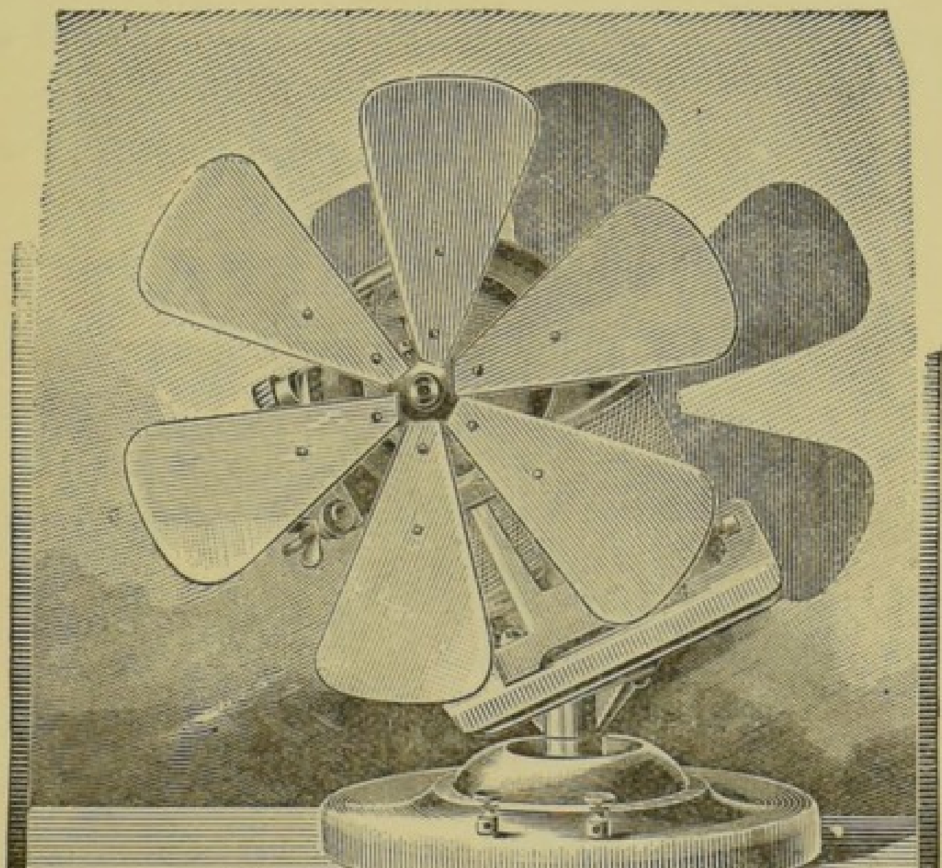
1 "Our Homes."

without appreciably improving the general atmosphere of the room.

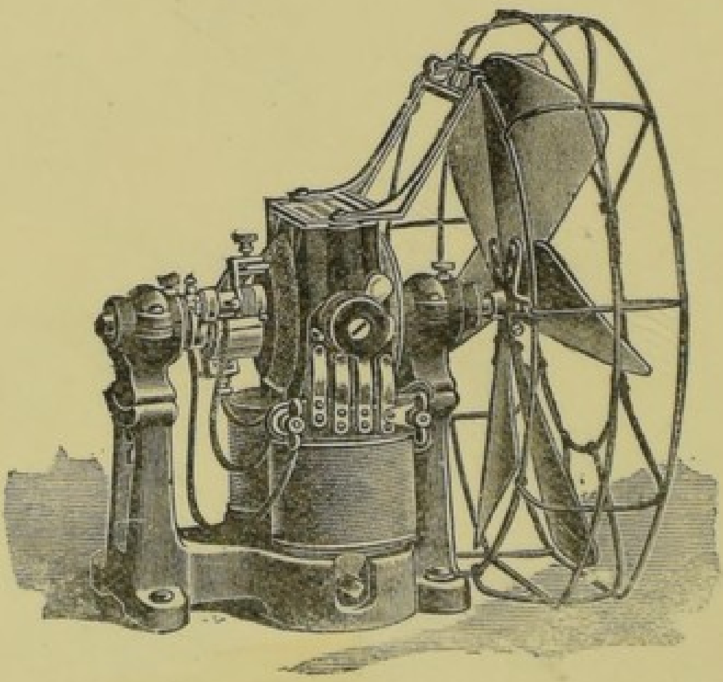
The Capitol in Washington and the London Law Courts are both examples of "propulsion"—the air being forced in under pressure by means of large fans on the "*Plenum*



Pivoted Electric Fan Motor.

FIG. 39.

system." This is aided by extraction of the vitiated air from the ceiling. Neither building, however, is said to afford a very satisfactory example of ideal ventilation. "The expert who prepared the report on the ventilation of the Houses of Parliament states:—'I think that *extraction* rightly applied is infinitely better all round than *propulsion*. I never knew of a system of propulsion pure and simple that effected an efficient and satisfactory ventilation of any large building. In the case of the House of Commons there is no lack of *fresh* air sent in, or that can be sent in; the trouble is rather to get rid of *all* the vitiated air—and that can only be done effectively by a proper system of extraction, by which the vitiated atmosphere would be drawn out from various points.'"[1]



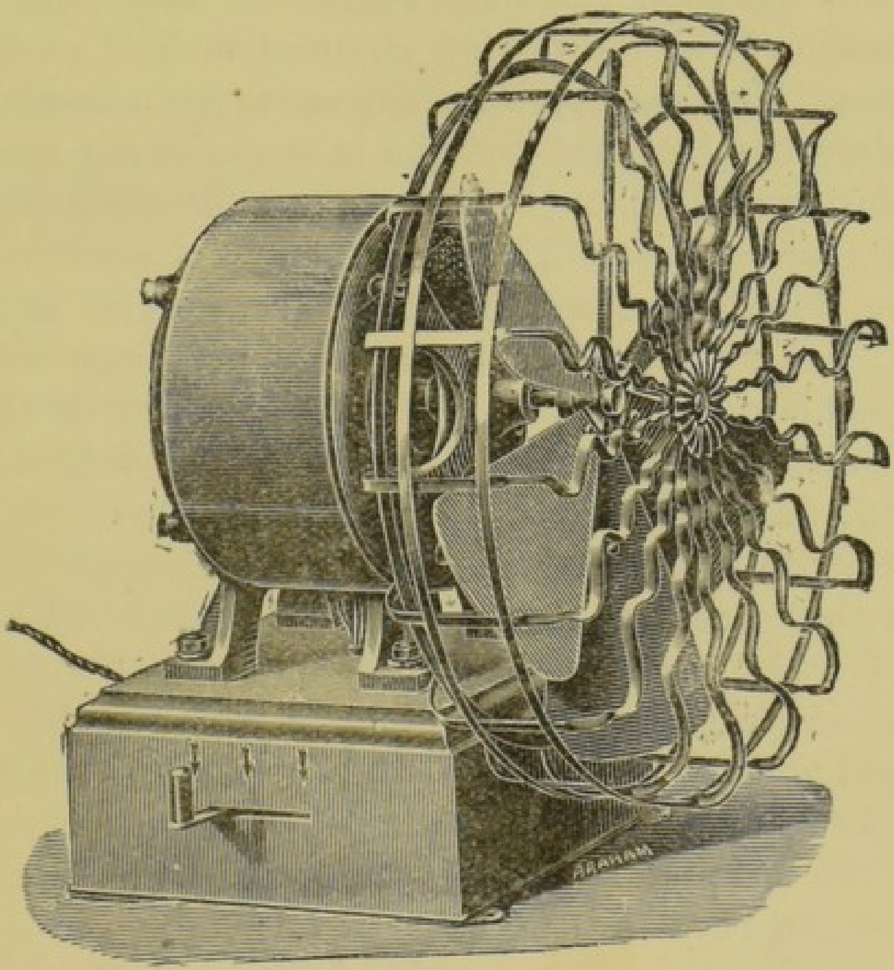
$\frac{1}{6}$-H.P. Electric Fan, with Wire Guard and Switch for Running Fast or Slow.

FIG. 40.

Electric Table Fans are manufactured by the General Electric Company, Ltd., London, for the purpose of setting up currents of air in the room. These machines, three forms of which are here illustrated (Figs. 39, 40, 41), can be moved about upon desks or tables or mounted on wall brackets, and are set in motion and stopped by turning a small button.

[1] "Building News," August 17th, 1894.

The fans are fitted with guards for protection, and to prevent anything coming in contact with them whilst in motion. They should be placed on a solid or firm foundation and the bearings kept well oiled, in order to run noiselessly. The "pivoted fan motor" is mounted upon an ornamental base of



Alternating Motor Fan.

FIG. 41.

dark red wood, and swings slowly around the circle upon a pivot—the object being to throw the breeze to every part of the room. Of course, such fans do not obviate the necessity for the proper provision of well designed "inlets" for the *supply of pure fresh air* to a room, and "outlets" for the speedy *removal of vitiated* air, but they may be very usefully applied in setting up a gentle breeze and circulation of air in stuffy offices, restaurants, kitchens, &c.

CHOICE OF A SYSTEM.

In the choice of a system of ventilation, it seems that a satisfactory decision can only be arrived at by the careful consideration of all the varying circumstances of each particular case. This may perhaps appear to be a compromise, but to draw any hard-and-fast line in favour of any system, to the exclusion of all others, is impossible. Speaking generally, however, *natural ventilation* seems to be most suitable for all ordinary dwelling-houses, hospitals, &c., whilst *mechanical systems* appear to be necessary in large buildings, especially where sudden assemblages take place, such as in theatres, public halls, law courts, &c. In regard to this subject of the selection of a system of ventilation, the remarks of Mr. Henry C. Burdett in his work—the most comprehensive and important on the subject extant—viz., "Hospitals and Asylums of the World," cannot fail to be of interest. He says, as a result of his large experience in these matters, "The really important point to be kept in view in regard to ventilation is that before any system depending upon mechanical contrivances can be pronounced worthy of adoption, it must be demonstrated beyond dispute that it is not only as good as ordinary methods, but appreciably better. For nothing but a substantial improvement would justify the largely increased cost, both of construction and maintenance, necessarily consequent on the adoption of mechanical ventilation."

CHAPTER IX.

Mechanical Systems Applied to Certain Buildings.

The proper ventilation of the Houses of Parliament has always been a matter of considerable interest, but at the same time one of great difficulty, and has consequently from time to time formed the subject of careful inquiry and report.

The matter was dealt with at some length by the Select Committee in their report published in July, 1891, and has since been analysed by Mr. J. Keith, A.M.I.C.E., of London, in his report of March, 1894, in which he gives the following brief general outline of the present system and arrangements:—

"The ventilation of the greater portion of the buildings, viz., the Debating Chamber and other sections of the House of Lords, and the various committee rooms, lobbies, corridors, &c. in both Houses, is arranged on what is called the natural system of ventilation, so far as regards the ingress of fresh air from the outside.

"The extraction of the vitiated air is solely obtained by the adaptation of the main towers as aspirating shafts, at the base of which coke fires are kept burning continuously throughout the year. Into these main upcast extract shafts the vitiated air is drawn considerable distances—upwards, downwards, and horizontally—from the ceilings or upper parts of the rooms, corridors, &c.

"In summer the incoming air is washed and cooled in the lower floors before being admitted into the chambers, rooms, and corridors. In winter the fresh air is warmed by steam pipes and steam-heated surfaces before being passed on to the different sections.

"The Debating Chamber of the House of Commons is, however, differently treated; and though the extraction of the vitiated air is secured in a similar manner by means of the upcast shafts in the towers, the system otherwise is entirely separate and different in principle from the rest of the buildings. The ventilation of the Debating Chamber of the House of Commons is, in fact, obtained by a combination of what is called the *plenum* and the *exhaust* or *extract* systems of ventilation, the fresh incoming air being blown in in volume under pressure by a powerful fan or propeller placed in the basement, the vitiated air being extracted from the ceiling, and then drawn downwards and onward by aspiration into the base of the heated upcast shafts mentioned. The action of the aspirating upcast shafts being much less effectual in exhausting, even in winter, than the action of the *plenum* fan is in blowing in the fresh air upwards through the grated floor of the chamber, there is always, as it were, a slight pressure of air from the interior of the Debating Chamber and division lobbies outwards, and this is sufficient to prevent any egress of air from the lobbies and corridors into the House of Commons proper. The incoming fresh air for the House of Commons is also washed and cooled in summer before being sent in under pressure, while in winter the air is warmed by steam-heated surfaces after being taken up and blown in by the propeller.

"In foggy weather the cooled or warmed air, as the case may be, is sent into a large, peculiar, and ingeniously constructed V-shaped screen arrangement, having a surface of about 1,000 square feet of cotton wool fixed to it, and through this the air is filtered on its passage between the propeller and the Debating Chamber."

It will now be instructive to note the following shortcomings and defects of the system, as pointed out by Mr. Keith, and next to consider certain remedies, also set out in the report, as an antidote to these.

Defects :—

1. The inadequate action of the upcast extraction shafts in summer, owing to the approximation of the outside temperature to that in the upcast shaft.
2. The heating of air admitted in cold weather by *steam-heated* surfaces is highly objectionable.
3. The unequal distribution of fresh air.
4. The inlet air comes almost entirely from the central grated passage in the House of Commons, rises nearly straight to ceiling extract, there being no extraction provided in side galleries to ventilate this part of the chamber.
5. The method of admitting air through the floor areas, grating, &c., is sanitarily defective, owing to the unavoidable accumulation of dust and dirt.

The remedies suggested to overcome these shortcomings are briefly—

1. The substitution of silent-running open fans or propellers of similar form to those already in use in the building for the coke fires, which are kept burning at the base of the shafts in the towers.
2. The filling of the present steam pipes with water, and the heating and circulation of the water by means of the steam.
3. The utilisation of Tobin tubes in the Committee Rooms for the purpose of securing a more equable diffusion of the fresh air admitted through the floor.
4. The formation of extract shafts under the side galleries in the legislative chamber, with the object of purifying

the air breathed by honourable gentlemen sitting on the back benches, and by the occupants of the various galleries.

The Victoria Infirmary, Glasgow.—Here the fresh inlet air is washed and purified from smoke, fog, &c. by means of a method devised by Mr. W. Key, and which has been in operation since 1890. The cold fresh air is drawn through an air-cleansing arrangement by Blackman fans, placed between the cleansing and warming chambers, and the air flues to the wards.

The fans draw in the fresh air from the outside down a large inlet, lined with white-glazed bricks. It is then admitted to a chamber divided by a close hanging screen, which is fixed to a beam near the ceiling, and connected with a longitudinal trough filled with water. The screen is of cocoanut fibre stretched from a beam at the ceiling to one near the floor, and is kept moist by water drawn from the trough by means of capillary attraction through a loose piece of flannel hanging over its edge. Dust, soot, &c. from the air, as it filters through at a low velocity, is thus retained on the wet screen and carried down two or three times an hour, to float away by flushes of water from an automatic flushing tank. After leaving the screen the air is warmed, if necessary, by contact with steam-heated surfaces. The air is then collected by a Blackman air propeller, worked by electric motors driven with power from the laundry engine, and passed in air ducts leading to the various rooms and buildings.

This system is said to remove every particle of fog from the air, so that even under conditions of dense fog outside, the air in the wards is kept clear and bright.

Guy's Hospital, London.—"This building is provided with an elaborate system of ventilation. The fresh air is taken in at the top of two towers and drawn down to the basement, where it is warmed and sent up to the wards and admitted at the floor level, and the foul air is extracted from the ceiling level, and drawn off through shafts to the top of a lofty tower by means of heat. The system has been anything but a success."[1]

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[1] "Hospitals and Asylums of the World," 1893. (J. & A. Churchill.)

CHAPTER X.

Examination as to Efficiency of Ventilation.

To examine as to the Efficiency of the Ventilation of a Room.—The following practical suggestions are given by Dr. Parkes[1] as to the general methods of ascertaining the efficiency of the ventilation of a room:—

1. Determine the amount of *cubic space*[2] and *floor space* assigned to each person, and their relation to each other.

2. Determine the amount of movement in the air, *i.e.*, the number of cubic feet of fresh air which each person receives per hour.

The velocity in feet per second or minute is usually ascertained at the "inlets" by the aid of an anemometer, or by the use of the formula (previously given) depending on the differences of inside and outside temperatures.

3. Examine the air by the senses, by chemical, biological, and mechanical methods, so as to determine the presence, and, if possible, the amounts and characters, of suspended matters, organic vapour, carbon dioxide, hydrogen sulphide, watery vapour, ammonia, &c.

For most practical purposes, a person in good health, on entering a chamber direct from the outside atmosphere, can

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1 "Practical Hygiene." (J. & A. Churchill.)

2 See "Calculation of Areas, Cubic Space, &c.," by W. H. Maxwell, A.M.I.C.E.

form a tolerably accurate estimate of the purity or otherwise of the air of the room.

The following method of *testing the air of a room* has been proposed by Dr. Angus Smith, is an exceedingly simple and good one, and is described as follows[1]:—

"Take a clean, transparent glass bottle of about 10½ oz. capacity, cram into it a clean, dry linen cloth, then take it into the room the air of which you wish to test; pull out the cloth, then air rushes in to supply its place. You have now a bottle full of air to examine. Add to the bottle ½ oz. or a tablespoonful of clear lime water, and shake it up; if the lime water becomes milky there is an excess of carbonic acid present, and the amount of CO_2 is a very good index of the amount of other impurities.

"Take a similar bottle to that mentioned above, and fill it with air, as before, to be tested; then pour into it 1 oz. of Condy's fluid of a pale rose colour, and shake well; if the colour disappears, an excess of organic matter is present. This experiment is not *exact*, although true in ordinary cases, for other substances than organic may be present in the air and produce the same result.

"In a ventilated room, the *dry* bulb thermometer in this climate ought to read 63 deg. Fah. to 66 deg. Fah., and ought not if possible to fall much below 60 deg. Fah. The *wet* bulb ought to read 58 deg. Fah. to 61 deg. Fah., *i.e.*, the differences between the two thermometers ought not to be less than 4 deg. Fah., or more than 8 deg. Fah."

For a strong and healthy person the ideal atmosphere is that of a hill-top on a cool, bright, still spring morning; and a person accustomed to breathe such air is, of all, the most competent to judge the degree of efficiency of ventilation of

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[1] Dr. J. J. Pilley, "Hygiene." (Gill & Sons.)

a room. Persons of long-established sedentary or indoor habits frequently acquire a preference for warm, stuffy atmospheres, and promptly object to the introduction of fresh air from the outside, owing to real or imaginary draughts which may be set up. It is the business, therefore, of the ventilating engineer to so instal a system for the regular change and warming of the air supplied, in order that even the most susceptible invalid may participate in the benefits of scientific ventilation without becoming cognisant of the fact.

CHAPTER XI.

SUMMARY OF NOTES ON VENTILATION.

THERE must be a complete and continuous change of air sufficient always to keep the CO_2 below six parts in 10,000—the "standard of purity."

The normal amount of CO_2 in pure air is four parts per 10,000.

The organic matter in air is proportional to the CO_2.

The changing of the air of rooms must be of such a nature that draughts are not produced.

All rooms should be provided with inlets for pure fresh air and outlets for impure air in proportion to their size and the number of occupants and lights.

The size of openings required for the efficient ventilation of an occupied room under average conditions is about 48 square inches per head, namely, 24 as inlet and 24 as outlet, but, according to Parkes, no single inlet should exceed 60, and no outlet 144 square inches.

Outlets should be from the warmest part of the room, usually from the ceiling, and inlets about 7 ft. above the floor, *i.e.*, just above the heads of the occupants, and the incoming air should be directed upwards.

Each room should have a separate ventilator, wherever possible, and rooms on different levels are best not connected with the same flue or ventilator.

In providing inlet and outlet openings, the chief causes of obstruction to the movement of air to be guarded against are—

(a) Irregularity of shape of opening—the simplest form is always the best.

(b) Clogging of opening with dust, &c.

(c) Too great length of shaft compared with its width. If a tube is bent at a right angle, half the air current is lost; if there be a second right angle only one-fourth of the current is obtainable.

(d) Dividing the opening into too many parts, and thus reducing the total air space.

The simplest way of ventilating a room is by taking advantage of the movement in the air produced by variations in its weight (due to differences of temperature) or by the action of the wind.

All windows should *open top and bottom to the external air.*

Chimneys should never be blocked up with a register or otherwise, and all windows and doors should be opened and the rooms thoroughly flushed with air at least once a day.

Always ventilate from the *outside* and not from a staircase.

The supplies of fresh air should be taken from suitable points free from risks of contamination, and, if necessary, the air may be screened through metal gratings or canvas, or through a cotton-wool filter. It may be washed by passing through a spray or film of water, or by being made to impinge upon a tray containing water.

There are two main sources of impurity of air, viz. :—

Combustion of candles, gas, oil, coal, &c. ; and

Respiration of persons and animals.

Impurity of air is also due to the dirty state of furniture, walls, and floors, corners, and places in rooms difficult of access for cleaning purposes, into which dust, cotton, wool, and hair fibre is circulated by wind currents, and which only get removed at the annual "spring cleaning," and in many cases not even then. All rooms should be emptied and cleaned, and wherever possible left unoccupied for some time *periodically*.

All unnecessary furniture, hangings, and curtains in a room should be avoided, for these obstruct light, take up space, reduce the amount of air in the room, hinder ventilation, and *harbour dust*.

Gas, as usually applied for lighting purposes and without ventilation, should be used sparingly in bedrooms. The ordinary gas-burner should not be used to warm the room, for not only is oxygen consumed, but much impurity is added to the air. All gas lights should be accompanied with an arrangement for carrying away the heated fumes.

Some of the products given off by the burning of coal-gas are sulphurous acid, carbonic acid, minute portions of carbonic oxide (extremely deadly), and water.

Unconsumed gas, as frequently detected in the air of living rooms, is highly injurious to breathe, especially for the sick. It may be derived from leaky fittings or be forced through burners by an increase of pressure. These dangers from the escape of unconsumed gas are much enhanced since the modern introduction of carburetted "water-gas," as now manufactured as a supplementary supply at large numbers of gas works.

The electric incandescent light (so far as yielding injurious products to the atmosphere is concerned) is *sanitarily* perfect, and in proportion as any form of light deviates from this ideal, its use must be restricted wherever the ventilation is at all inadequate.

Coal of average quality gives off in combustion—

Carbon, carbon dioxide, carbon monoxide, carbon disulphide.

Sulphur, sulphur dioxide, sulphuric acid.

Ammonium sulphide or carbonate.

Hydrogen sulphide (sometimes).

Water.

When we breathe pure air we live faster, are more lively, use more exertion, and therefore require more food.

3,000 cubic feet of fresh air are required per hour per head for health, and 1,000 cubic feet space is necessary in order that this amount of air may be supplied without draught or inconvenience.

Each person ought to have as much *cubic space* as possible; the lowest amount ought not to be less than 600 cubic feet, which must be given free of the space taken up by furniture.

About 3 ft. per second is a convenient rate of movement for inlet air.

As no room need be higher, for purposes of ventilation, than 12 ft., 600 cubic feet (space), divided by 12 ft. (height) = 50 square feet, which is the *lowest permissible amount of floor space.*

No room ought to be less than 9 ft. in height.

For health, a uniform temperature of from 50 to 65 deg. Fah. should be maintained in dwelling rooms.

In cold weather the incoming air should be warmed. This may be accomplished by passing it through boxes containing coils of hot water pipes; or it may be passed into air chambers behind or round grates and stoves, as in the grate contrived by Sir Douglas Galton and others. Care should be taken in all methods of warming that the inlet air be not *scorched.*

All diseases of a contagious or infectious character are much aggravated in close, ill-ventilated places, especially small-pox, scarlet fever, typhus fever, &c. One of the essential causes of typhus fever and plague is the crowding of poverty-stricken and destitute persons together in a badly ventilated space.

RECOMMENDATIONS OF THE ARMY SANITARY COMMISSION.[1]

Provide separate ventilation for each room by shafts passing from near the ceiling to above the roof.

Inlet for air near the ceiling, one square inch for each 60 ft. of room space; or (if the air be warmed) for each 120 ft.

Outlet, one square inch for each 60 ft. on ground floor, for 55 ft. on first, and 50 ft. on upper floor.

Separate ventilation provided for all passages and staircases.

Gas burners ventilated by funnels and pipes communicating with the open air.

Several inlets are recommended to avoid draughts.

WIND FORCE.

The velocity of the wind in this country varies from a minimum of about 1½ miles up to about 100 miles per hour, but the average may be taken at about 12 miles per hour (*i.e.*, a fairly strong breeze). Velocities of from 50 to 100 miles per hour would represent storms and hurricanes, and would give a pressure of from 12 lb. to 49 lb. per superficial foot.

COMPARING COST OF SYSTEMS OF VENTILATION.

In comparing systems of artificial ventilation the cost of maintenance is of great importance, and by capitalising the working expenditure and adding it to the first cost a comparison may be drawn between different tenders.

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[1] Molesworth's Engineer's Pocket Book.

CHAPTER XII.

Sewer Ventilation.

The air of sewers is rendered impure by the natural process of decomposition of sewage matters commencing immediately upon their deposition, causing offensive vapours and gases to be continuously given off. The object of sewer ventilation is to regularly remove such impurities, and to supply in lieu thereof fresh atmospheric air from the outside. Sewer air usually contains a large proportion of complex hydro-carbon and nitrogenous vapour derived from decomposing animal and vegetable matters; also comparatively large amounts of carbonic acid, sulphuretted hydrogen, ammonia, ammonium sulphide, and marsh gas. Ordinary sewage contains large numbers of bacteria, through the agency of which the organic matters become broken up into simple chemical compounds, and gases are evolved in the process. From the investigations of Laws, Andrews, Frankland and others, it appears that *sewer air* does not ordinarily contain any of the micro-organisms present in sewage, but usually only those commonly found in the atmosphere. Splashing of sewage into a fine spray, however, has the effect of liberating the organisms, and causing them to be carried even 50 to 60 yards. Experiments have also shown that in ordinary sewage typhoid organisms do not tend to survive, and their death is probably only a matter of a few days, or at most one or two weeks; but this may, of course, be quite sufficient to admit of their being conveyed great distances, and of such organisms being able to produce disastrous results should they gain access to water or food supplies.

Although sewer air, as has been shown by numerous experiments, may be quite free from pathogenic bacteria or "germs," such, for example, as those of typhoid and diphtheria, it must be remembered that a prolonged inhalation of air from sewers and drains may indirectly prove injurious to health by lowering the vitality of the system and predisposing a person to disease. It becomes necessary, therefore, to take all practicable steps for the maintenance of the air of sewers in as pure a condition as possible.

The best of all means of minimising the impurities commonly detected is, as far as possible, to so design the sewerage system that all sewers may have such gradients as shall give self-cleansing velocities to the sewage flowing within them. By this means the sewage passing through is kept as fresh as possible, and time is not allowed for the processes of fermentation and decomposition, with the attendant evolution of offensive gases, to take place. To the same end, the internal surface of a sewer should be as smooth and impervious as possible, so as to avoid the retention of filth. Many old brick and stone sewers with defective inverts still exist in most towns, and these in particular are very productive generators of offensive gases, owing to the undue retention of the sewage in lodgments within the sewers. In fact, the slow travel or detention of sewage, in its journey from the various streets of a town to its final outfall at the disposal works, is oftentimes taken advantage of at such works, and necessarily so, by the limitation of the amount of septic action to be provided for preliminary to treatment upon bacterial lines. Recent experience shows that this septic action taking place within the sewers is ordinarily a sufficient preparation in itself, given, of course, the needful screening and sedimentation prior to the final stage of purification.

Many methods have been adopted from time to time for the purification and ventilation of sewers. Amongst these may be mentioned—

1. Deodorization of the sewage and sewer air by the addition of chemicals, disinfectants, &c.
2. Extraction of sewer air by heat; as, for example, by—
   (a) Connecting sewers with chimney shafts;
   (b) Connecting with iron or other columns or shafts erected along the lines of sewers, each of such erections being provided with heat, such as open fires, gas jets, &c., with the object of creating an upward draught.
3. Mechanical ventilation by means of fans.
4. Natural ventilation by means of open surface gratings at road level, combined with iron ventilation columns erected along the line of sewers, either at the kerb line or other suitable positions, or by carrying vent-shafts up the sides of houses, trees, and other available places.

The first method, *deodorization*, though mentioned here, can scarcely be properly classified as "ventilation," inasmuch as the removal of foul and supply of fresh air by the inducement of a proper circulation is not its object. It relies upon the suppression, covering, disinfection, and deodorization only of the offensive gases emanating from sewage. It is, moreover, an expensive process, both in regard to the supply of chemicals and the attention necessary for the application of the same. The addition of such deodorants to the sewage also oftentimes seriously interferes with the process of purification at the disposal works, particularly if conducted upon bacterial lines.

Extraction by heat, under proper safeguards, is a good method of ventilation when it can be applied without incurring an excessive initial outlay and subsequent large maintenance costs. Connections from sewers to chimney shafts involve considerable risks of causing explosions, owing to the inflammable nature of sewer gases. Accidents have arisen in this way, and the practice is now discontinued. Similar trouble may arise from ventilating columns containing gas jets or other heat, to which sewer air consisting of an explosive mixture gains access. Accidents of this sort are, however, not frequent. The principal practical objection to the use of gas-heated ventilation columns is that of the large annual expense involved for gas and attendance. This commonly amounts to as much as £12 to £14 per year, and, as the number of such columns, in even a medium-sized district, would require, in all probability, to be at least well over a hundred, it will be seen that the system is impracticable of wide adoption, though serviceable in special situations. Webb's sewer gas extractor reduces this cost to a minimum, by employing the heat of gas ordinarily used for lighting purposes as the means of quickening the upcast of sewer air in the column, which latter is also surmounted by a special form of street lighting lantern. This system is largely used.

Mechanical ventilation by means of fans is, again, found to be impracticable of wide adoption, on account of the large initial outlay, running, and maintenance charges. The effect of a single fan is discernible only over a very short length of sewer, and is often overpowered and counteracted by wind currents and natural differences of temperature.

Natural ventilation is the method mainly relied upon in practice for the ventilation of sewers, and the laws which govern the circulation of the air are similar to those regulating the natural ventilation of buildings. Motion is set up by differences of temperature between the inside and outside of the sewers; by the fluctuations of flow within the sewers and the consequent displacement of the air; and also by outside wind currents setting up aspirating or extractive effects by blowing across the tops of ventilation columns, manhole covers, and other openings.

As has been pointed out in the case of buildings, natural ventilation, as the name implies, depends very largely upon the conditions of the atmosphere, the wind, and so forth. Columns, therefore, unaided by heat or other extractive force, are at times inoperative, except as points of pressure-relief should the sewers become fully charged. This advantage is not to be disregarded, inasmuch as it materially relieves the air pressure upon house drains and traps, and so tends to prevent leakage of sewer air into dwellings.

Street columns for sewer ventilation should not be less in any part than 6 inches in diameter, and, to avoid losses by friction, the connection to the sewer should be 9 inches in diameter. These shafts give the greatest ventilating effect when fixed at the high and dead ends of the sewers, and are frequently spaced at from 100 to 200 yards apart.

From an interesting recent report on sewer ventilation by the Borough Engineer of West Hartlepool, it appears that tests were made for the purpose of ascertaining whether columns could be relied upon as ventilators when the external temperature corresponded, as nearly as possible, with the temperature of the sewer, and when the velocity of the wind was so small as to be hardly perceptible, viz., from $\frac{3}{4}$ to $1\frac{1}{2}$ knots per hour. It was then found (by anemometer tests) that the average discharge amounted to 26 cubic feet of sewer air per minute per 6-inch column. Ventilating shafts up the sides of houses were found to be much less effectual, being smaller in diameter and fixed with bends, which very seriously impair the efficiency. Every right-angled bend diminished the ventilating effect by about one-fourth. Bends also afford means for the accumulation of rust and dirt, and thus further reducing the sectional area of air-way.

Of sewer ventilation it may be said generally that whatever system be adopted, it should be as simple as possible, free from complicated apparatus and independent of mechanical aid. The cost of installation and annual maintenance must be confined within moderate limits, in order that the system may be extended over large mileages of sewers. The object to be aimed at is, of course, the removal of all impure sewer air, the prevention of the accumulation of sewer gases in any part of the system, and the regular admission, during all conditions of atmosphere, of continuous streams of fresh air.

The position and direction of the outfall sewer with relation to the prevailing winds, and the configuration of the ground over which the sewerage system extends, materially affect the question of the proper ventilation of the sewers. In very hilly districts it is a common practice to break the length of the sewers into short sections by means of ramps, or drop pipes fitted with flaps, so that the gases accumulating in each section may be independently dealt with instead of passing the whole length of the system. The question as to whether sewer gases will accumulate at the upper or fall to the lower parts of a sewerage system necessarily varies from time to time, according to the relative specific gravities of the gases which obtain at any given moment.

Entry of Sewers.—Where any doubt exists, or where sewers are of considerable depth, the condition of the air therein should be carefully tested before descending into the sewer. This is best done by first lowering a lighted candle.

If the light burns dimly, or, in bad cases, goes out altogether, the sewer should not be entered until thorough ventilation and change of the air has taken place. If there be any sign of the presence of explosive gases, safety lamps should be used in the sewer and only experienced sewer-men employed. To change the air in some cases of deep sewers before entry thereto, it becomes necessary to propel air into the sewer at one end of the section under examination and to extract the vitiated air at the other (usually the higher end) by means of large fans driven by motive power.

HEATING.

CHAPTER XIII.

General Remarks.

As the subject of *Heating* has an important bearing upon that of ventilation, a few brief remarks as to the methods in general use will now be given.

Heat is communicated in three ways:—

(a) By direct contact, known as "*Conduction*."
(b) By conveyance or carrying, known as "*Convection*."
(c) In right lines, and known as "*Radiation*."

Conduction means that the heat is propagated through the mass of a body from molecule to molecule, as, for example, when a metal poker is held with one end in the fire, heat is transmitted along the poker to the hand by "*Conduction*." The transmission of heat by conduction is so slow a process that it may be disregarded for purposes of heating rooms, and the heat only passes between points of different temperature *by heating the intermediate medium*.

Convection means the transference of heat by the actual motion of the parts of the heated fluid, or, in other words, the air or water next the incandescent fuel or hot apparatus becomes heated, diffuses and ascends, thereby giving place to other fluid to be in turn similarly heated and diffused. The heating of a vessel of water by "conduction" by means of the application of heat at the top would be a very slow process, but it may be readily warmed by applying the heat at the bottom of the vessel, when the warmed particles of the fluid are rendered relatively lighter, ascend, and thereby heat the mass by "convection."

Warming by hot water pipes is a good example of heating by conduction and convection combined. The heat is communicated by "conduction" from the incandescent fuel through the metal plates of the furnace to the water in the boiler, is then transferred by "convection" through the water pipes to the various parts of the building. It is conducted to the air around the pipes, and is then conveyed ("convection") by this heated air to the various parts of the room.

Radiation differs from "conduction" or "convection" in that radiant heat, like light, is emitted by a hot body *in all directions* and in *straight lines*. "Heat is said to be transmitted by radiation when it passes from one point to another in straight lines, with great speed *and without heating the medium through which it passes*."[1]

The rays of heat strike objects impeding their path, and these, absorbing more or less heat according to their capacity, afterwards communicate it to the surrounding air.

Much more heat is radiated from a blackened rough surface than from a brightly polished one.

In the presence of a cold body an adjacent warm body will rapidly lose its heat, and the emission of heat will be in direct proportion to the difference of temperature between the two bodies.

"Radiant heat" warms the walls and furniture of a room,

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[1] "Heat, Light, and Sound," by W. E. Jones, B.Sc.

but leaves the air comparatively cool. The *open fireplace* warms by radiation, whilst *close stoves* and *hot pipes* warm chiefly by convection—making the air warm, but leaving the walls and furniture relatively cool. The radiant heat from the open grate is the most pleasant form of heating, and is held to be the healthiest; also the powerful ventilating action of the heated chimney flue is a strong argument in favour of its universal adoption.

There are some important disadvantages, however, to the use of radiant heat on a large scale. It is not economical—a very large percentage, indeed, of heat is carried away and lost up the chimney. There is also considerable loss from imperfect combustion, the unconsumed carbon passing away as smoke. The warming effect of radiant heat is also very feeble at a little distance. Its intensity lessens by the same law as does that of light and sound, viz., inversely as the square of the distance from the source, so that long rooms cannot be effectually warmed by radiation from one source of heat only.

PRACTICAL METHODS OF HEATING.

The heating of a building is usually carried out on one of the following plans:—

1. *Open fires*, burning *coal* or *gas*, with the ordinary chimney.
2. *Close fires*, as cockles, stoves, furnaces, &c., burning either coal or gas.
3. *Hot air* conveyed along flues from a central source of heat.
4. *Hot water* on the *low-pressure system*, with about 3 in. diam. pipes.
5. *Hot water* on the *high-pressure system*, with small pipes about 1 in. diameter.

Steam, either on the high or low-pressure system.

OPEN FIRES.

Coal Fires.—A good deal has already been said in respect to the heating and ventilating of rooms by this means; it is certainly the most cheerful, and also the most generally applied method for warming comparatively small rooms. In regard to its efficiency a good deal depends on the form and design of grate. That illustrated in detail in Figs. 30 to 34 may be regarded as a typical form embodying many points of good construction.

Gas Fires.—Although as an illuminant coal-gas has to some extent been superseded by *electricity*, yet on the other hand a successful effort is being made to popularise its use as a fuel in place of coal, and also as a source of motive power. Gas fires afford a very convenient means of heating sitting-rooms, offices, &c., where fires are only required intermittently for short periods. For *continuous use* they will be found more expensive than the ordinary coal fire, but they afford certain counteracting advantages, such as perfect cleanliness, absence of dust, also there is practically no labour or attention required, and they are ready at any time for use at a moment's notice. What seems to be required in gas heating, whether for sitting-room or cooking, is a stove which shall, when in continuous use, be as economical, or more so if possible, as the ordinary coal fire. When this stage is arrived at the system of heating by gas will no doubt become general, and by its means the troublesome smoke and fog nuisances, common in all large towns, may be materially reduced.

It is as essential, however, as with the common open fire, that all gas fires, whether for heating or cooking, shall have a suitably constructed flue to carry off the gaseous products of combustion, which otherwise will prove most deleterious and objectionable, and soon bring the stove into ill repute. At the same time it is not desirable to have a long length of iron flue in the room before arriving at the point of exit, as wherever the heating flame is brought into contact with surfaces cooler than itself there will be incomplete combustion, and impurities will be given off through the heated iron.

"A good gas stove should not depend too much for its heating effect upon discharging warm air into the room, but

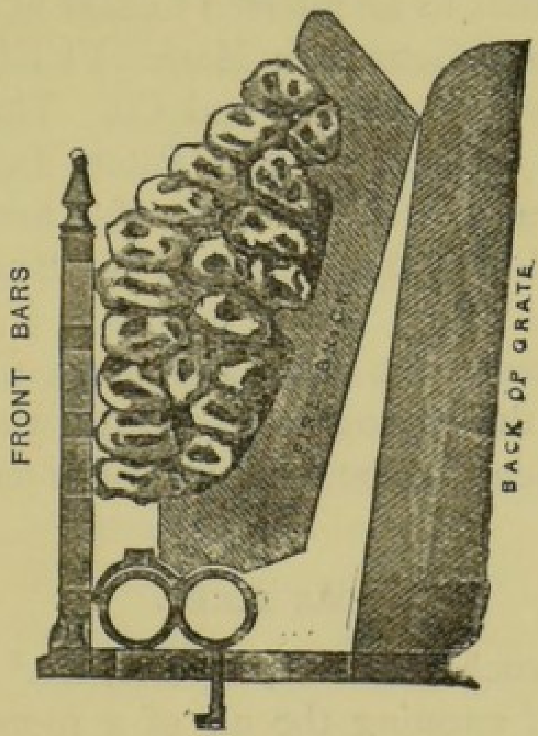

FIG. 42.

should distribute a considerable proportion of its heat by radiation, and so raise the temperature of the floor and furniture in the lower parts of the room."[1] This object, it has been pointed out by Professor Lewes, is to be gained by the application of the principle of "regeneration" in the manufacture of stoves, for "as the temperature of a luminous flame

[1] Transactions of the Incorporated Gas Institute (1895). Professor Lewes on "The Combustion of Coal Gas for Fuel Purposes."

is raised, the *amount of heat radiated* by the incandescent carbon particles increases at a far greater ratio than the heat of the flame itself."[1]

"Mr. Siemens, who introduced the first practical form of regenerative lamp, has also applied regeneration to gas stoves, which are largely used on the Continent,"[1] and with economy and success.

Of English stoves and fires the various forms and varieties are far too numerous to be referred to here in detail, but many good types are manufactured by Messrs. Fletcher, Russell, and Co., also by Messrs. J. Wright and Co. That illustrated in section (Fig. 42) is Fletcher's New Patent Incandescent Fire for ordinary coal grates. It consists of a firebrick back with fireclay balls, and a patent burner of the "new non-lighting back" type.

A practical objection to many gas stoves, which requires to be eliminated, is the hissing noise emitted when burning, and stoves have frequently to be removed solely on this account.

CLOSE FIRES.

Close Fires, such as stoves, cockles, &c.[1] These afford a simple method of warming the air of a room from a central source of heat, and were much used before boilers and hot water pipes became so general. They are usually provided with large flanged surfaces (in order to increase the heated area), which attain a temperature of about 280 deg., and which heat the air passing over them. They are commonly made of cast iron, with a metal flue to convey away the products of combustion, and although not so effectual a ventilating agent

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[1] Transactions of the Incorporated Gas Institute (1895). Professor Lewes on "The Combustion of Coal Gas for Fuel Purposes."

as the open grate, the hot flue may with advantage be utilised to assist the draught in an upcast ventilator.

An important disadvantage, however, to this mode of heating is the unequal warming of the air, and the likelihood of the air being over-heated and scorched. The Smead air warmer—an American invention—is designed with a specially large heating surface, with a view to minimising these defects as far as possible.

Iron, especially cast iron, when heated to a high temperature, is said to allow the passage through it of carbonic oxide from the imperfect combustion of the fuel in the grate, as is found to be the case with the "slow combustion" stoves, burning as they do with a limited supply of air. This gas also escapes by the space around the lid. Highly heated iron in contact with air is also said to have a deleterious action upon the organic matter to diminish the oxygen, and to interfere with the freshness of the atmosphere, making it hot and dry, a defect which is often mitigated by placing vessels of water on the stoves and allowing it to evaporate. All the joints of the flue and stove should be perfectly air-tight; the stove should be lined throughout with fireclay and earthenware, or even wrought iron may be used with advantage in lieu of cast iron.

Close stoves heat the air directly surrounding them chiefly by conduction, and the air thus warmed gradually heats that of the whole room by its convection. Very little radiant heat is given off unless the stove is raised to an undesirably high temperature.

HOT AIR.

Hot Air conveyed along Flues from a Central Source of Heat.—In this case the fresh air is usually admitted to a chamber in the basement, and, after being well filtered through screens of canvas, cotton wool on wire netting, cocoa-nut fibre, or of other material, the air is warmed by contact with heated surfaces, preferably of large area and moderate temperature rather than of small area at a high temperature. It is then collected and conveyed along suitably proportioned ducts, generally by the aid of some mechanical means, such as propulsion fans, to the various chambers of the building under treatment. This method of warming is very generally adopted for public buildings, halls, churches, &c., but the breathing of air delivered through dusty channels, floor gratings, &c., as is often the case, cannot be very desirable from a hygienic point of view.

The central heating and ventilation of the Houses of Parliament, and the application of a similar system to the Victoria Infirmary at Glasgow, has been already described.

Grundy's Patent Hot Air System.—The air is admitted from the outside and conveyed through earthenware pipes to a heating chamber usually constructed in a basement. From thence it is brought through brick flues and admitted through open pattern gratings in the floor. At the same time the apparatus draws out the cold air through other gratings. Also, in summer, the building is ventilated and cooled by a supply of fresh air which passes through the cold air flues.

In methods of warming by hot air delivered through flues, the temperature of the walls and furniture is, of course, less than that of the air in the room—the heat of the body is therefore radiated to those colder surfaces, thus giving rise oftentimes to the sensation of draught. For comfort the system requires to be aided by the open fire or hot water pipes to warm the walls, &c.

For *Warming by Hot Air*, the following formula is given by Molesworth for calculating the flow of air in the flues:—

Let C = cubic feet of air discharged per minute.
H = height in feet to which flue rises.
A = sectional area of flue, square feet.
P = temperature in flue, Fah.
t = temperature of external air, Fah.

$$C = 480 \times A \sqrt{\frac{H(P-t)}{461+t}}$$

In practice this quantity should be reduced by ¼.

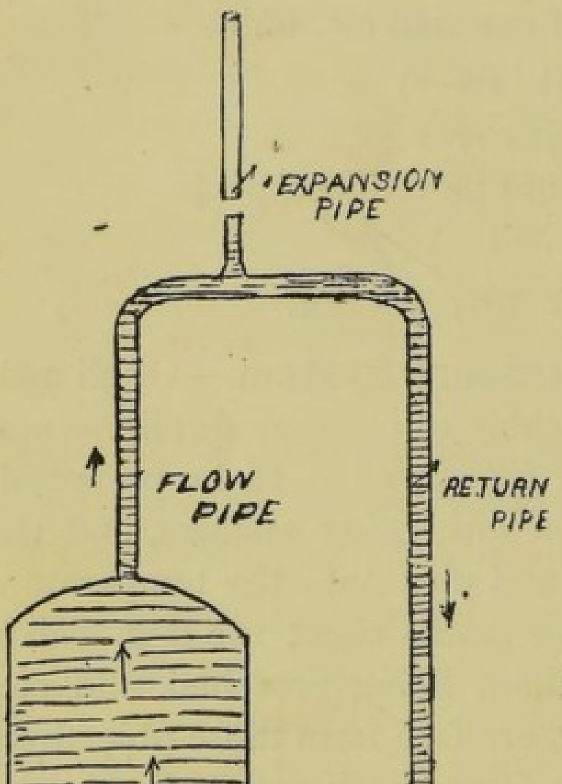
LOW-PRESSURE HOT WATER.

Hot Water on the Low-pressure System.—Of all artificial methods of heating applicable to ordinary dwellings and buildings, that of "*low-pressure hot water*" is to be preferred. It is economical in comparison with other systems, and the heat evolved is healthy, mild, and pleasant—the temperature of the pipes being moderate (maximum about 190 deg. Fah.), the air is gradually warmed without being scorched, and can be regulated at will. The pipes are free from those objections (already referred to) which arise from the direct application of heat to iron. The amount of fuel required by the system is small, and skilled attendance is unnecessary.

In the hot water low-pressure or "large pipe" system, as it is termed, the water cannot be heated above 212 deg. Fah., *i.e.*, boiling point at about sea level under the ordinary atmospheric pressure of 14·7 lbs. per square inch, or 30 in. of mercury, but in the "high-pressure" or "small-bore system," where the water is heated under pressure in a hermetically sealed apparatus, a temperature often exceeding 300 deg. Fah. is attained.

The "*boiling point*" of a liquid by no means represents a constant temperature, but depends upon the atmospheric pressure. The boiling point of water may be defined as *that* *temperature at which its vapour pressure is equal to the pressure of the atmosphere.*

For a given atmospheric pressure, whatever may be the intensity of the source of heat, as soon as ebullition commences the temperature of the liquid remains stationary. By placing a vessel of water under the bell-jar of an air pump, and exhausting the air so as to produce a comparative vacuum, the water is made to boil without raising its temperature. On Mont Blanc, at a height of about 15,800 ft. above sea level, water boils at 184 deg. Fah.



The Principle of Circulating Systems.
FIG. 43.

The efficiency of a hot-water system depends upon the circulation of water in the pipes. The general principle upon which this acts is illustrated by the accompanying diagram (Fig. 43), showing a closed cylinder fitted with a "flow" pipe at the top and a "return" pipe at the lowest part of the side. When heat is applied at the bottom of the vessel the water expands, becomes lighter, and ascends towards the "flow" pipe, and is replaced by colder and heavier water from the bottom of the "return" pipe. This circulation continues so long as the heat is kept up, and the *motive power* is the difference of weight between the hot-water column ascending in the flow pipe and that of the comparatively cold-water column descending in the return pipe. The efficiency of the apparatus will depend, amongst other things, upon the sizes of the pipes, and also upon the velocity of flow in them, which will be proportional to the difference of the specific gravities of the columns of water as above mentioned.

The calculations relating to the practical details connected with a hot-water supply system, such as the length and diameter of pipes, sizes of boilers, &c., are based upon rules and data as given in the works of such authorities as Hood and Box.[1]

To Find the Length of Pipe Required to Warm a Building by Hot Water:—[2]

Let P = temperature of pipes, Fah.
T = temperature required in building, Fah.
t = temperature of external air, Fah.
C = cubic feet of air to be warmed per minute.
D = diameter of pipe in inches.
L = length of pipe in feet;

$$L = \frac{\cdot 018C\,(P - t)\,(T - t)}{D\,(P - T)}$$

For every 100 square feet of pipe surface, from 30 to 50 square inches of fire-grate area is required.

The length of 4 in. pipe required to warm a room may be calculated by dividing the cubic contents of the room, in feet, by the divisor 150, in order to maintain a temperature of 60 deg. Fah.[3]

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[1] Hood's "Practical Treatise on Warming Buildings."—Box, on "Heat."

[2] Molesworth's "Engineer's Pocket Book."

[3] Hood's "Practical Treatise on Warming Buildings."

Three-inch pipes require to be one-third longer, and 2 in. pipes require to be double the length of 4 in. pipes to heat the same number of cubic feet.[1]

Five feet of 4 in. pipe will warm 1,000 cubic feet in a public room to 55 deg.

Allow 12 ft. of 4 in. pipe to every 1,000 cubic feet of space in dwelling houses for securing a temperature of 65 deg.

In workrooms and shops from 6 ft. to 10 ft. of 4 in. pipe should be allowed per 1,000 cubic feet of space.[1]

If the "small bore" high-pressure system of heating is used, about two-thirds of the above amounts will be sufficient.

Mr. James Keith, C.E., London, gives the following information for estimating the amount of pipe or radiator surface required to maintain the temperature of rooms by hot water, for direct radiation and where no special artificial ventilation is arranged for:—

"Divide the difference in temperature between that at which the room is to be maintained and that of the outside atmosphere, by the difference between the temperature of the pipes or radiators and that at which the room is to be kept, and the product will be the square feet, or fraction thereof, of pipe or radiator surface to each square foot of glass or its equivalent."

e.g. Assuming the average temperature of pipes to be 150 deg. Fah., while the outside temperature is 30 deg., and the room is to be kept at 70 deg., we have—

Room	Minus	Outside	=	Difference in temperature.	
70 deg.	–	30 deg.	=	40 deg.	
150 deg. Pipes.	–	70 deg. Room.	=	80	= ·5 or ½ sq. foot.

Therefore, about 1 ft. of 2 in. pipe to every square foot of glass, or its equivalent, will be required to maintain a differ-

[1] Hood's "Practical Treatise on Warming Buildings."

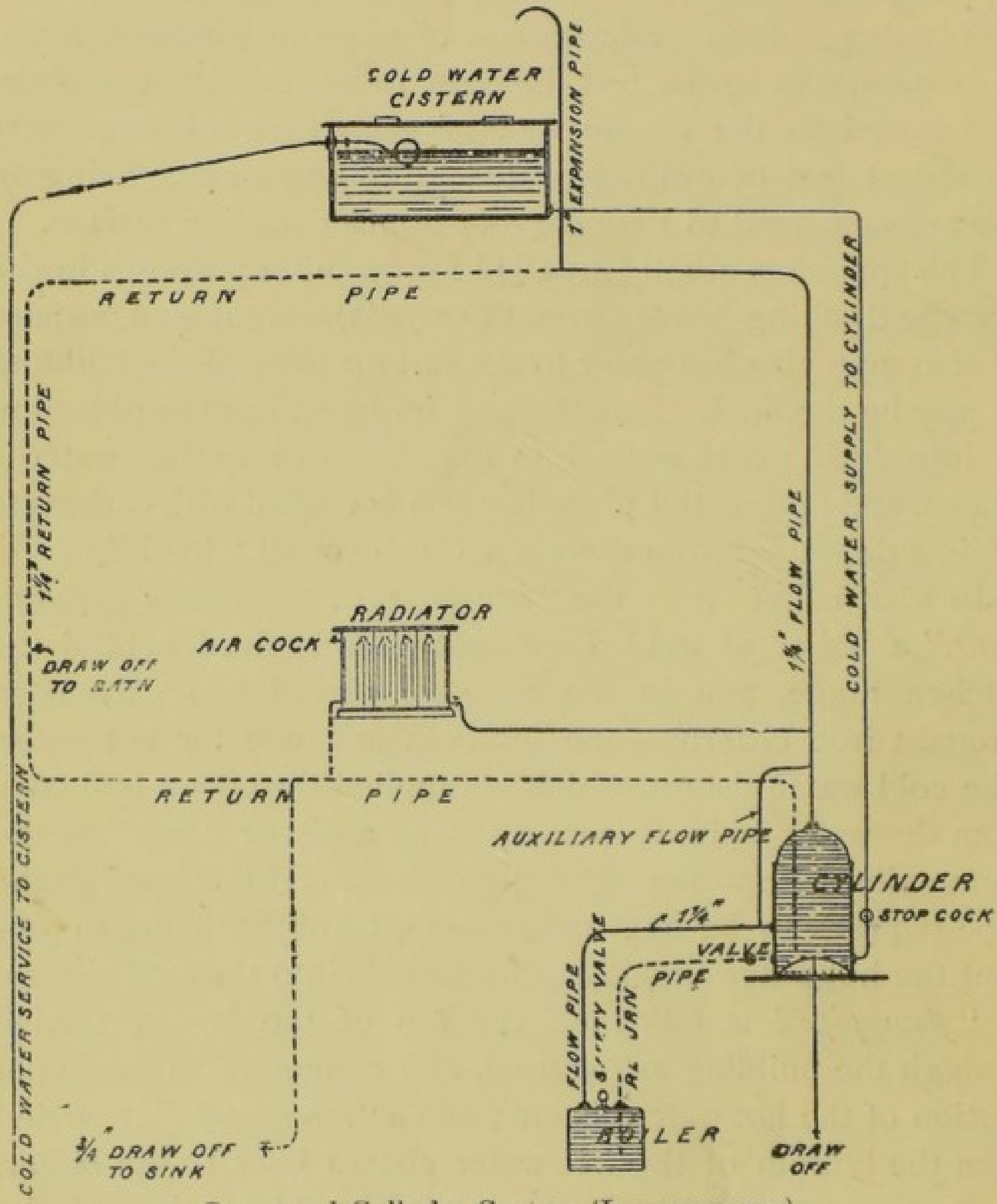
ence of 40 deg., about 25 per cent. to the total being added for safety.

To estimate the total cooling surface in a room, the wall and ceiling surface—independent of glass in windows, &c.—is calculated in square feet, brought to its equivalent in glass, and added to the square feet of glass in windows; every 10 square feet of ordinary wall and ceiling surface being on the average equal to 1 square foot of glass cooling surface.

The apparatus usually installed for warming purposes in the average dwelling-house generally serves the combined purpose of also supplying hot water to the various parts of the building as may be required. This method, however, has the objection of introducing cold water into the system every time water is drawn, and in time the pipes become incrusted with carbonate of lime deposited from the water if it be at all "hard."

In what is known as the "*low-pressure, two cistern arrangement*," a boiler of welded wrought iron is fixed behind the kitchen range, and in the roof are placed two galvanised wrought iron cisterns—one for cold and one for hot water. The cold water cistern, which is supplied through a ball cock from the water main, is connected by a dip or "bag" in the connecting pipe to the hot water cistern. This "bag" in the pipe requires to be kept rather deep, its object being to prevent the hot water circulating backwards into the feed cistern. A "*flow pipe*" is taken off the top of the boiler, carried through the building as required, and connected to the upper portion of the hot water cistern; and a "*return pipe*" is carried from the bottom of the hot water cistern back to the boiler, either connecting to the lower part of its side or through the top and carried down about 1 ft. inside. Thus the circuit is completed, the principle of action being as explained in connection with Fig. 43.

The supply pipes to baths, lavatory basins, sinks, &c. are branched off the "flow pipe."



Improved Cylinder System (Low-pressure).

FIG. 44.

In the above arrangement an objection is that should the ball cock get out of order the system could be drained of water to the level of the lowest draw-off branch, and the remaining water may be soon evaporated and a hole consequently burnt in the boiler.

"Low-pressure, Improved Cylinder System" is a better arrangement than that just described, and is illustrated by the accompanying Fig. 44. A hot water cylinder, usually constructed of galvanised iron plate from about ·094 to ·25 of an inch in thickness, is placed somewhere near the boiler, and the "flow," "return," and cold water pipes are connected as shown in the section. There is also an *auxiliary flow pipe* connecting the boiler flow to the cylinder flow, thereby accelerating the circulation. A *stop cock* should always be fixed in the cold water supply pipe, so that the water may be readily shut off from the cylinder without sending to the top of the house, or wherever the cold water cistern may be placed. The *expansion pipe*, fixed from the highest point of the circulation, is shown to discharge at a height of about 5 ft. over the cold water cistern in the roof.

General Remarks connected with Hot Water Fitting.—The "flow pipes" should not project inside the boiler, but may be fixed by cutting a hole with a thread to suit the pipe and screwing on a "back-nut" outside, so that the pipe need not be screwed in too far. If the iron of the cistern is of a light substance a "boss" may be riveted on, to which the pipe can be screwed.

In good work not less than 1¼ in. diameter galvanised iron or tinned copper pipes should be used—the iron being what is known as the lap-welded steam pipe. The "return" should always be the same size as the "flow" pipe, or the circulation will be impeded.

In practice it is found that water will not circulate so freely in horizontal as in vertical pipes, and the "flow" and "return" are best laid with at least a slight fall of not less than about 1 in 120. In order to secure the maximum circulation, the hot water should be drawn off the "return" pipes.

All cisterns and pipes should, of course, be so placed and protected as not to be exposed to any danger from frost. The hot-water cylinder is best fixed as near the boiler as possible, and should be enclosed and covered with a non-conducting material, to prevent the waste of heat by radiation.

Safety Valves.—As a security against the possible explosion of the boiler through the generation of steam, a safety valve should be provided and connected with the boiler by a separate pipe apart from the circulation pipes. Some of these are similar to the valves attached to steam boilers, but the "dead-weight safety valve," to which weights are added proportional to the pressure to be resisted, is best and is in general use. It should be fixed where it can be seen.

Domestic Boiler Explosions.—The *cause* of domestic boiler explosions, judging from the various explanations which have been put forward from time to time, is a matter greatly misunderstood. It has frequently been attributed to the fact of the boilers becoming empty and red hot, and, while in this state, receiving a sudden supply of cold water; but, whilst the rupture of a boiler might occur under these circumstances, it has been shown experimentally that a disastrous explosion cannot thereby be caused. The inadequacy of this solution was also pointed out in *Engineering*, 2nd February, 1894, where it is referred to as an "*exploded* engineering fallacy."

Other causes which have been suggested are the "generation of an unknown and highly explosive gas" (by no means a satisfactory theory), and the "instantaneous evolution of steam under enormous pressure," consequent upon the inrush of water upon the red-hot boiler surfaces, which latter is the most readily accepted explanation. The presence of free steam in the apparatus, causing an accumulation of pressure within, by reason of the outlets being sealed by frost or other cause, when fires are in use and the boiler contains water, is undoubtedly the immediate cause of these explosions. Should the boiler, however, be *full* of water, steam will not be thus generated within; but assuming the fire to be hot enough, and the boiler hermetically sealed, the expansion of the water by heat would doubtless fracture the boiler and cause rapid leakage, but would give rise to no disastrous *explosion*.

That portion of the "expansion tube" which passes through the roof and becomes exposed is a frequent source of danger in hot-water fitting, and should therefore be fixed with care, and protected so as to avoid risk from frost.

"Domestic boilers, working under a pressure due to the head of water produced by cisterns at a high level, should be constructed with the same care and caution as if they were steam boilers, and be capable of sustaining safely at least four times the normal pressure."[1] Also, some system of authoritative inspection may be beneficial as a possible preventive of accidents.

"In January, 1881, during a period of nine days' frost, thirty-two domestic boiler explosions were *recorded* in the United Kingdom, and these thirty-two resulted in the deaths of nine persons and in serious injury to twenty-five persons.

"In January, 1894, during a period of five days' frost, twenty-two domestic boiler explosions were recorded, resulting in the deaths of ten persons and in serious injury to twenty-nine. In the year 1895, between the 3rd and 17th of February, forty-four domestic boiler explosions were recorded,

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[1] Transactions of the Institution of Civil Engineers of Ireland (Vol. xxiv.).

resulting in nine deaths and fifty-nine personal injuries in a period of one fortnight. Numerous explosions of heating apparatus, boilers in churches, schools, and other buildings also occurred.

"In all domestic circulating boilers the flow and return pipes, so long as they are unobstructed, act as safety valves, but the amount of safety depends on the skill of the engineer or contractor, and on the arrangement he designs. The actual safety grows less in proportion to the length of pipes, the number of bends, the head of pressure, the risk of frost or incrustation, the existence of stop-taps, and *the tendency to deteriorate the strength of materials in boilers and fittings owing to the demand for cheap work.*"[1]

Walker's Steamless and Non-explosive Hot Water Supply Principle.—This is a comparatively recent invention of Mr. James Walker, of Liverpool. Its object is to obviate the bursting of hot-water boilers and expansion pipes, which so frequently takes place, especially in times of frost, with the disastrous and fatal results referred to above.

The accompanying Fig. 45 illustrates one form of application of the principle, and is briefly described as follows :—

"Hot water from the kitchen boiler A circulates through the closed chamber C of the cyclinder D, by means of the flow and return pipes B, B^1, thereby heating the water contained in D. The cylinder D has water supplied to it by pipe G from the store cistern above, while the boiler A receives water from the cistern I, which is itself supplied from the cylinder D by the pipe J and ball-float valve K. A stand-pipe F is fitted to the boiler A for withdrawing hot water by means of the pipe P; a siphon L is fitted to the supply pipe M of the boiler A to prevent water entering the boiler when the latter

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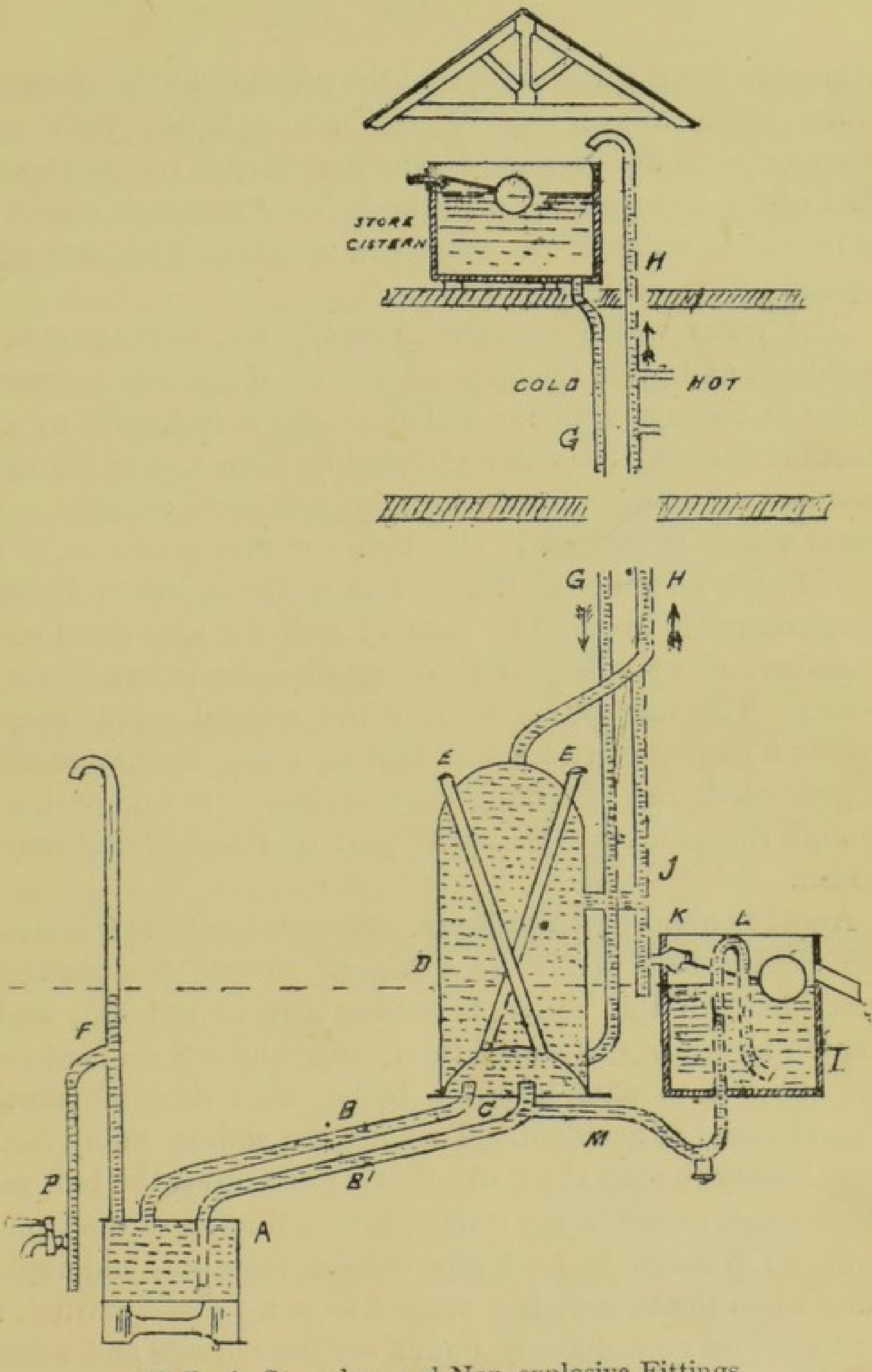
[1] Transactions of the Institution of Civil Engineers of Ireland (Vol. xxiv.).



Walker's Steamless and Non-explosive Fittings.
FIG. 45.

is empty. Vent pipes E prevent the pressure in the chamber C from rising above that of the atmosphere. With these arrangements the pressure in any part cannot rise much above that of the atmosphere; or if the boiler A becomes empty and is heated to redness, no water can pass into it because of the siphon tube L on its supply pipe."

The water which circulates through the upper part of the building, and gives the general supply of hot water, does not come in contact with the boiler at all; it is heated by conduction only by the water circulating from the boiler to the bottom or heating chamber of the steamless cylinder. The water which is heated in the boiler merely passes on to this condensing chamber at the bottom of the cylinder, where its temperature is lowered by contact with the upper and cooler chamber of cylinder, and so returns back again to the boiler. This method of heating the general supply keeps it always a degree or two below boiling point, so that no steam is generated, and the danger of explosion is removed, even though the pipes in the upper part of the building may be frozen.

Another important feature in connection with this system is the *Siphon Feed to the Back Boiler*. Should a stoppage of water lead to the boiler becoming dry or red hot, and a sudden return of the supply then occur, the siphon feed L will not allow it to pass into the boiler, thus avoiding another fruitful cause of accident. To start the siphon safety feed it is necessary to stop the "overflow," press down the ball valve till the water rises in the cistern above the top of the siphon, remove tap screw in feed pipe whilst charging, and replace same when the siphon has started to act. Once started, the feed goes on continuously under ordinary usage and without attention.

The circulation of the water in the cylinder and pipes above the enclosed heating chamber at the bottom of the cylinder depends for its action, as in other systems, on the difference of weight between the cold water column in pipe G, G, and the hot-water column H, H, thus setting up a motion, as indicated by the arrows.

This system is undoubtedly free from explosion, but, as the water is heated indirectly, it would appear that a considerable space of time must necessarily elapse before a large quantity of water could be heated as compared with the ordinary systems of circulation.

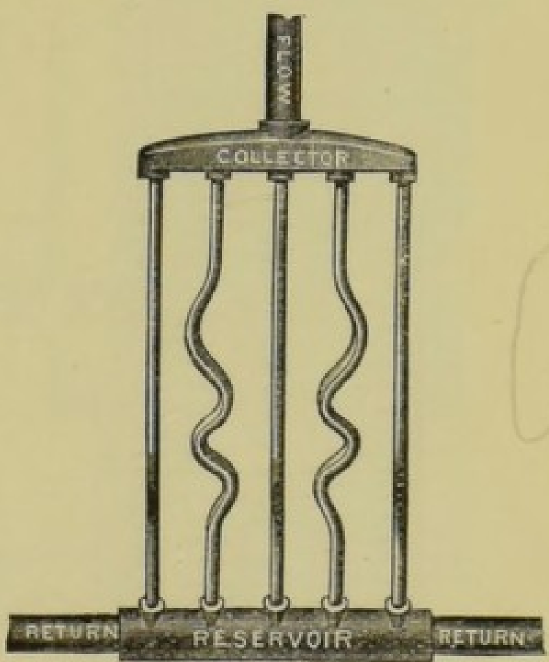


FIG. 46.

Prior's Patent Heat Distributor is an ingenious device for utilising the waste heat from a sitting-room fire for the purpose of warming adjacent rooms. The apparatus (Fig. 46) is fixed in the back of the fire-grate for the purpose of intercepting the waste heat, probably some 80 per cent. of the total generated, which is ordinarily lost by escape up the chimney. From Fig 47 it will be seen the "distributor" is fixed in the back of the fire-grate in most general use during the winter months, and is connected with hot water pipes and radiators placed in the rooms to be warmed. The distributor derives sufficient heat from the back of the fire to set up a circulation of heated water in the pipes and radiators. Taps are provided to control the radiators and temperature, and for the purpose of turning off the heat from any room when not required. It is claimed that one fire can thus be made to heat three rooms, and that great consequential economy is derived from the coal used.

The distributor is made of strong oblong copper tubes, of such a shape as not to interfere with the radiation of the heat from the fire, and corrugated in a manner to increase the heating power and form expansion loops. The corrugated

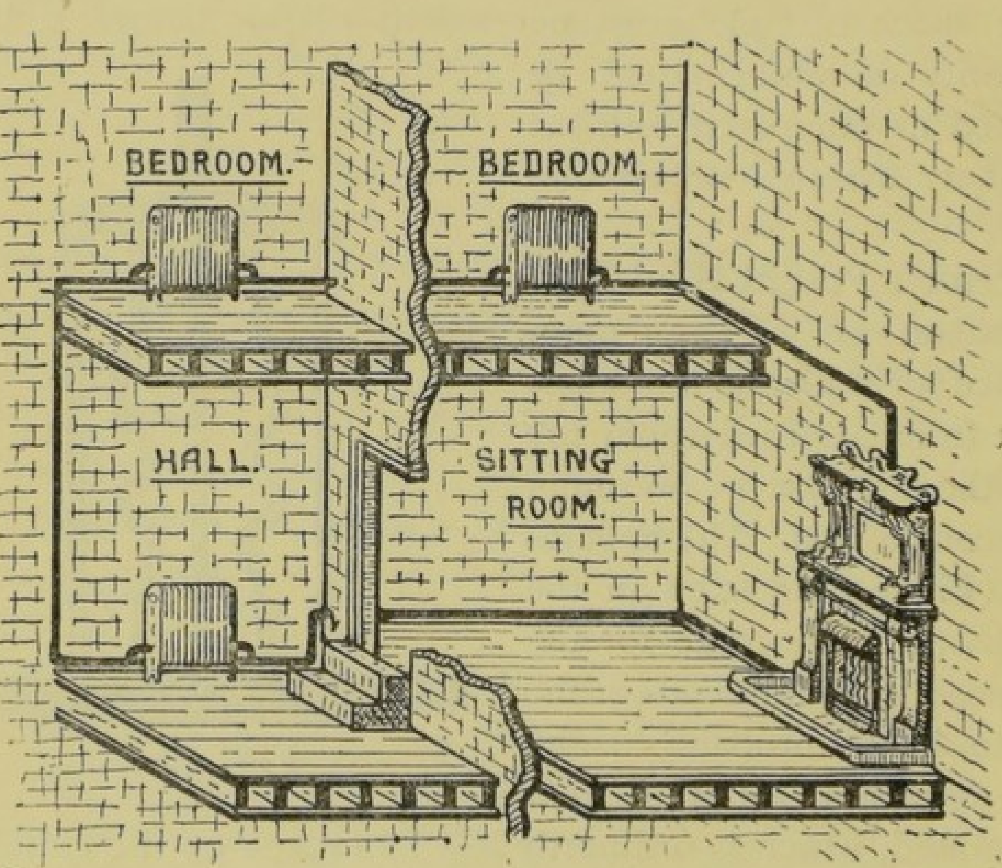
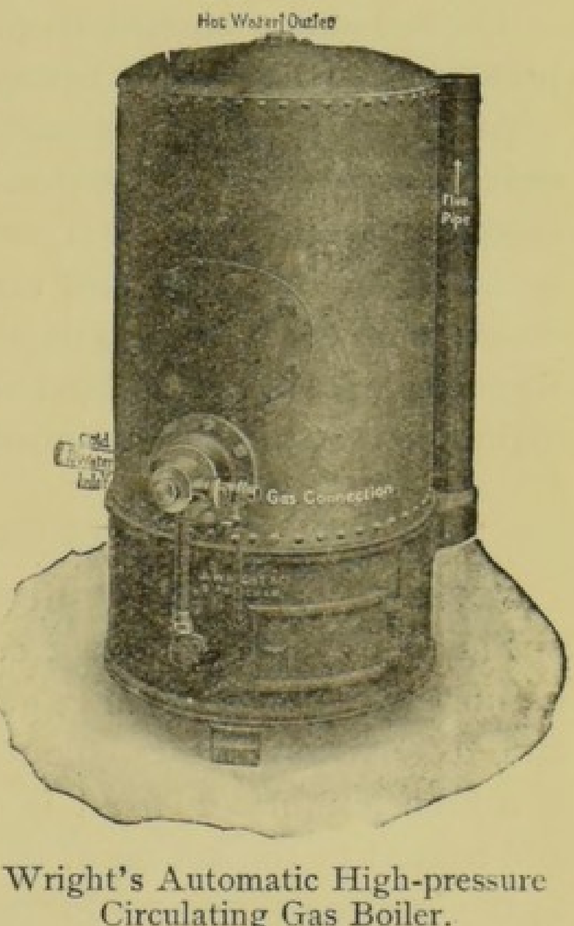


FIG. 47.

tubes quickly absorb heat, and the water contained in them circulates through the reservoir and collector to the flow pipe leading to the rooms above, as shown in the illustration. The tubes are drawn from copper and are seamless, whilst the reservoir and collector are of gun metal. The flow and return pipes are usually 1 in. in diameter, and the method of circulation and connection to radiators will be clear from the illustration (Fig 47). The maker of the apparatus is J. D. Prior, of Holliday Street, Birmingham.

Wright's Automatic High-pressure Circulating Gas Boiler (Fig. 48) is an ingenious apparatus for delivering water at a given temperature regulated by an automatic valve. It is thus described by the manufacturers :—



Wright's Automatic High-pressure Circulating Gas Boiler.

FIG. 48.

"This heater is designed to deliver hot water by means of pipes to any part of the house. The apparatus consists of a multitubular boiler and a strong riveted steel cistern (tested to 30 lb. to the square inch) holding 20 gallons of water. An automatic gas valve is fitted which automatically shuts off or turns on the supply of gas as the temperature of the water rises above or falls below the desired temperature. Thus, supposing it is desired to keep the water at a temperature of 150 deg., the gas is lighted, and when the temperature of the water rises to that point, the automatic valve (having been adjusted) cuts off the supply of gas. If hot water is then drawn off, the cold water running in operates on the automatic valve, which at once turns on the gas supply, the gas being ignited by a pilot light kept continually burning. The water is in a short time again raised to the desired temperature, when the gas is again automatically cut off. The quantity of hot water at command, of course, depends upon the size of the cistern, which can be had ranging from 10 to 60 gallons. This quantity of water at 150 deg. is sufficient for two baths, and as the gas is automatically turned on the moment any water is drawn off, the quantity of water required for further baths is heated whilst the bath is in use."

These heaters should not be subjected to a greater water pressure than 25 lb. per square inch.

As to adjusting the automatic Regulator—the apparatus is sent out with the Regulator adjusted to deliver water at a medium temperature. If it is desired to alter the temperature, unscrew cap and turn finger to right or left hand, which will give 20 degrees either way. When once the Regulator is adjusted the temperature of the water will be maintained at the desired point.

HIGH-PRESSURE HOT WATER.

Perkins' "High-pressure" or "Small-bore" System.—This system consists of a continuous length of small-bore hermetically-closed piping, generally about 1 in. in diameter, and, to serve as a boiler, about one-sixth of its length is coiled in a firebrick furnace fixed in the basement of the building, and heated by the action of the fire in immediate contact with it, thus raising the water in the pipe to a temperature of from 300 deg. to 400 deg. Fah.

Owing to the expansion of water by heat, an *expansion chamber*, having a capacity equal to from one-tenth to one-twentieth of the entire apparatus, is provided at a point above the highest level of the system, and is fitted with a screw cap. After the pipes are fixed they are filled with water through a filling tube at the bottom of the expansion tube, care being taken to expel all air by repeatedly forcing the water through the circuit. When completely filled (none, of course, entering the expansion tube), the apertures in the feed and expansion tubes are then hermetically closed with screw plugs, so that there is no waste from evaporation. The apparatus contains about a gallon of water per 40 ft. length of pipe.

To heat the various rooms coils of pipe are enclosed in box skirtings fitted with open gratings, and hot water is obtained by inserting coils in cold water cisterns.

The air warmed by this system is often scorched and somewhat unpleasant to breathe, as is the case with the high temperature iron stoves. Another objection is that the coil, holding only a small quantity of water, may become overheated and cause an explosion. The system also requires some skilled attendance. The small size of the pipes is a convenience for fixing, and the system is very suitable for mechanical drying processes, and heats quickly.

STEAM HEATING.

Heating by Steam is seldom adopted except where waste steam can be turned to account for the purpose, as in factories, workshops, drying rooms, Turkish baths, &c. using steam power. The principle depends on the steam giving out its latent heat upon its condensation by contact with cold surfaces.

To heat a room to 60 deg. Fah. the length of steam pipe may be found by the following method. The length in feet of steam pipe is given by multiplying the volume of air in cubic feet to be warmed per minute, by the difference of temperature in the room and the external temperature, and divide the product by 304 for 4 in. pipe, or by 228 for 3 in., by 152 for 2 in. pipes, and by 76 for 1 in. pipe.[1]

[1] Hutton's "Works Manager's Handbook."

An approximate rule for pipes heated with exhaust steam, when the external temperature is 10 deg. below freezing point, in order to maintain a temperature of 60 deg., is as follows [1]:—

1 superficial foot of steam pipe for each 6 superficial feet of glass in the windows.

1 superficial foot of ditto for every 6 cube feet of air escaping for ventilation per minute.

1 superficial foot of ditto for every 120 superficial feet of wall, roof, or ceiling, allowing about 15 per cent. additional for contingencies.

1 cube foot of boiler is required for every 2,000 cube feet of space to be heated.

1 H.-P. boiler is sufficient for 50,000 cube feet of space. Steam at 212 deg. Fah.

In the *Low-pressure System* a "flow" pipe of wrought iron is taken from the top of the boiler placed in the basement, is conducted to the rooms above, and there connected with coils or radiators, &c., and a return pipe into the bottom of the boiler carries back the water of condensation. "The general principle of the low-pressure form of steam service is that the steam should rise direct from the boiler into the main distributing pipe, and that this pipe should always have an incline downwards, so that all condensed water should run to the lower end, where it is passed by a relief pipe into the return main," which is slightly inclined towards the boiler. "By this plan the steam and condensed water always flow in the same direction, and this is a great safeguard against noise." [2] In this system the temperature of the pipes is moderate and uniform, varying from about 180 deg. to

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[1] Molesworth's "Engineer's Pocket Book."

[2] Galton's "Hospitals."

230 deg. Fah. The system is also safe and noiseless, but requires careful fitting and regular attention.

In the *High-pressure System* the steam is generally supplied direct from a steam boiler or exhaust of a steam engine, the steam either escaping after use or passing into a feed-water tank to be pumped back into the boiler. The steam is conveyed in strong wrought iron pipes to coils or radiators, as required; the pipes attaining a temperature of from 300 deg. to 400 deg. Fah. The air is therefore liable to be overheated, is dry and unhealthy, and not adapted for warming dwelling-houses. The condensation in the pipes sometimes gives rise to objectionable noises, and the system needs careful fitting and attention.

WARMING IN PUBLIC ELEMENTARY SCHOOLS.

The following observations on the warming of Public Elementary Schools are contained in the *Building Rules* as to the planning and fitting up of these buildings, issued by the Board of Education[1]:—

"The heat should be moderate and evenly distributed, so as to maintain a temperature of from 56 deg. to 60 deg. When a corridor or lobby is warmed, the rooms are more evenly dealt with, and are less liable to cold draughts. Where schools are wholly warmed by *hot water*, the principle of *direct radiation* is recommended. In such cases *open fire-places*, in addition, are useful for extra warming on occasions, and their flues for ventilation always.

"(a) A common stove, with a pipe through the wall or

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[1] July 7th, 1905. (Extracted by permission of the Controller of His Majesty's Stationery Office.)

roof, can under no circumstances be allowed. Stoves are only approved when—

"(1) Provided with proper chimneys (as in the case of open fires);

"(2) of such a pattern that they cannot become red hot, or otherwise contaminate the air;

"(3) supplied with fresh air, direct from the outside, by a flue of not less than 72 in. superficial; and

"(4) not of such a size or shape as to interfere with the floor-space necessary for teaching purposes.

"(b) A thermometer should always be kept hung up in each room.

"(c) Fireplaces and stoves should always be protected by fireguards.

"(d) If a room is warmed by an open fire the fireplace should be placed, if possible, in the corner of the room, in order to leave space for the teacher's desk and blackboard."

LIGHTING.

CHAPTER XIV.

General Remarks.

The *lighting* of buildings, including that effected by "natural" as well as by "artificial" means, is inseparably associated with the question of their "ventilation," and with the purity, or otherwise, of the atmosphere of rooms. The amount of *daylight* admitted throughout a dwelling also has an important bearing upon its cleanliness and general sanitary condition.

An abundance of sunlight and air is essential for the organic development of both vegetable and animal life, and the effect of the sun's rays "has been shown to kill some classes of spores and bacilli, and to check the development of certain forms of micro-organisms in connection with disease."[1]

The germicidal action of bright sunlight, and also, but to a less extent, of diffused daylight, has been further observed in connection with the purification of the running water of rivers and streams.

Living in rooms with only a limited supply of *daylight*, as is so frequently the case in the narrow streets of crowded

[1] Galton's "Hospital Construction."

towns, contributes largely to a low standard of health, and soon results in a weakened physique. Light is also required as an "antagonist to dirt"—dark rooms being always favourable to the collection and prolonged retention of dust and dirt of all kinds.

NATURAL ILLUMINATION.

The question of *natural illumination* in connection with the design of buildings has not received a great deal of attention by the architectural profession. The main object usually aimed at by the designer is to secure good outside effects. Dr. Förster, of Breslau, has, however, given the subject his consideration, and, according to him, so far as fine work or reading is concerned "the most perfect ease is felt in the open air on a summer's day when the sky is overcast. Under these circumstances the light is ample, but it is *perfectly diffused;* there is neither glare nor shadow, and the light may be said to come from all sides, but from no one in particular." [1] These may be regarded as the *ideal conditions* to be aimed at by all engaged upon the subject of *artificial* illumination, and their success or otherwise will be measured by the degree of efficiency with which these conditions are attained.

Dr. Förster further states that "roof lighting, where practicable, is the very best, but failing this, opposite windows facing east and west are to be recommended. The light must come *direct from the sky*, and no part of a room may be deemed sufficiently lighted from which a certain extent of sky cannot be seen." He also lays down that the arc of sky visible from any part of a room should not be less than 5 deg., and that the inclination of the rays of light with the floor should under no circumstances be less than 25 deg., and therefore suggests the reducing, so far as possible, of the relative width of rooms

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[1] Dr. Willoughby's "Health Officer's Pocket Book."

to not more than from two to two and a-half times the height of the window heads from the floor.

"The loss of light through windows varies with the quality of glass," as shown in the accompanying table:—[1]

Polished British plate glass, ¼in. thick	Intercepts	13	p.c.	of the light
36 oz. sheet glass	,,	22	,,	,,
Cast plate glass, ¼in. thick	,,	30	,,	,,
Rolled plate glass, four corrugations in an inch	,,	53	,,	,,

LIGHTING IN PUBLIC ELEMENTARY SCHOOLS.

The following instructions for Public Elementary Schools, as to the points to be observed in order to obtain the best "*natural illumination*" possible in these buildings, are given in the *Building Rules*[2] of the Board of Education:—

"Every part and *corner* of a school should be well lighted. The light should, as far as possible, and especially in class-rooms, be admitted from the *left side* of the scholars. All other windows in class-rooms should be regarded as supplementary, or for ventilation. Where left light is impossible, right light is next best. Windows full in the eyes of scholars cannot be approved.

"Unless the top of the windows be more than 14 ft. above the floor the plan should show no space more than 24 ft. from the window-wall in any room used for teaching.

(a) "Windows should never be provided for the sake merely of external effect. All kinds of glazing which diminish the light[3] and are troublesome to keep clean and in repair

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[1] Galton's "Hospital Construction."

[2] July 7th, 1905. (Extracted by permission of the Controller of His Majesty's Stationery Office.)

[3] See Table as to loss of light through windows given above.

must be avoided. A large portion of each window should be made to open for ventilation and for cleaning.

(b) "The sills of the main lighting windows should be placed not more than 4 ft. above the floor; the tops of the windows should, as a rule, reach nearly to the ceiling; the upper portion should be made to swing. The ordinary rules respecting hospitals should here be remembered. *Large spaces between the window heads and ceiling are productive of foul rooms.*

(c) "Skylights are objectionable. They cannot be approved in school rooms or class rooms. They will only be allowed in central halls having ridge or apex ventilation.

(d) "The coloring of the walls and ceilings and of all fittings in the rooms should be carefully considered as affecting the light. This point and the size and position of the windows are specially important in their bearing on the eyesight of the children.

(e) "The windows should be properly distributed over the walls of the class rooms so that every desk shall be sufficiently lighted. The glass line of the window furthest from the teacher should be on a line with the back of the last row of desks."

ARTIFICIAL ILLUMINATION.

All artificial sources of light depend upon the raising of some substance to such a temperature that it becomes incandescent.

For ordinary lighting purposes in practice our light, except in the case of electricity, is obtained from the combustion of compounds of carbon and hydrogen. Whether the light be derived from common coal gas, candles, or oil lamps, there is no material difference in this respect, the same constituent, viz., hydrocarbon gas, being present in each case.

"The carbon which is found in the organic kingdom, whether in a pure form as *graphite*, in solid combinations, as *coal*, or in liquid combinations, such as *petroleum* and other so-called *mineral oils*, has all been originally withdrawn from the atmosphere by vegetable growth, under the stimulus of solar light; and the hydrocarbons of the animal kingdom, such as the various forms of fat, have derived their carbon from the employment of vegetable matter as an alimentary material; so that, in point of fact, *all the forms of combustion by which we ordinarily produce light and heat are nothing but reversals, on a small scale, of the solar action of former periods, and all artificial light is derived, at least indirectly, from the sun.* The cheerful glow and the genial warmth of our coal fires are but the re-appearance, in those forms, of the solar force which caused the growth of a primeval forest, and which has since been engaged, until liberated by human agency, in binding together the elements of which the coal was composed."[1]

Flame is a stream of burning vapour or gas raised to incandescence by chemical combination and emitting light and heat. To produce flame the burning substance must either be gaseous or be first converted into gas before the combustion takes place. In order to emit much *light* a flame must contain solid matter. The luminosity of the ordinary candle and gas flame is due to the presence in it of solid particles of carbon which become heated to whiteness. A flame—take, for example, that of the candle—has a definite structure, and is generally described as consisting of three parts—

1. The dark central zone containing unburnt gases produced by the action of the heat on the wax;

[1] "Lighting," by R. B. Carter, F.R.C.S., in "Our Homes."

2. The luminous zone of incomplete combustion of gases, the carbon being separated in the solid state and rendered incandescent ;

3. The flame mantle or non-luminous zone of complete combustion.

The intensity of light at any given distance from its source is measured by what is known as the "law of inverse squares," viz., *its intensity varies inversely as the square of the distance*, so that the intensity of the light received respectively by three surfaces placed at distances of 1 ft., 2 ft. and 3 ft. from the source would be as 1, $\frac{1}{4}$ and $\frac{1}{9}$.

Upon the above law is based the principle involved in the measurement of light by "photometers." The instruments are of various forms, *Rumford's shadow photometer* and *Bunsen's grease spot photometer* being the best known. In the former the sources of light to be compared are adjusted at such distances from a screen that the shadows thrown from a solid opaque rod are equal in intensity. The relative intensities of the lights are then given by the squares of their distances from the screen. In the Bunsen photometer the two lights are placed one on each side of a screen of opaque paper with a small grease spot in the centre, and are then arranged at such distances from the screen that the spot becomes invisible, the relative intensities being then compared as before.

For the information of those who may be further interested in the testing of the candle-power of lamps and other photometrical observations, it will be useful to state that excellent apparatus for this work is made by Alexander Wright & Co., Victoria Street, Westminster, S.W., and by Everett, Edgcumbe & Co., Hendon.

Illumination is usually expressed in terms of *candle-power* and *distance*. The standard adopted is that of a No. 6 sperm candle burning 120 grains per hour. The amount of illumination given by one standard candle at a distance of 1 ft. is known as a "*candle-foot*," and is the unit used for the measurement of light.

The comparative amounts of heat emitted by the various forms of light, reckoning the paraffin candle as giving 100 per cent., is given[1] approximately as follows—

Paraffin candle	100 per cent.
Colza oil lamp	66 per cent.
Argand gas burner	52 per cent.
Petroleum lamp	30 per cent.
Electric incandescent lamp	5 or 6 per cent.
Electric arc lamp	½ to 1 per cent.

In any practical considerations as to the form of light to be adopted, the hygienic aspect of the question, combined with good illuminating efficiency and little heat, is the object to be kept in view. In lighting by means of the combustion of some substance, as is the case with gas, oil, candles, &c., it is, of course, a first essential that the compounds used should be as pure as is possible in order to maintain the purity of the air of the room. In this connection, much, no doubt, has been done towards effecting improvements in the manufacture and methods of purification of coal gas, as well as in the perfecting of forms of "burners," with the view of obtaining a maximum illumination with a minimum gas consumption, and consequently, therefore, a minimum also of air pollution.

[1] By the "General Electric Company."

Table of Comparison of Light-producing Materials.[1]

Light-producing material equal to 12 standard sperm candles, each burning 120 grains per hour.	Cubic feet oxygen consumed.	Cubic feet air consumed.	Cubic feet carbonic acid produced.	Cubic feet air vitiated.	Heat = lbs. of water raised 10 deg. Fah.
Cannel gas	3·30	16·50	2·01	217·50	195·0
Common gas	5·45	17·25	3·21	348·25	278·6
Sperm oil	4·75	23·75	3·33	356·75	233·5
Benzole	4·46	22·30	3·54	376·30	232·6
Paraffin	6·81	34·05	4·50	484·05	361·9
Sperm candles	7·57	37·85	5·77	614·85	351·7
Wax	8·41	42·05	5·90	632·25	383·1
Tallow	12·00	60·00	8·73	933·00	505·4
Electric light	None	None	None	None	13·8

The vitiating effects of the combustion of lights upon ventilation have already been dealt with in Chapter I., when considering the causes of impurity of the atmosphere in inhabited rooms, as also have the means to be adopted for the purpose of conveying away the products of combustion (see Fig. 1), and in which arrangements the heat derived from the illuminating agent is turned to account to accelerate the extraction of the impure air. Some such means of removing the vitiated air is essential in connection with every known form of lighting where there is combustion, no matter what may be the extent of the elaboration of the form of "burner" or lighting apparatus used. The sources of impurity are very numerous (see pp. 6 to 11), and the air of a room must on no account be allowed to stagnate; in fact, thorough ventilation or entire and continuous *change of air*, by the provision of adequate inlets and outlets, is *the only means* by which the purity of the atmosphere of a room can

[1] By Dr. M. Tidy in "Handbook of Modern Chemistry."

be maintained within the "limit of permissible impurity." The adoption of the most hygienic system of lighting is certainly an important step in the right direction, but it would be obviously wrong to assume that by this means the necessity for an adequate ventilating system is dispensed with—there must be an imperceptible and regular change of air constantly taking place, in order that the impurities from combustion, respiration, and all other sources may be removed as fast as created.

In addition to improvements made of late years in the manufacture and adaptation by improved burners of coal-gas as an illuminant, it has also been found advisable, due, without doubt, to the wholesome influence of its modern competitor, viz., electricity, to broaden the basis of its popularity by opening up new fields of usefulness, such as for cooking, heating, and motive power. Also, the more general use of gas has been encouraged amongst the working class population by the invention of the "penny-in-the-slot" meter.

The application of the principle of "*regeneration*" to burners has effected an improvement in illumination. It consists in the heating of the air and gas previous to their union by causing the heat of the combustion, which is otherwise wasted, to heat the gas and air, which come next in turn to be consumed. In Siemens' regenerative burner the waste heat and products of the flame are collected in a central regenerative heating chamber, and the gas and air in the surrounding chambers during the progress of their ascent from the bottom to the top of the burner are raised to a high temperature, thereby practically increasing the illuminating power three-fold, but a large amount of radiant heat is also emitted.

Another important advance was made by the introduction of the improved system of lighting afforded by the "*incandescent gas light*," based upon the patents of Dr. Auer von

Welsbach. The lamp consists of a specially constructed Bunsen burner, over which is suspended a filament, technically termed the "mantle." The burner is so designed that the flame is used as a heat-giving medium only. The gas combines with about two or three times its own quantity of air in a special tube, through which the mixture is carried to the top of the burner, where it burns with a non-luminous heating flame. The mantle, which entirely surrounds and covers the whole of the flame, then becomes brilliantly incandescent, and gives out a clear, steady white light.

The system, both as regards its superior illuminating efficiency and also as to its hygienic advantages, has been favourably reported upon by many eminent authorities, and the conclusions drawn from the experimental investigation of the system by the *Lancet*[1] special analytical and sanitary commission contain the following points:—The burner, with or without the mantle, is not prejudicial to health, and there is not a trace of any poisonous gases—such as carbon monoxide or acetylene—in the products of combustion. The heat and carbonic acid produced is one-half that of an ordinary gas burner, and less even than that of the average oil lamp, although the light given is more than three times as great.

In addition to the hygienic advantages of the light, it also holds out great temptations in favour of its adoption on the score of its economy. It is claimed that the "C" Welsbach burner gives a light of about 60 candle-power, with a consumption of about $3\frac{3}{4}$ cubic feet of gas per hour, whilst the ordinary open-flame burner gives about 14 candle-power, with a consumption of 5 or 6 cubic feet per hour, thus resulting in a considerably increased light, with a largely reduced con-

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[1] January 5th, 1895.

sumption of gas—a circumstance which *should* naturally result in a proportionately reduced gas bill.

The light of the incandescent burner is rich in blue rays, is of great brilliancy, and requires for indoor lighting to be softened by means of suitable globes or shades.

This burner has already been adopted by many towns for the purpose of *Street Lighting*, and, when properly fitted up, has effected a distinct improvement in street illumination.

Still more recently, the *Welsbach-Kern burner* has been introduced, and over two millions of these burners are now in use. It is claimed to be an improvement of nearly as great a value in comparison with the "C" burner above referred to, as the last-named burner was upon the old methods of burning coal gas. The "Kern-burner" is suitable for use with any existing gas fittings or outside lanterns, without alterations, in a similar way to the "C" pattern. The "Kern" is claimed to present a lighting efficiency of about 25 candles per cubic foot of gas as compared with 16 to 18 candles obtained with the "C" burner. It is supplied in a variety of sizes, consuming from ¾ cubic foot up to 4 cubic feet of gas per hour, and yielding a candle-power of from 20 to 100, according to the size of burner, with a constant lighting efficiency throughout this range of power. Neither chimney nor governor is needed with this burner, which is obviously a considerable advantage. With a Welsbach-Kern burner consuming 2¼ cubic feet of gas per hour, about the same candle-power is secured as when using a burner of the "C" type taking 3¾ cubic feet.

For outside lighting the "self-intensifying Welsbach-Kern burner" is the latest development of the "Kern" principle, and by means of this a large unit of light is obtainable at ordinary pressures as compared with burners of other forms. Six hundred candle-power is obtainable from a single burner consuming something less than 20 cubic feet of gas per hour at a pressure of 2 inches. This self-intensifying burner is largely used at Tyneside, and a new burner of this type is shortly to be introduced giving an efficiency of 1,000 candle-power from one mantle. On careful comparison of cost of this description of light with electricity the odds will invariably be found to be greatly in favour of the former for all ordinary lighting purposes.

For industrial purposes, shop lighting and such like, the Keith intensified gas light is now largely used. The gas is used under pressure obtained by means of an automatic compressor usually worked off the ordinary water service.

The "Kitson" light is another modern form of illuminant now largely used.

In the Scott-Snell high-power system (Scott-Snell-Anderson patents) intensification of the gas is obtained by the direct expansive action of the waste heat from the burner upon the air to be used for combustion, thus automatically and economically delivering a jet of air at a pressure of over a pound to the square inch to burners of some 600 candle-power. This system has been applied to the lighting of the Vauxhall Bridge, Parliament Street, Westminster, and other parts of London, and to the Mersey Docks, Liverpool. A guaranteed efficiency of 40 candles per cubic foot of gas consumed is given. The manufacturers of these lamps are Messrs. Anderson and Duffield, of Farringdon Road, London.

What is known as the "Block Light" is another powerful and economical form of gas burner with mantle which is now being extensively used, and affords a further prominent example of the vast strides made in the scientific use of gas as an illuminant during very recent years. These modern improvements, it should be noted, have successfully raised the gas industry to the position of a very competent and formidable competitor to the growth of electricity as an illuminant.

As regards the use of *electricity*, the hygienic advantages of the incandescent electric lamp are those of an ideal light; it gives but very little heat, consumes no oxygen, yields no impurities to the atmosphere, and the finest decorations, furniture, pictures, or books are unharmed by it. It also lends itself to a most fanciful and decorative style of fitting to rooms, and, when properly installed, is free from the danger of being the cause of fire from leakage, explosion, &c., as is the case with the older forms of lighting with the naked flame in direct contact with the air. The electric arc light in some of its properties and effects closely resembles sunlight, and will, it is said, with the aid of heat from hot water pipes, support the growth of plants, produce flowers and ripen fruit as rapidly as under sunshine, and will also develop their *continuous* growth if exposed to this light as soon as the daylight ceases.

CHAPTER XV.

Useful Information.

Air—

One atmosphere = 14·7 lbs. pressure per square inch = 2116·4 lbs. per square foot.
= 29·922 in. of mercury at 32° Fah.
= 33·947 ft. of water at 62° Fah.

One cubic foot of air at 14·7 lbs. per square inch at 62° Fah. = ·076097 = 1·217 ozs.

One pound of air at 62° Fah. = 13·141 cubic feet.
,, 32° Fah. = 12·38 cubic feet.

Air expands with heat, and each degree Fahrenheit is equivalent to an addition to its volume of $\frac{1}{461}$. Volume is inversely as the pressure.

Air rushes into a vacuum near sea level with a velocity of about 1,157 ft. per second.

Air is a very slow conductor of heat: hollow walls retain the heat of buildings, and also serve to keep the interior cool when the outside heat is excessive.

The term "*absolute pressure*" means the total, including atmospheric pressure.

"*Gauge pressure*" = the excess of pressure above that of the atmosphere. A gauge pressure of 44·1 lbs. per square inch (three atmospheres) equals an absolute pressure of 58·8 lbs. per square inch.

Moist air is lighter than *dry air* at the same temperature.

Water—

Pure water (distilled) is composed of two gases, hydrogen and oxygen, the chemical symbol being H_2O.

One imperial gallon = 10 lbs. = 277·463 cubic inches = ·16 cubic feet.

One cubic inch = ·03604 lbs. = ·0036049 imperial gallon.

One cubic foot = 6·22786 galls. (commonly taken at 6¼ galls.).
= 62·2786 lbs.[1] = ·55606 cwt. = ·0278 ton.

One pound of water = 27·7463 cubic inches = ·10 gall. = 7,000 grains.

One cwt. of water = 11·2 galls. = 1·798 cubic feet.

One ton of water = 35·967 cubic feet = 224 galls.

A column of water 1 ft. in height = a pressure of ·4325 lbs. per square inch.

A pressure of 1 lb. per square inch = a column of water 2·31219 ft. high.

Gallons × ·1606 = cubic feet of water.

Cubic feet × 6·288 = number of gallons.

If H = head of water in feet; P = lbs. pressure per square inch, then $H = P \times 2{\cdot}311$; $P = H \times {\cdot}4326$.

Cubic feet per minute × 9,000 = gallons per twenty-four hours.

One horse-power = 33,000 foot-pounds per minute = 550 foot-pounds per second.

Boiling point of water at sea level, barometer 30 in. = 212° Fah., and 1° less for every 520 ft. above sea level.

Freezing point = 32° Fah.

Point of maximum density = 39° Fah. (or 4° Centigrade).

From about 39° Fah. water expands either by cold or by heat.

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[1] At 62° Fah., barometer at 30 inches of mercury. *Sea water* weighs from 64·02 lbs. to 64·27 lbs. per cubic foot.

WATER—*continued.*

The temperature of 32° Fah. reduces it to *ice*, and the *weight* is then about 57·2 lbs. per cubic foot, the *specific gravity* being ·9175.

Upon freezing, water expands about $\frac{1}{12}$th of its original bulk as water. The *sudden expansive force* exerted at the moment of freezing is almost irresistible, being probably not less than 30,000 lbs. per square inch.

Water evaporates at all temperatures.

Water dissolves more substances than any other agent.

Water has a greater capacity for *heat* than any other known substance.

Water can be *compressed* at the rate of about $\frac{1}{21740}$th by each atmosphere of pressure (14·7 lbs. to the square inch). This compression represents about $\frac{1}{100}$th of an inch in 18·1 ft. Upon removal of the pressure the *elasticity* of the water restores it to its original bulk.

There is a popular notion that hot water freezes more quickly than cold, with air at the same temperature, but this is incorrect.

Comparison of Imperial or English gallon with that used in the United States :—

	Cubic inches in a gallon.	Weight of a gallon in lbs.	Gallons in a cubic foot.
English	277·274	10·00	6·228
United States	231	8·33	7·48

Horse-power.—The theoretical horse-power necessary to raise water to any required height is found by multiplying the weight of the water raised per minute in pounds

WATER—*continued.*

by the height in feet, and then dividing the product by 33,000.

Doubling the diameter of a pipe increases the capacity four times.

Steam and Heat—

"*Saturated steam*" means steam at the temperature due to its pressure.

"*Superheated steam*" has a temperature in excess of that due to pressure.

Heat is measured in "units."

British thermal unit (B.T.U.)=the amount of heat necessary to raise 1 lb. of water 1° Fah., and its mechanical equivalent is J (Joule)=778 lbs. raised 1 ft.

The metrical, or French *calorie* ("great calorie") is the heat necessary to raise 1 kilogram of water through 1° C.

One great calorie=3·968 B.T.U.

Calories × 3·968=B.T.U.

One B.T.U.=·252 great calorie.

B.T.U. × ·252=calories.

Horse-power.—42·41 B.T.U.=33,000 ft.-pounds=746 watts =1 h.p. per minute.

The heat which will raise 1 lb. of water 1° will raise 1 lb. of air 3·7°.

One pound of water heated from 32° to 212° requires as much heat as would raise 180 lbs. 1°.

26·64 cubic feet of steam at atmospheric pressure=1 lb. avoirdupois.

STEAM AND HEAT—*continued.*

Thermometers, English and French—

Freezing point=32° Fah.
=0° (zero) in Centigrade or Réaumur.

Boiling point=212° Fah.
=100° Centigrade, or 80° Réaumur.

If F, C, and R represent any number of degrees in the three scales respectively, then—

$$C=\frac{5}{9}(F-32)=\frac{5}{4}R.$$

$$F=32+\frac{9}{5}C=32+\frac{9}{4}R.$$

$$R=\frac{4}{9}(F-32)=\frac{4}{5}C.$$

Barometers are of two kinds—*mercurial* and the *aneroid*—and are used for measuring the pressure of the air. The graduations are in inches, tenths, and hundredths, and this instrument can be used to approximately measure the relative heights of places. A fall of $\frac{1}{10}$th of an inch indicates a rise of about 100 ft., but the true rate of fall decreases continually as we rise. Where B and *b* represent the barometrical readings at two different levels, the height (H in feet) of one above the other can be roughly found from the formula, $H=60350\times\log.\frac{B}{b}$.

The *atmospheric pressure* is commonly taken at 15 lbs. per square inch=34 ft. head of water$=\frac{34 \text{ ft.}}{13{\cdot}6}=30$ in. of mercury, which is the standard height of the mercurial barometer. (N.B.—13·6 is the specific gravity of mercury.)

STEAM AND HEAT—*continued.*

Expansion of water by heating :—

Temperature deg. Fah.	Relative volume by expansion.	Weight of one cubic foot.	Weight of one gallon.
32°	1·0000	62·418	10·01
212°	1·0466	59·64	9·565

The theoretical draught of a *chimney* (as from fireplaces) is given by the formula, $v=\sqrt{2ga\,(t^1-t)\,h}$,

where g=the acceleration of gravity.

a=the co-efficient of the expansion of air.

h=the height of the chimney.

t^1=the mean temperature of air inside the chimney.

t=the temperature of the surrounding air.

The actual velocity may be reduced from one-fourth to one-half the theoretical velocity owing to frictional resistance of the flue.

APPENDIX I.

LIST OF MANUFACTURERS, ENGINEERS, &c.

FOR the convenience of those who desire to obtain more detailed information, descriptions, prices, &c. in regard to the numerous different kinds of ventilating, heating, and other fittings and apparatus now on the market, the following list of manufacturers is appended in order that readers may, if desired, promptly place themselves in touch with all the chief sources of information of this class.

Ventilating, Heating, &c.—

Acme Ventilating & Heating Co., 11, Queen Victoria Street, E.C.

Ash, T., & Co., Broad Street, Birmingham.

Ashwell & Nesbit, Ltd., 12, Great James Street, Bedford Row, W.C.

Barnard, Bishop & Barnards, Ltd., Norfolk Ironworks, Norwich.

Beavan & Sons, 27, Victoria Street, Westminster.

Benham & Sons, Ltd., 50, 52 and 66, Wigmore Street, W.

Bourne Drying & Ventilating Co., Ltd., 19 and 21, Queen Victoria Street, E.C.

Boyle, R., & Son, 64, Holborn Viaduct, London.

Buchan, W. P., & Co., 36, Renfrew Street, Glasgow.

Burn Bros., 23 and 24, Charing Cross, S.W.

Ventilating, Heating, &c.—*continued.*

Clark, Bunnett & Co., Ltd., 22, Queen Street, Cheapside, E.C.

Consland & Mackay, 150, Hope Street, Glasgow.

Crispin, Jas., & Sons, Nelson Street, Bristol.

Davis & Bennett, Princess Mews, Princes Street, Westminster.

Deards, Sam., 34, Old Broad Street, E.C.

Elsley, Thos., Ltd., 28 and 30, Great Titchfield Street, W.

Ewart & Son, 346—350, Euston Road, N.W.

Haden, G. N., & Sons, Trowbridge.

Hartley & Sugden, Ltd.

Jennings, Geo., Ltd., 63—67, Lambeth Palace Road, S.E.

Jones & Attwood, Stourbridge.

Keith, James & Blackman Co., Ltd., 27, Farringdon Avenue, E.C.

Key, William, 11, Queen Victoria Street, E.C.

King, John, Ltd., Benson Street, Liverpool.

Kite, C., & Co., Charlton Street, London, N.W.

London Warming & Ventilating Co., 105, Regent Street, W.

Mason, W. F., Ltd., Manchester.

Mather & Platt, Ltd., 14, Victoria Street, S.W.

Matthews & Yates, Ltd., Cyclone Works, Swinton, Manchester.

Maughan's Patent Geyser Co., Ltd., Holywell Row, Finsbury, E.C.

Meadow Foundry Co., Mansfield, Notts.

Messenger & Co., Loughborough, Leicestershire.

Moffats, Ltd., 155, Farringdon Road, London.

Musgrove & Co., Ltd., 97, New Bond Street, W.

Offa Ventilating Co., 64, Basinghall Street, E.C.

Royles, Ltd., Irlam, near Manchester.

Seward, A., & Co., Market Street, Lancaster.

VENTILATING, HEATING, &c.—*continued.*

Shorland, E. H., & Brother, Drake Street Works, Manchester.

Shrivell, Wm., 1, 2 and 4, Castle Street, Endell Street, London, W.C.

Sturtevant Engineering Co., 147, Queen Victoria Street, E.C.

Sugg, William, & Co., Vincent Works, Westminster, S.W.

Sutcliffe Ventilating & Drying Co., Cathedral Corner, Fennell Street, Manchester.

Teale Fireplace Co., 28, Berners Street, W.

Thames Bank Iron Co., Upper Ground Street, London, S.E.

Tucker, W. Duncan, South Tottenham, N.E.

Werner, Pfleiderer & Perkins, Ltd., 43, Regent's Square, Gray's Inn Road, W.C.

Wippell Bros. & Row, High Street, Exeter.

Young & Marten, Ltd., Caledonian Works, Stratford, E.

Gas Lighting—

Anderson, D., & Co., Ltd., 73, Farringdon Road, London. (Manufacturers of the Improved Scott-Snell System.)

Block Light, Ltd., Worship Street, E.C.

Moffats, Ltd., 155, Farringdon Road, E.C. (The "Sydney" lamp.)

Stott & Co., 174, Fleet Street, E.C.

Sugg & Co., Vincent Works, Westminster.

The Anti-Vibration Incandescent Lighting Co., Albion Works, Otley.

The Lune Light Co., 1, Wheatfield Street, Lancaster. (The "Lancaster light.")

The New Inverted Incandescent Gas Lamp Co., 23, Farringdon Avenue, E.C.

The Keith Light, 27, Farringdon Avenue, E.C.

Gas Lighting—*continued.*

The Kitson Hydro-carbon Heating & Incandescent Lighting Co., 1224—32, Callowhill Street, Philadelphia, Pa.

The "Star" Inverted Incandescent Burner Co., Ltd., 104 and 105, Great Saffron Hill, E.C.

The United Kingdom Lighting Trust, Ltd., 231, Strand, W.C. (High-pressure gas light.) Works at Coventry.

The Welsbach Incandescent Gas Light Co., Ltd., 2—14, Palmer Street, Westminster, S.W.

Testing of Illumination by gas and electricity—

Elliott Bros., Century Works, Lewisham.

Everett, Edgcumbe & Co., Ltd., Colindale Works, Hendon.

Wright, Alex., & Co., 1, Westminster Palace Gardens, Artillery Row, Victoria Street, S.W.

APPENDIX II.

LIST OF TECHNICAL PUBLICATIONS ON

VENTILATION, HEATING, AND LIGHTING.

Practical Treatise on Heat. By THOS. BOX. 12*s*. 6*d*.
Heat. By P. G. TAIT. 6*s*.
Theory of Heat. By J. C. MAXWELL. 4*s*. 6*d*.
Elementary Treatise on Heat. By BALFOUR STEWART. 8*s*. 6*d*.
Elasticity and Heat. By LORD KELVIN. 6*s*.
Lander's Handbook of Heat. By B. LOEWY. 6*s*.
"Heating by Hot Water." By WALTER JONES. 6*s*.
Steam Heating for Buildings. By J. W. BALDWIN. 10*s*. 6*d*.
A Practical Treatise on Warming Buildings. By C. HOOD and F. DYE. 15*s*.
Steam Heating, &c. By FK. DYE. 10*s*.
Heating and Ventilating of Buildings. By R. C. CARPENTER. 17*s*.
Plumbing, Steam and Hot Water Heating. By J. J. LAWLER. 21*s*.
Hot Water Supply. By F. DYE. 4*s*. 6*d*.
Principles of Hot Water Supply. By J. W. HART. 7*s*. 6*d*.
Ventilation. By W. P. BUCHANAN. 3*s*. 6*d*.
Healthy Hospitals. By Sir DOUGLAS GALTON. 10*s*. 6*d*.

Ventilation, Warming and Lighting. By Dr. LITTLEJOHN.

"Ventilation and Heating." By J. S. BILLINGS (Washington).

Kitchen Boilers, their Arrangement and Management during Frost. By H. GRIMSHAW. 1*s.*

Experiments on Hot Water Systems. By A. SAYERS. 3*s.*

"The Plumber, Decorator and Journal of Heating, Ventilating, Gas, and Sanitary Engineering." 6*d.* monthly. (Will be found of great service in these branches of technical work.)

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Illuminating Power of Gas. A Table for ascertaining the True Illuminating Power of Gas, deduced from Pole's Law. By W. J. DIBDIN. 30 in. by 22 in. 21*s.*

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(Lond.), D.P.H. (Cantab), M.R.C.P., Physician to the North London Hospital for Consumption and Diseases of the Chest and to the St. Marylebone General Dispensary. With an Introduction by Sir WILLIAM BROADBENT, Bart., M.D., F.R.C.P., &c. Demy 8vo. 10s. 6d. net. [1900

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