LECTURE TO SANITARY OFFICERS.

On "Ventilation and Measurement of Cubic Space,"

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THE Public Health Act and Model Bye-Laws place certain duties upon the Sanitary Inspector in relation to cubic space and to ventilation, and it is therefore necessary that he should have a clear knowledge of the principles on which these questions are based; and the object of this lecture is to explain to you these principles.

Cubic space is the amount of air space which is allotted to each individual in any room which he may occupy; that is to say, assuming that there is an empty room 10 feet long, 8 feet wide, and 9 feet high, the cubic contents of that room will be 720 cubic feet.

If you place one individual in the room, he will have 720 cubic feet of air space. If you place two individuals, each will have half of 720, or 360 cubic feet; if three individuals in it, each will have 240 cubic feet of air space, and so on.

If in that room, instead of being simply rectangular, there are recesses, you must add the contents of the recesses to the room.

Thus, if there is a projecting window, 4 feet wide, and 3 feet deep, and 7 feet high, you will add 84 cubic feet; and the air space afforded would be 804 cubic feet to one individual, 402 cubic feet to two individuals, and so on.

On the other hand, if there are projections such as a chimney breast, you must take that out in calculating the cubic space.

Thus if there is a chimney breast 4 feet wide, projecting 2 feet 6 inches into a room of the general dimensions above-mentioned, you must deduct the 4 feet $\times$ 2 feet 6 inches $\times$ 9 = 90 feet; thus the room would then have only 630 cubic feet.

You must, moreover, make a further reduction if there is much solid furniture in the room. In practice, however, it is scarcely necessary to make allowance for light articles; nor where there is not a material quantity of furniture.

Let us consider what are the reasons, on the ground of health, why a certain air space or cubic space is wanted in an occupied room.

If you are in an open space out of doors, fresh air is perpetually flowing round you.

It has been estimated that the air of the atmosphere moves

1. Public Health Act and Model Bye-laws impose certain duties upon the Sanitary Inspector in respect to cubic space and ventilation.

2. Object of the lecture is to explain the physical laws which should govern the exercise of these duties.

3. Definition of, and method of calculating cubic or air space in a room.

4. Conditions which render space necessary

at a rate of rarely less than 4 feet per second, and the average movement is from 8 to 10 feet per second.

In a room it is very different. In an occupied room you must more or less breathe air which has been already breathed.

Even out of doors the effect of congregating large numbers of persons together may prevent the free access of fresh air to those in the middle of a crowd.

As an instance of this it has happened that on a still day persons in the middle of a crowd have fainted for want of air.

We all know that in a room the assembly of a large number of people soon becomes unbearable. The reason of this is, as you all well know, because the respiration of the individuals in a room, their perspiration, the burning of candles, and all such matters, vitiate the air of rooms at a certain rate.

I will here briefly explain what is the nature of this vitiation.

Pure air consists of a certain amount of oxygen and a certain amount of nitrogen.

The oxygen supports life, but if we breathed it pure it would burn us away.

The nitrogen is an inert gas which dilutes the oxygen, and prevents it from being injurious to us in the process of breathing.

Every human being, in order to live, must be constantly breathing: in the act of breathing he takes in oxygen, and throws out from his lungs carbonic acid (CO_2); but he also throws off organic matter. This organic matter consists of epithelium, and molecular and cellular matter from the lungs; and is more or less in a condition ready to putrefy.

In addition to this matter from the lungs, portions of epithelium are constantly being given off from the skin. In hospitals you sometimes find pus cells in the air, which are given off from suppurating surfaces.

In the act of breathing there is also a large amount of watery vapour given off chiefly from the lungs, but also from the skin. Of this you may easily satisfy yourself whenever you occupy a confined space.

For instance, in a railway carriage, with the windows and ventilators closed, the glass panes will soon be coated with moisture, which is the condensation from the breathed air which has been saturated with this watery vapour.

The amount of watery vapour varies; but taking the amount given off by an individual from the skin and lungs together, it is enough to saturate about 90 cubic feet of air per hour, at a temperature of 63° Fahr.

This watery vapour is full of the organic matter which I told you just now is thrown off from the body, this organic matter being in a condition very ready to putrefy.

5. Impurity of air caused by the operations of life and breathing.

It is chiefly from the presence of this, in air which has been breathed, that injury arises.

If you shut up a person or an animal in a confined space without any change of air, they could not live for any length of time.

You all know the instance of the Black Hole at Calcutta.

In the year 1756, 146 individuals were confined in a small cell, known as the Black Hole of Calcutta. This cell was 18 feet long by 14 feet wide, by 10 feet high, being so small that the last person of the 146 had to be crushed in upon the rest with violence as the door was closed and locked. The only means of ventilation were two small holes in the door. In the morning 123 corpses were taken out, and 23 beings, who could scarcely be said to be alive.

Of course the larger the space, the longer would people live; but if there is no change of air, whatever the size of the room or space, the occupants would begin by suffering from head-ache or other forms of discomfort in proportion to the progressive vitiation of the air, and would all die after a certain time.

Thus the impurity of air caused by breathing is partly due to the organic matter thrown off the body, and partly to the carbonic acid which is dislodged from the lungs.

6. Measure of impurity in breathed air.

In most cases of bad ventilation the carbonic acid is not the chief cause of injury.

You may hold your head over a beer vat, where a very large amount of carbonic acid is being disengaged, without injury.

It would require the air to be vitiated with 5 per cent. of carbonic acid (CO_2) to destroy life.

The reason why breathed air, which may contain a much smaller amount of CO_2 , produces such deleterious effects, is because the breathed air contains also putrefactive organic matter. It is this organic matter which is especially deleterious.

But the quantity of CO_2 in breathed air affords, under ordinary circumstances, a fair test of the quantity of organic matter present; and it used to be found less difficult to ascertain by test the amount of carbonic acid present in the air than the quantity of organic matter.

Carbonic acid has generally therefore been accepted as a measure of the impurity present in breathed air. It must be borne in mind that there is always a proportion of carbonic acid (CO_2) present in air; for instance, in air out of doors in the open country, there are from 3 to 4 parts of carbonic acid (CO_2) in 10,000 parts of air; and even this amount will sometimes be increased in a wood, or in proximity to a flock of sheep. In towns you will find sometimes a much larger quantity. Dr.

Angus Smith found as much as 6·8 parts per 10,000 parts of air in confined streets in a fog in Manchester; and Dr. Russell has found as much as 9, 11, and even 14 parts of CO_2 in 10,000 volumes of air, in a dense fog in London. It is the excess of carbonic acid found in confined spaces over that found in pure country air that is the measure of impurity; 4 parts of CO_2 in 10,000 parts of air is assumed as an average for air out of doors; when the air of an occupied room contains 6 parts per 10,000, the sense of smell enables the impurity to be detected, hence 6 parts in 10,000 have been allowed as the permissible measure of impurity in the air of occupied rooms. The presence of those minute organisms which have been recently brought into prominent notice by the increased attention given to the study of bacteriology, is also to some extent an index of impurity in air; but it is too soon as yet to lay down any fixed rules in this matter.

In order to counteract the effect of breathing, it is necessary continually to replace the air of an occupied room by fresh air, but it is of course impossible to keep the air of an inhabited room in as pure a condition as the outside air.

7. Quantity of air required to maintain a standard degree of impurity.

It is unnecessary to enter here into the details of the theoretical calculations of the quantity of air necessary to be introduced into a room in order to maintain the air at a sufficient degree of purity, or rather of impurity.

The results of these calculations are that, according to theory, it would require 3,000 cubic feet of fresh air to be supplied to each occupant of a room per hour to keep the atmosphere in a uniform condition. That condition is not the same as pure air out-doors. It is something less pure; and, as I told you above, it has been generally assumed as a standard of admissible impurity that the carbonic acid gas in the air of an occupied room, may amount to 2 parts per 10,000 over normal or outside air; that is to say that the air of the occupied room may contain 6 parts per 10,000 in all, without being deleterious.

If you place an individual in a room in which there is no change of air, the time required for the air to arrive at this state of impurity will depend on the size of the room; that is to say, on the cubic space in the room.

The following table shows the time required to effect this:—

One man in 10,000 cubic feet, 3 hours 20 minutes.			
”	5,000	”	1 hour 40 ”
”	1,000	”	20 ”
”	600	”	12 ”
”	200	”	4 ”
”	50	”	1 ”
”	30	”	36 seconds.

Hence the possibility of people occupying continuously a given space depends upon the change of the air.

If you introduce fresh air into the room, and remove the vitiated air, the same quantity of air would have to be introduced in the case of the large room as in the case of the small room, but in the large room the change of the whole air of the room would occupy more than 3 hours; that is to say, would take place almost imperceptibly; whereas, if you shut a person up in a coffin, provided you passed continually fresh air through the coffin, so as to force out the air which had been breathed, a person could live perfectly well; but this would be a very uncomfortable arrangement, because he would live in a perpetual current of air.

8. Effects of different proportions of air space on supply of air.

On these grounds the cubic space, or the air space, which a room affords, is a very important element in considering the number of occupants which can conveniently and safely be allotted to a room, having regard to their comfort.

In barrack-rooms, it has been decided that 600 cubic feet per man should be afforded; that means a space of 10 feet long by 6 feet wide and 10 feet high. These are living rooms as well as sleeping rooms.

In workhouse dormitories, 300 cubic feet per occupant has been considered sufficient: that means a space of 4 feet by 7 feet 6 inches, by 10 feet high.

But although cubic space has been taken as the measure of accommodation which a room will afford, it is perhaps a somewhat unfortunate term, for if you put a certain number of individuals to sleep in a room, their being able to do so with either comfort or a due regard to health would rather depend upon the distance at which you place their beds apart than upon the cubic space they occupy.

9. Floor space as contrasted with cubic space.

Thus in a room, 15 feet high, affording a cubic space of 300 cubic feet per bed, each bed would be limited to 20 feet of floor space, or 6 feet by 3 feet 4 inches. But in a room affording the same amount of cubic space, viz., 300 cubic feet, but 10 feet high only, there would be 30 feet of floor space to each bed, or 6 feet by 5 feet.

Therefore, whilst a lofty room would leave the surface space very crowded, a lower room, having the same amount of cubic space, would afford access to the sides of the beds.

You will thus see that so far as comfort is concerned the floor space or surface space is a matter of far more importance than cubic space in the convenient occupation of a room.

But besides the question of convenience, there are other very important reasons why, in placing a number of persons in

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one room, it is essential that they should not be placed too close together.

Each individual is a centre from which the deleterious emanations proceed. Therefore, the further apart you can place the occupants, the better opportunity do you afford for the air breathed by the various persons to be diffused.

If you have a number of people sleeping in a room, and if you desire to prevent them from suffering from the pollution of air as much as possible, you should have as large an interval as can be arranged between the different beds.

Therefore if you were building a room to accommodate a certain number of persons, and if you wished to provide a certain amount of cubic space, it would be better to keep the room as low as is compatible with efficient ventilation, rather than to have a very lofty room. And for this reason, in fixing the number of occupants in a room, your attention should be directed rather to the floor space than to the cubic space.

When I say that the room should be as low as possible, I mean as low as is consistent with the due circulation of air, and with the conditions necessary for renewal of air.

I have endeavoured to explain to you how the air of a room is rendered impure by the presence of persons in it. I have also told you that in order to counteract this, it is necessary to remove the breathed air and to replace it by fresh air.

I have also told you that theoretical results have pointed to 3,000 cubic feet of air per occupant as the quantity of air which should be supplied to keep the air in a satisfactory condition.

In practical experiments made in barrack rooms, it was found that an inflow through the special apertures for admitting fresh air and removing foul air equal to 1,200 cubic feet per occupant of air removed and replaced per hour, was sufficient with 600 cubic feet of space to keep the impurity of the air down to the standard before mentioned.

In hospital wards, where the emanations from the sick cause different conditions to prevail, an inflow of 2,000 cubic feet per hour, with a cubic space much enlarged, dependent on the condition of the sick, was found desirable.

You will see that this is less than that given above by theoretical calculation. This need not be set down to errors in calculation or in theory, because the conditions under which the air flows in and out of a room are so varied.

The walls and ceiling themselves allow of a considerable passage of air. All building materials are porous.

If you look at any ceiling, you will see that an old ceiling is often blackened where the plaster has nothing over it to check the passage of air, and that where the wooden joists come and

the air has not passed so freely, it is less black.* If you break the plaster, you will find that its blackness has arisen from its having acted like a filter, and retained the smoky particles while the air passed through.

Moreover the porosity of the walls materially influences the moisture, for a porous wall may absorb much moisture; and on this account rooms with walls of polished impervious material require much more air to pass through them than rooms with porous walls, because, in the absence of sufficient ventilation, when the walls are colder than the air, moisture condenses on the walls, and runs down them.

Where no special arrangements are made for changing the air, ill-fitting doors and windows allow of the passage of a considerable quantity of air.

In a temperate climate, where the changes of temperature of the outer air are rapid and considerable, these means of producing the outflow from, and the inflow of air into, a confined space are in constant operation. A sleeping room is very warm at bed-time; a rapid fall of temperature outside occurs, and at once a considerable movement of air takes place through every available opening.

The majority of occupiers of sleeping rooms in England close their windows at night; they often block up the chimney by a register or otherwise to prevent the blacks falling. They have no special inlet or outlet for changing the air, and if it were not for the continual insensible change of air which passes through the walls, doors, and window chinks, &c., the occupants would be asphyxiated. A well-built house unprovided with special means for the inflow of fresh air is a real source of danger.

In order to afford the necessary change of air in a convenient manner, you must have a certain cubic space; and the great object of efficient ventilation is to enable change of air to take place without its being unpleasant from the draughts which it occasions.

11. Efficient ventilation should be imperceptible

This change of air is governed by certain natural laws.

Air consists of molecules, which are very loosely attached to each other, and small increases of temperature, or slight diminutions of pressure, allow these molecules or particles to separate: and thus a cubic foot of warmed air weighs less than a cubic foot of cold air.

12. Causes of movement of air.

For instance, at a temperature of 32° Fahrenheit, a cubic

* Where a ceiling is of brick with iron joists other conditions prevail, which I shall not enter into here, and the position of the iron joist is often marked by a black line.

foot of cold dry air, at the level of the sea, would weigh about 567 grains. At a temperature of 100° Fahr., a cubic foot of air would only weigh 497 grains; and at a temperature of zero, that is 32° below freezing-point, it would weigh 606 grains.

It follows from this that air, when it is warmed, expands and ascends; and air, when it is cooled, contracts and falls.

It also follows that as the warm air ascends, the colder air around rushes in to fill its place.

Everywhere this heating and cooling of the air is going on; the sun's rays warm the objects on which they impinge, these objects in their turn warm the air: the vicinity of a shaded surface cools the air: and thus both in turn cause movements in the currents of air.

In this room, as air is warmed by your bodies, it ascends; it comes against the glass of the windows or skylight, cools, and falls down. You say that you feel a draught from the window; that is not necessarily air coming in from the window; it may simply be the cooled air falling on you.

It is on this law of the dilatation of air that all the movement of the atmosphere depends, from the winds and hurricanes to the ventilation of our houses, except where we propel air by fans or other mechanical appliances.

The law which regulates this movement of the air in a confined space, when the temperature is higher than that of the outside air, depends upon the following considerations:—

1. Upon the difference of temperature of the air inside the confined space, as compared with that outside.

2. Upon the area of the aperture through which the air passes.

3. Upon the height of the column of ascending air.

If A B represent the height of a column of air of the outside temperature t , and A C the height of a column of the same quantity of air expanded by the warmer temperature t' , then the velocity at which the warmer air ascends will be that which would be acquired by a body falling from C to B.

The theoretical formula due to this is:—

$$V = \sqrt{BC \times 2g}.$$

And where V = velocity in feet per second.

H = height of shaft.

t' = temperature in shaft.

t = temperature out of doors.

a = co-efficient of dilatation of air, which for 1° Fahrenheit = .00203.

The theoretical equation becomes $V = 8.204 \sqrt{Ha(t' - t)}$.
But the actual movement of air in a flue is very different.

13. Laws which govern the movements of air due to natural causes.

It is diminished by the resistance afforded by the chimney or flue in which the column of ascending air is contained. This resistance increases directly with the length, and inversely with the diameter or area, of the flue; and it also increases with the square of the velocity of the air currents. The resistance is, moreover, much influenced by the material forming the sides of the flue; with a sooty flue the velocity, with equal temperatures, has been found to be one-half that of a clean flue. The velocity is, moreover, diminished by any impediment to the ingress of the fresh air required to supply the place of that which flows out, and therefore an efficient system of ventilation requires that the extraction of air should be accompanied by arrangements for the supply of fresh air.

For these reasons it is preferable, in estimating the amount of air removed for purposes of ventilation from buildings already constructed, to measure the actual volume of the air in the flues or air passages; that is to say, to cause it to pass along a channel, the size and area of which are known, and then to measure the velocity with which the air passes through this channel.

The multiple of the area into the velocity in a given time gives the volume which passes through in that time.

There are various ways of measuring the velocity. It may be done by puffs of vapour of turpentine; by little balloons filled with hydrogen, and weighted to be of the exact specific gravity of air. A very convenient instrument is the anemometer, of which I show a specimen. The vanes are turned by the air, and the number of the revolutions, apportioned to the movement of the air, has to be ascertained in the first place by direct experiment, that is, by forcing a known bulk of air through a channel of a given size. That is to say, you provide a box or a cylinder of a certain size with a piston, and in connection with this box you place a tube of a known area and fitted to the size of the anemometer. You place the anemometer in the tube, and you note its reading. You then cause the piston to descend in a given time, and thus force the air contained in the box through the tube. You then note the reading of the anemometer; and thus ascertain the number of revolutions which coincide with the volume of air which has passed through the tube out of the box.

14. Methods of measuring the movement of air.

This method requires great care and attention, and the absence of all cross currents in the place where the experiment is made.

Another method for very roughly ascertaining the value of the revolutions of the anemometer is to draw the anemometer through the air at a given rate in a given time, and note the revolutions; but this is liable to many errors.

In heated flues and chimneys of manufactories Fletcher's anemometer is a very convenient form for measuring the speed of the air and gases.

The instrument consists of two parts. The first part consists of two metal tubes of about $\frac{3}{16}$ of an inch internal diameter, open throughout, and of any length; secondly, of a manometer, or pressure gauge.

Of these tubes the end of one is straight, while that of the other is bent to a right angle. When in use these tubes are placed parallel to each other, so that their ends are exposed to the current of air to be measured. They lie at right angles to the current, which thus crosses the open end of the one, and blows into the bent end of the other.

By this means a partial vacuum is established in the straight tube, whilst the pressure of the current forces the air into the bent tube. A differential manometer attached to the outer ends of the tubes shows the excess of pressure in the bent tube over that in the straight one.

The manometer used is a simple U tube set vertically, fitted with microscopes and vernier scales, and containing ether.

The difference of level of the surfaces of the ether in the two limbs can be measured to $\frac{1}{1000}$ of an inch. This difference of level between the columns of ether becomes a measure of the speed of the current passing the ends of the anemometer tubes; the law which governs the speed is expressed generally by the formula $v = \sqrt{p} \times 28.55$. The corrections to be made for small variations of barometric pressure and temperature are unimportant.

This is a very convenient form of anemometer, because the pressure-tubes may be of any length or diameter, and may be connected with the manometer by india-rubber tubing of any length. Therefore the readings may be observed in any convenient place at a distance from the flues.

The pressure-tube should project into the air current to the extent of one-sixth part of its diameter, to measure the average velocity.

It is desirable, after observing the height of the ether in the tube then to reverse the connection with the manometer, and to take a second reading; if the smaller reading be deducted from the greater, twice the height of the column supported by the difference of pressure is obtained, and the error of observation is halved. But in this, as in the anemometer with vanes, there is a difficulty in accurately observing low velocities, *i.e.*, under one foot per second.

It is worth noting that a sheet of light tracing paper moved through the air at 2 feet per second takes up an angle of 45° ,

and affords a ready means of measuring that velocity; and for smaller velocities the angle assumed by the flame of a candle affords a fairly accurate index, according to the following table:—

Velocity of flow of air. Feet per second.	Angle of inclination of flame of candle with horizon.
1·6	30°
1·0	40°
0·75	50°
0·50	60°
0·40	65°

Artificial methods in use for moving air may be classed as follows:—

15. Mechanical appliances for moving air.

1st. Movement by the application of heat to extract air, thus causing a vacuum which is filled up by fresh air rushing in to fill its place. Of this method the open fireplace is a familiar instance.

2nd. The use of pumps to draw out or to force in air.

3rd. The use of fans either to extract the air from or to force it into the space to be ventilated.

You will see from the formula for calculating the velocity of air in a shaft or flue that the velocity will vary either with the height of the shaft or with the temperature of the shaft.

Hence a tall shaft with a small increase of temperature of air may produce as high a velocity as a short shaft in which the temperature is high.

16. Direct application of heat to movement of air.

In this latter case, it would be necessary to consume a large amount of fuel to increase the temperature of the air which passes up the shaft.

Therefore the economy with which the law of dilatation of air can be applied in practice depends on the height of the shaft available.

If you require the extraction of air to go on continuously, you will find that a lofty chimney shaft will be the cheapest and most effectual way of securing your object. It is simple and permanent. It requires comparatively little repair, and no skilled labor to look after it.

Moreover, whilst a chimney flue acts by means of the dilatation of air, it also acts in another and occasionally very efficient manner. Whenever wind blows over the top of a shaft, it draws with it the air in the shaft, and causes an extraction; and as movement is almost always taking place in the atmosphere out of doors, you may almost always rely upon a certain degree of extraction of air from a house or a room by means of shafts carried up to above the roof, which is independent of the temperature of the air in the shaft.

17. Indirect application of heat by means of fans.

But if you only want ventilation to be put in operation from time to time, as in a meeting hall, it may often be found that when you take into consideration the first cost, the extraction of air by a properly constructed fan worked by a gas or other heat engine, would in many cases be more economical than the flue extraction: in all cases the warming of the air which takes the place of that removed must be taken into account.

18. Effect on movement of air of windows, and simple forms of inlets and outlets in rooms.

There are various methods by which the extraction of air may be effected by shafts and flues on a large scale; but we are here chiefly concerned with the application of these laws to ventilation on a small scale, that is, to the ventilation of separate rooms rather than of large buildings. All that I have told you respecting the movement of air governs the ventilation of your rooms where you have sash windows and fire-places; and the simplest way of securing an efficient change of air in a room without having resort to mechanical appliances, such as fans, or the direct application of heat, is to utilise the movement of the atmosphere, to which I have already alluded.

You have only to make an opening at the upper part of a room, out of which the warmed air can pass, and an opening at a lower level through which fresh air can flow in, to obtain a change of air.

For instance, if the top sash of your window is lowered and the bottom sash raised, the warmed air passes out of the room at the top, and the cooler outer air flows in below.

Your window can be arranged to form a very convenient inlet for fresh air, without causing a perceptible draught, by cutting a slit in the lower bar of the upper sash of a window, so as to leave a clear space of about a quarter of an inch along its whole length, through which the fresh air will be drawn in an upward direction.

Ventilators which act similarly to direct the current of air towards the ceiling are sometimes introduced into the upper panes of window-frames, such as hopper ventilators, or Moore's louvred panes; but these are all makeshifts: and although the windows, when they can be kept open, are the best means for the periodical renewal of the whole air in a room, every room should have special inlets and outlets for air, arranged so as to be independent of the windows.

If you have a room to ventilate which has no fireplace, and which is without openings in the lower part, and has no rooms above it, such for instance as a chapel or meeting house, or sometimes a stable, you can do so by means of a Watson's ventilator. This ventilator consists simply of a tube carried up to above the roof, divided into two parts by a vertical diaphragm

down the middle, one part being carried up rather higher than the other.

This diaphragm will cause a double current to be set up in the tube; an upward current of air will be established in the side of the tube which is carried up above the other, and a downward current will prevail in the other compartment of the tube, and the movement of air will generally be unaccompanied by unpleasant draughts.

There are now in general use several forms of simple ventilators, such as Watson's and Sheringham's, which *all* act more or less efficiently.

The most efficient, and at the same time most simple, method for removing the air of a room without having recourse to fans or other mechanical appliances is to carry up shafts from the room to above the roof so as to utilise the movements of the atmosphere, to which I have already alluded, to assist the movement which would naturally take place, partly from the warmer air of the room rising up through the shaft, and partly from the movement of the atmosphere outside, which, as I have already mentioned, will draw air up the tube.

19. Effect of shafts without heat.

Thus, if the atmosphere should be without perceptible movement in cold weather, when the temperature indoors is maintained for comfort above that out of doors, the difference of temperature will cause an upward movement in the shaft. In hot weather, if the shaft is colder than the outer air, a down current may probably ensue; but if in hot weather there should be little or no movement in the shaft, this occurs at a time when the windows can be kept open, and the air be renewed by this means.

The velocity due to the action of the wind which prevails in a shaft is modified by friction. This friction varies inversely with the area of the shaft, and in the case of small tubes it forms a very perceptible element of retardation.

Experiments made with tubes 3 inches in diameter tend to show that the velocity obtained in the tube was about $\frac{2}{3}$ of that of the wind; larger diameters on the other hand produce better results.

These results were obtained in a place supplied as far as possible with fresh air to replace that removed, in a manner as far as possible independent of the movement of the atmosphere, and with the top of the tube freely exposed on all sides.

These shafts will very rarely be found to be without action, for the atmosphere is always more or less in movement; and whenever there are currents passing over the top of the shaft an upward current is produced in the shaft.

Inventors frequently maintain that this action of the flue or

shaft is influenced by special forms of cowls. No doubt you must have a top or cover to the shaft to prevent rain coming down; but numerous experiments which have been made by a Committee of The Sanitary Institute tend to show that, with equally sized apertures at the top, an open tube would act best, and that the principal condition in the shape of the top which influences the velocity, under similar conditions of force of wind, is the area of the aperture as compared with the area of the upcast flue.

That is to say, an increase in the area of the aperture of the top, properly regulated as to shape, may, under certain circumstances, produce an increased velocity in the upcast flue; and where a cowl appears to show an increased velocity in an upcast flue, it results from the enlarged area afforded by the cowl as compared with the area of the shaft.

In certain positions where surrounding buildings affect the current, there are forms of cowls which appear to protect the flue from down-draught. But in the majority of cases, it would seem as if intricate forms of cowls serve to diminish the natural effect of the wind; whilst they act in chimneys to impede the escape of the smoke.

These shafts for removing the air must be supplemented by inlets to admit fresh air.

If you have a fire place with a fire in the grate, the heat of the fire will draw a large volume of air up the chimney, which is of itself a most efficient extracting flue.

Hence every room which possesses an open fire place is furnished with a very powerful engine of ventilation.

But the efficiency of the fire place depends on mechanical force, that is to say, upon the heat developed by the fuel consumed.

The open fire place, by means of the heat which it generates, acts just like a fan or a pump to force or draw the air out of the room. So long as the fire is lighted it is continually at work.

The way in which an ordinary open fire place acts to create circulation of air in a room with closed doors and windows is as follows. The air is drawn along the floor towards the grate; it is then warmed by the heat which pervades all objects near the fire, and part is carried up the chimney with the smoke, whilst the remainder, partly in consequence of the warmth which it has acquired from the fire, and partly owing to the impetus created in its movement towards the fire, flows upwards towards the ceiling near the chimney breast.

It passes along the ceiling, and as it cools in its progress towards the opposite wall, descends to the floor, to be again drawn towards the fire place.

The open fire place thus presents special advantages for securing efficient ventilation by means of the circulation of air which it creates. Up to a certain point it makes the room in which it is in use independent of other means of extraction of air. For instance, a fire place with an ordinary sized flue and a good fire, will extract somewhat above 30,000 cubic feet of air per hour from a room. If the room is crowded the fire will not suffice for ventilation; and, moreover, the degree of vitiation of the air tends to make the fire dull and diminish its efficiency.

The air thus extracted must be drawn into the room from somewhere, and unless arrangements be made for supplying the room with warmed fresh air, cold air finds its way into the room through the special inlets, if any are provided; if not, through the chinks of the windows and doors, or wherever it can get in most easily. There is this objection to the open fire, namely, that the large volume of fresh air required to supply that drawn up the chimney cannot always be warmed with sufficient rapidity by contact with the walls and furniture only; the temperature in different parts of the room is therefore frequently very unequal, and the occupants are subjected to draughts; and if there are two fireplaces in the same room unprovided with special means for the admission of fresh air, one of which is not lighted, the air is often drawn down the vacant chimney.

It is therefore desirable in cold weather to replace some part at least of the air drawn up the chimney by air partially warmed. This can be effected in various ways, either by a service of hot-water pipes carried into all the rooms, to coils placed in front of the fresh air inlets, so as to warm the fresh air as it enters the room; or by bringing warmed air into the room by flues from a central heating apparatus.

The advantage of this latter arrangement is that the air can be brought to the heating apparatus from a pure source, and that it can, if desired, be filtered through jute cloth so as to free it to a great extent from dust.

Where large numbers of persons are to be provided for, especially for instance in schools, some mechanical means of supplying air is absolutely necessary; but in ordinary houses the simplest plan of providing warmed air is to utilise some of the waste heat which, in the case of an ordinary open fire-place, passes away unused up the chimney.

The ventilating fire-place, which has been generally adopted in barracks, was designed with the object of obviating the above-named objections to the common fire-place, and to utilise the spare heat, as well as to provide such adequate means of ventilating the soldiers' rooms in cold weather when the windows are shut, as would not be liable to be deranged.

Fresh air is admitted to a chamber formed at the back of the grate, where it is moderately warmed by a large heating surface, and then carried by a flue, adjacent to the chimney flue, to the upper part of the room, where it flows into the currents which already exist in the room.

Barrack rooms have fireplaces and windows, but these are not sufficient as ventilating appliances in rooms where there are many occupants.

The ventilation is therefore supplemented by Sheringham's valves near the ceiling, and by shafts carried from the ceiling to above the roof.

These shafts have generally been made of wood or brick; for if made of zinc, exposed to the outer air, that part of the action which is due to the excess of the warmth of the air of the room over that of the outer air would be retarded in cold weather.

21. Limits of ventilation with out mechanical appliances.

The methods of ventilation which are adequate for barrack rooms would not suffice for places where large numbers are congregated, as, for instance, in large schoolrooms. In these it would be preferable to adopt either a method of forcing in fresh air by means of a fan, or of extracting the air by means of a powerful shaft, and replacing the air thus extracted by fresh air. In a properly devised building the latter would be the most economical arrangement.

With proper arrangements for the supply of fresh air, the purity of the air would be the same in either case. But in our large board schools you may take it as an axiom that you cannot secure adequate ventilation without the application of some mechanical system; and that, in order to obtain the greatest economy in the application of a mechanical system, it is essential that it be made a part of the original design.

This question is, however, somewhat beyond the limits of my present lecture.

There are, however, many points to be considered in connection with this question of simple natural ventilation.

22. Conditions in the atmosphere which may operate to impede artificial arrangements for ventilation.

The action of wind, whilst it tends to exhaust the air through the tube, is, at the same time, acting on all other openings in the building, either to exhaust or to force in air. Hence gusts of wind will sometimes cause a reverse action in the tube, in consequence of some other opening acting temporarily as a means of extraction. The position of rooms in a building materially affects the question of ventilation.

If you have a house with a central staircase from top to bottom, and with a skylight at the top, this will act as a shaft, and being large it is more powerful than smaller shafts, and it will tend to draw air into itself from the rooms, and often counteracts the effect of the chimneys, especially when the

chimneys are cold, or when their size is greater than required for the removal of the air provided for their supply.

In the latter case, a double current, one up, one down, and both sluggish, is sometimes established in the chimney.

A smoky chimney may, therefore, often be cured by being reduced in area, so as to reduce the volume of air required to fill it, or by an adequate provision of fresh air to the room in which it is placed, or by a supply of air in an adjacent hall or staircase.

The effect of a high wind is to diminish the air pressure in a house when all windows are closed on the side of the outer-air pressure: hence, although some of the chimneys may have an accelerated draught due to the velocity of the wind, the action of the air pressure may be to cause others of the chimneys to smoke. The remedy for this would be to open slightly the windows on the side of the air pressure, so as to allow the pressure to act equally through the house.

It will frequently happen that the open fires in the rooms which require to be fed with fresh air, together with the warm air shaft formed by a central staircase, will combine to draw in the air from every available opening. They will draw up the air from the basement; they will draw it, if they can, from the water-closets and sink-pipes, unless the water-closets and sinks are in projecting buildings cut off by lobbies ventilated from the open air.

23. Conditions which should regulate the obtaining of fresh air for ventilating purposes.

For these reasons it is of importance not only to shut off the staircase from the basement, but to provide fresh air to the staircase; and when open fires are used, to supply each room in which there is an open fire-place with its own supply of fresh air. If the temperature of the room is to be kept up to a pleasant heat, this must to some extent be warmed air.

The fresh air should be obtained from places where there are no adjacent sources of impurity; especially not from the vicinity of ash-pits, manure heaps, gully gratings, or other sources of foul air. The inlets from the outer air should be at least two feet from the ground, and the surface near should be paved and sloped away from the inlet, so as to carry off wet rapidly.

It has been estimated that the impurities of town air are very much diminished at 200 yards height, and are not found above 600 yards in height. A London fog will rarely be perceptible at a height of above 100 yards; consequently, to bring pure air into a large town, the simplest way would be to draw it down from a height by means of a high shaft or tower. The Houses of Parliament could be supplied with very much purer air than is now provided for them by bringing the air from the top of the Victoria Tower.

The temperature at which air should be delivered in a room depends somewhat on the temperature of the outer air. With a temperature out of doors of 86° , air delivered at 60° would be felt as too cold. Similarly, in the Arctic expedition, with an out-of-doors temperature — 40° below zero, a temperature of $+40^{\circ}$ was felt to be hot.

In this climate the temperature indoors should be maintained at from 50° to 64° , and the warmed inflowing air should not vary much from this temperature; in any case it would not be desirable to exceed from 68° to 70° .

The hygrometric condition of the air must also be considered. If the air is too dry, it may, after it has been warmed, be passed over vessels containing water, to allow it to take up additional moisture—but the natural dampness of an English climate renders this less necessary here than it may be on the continent of Europe, or in Canada and North America where the air is often very dry.

It has not unfrequently happened that complaints of the oppressiveness of dry air artificially warmed have been caused rather by the insufficiency of the supply of warmed air than from its dry condition.

The channels for the admission of air should as a rule be short, direct, and accessible.

Long channels collect dirt, and form a refuge for insects. But if it is necessary to make them long they should be easily accessible for cleaning.

24. Conclusion.

In this single lecture I have only had time to give you some general suggestions upon this important subject.

I would, in conclusion, say that it should be accepted as an axiom that by the best ventilating arrangements we can only obtain in our rooms air of a certain standard of impurity: and that ventilating arrangements are only makeshifts to assist in remedying the evils to which we are exposed from the necessity of obtaining an atmosphere in our houses different in temperature from that of the outer air.

To obtain that temperature we sacrifice purity of air; therefore, whenever the outer temperature permits it, windows should be widely opened, so as to replace the air of the room by fresh air as often as possible.