ARMY SANITATION

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ARMY SANITATION

A Course of Lectures

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BY

SIR DOUGLAS GALTON, K.C.B.

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ON

ARMY SANITATION.

LECTURE I.

PRACTICAL HYGIENE.

Practical hygiene is of vast importance to your profession, because the efficiency of an army very largely depends upon the freedom from disease of the troops which compose it.

Preventable Disease.

Of the diseases to which the human frame is subject, a certain number accompany the condition of our surroundings, and are classed as preventable diseases—that is to say, diseases over which human agencies can exercise more or less control. The study of hygiene is based upon a knowledge of the causes which allow of the spread of this class of diseases, which have been called zymotic. Dr. Farr has termed them filth diseases.

So far as the soldier is concerned, they may be said to include fever, cholera, bowel diseases, small-pox; to these may be added lung disease.

Epidemics of fever, cholera, small-pox, &c., break out occasionally, and numerous deaths ensue; we do not know why they appear or whence they come; but if we trace their course, we find that they only attack those localities which offer to them the best inducements to visit them in their filth, decaying refuse, crowded and dirty population, bad water, damp polluted subsoil, and other insanitary conditions.

Influence of Aggregations of Population.

The central pivot upon which sanitation hinges is the dwelling and its surroundings. And the dangers to which we are exposed arise from insufficient arrangements for the removal of the refuse matter which the mere processes of life are perpetually accumulating around us.

In a house separated from all other houses you can easily have plenty of fresh air. You can provide for removal of refuse; and every short-coming can be traced to individual responsibility, and can be set straight at once. When, however, houses come to be placed close together, the individual responsibility can no longer be strictly enforced. Some system of combined administration has necessarily to be brought into play, and thus the dangers to health increase in an accelerated degree; and it may be assumed that whilst the population and the houses increase in an arithmetical progression, the risks—that is, the dangers to health—increase in a geometrical ratio.

Moreover, it is abundantly clear, from a study of sanitary science, that if you once allow epidemic disease to prevail in the midst of a population, it is very difficult to extirpate it; whilst, on the other hand, if you were to transplant a colony of emigrants enjoying perfect health into a new country which was entirely uninhabited by man, and if those emigrants took care that the air which they breathed, the ground on which they lived, and the water which they drank, were not polluted by refuse, or by decaying organic matter, they would probably remain altogether free from all forms of epidemic disease.

The householder can exercise an influence on the condition of his surroundings, but the soldier stands in a very different position; he is separated from his family, he is forced to live under conditions which take from him all power of initiative, all power of making provision for his own health. In this respect he is as helpless as a child, and the Government places itself in respect to him *in loco parentis*.

There is, therefore, a moral obligation on the Government to adopt the best means to promote the health of the soldier; whilst, on the other hand, the State has every inducement to keep the soldier in health, because every case of sickness means that an additional man must be maintained in order to obtain the required number in a condition efficient for duty, and every death of a soldier means the loss to the State of the money which has been expended on training him; therefore economical as well as moral reasons all point in the same direction. Unfortunately both were long disregarded.

A striking instance of the influence of sanitary measures on the death-rate of a civil population is afforded by the cholera deaths at Bombay during a period of thirty-two years, from 1850 to 1880 inclusive. During the earlier half of this period the water supply was bad, and the arrangements for the removal of refuse had been very defective. During the second half, a thorough system of cleansing and removal of refuse was introduced; good water was laid on from the Tulsi and Vehar reservoirs, and the main drainage of the city had made much progress, though still far from complete.

In the first sixteen years the total registered deaths from cholera aggregated 39,144, although during the earlier part of this period the registration was very imperfect, and in all probability many deaths were unrecorded. In the second, when sanitary arrangements were in progress, thorough cleansing of the town enforced, and the registration good, the cholera deaths amounted to only 7,612, although these years included the famine years 1877–78, which two years alone furnished 3,675 deaths.

Death-rate an Index to Sickness.

It has been established that the proportion of deaths to the number of a given population affords a tolerable index of the numbers of those of the population who are disabled by disease; in civil life, it has been computed, from returns of various friendly societies, that there are from fifteen to twenty cases of such sickness as would incapacitate from work to each case of death.

In the army, the admissions to hospital include many who in civil life would be capable of working. I find that in time of peace, on an average of ten years, in Great Britain, excluding venereal disease, there were nearly 100 admissions to hospital to every death; and that, on an average, there were between five and six men constantly sick to each case of death. Therefore, as regards the efficiency of the soldier, each death may be said to represent a permanent diminution of the numbers available for duty by six men.

The reduction of the disease-rate in a garrison town in time of peace by those diseases termed preventable, practically adds so many soldiers to the effective list for the ordinary duties. It is, therefore, of the greatest importance to obtain conditions in the soldiers' dwellings and surroundings which will prevent disease.

In a siege, the strongest fortifications would be of little value if the soldiers were located in unhealthy dwellings within their precincts; and the prevalence of disease in an army in the field may so cripple its strength as to alter the whole course of a campaign.

We pride ourselves on the success of the Egyptian campaign of 1882; but there can be no question that if that campaign had extended over as many months as it extended over weeks, the number of available fighting men would have been seriously reduced by fever and other forms of preventable disease, and the resources of England would have been severely taxed to meet the drain.

The chief causes which led to the spread of fever and cholera in Egypt after the termination of the war were partly the universal habit of polluting the surface of the ground, and partly the habit of disposing of the carcasses of animals by throwing them into the canals, the contents of which were subsequently used for drinking water. The troops on the march were allowed to drink the water of the canals and of impure wells. After the arrival of the troops in Cairo they suffered mainly from enteric fever, dysentery, diarrhœa, and ophthalmia.

These ailments may be partly traced to climatic influences, but mainly to the use of unwholesome water, to the occupation of foul buildings and camping-grounds, and other local causes acting on the constitutions of men weakened by the privations and fatigues of a campaign which, though short in duration, was conducted in the hottest and most unhealthy season of the year. The buildings at Cairo were in so filthy a condition that the troops who at first occupied them had to be removed and placed under canvas, and some time elapsed before they were rendered fit for permanent occupation. These are similar to the causes which led to the vast loss of life from disease in the Crimean war.

But the Egyptian War terminated before the evils due to the neglect of hygienic laws became prominently apparent. Hence the Crimean War still continues to afford the most graphic picture of the results of sanitary neglect in our army.

It is because the want of attention to sanitary administration, which had been so painfully apparent in the Crimean War, was again repeated in the Egyptian campaign, that I feel it the more incumbent on me to urge these facts strongly on your notice and to recall to your memory some of the results of the Crimean campaign.

Sanitary Experience of Crimean War.

In the first winter of the Crimean War, the number of men who were disabled by preventable disease amounted to more than one third of the whole strength of the army which went out from England. In the following year, the care which was given to the health of the troops reduced the disease and death-rates to comparatively small proportions.

A comparison between the total mortality and the zymotic mortality, showed that the first diseases from which the army suffered in Bulgaria were zymotic or preventable diseases. They were principally fever and cholera, brought on by neglect of sanitary precautions, and chiefly arising from the original bad selection of the sites for camps. See diagram, Fig. 1, Plate I.

The first outbreak began to subside in September, at which period the camps in Bulgaria were broken up and the troops were moved to the Crimea; and the disease-rate continued to decline until the army sat down before Sebastopol. Another and far more terrible invasion of zymotic disease followed that event. The men were hard worked, but hard work by itself never induced zymotic disease. We must look for other causes, and these causes once existing, fatigue would co-operate powerfully with them. The men had not sufficient shelter; no arrangements were made for the removal of refuse, or for cleanliness; they were in want of clothing suitable to the weather. They suffered from wet and damp. Scurvy and scorbutic diseases appeared at a very early period; with the fouling of the surface of the ground round the camp, fever, cholera, diarrhœa, dysentery, increased so as to threaten the total destruction of the force. The requirements of hygiene had been disregarded, and the natural results ensued.

In the spring of 1855, a Sanitary Commission, consisting of Dr. Sutherland, Dr. Gavin, and Sir R. Rawlinson, was sent out. The necessity for issuing such a commission was a reflection upon the Medical Department, as well as upon the Quartermaster-General's Department and the Royal Engineer Department of the army. For a perfect army should be so organised that after the provision of arms, ammunition, and food, the regulations for securing the health of the troops should be the most important consideration.

Upon the arrival of the Commission in the Crimea, remedial sanitary measures were at once commenced. Mark the result. During the winter of 1855-56, all the previous causes of disease had been removed. The men were well clothed, fed, and sheltered, their huts were properly drained and ventilated, and nuisances had been removed.

Compare the mortality from September, 1854, to April, 1855, with that from September, 1855, to April, 1856, and no more instructive lesson on army hygiene could be given.

The men were the same; the conditions only had been altered. The requirements of Nature had been disobeyed in every particular during the first winter, and she has left on that diagram an everlasting vindication of her broken laws. During the second winter Nature had been more perfectly obeyed, and the stigma of her displeasure has almost ceased to appear.

This illustration would be incomplete without a reference to what occurred in the hospitals at Constantinople. Of the soldiers who were landed from the Crimea to be taken to those hospitals, two men were lost out of every five treated in the hospitals of the Bosphorus during the month of February, 1855, and one man out of every two at Koulali. When the sick arrived they were crowded into buildings which had undergone no sufficient sanitary preparation for their reception—the drainage, ventilation, limewashing, and other arrangements, were so defective, that the buildings were little better than pest-houses. They were spacious and magnificent in external appearance, far more so, indeed, than any military buildings in Great Britain, but the mere external appearance was fatally deceptive. Underneath these great structures were sewers of the worst possible construction, loaded with filth, mere cesspools, in fact, through which the wind blew sewer-air up the pipes of numerous open privies into the corridors and wards in which the sick lay.

The wards had no means of ventilation, and the number of sick placed in the hospitals during the winter was disproportionately large. The population of the hospitals was increased, not only without any sanitary precautions having been taken, but while the sanitary conditions were becoming daily worse, for the sewers were getting more and more dangerous, and the walls more and more saturated with organic matter.

Improvements were begun in March, 1855, but it was not till the end of June that they were completed.

The effect of the completion of the sanitary works is most striking. The mortality fell in June, 1855, to less than a sixth part of what it was when the hospitals were occupied in October, 1854, and to a nineteenth part of what it was in February, 1855.

General Conditions which influence Health in an Army.

Army hygiene is a complex subject.

An army is a body of men generally stationary when at home, sometimes moving, sometimes engaged in field service, sometimes stationary for a time in sieges, liable to service in a variety of climates and seasons of the year. Hence the conditions necessary for the protection of health are very various, and require more care in adaptation than those of civil life.

The health of regiments depends on several agencies :—

1. Age of men, especially for service in warm climates, such as India.

2. The sanitary arrangements of stations, including barracks and hospitals.

3. Arrangements on march, including camping and camping-grounds.

4. Administrative arrangements, including sanitary police of stations, lines, camps, duties, drills, clothing, food, drinks, transport.

5. The removal of sick and wounded, their medical care; the position of temporary hospital accommodation where necessary.

Hence you will see that army hygiene carries us far beyond the consideration of questions of a purely engineering nature; and that, with an army of a given composition as to age and stamina, the sanitary care of the army involves three things :—

1. A good sanitary condition of stations, barrack buildings, and hospital buildings.

2. An efficient administration for supplying at once every necessary for the troops.

3. Care of the habits of the men, and of the useful and wholesome occupation of their time.

Effect of Age and Residence on Health in India.

Before passing to those questions which more immediately concern the engineer, a few words upon the age of the soldier may be useful.

The British army occupies an exceptional position; it has to provide for home defence, but a large part of its duties take it to India and to colonies where climatic considerations have especially to be considered.

The Indian experience affords the best illustration.

According to recent experience, the newly arrived regiments afford a death-rate of 19·96 per 1,000, as compared with 10·88 per 1,000 in the army generally; and whilst in the newly arrived regiments the deaths from enteric fever were 8·95 per 1,000, and from apoplexy 4·82 per 1,000, the deaths in the army generally were 2·40 from enteric fever and 1·10 from apoplexy.

The following tables show the effect of age and length of residence on the death and invaliding rates of the British army in India :—

Effect of Age.

	Per 1,000	
	Death-rate	Invaliding rate
Under 24 years of age	10·31	29·30
25 to 29 ,, ,,	8·63	30·30
30 to 34 ,, ,,	11·73	33·31
35 and upwards	12·58	66·24

Effect of Length of Service.

	Per 1,000	
	Death-rate	Invaliding rate
1st and 2nd years	12·68	19·42
3rd to 6th year	8·99	39·72
7th to 10th year	7·57	28·35
10 years and upwards	10·94	63·55

From these tables it would appear that if we desire to have our army in India in the most efficient and healthy condition, we should not send out men much before 24 years of age, and not retain them there beyond 30 to 33 years of age.

Responsibility of Royal Engineer.

No doubt the medical officer has much to say to the precautions which are necessary for the prevention of disease, but there is no section of the army upon whom a higher responsibility rests to remove causes of disease than the corps of Royal Engineers.

You have all heard of the famous retreat of the 10,000 under Xenophon. The most notable feature of that retreat was the absence of disease in the army. In his account of that retreat Xenophon shows himself to have been a competent engineer ; but he was also a master in the science of hygiene.

It is upon the engineer that the duty devolves of constructing healthy barracks, of providing a pure water supply, and of devising the appliances which will maintain and deliver it in a pure condition to the troops, of arranging for the disposal of refuse, both liquid and solid, in such a manner that it shall not be a cause of offence ; and if the necessities of war compel a commanding officer to encamp his troops in an unhealthy situation, it is upon the engineer that the duty devolves of devising the measures necessary for diminishing the causes of unhealthiness.

In civil life the functions of the sanitary engineer trench very closely upon those of the architect. For instance, the works of sewerage carried through the streets of towns do not terminate at the precincts of the individual house; they only form part of a system which penetrates into the house itself. As in the human body the minor veins and smaller blood-vessels constitute, with the main arteries, one system of circulation, so also the method of conveying the waste water from the kitchen, the housemaid's closet, the w.c., and other parts of a house, is an integral part of the drainage system.

Similarly in the case of water supply, the mere placing of water pipes in the streets is but a small branch of the question of water supply. The various appliances through which water is distributed in the houses have so important a bearing on the quantity, and more especially on the quality, of the water, that the larger works must be designed with reference to those internal works of greater detail.

For these reasons an efficient sanitary engineer must be somewhat of an architect, at least so far as that term implies a knowledge of house construction, as well as what is more ordinarily designated an engineer.

The military engineer, on the other hand, is necessarily an architect as well as an engineer. He constructs the dwellings for the soldier as well as provides the adjuncts of water supply and drainage.

Sanitation resulting from Crimean Experience.

Before the attention of the authorities had been directed to the health of the army by the terrible evils of the Crimean War, the condition of the barracks at home and in the Colonies was very unsatisfactory.

In the barracks in Great Britain there was overcrowding, bad ventilation, no proper warming of the rooms; basements below the ground level were occupied as barrack-rooms;* the means of cooking were very imperfect. There were few or no good lavatories, the drainage and privies were abominable, the water supply was not good, and the accommodation for the wives and children of married soldiers was, as a rule, execrable —indeed, in many barracks they were still placed in rooms occupied also by single men.

The following was the mortality of the troops at home stations at that time:—

	Deaths per 1,000 living.
Zymotic diseases	4·1
Chest and tubercular diseases	10·1
All other diseases	3·7
Total annual mortality	17·9

This was nearly double the mortality amongst the civil male

* I regret to see that even now, when cellar-dwellings are forbidden by law for the civil population, there are still some cases where the soldier is lodged in basements.

population of soldiers' ages in England, which was 9·8 per 1,000, although the soldier is specially selected after medical inspection as a healthy man; and therefore the rate of mortality of the soldier in peace time ought to be much less than that of the civil population of similar ages.

In the years 1858 to 1860 measures were taken to effect improvements in the ventilation and warming of barrack-rooms, in the latrine and drainage arrangements, in the water supply, and more attention was paid to clothing and to diet, as well as increased care in the distribution of duties and in the cultivation of physical exercises, and other accessories to health. The result on the death-rate of the army, as evidenced by the average of recent years, has been as follows :—

	Deaths per 1,000 living.
Zymotic diseases	0·42
Chest and tubercular diseases	3·05
All other diseases	2·81
Total annual mortality	6·28

Having regard to the fact that short service has been introduced, and that other conditions favourable to the health of the soldier have been put in force, this mortality in peace time is still far too high, and is an evidence that the sanitary state of many barracks is still very defective. In the German army, which is especially a short service army, the death-rate in peace time does not exceed 5 per 1,000.

Similarly, in the older barracks the stables were low-roofed, the only ventila ion was by windows, or doors placed at the ends; they were dark; the drainage was defective; the paving in use was of cobble-stones, which could never be properly cleaned. The horses had, in short, no fresh air to breathe, and suffered from glanders, coughs, catarrhs, and other chest diseases.

These older stables have been ventilated, and the paving and drainage improved as far as practicable.

New stables have been constructed on principles the reverse of the old; they have sufficient cubic space; they have abundant means of light and fresh air; the horses' heads are turned to the outer walls, and provision is made for fresh air being supplied to the horse while he is lying down; the paving and drainage have been properly constructed. Since then glanders has scarcely been heard of, coughs and catarrhs have disappeared, and the horses are healthy.

But important as have been the results of sanitary measures on the health of the army in Great Britain, the results in the colonies and India have been more important.

After the mutiny, the number of the British army employed in India was increased from the comparatively small force previously employed to 60,000 men.

The statistics of the Bengal Presidency (which are the only available statistics of the period under review) showed that from 1830 to 1845, the deaths of the European army in Bengal averaged 69 or 70 per 1,000, of which 58 per 1,000 were from zymotic or preventable diseases, 3 per 1,000 from lung and tubercular diseases, and only 6 per 1,000 from all other causes. If this death-rate had continued, the population of Great Britain could scarcely have sustained the drain for recruits.

The sanitary examination of Indian stations showed that the sanitary works required there were essentially of the same character as those required for England; but that the sanitary problem was intensified by the climate and by the habits of the people. The wells, tanks, and watercourses were used by the natives at many stations for washing; their edges were used for deposits of fæcal matter; and dead bodies were frequently thrown into them.

Since 1859 gigantic efforts have been made to improve the sanitary condition of Indian stations. The results at present obtained may be briefly summed up as follows:—

The average death-rate for the English army for the year 1883 was 10·88 per 1,000. This death-rate per 1,000 may be classed as follows:—

Preventable or zymotic diseases	4·36
Chest diseases	1·35
All others	5·17
	10·88

These figures represent an actual saving of life, over the old death-rate, to the extent of 59 per 1,000, or, on an army of 60,000 men, of nearly 3,500 men a year, besides an enormous diminution in sickness, and its consequent inefficiency and suffering. But the very favourable result for 1883 is due to the almost complete absence of cholera; and, great as the reduction in the death-rate has been, the loss from preventable diseases is still too great, and in a year of cholera epidemic might be largely increased.

Observations on some General Causes of Malaria.

These conditions of ill-health are chiefly due to local causes, which may be removed by care in details, such as getting rid of refuse, keeping the water supply free from pollution, and such like matters. But there are also more general causes, for the removal of which the efforts of the engineer are required on a larger scale. Remedies are required for the general malaria-producing causes incidental to the climate and country, such as the drainage of marshy ground and improved cultivation.

The system of agriculture in large districts of India is dependent on irrigation. But in many places the irrigation has been provided without regard to the subsequent removal of the water. Water in or on the soil in a stagnant condition is a source of danger to health, whereas if the water is kept in movement, and flows gradually away, its fertilising effect may not be diminished, whilst its action on health may not be injurious.

I will give you some instances of this.

The first is in India, where disease was caused in a district containing thousands of people by what may be termed misdirected engineering operations. The Kala Nuddee, which takes its origin in the Damoodah River, and joins the Hooghly at Moogra, had its entrance closed, some thirty years ago, by a native zemindar, in order to turn the water over his own land, by which means the water supply, drainage, and irrigation of this district had been cut off. The banks of the Kala Nuddee for a distance of forty miles are densely populated, but the villages had few tanks, and depended for their drinking water on the stagnant and putrid pools in the bed of the nullah, the condition of which was filthy in the extreme, cremation being practised on the banks, and the channel itself used for the reception of all the refuse of the neighbourhood. Fever and other forms of disease prevailed to an enormous extent over the whole district. The continued prevalence of disease directed the attention of the sanitary commissioner to this district, and in consequence of his representations the entrance of the Kala Nuddee was reopened in 1872, and a clear stream of from forty to eighty feet wide, and forty miles in length, was allowed to flow through the nullah, which provided for irrigation as well as for domestic purposes. The result was a great decrease of sickness in the district. But the most remarkable part of the story is that, after this wonderful improvement had been effected, the engineers left in charge were apparently ignorant of the relation which these works bore to the health of the district; and, to save a few hundred rupees a year, they have allowed the channel thus formed to silt up, and fever has reappeared.

Algeria, perhaps, offers some of the best illustrations of the manner in which engineering operations have remedied the evils of the proximity of marshes. Bona stands on a hill overlooking the sea; a plain of a deep rich vegetable soil extends southwards from it, but little raised above the sea level. The plain receives not only the rainfall which falls on its surface, but the water from adjacent mountains, and is consequently saturated with wet. The population living on and near this plain suffered intensely from fever; entire regiments were destroyed by death and disease. It was at last determined to drain the plain. The result of this work was an immediate reduction of the sick and death rate.

Fondouc, in Algeria, is situated on sloping ground, immediately above the marshy plain of the Mitidja; mountain ranges rise immediately behind it. It was first occupied in 1844, and in the succeeding year half the population was swept away by fevers and dysentery. During the first twenty years the mortality was 10 per cent. The surrounding marsh has since been drained and cultivated, and the mortality is 20 per 1,000.

In the Northern Doab districts in the North-West Provinces of India, the excessive fever mortality for which these districts were noted has been mitigated by extensive drainage works, by means of which the water which formerly stagnated in the land is now led away by continuously flowing streams.

On the other hand, if a district is too dry, the engineer may sometimes modify this condition to a certain extent by the encouragement of vegetation and the planting of trees.

The island of Ascension formed a convenient point for ships to call at for obtaining water on their way home from the East Indies. It was a barren rock, to which formerly the water had to be conveyed in ships and stored in tanks. About fifty years ago trees were planted on the island. These have thriven, and now the rain which falls, instead of passing away at once into the atmosphere by evaporation, is retained in a sufficient quantity, and runs out gradually from springs whence the water is collected for the supply of the ships which call at the island.

Thus the engineer has the health of an army, whether moving or stationary, largely in his hands.

He can prevent the occurrence of, and remove, local causes of disease; and he can by his operations prevent the evils which are known to arise from irrigation when not combined with drainage; and he can mitigate the evils of unhealthy marshy districts by removing the stagnant water.

But whilst the engineer may modify the conditions and temperature of the soil, and diminish local atmospheric damp by drainage, and may alter the moisture and temperature of the air by planting or removing forests, and may produce changes in the immediate surroundings of a locality, there are general climatic conditions of a country—such, for instance, as those due to position on the globe and to the vicinity of seas or continents—which are beyond the control of an engineer.

In the exercise of his duties the engineer must have continually present to his mind the conditions which govern—

1st. The healthiness of the site upon which the soldiers' barracks or camps are to be placed;

2nd. The form of dwelling which will best allow of a pure atmosphere within the dwelling;

3rd. A pure water supply;

4th. The rapid removal of all refuse.

In this Lecture I propose to deal with the first of these conditions, viz.:—

Conditions of Health in a Site.

The British soldier has to serve in all parts of the world; and although the temperature and local conditions may vary, yet you will find that there are two conditions which mainly govern the question of the healthiness of a locality in every climate.

These are the organic matters in and on the soil, and the water in the soil.

The effect of these is influenced by the temperature, the rainfall, and the nature and prevalence of winds. You will find in books on meteorology the principles which govern the alternations of temperature in different localities and countries, resulting from radiation, from the proximity of mountain ranges, or of the ocean, and from other causes. I shall therefore limit myself to mentioning a few points connected with temperature which bear in a more detailed manner on the health of a site.

The position of a site as compared with the level of the adjacent country affects its temperature. For instance, when the air in contact with declivities of hills and rising ground becomes cooled by the ground, the cold air will flow down the sides of hills into the valleys, displacing the warmer air, and forming as it were, pools of cold air. Thus rising ground is never exposed to the full intensity of the cold.

In hot climates, especially where there is much rain, the vegetation is often rank, and the heat and moisture especially favour the decomposition of animal and vegetable matter; these climates are, from this cause, liable to be eminently unhealthy.

In the temperate and cold latitudes the conditions of decomposition are not so intense, and where they exist they are more easily controlled.

Although the temperature of the air may be considered to decrease with altitude above the sea level, yet there are local conditions bearing upon the question which the engineer should not disregard.

One of the advantages of living at the sea-side for delicate persons is the greater uniformity of temperature; and the climate in the upper rooms of a house approximates somewhat in the character of equableness to that of the sea-side.

For instance, at a height equal to that of upper rooms in a house, say from 45 to 60 feet, a more equable and drier climate prevails than at lower levels, and the air is much less cold on the coldest and on foggy nights than down below.

The temperature of the air influences that of the soil. You all know that the general temperature of the earth increases with depth, but the temperature of the soil varies to a certain extent from day to day. Daily changes of temperature do not affect the soil to a greater depth than three feet, varying with the daily range of temperature.

The annual variation is dependent on the conductivity and specific heat of the soil, but it does not penetrate below 40 feet, and below 24 feet it is very small. The mean temperature of the soil follows slowly the mean temperature of the air. The highest annual temperature of the trap rocks at Calton Hill, Edinburgh, at a depth of 24 feet, takes place about the 4th of January, and the greatest cold about the 13th of July.

At Greenwich, which is on the tertiary gravels, the highest temperature at a depth of 25·6 feet occurs on November 30, and the lowest on June 1. At a depth of 12·8 feet, the highest temperature occurs on September 25, and the lowest on March 27. For all practical purposes the temperature in the soil at a depth of from 6 to 8 feet, may be said to be practically fixed all the year round, because it follows so slowly the summer and winter changes that it never attains summer heat or winter cold.

Where the rainfall is tolerably evenly divided over the year, the average annual temperature of the soil will be that of the climate of the locality. But in countries with distinct wet and dry seasons, the mean temperature of the soil will not necessarily be the same as that of the mean temperature of the air. Snow, being a bad conductor, prevents the passage of the heat from the earth into the air, and thus in countries where snow lies for some time on the ground, the mean temperature of the earth exceeds that of the air.

The temperature of water in permanent springs is necessarily derived from the subsoil line of fixed temperature, and, except in the cases just alluded to, it will not be found to vary more than 1° or 2° from the mean temperature of the locality; therefore the temperature of a permanent spring may be assumed to afford a certain guide to the mean temperature of a district.

Thus, in England, the permanent springs range in temperature from 49° to 51°, the mean annual temperature being 50° Fahr. In India the springs will be found to vary in different parts, according to the temperature of the locality; in some instances they attain a temperature of from 70° to 80°.

But whilst the mean temperature of the ground depends on the climate, soils have a very varying conducting capacity for heat; loam, clay, and rocks, are better conductors than sand, and by allowing the sun's heat to pass more rapidly downwards, do not become heated to so high a degree.

The conducting capacity of the soil has a very important bearing upon the comfort, if not upon the health, of those who live upon it.

The following table shows the relative power of soils to retain heat; sand being the worst conductor, 100 is allotted to it as the standard:—

Sand, with some lime	100·0	Clayey earth	68·4
Pure sand	95·6	Pure clay	66·7
Light clay	76·9	Fine chalk	61·8
Gypsum	73·2	Humus	49·0
Heavy clay	71·11		

Sand stands highest in its retentive power, *i.e.*, it is the worst conductor of heat.

Clay is a good conductor.

The temperature of the air over sand will be more equable, whilst a clay soil will be colder, because the radiation is greater. Clay prevents the percolation of rainfall; the air over it is damper than over dry sand. Hence it favours the production of rheumatism and catarrh.

Moreover, the prevalence of fever is largely dependent upon atmospheric changes from the radiation at night, and consequent lowering of temperature; and the Indian experience in some cases has shown that fever rates are highest in alluvial clay soils and water-logged ground, whilst the general death-rate was highest on porous wet soils; but porous wet soils possess no advantage in the way of escape from fever if they be deluged with water periodically.

But, on the whole, sands are generally the healthier soils in this climate.

On the other hand, in hot countries the air over sand, unless covered with grass, is hot day and night.

Herbage lessens the absorbing power of the soil from the sun's rays, and radiation is more rapid from it, because a portion of the heat is lost by the evaporation which goes on from the pores of plants, and the leaves are rapidly robbed of their heat by the adjacent air. Moreover, grass or other low-growing vegetation neutralises malaria, and hence should be used to cover bare surfaces.

Changes of temperature take place slowly in trees as compared with the temperature of the air. Trees acquire the maximum temperature after sunset, whilst the maximum temperature of the air occurs between 2 and 3 P.M. Hence the influence of trees is to make the night warmer and the day colder; and the heat is more evenly distributed over the twenty-four hours in countries covered with vegetation than in those free from it.

Evaporation goes on slowly under trees; but the vapour, not being so liable to be removed by the wind, accumulates among the trees. Hence, whilst forests diminish evaporation, they increase humidity, and they keep the summer temperature lower, and the winter temperature higher, than it would be without them. For these reasons, forests may act the same as a range of hills, and increase the rainfall in the summer by causing condensation of warm moist winds.

In the case, already mentioned, of the island of Ascension, the power of retention of water in the soil exercised by the planting of trees was exemplified.

Surgeon-General Gordon, C.B., states that the climatic conditions of Upper India have undergone change and deterioration within historical times by the disturbance of forests. During the wars preceding the subjugation by the Aryan invaders of what now constitutes a considerable portion of the Punjab, dense forests covered the surface of the country.

According to the great Hindoo epic poem, the 'Mahabharata,' prosperous cities and richly cultivated lands became established; inhabitants had abundant food; they were long-lived; epidemics were of rare occurrence; illness was looked upon as punishment by the gods for some sin committed; the natural duration of life was said to be 100 years. But now, and for a long period of years, much of the forest has ceased to exist; long wastes of semi-desert country have taken its place; the surface yields only stunted acacias, capers, and asclepias; rivers which then existed are decreased in size; one historic stream, the sacred Suruswattee, has for centuries ceased to flow, and cities situated in the less arid localities are periodically swept by epidemics, terrible from their fatality.

Whilst, however, on the one hand, trees and vegetation favour the retention of water in the soil, on the other hand, all growing vegetation evaporates a large quantity of water. In order to form 1 lb. of woody fibre, a plant evaporates 200 lbs. of water; consequently, a country covered with forest evaporates an enormous quantity of water out of the soil, in order to produce a growth of timber.

The condition which, more than any other, governs the healthiness of the soil, is the relation which the ground air, or air in the soil, bears to the ground water; that is to say, the presence or absence of moisture in the soil.

The moisture in the soil, or ground water, depends upon the amount and mode of incidence of the rainfall; for, as a rule, rainfall is the parent of the ground water.

Rain varies greatly, both as regards frequency and rate of fall. In some places it never rains. The heaviest recorded average annual rainfall anywhere is said to be 600 inches. This occurs on the Khasia Hills, which rise abruptly opposite the Bay of Bengal, and are separated from it by 200 miles of swamps. As much as 700 inches have fallen in a year. Five-sixths of the quantity of rain falls in about half the year; 264 inches have been recorded to have fallen in the month of August alone, and 30 inches to have fallen in one period of 24 hours.

The basin of the Indus contains districts where the rainfall is sometimes as low as six inches in the year.

In England the average rainfall is 32 inches, but the average gives a wrong impression of the condition of different parts of the country.

In the west of Great Britain and Ireland, in the immediate neighbourhood of hills, the average rainfall is above 75 inches; and in some localities 150 inches have been observed; in some years it is even higher. In the east of Great Britain, from 20 to 28 inches of rain falls. The amount of rainfall is affected by proximity to the sea, as well as by mountain ranges and hills; from these latter, and other causes, it varies materially at places a short distance apart, and therefore each locality must be considered separately.

The average of a series of years is not what an engineer must look to. He has to deal with the maximum or minimum. In questions of water supply, the minimum of the yearly fall is what must influence his calculations. But in questions of the removal of water, he must look to the maximum, not of the yearly fall only, but to the greatest amount which may fall in a limited period. The driest years test water supply; the wettest years test works.

You may take it as an approximate rule in this country that the maximum annual rainfall exceeds by one-third, and the minimum annual rainfall is less by one-third than, the mean rainfall of a series of years. It has also been observed that the average annual rainfall of three consecutive dry years amounts to 80 per cent. of the mean annual rainfall of a series of years.

The time of the year at which the rain falls, and the resulting effects on the air and the soil, are points of great sanitary importance.

In dry seasons the re-evaporation is rapid. In India, rain may fall at such intervals in a dry season as to allow of entire re-evaporation. In wet seasons water falls on water and flows off in floods.

In this country, on an average, nearly two-thirds of the mean annual rainfall goes back at once into the atmosphere as evaporation. A further portion evaporates slowly from the soil, or is absorbed by vegetation. The water which is not evaporated, or absorbed by vegetation, percolates into the soil, to flow out in springs, streams, and rivers to the sea, whence it again passes into the atmosphere, and returns as rainfall or as dew. For it is evident that if the humidity of the atmosphere be assumed to be constant for an average of years, the evaporation over the whole globe must equal the rainfall.

The proportion of evaporation and percolation in different soils varies—

(1) With the time of year in which the rain falls.

(2) With the quality of the soil, with its capacity for heat, and with the character and extent of the vegetation with which it is covered.

In England, on an average of years, the spring is the driest and the autumn the wettest part of the year. The driest months are March and April, the two wettest months are October and November.

The greatest percolation takes place after a wet period, when the soil becomes saturated. In the summer there is scarcely any percolation. A series of experiments on percolation in England, extending over fourteen years, showed that in five of the years there was no percolation during a continuous period of seven months; and that in one year only, viz. 1860, did percolation take place every month.

The nature of the soil affects the percolation. Through sand the percolation is great. The evaporation from sand in this country has been found to be 16 per cent., and the percolation 84 per cent., whereas with clay and loam the percolation is 27, and the evaporation 73 per cent.

PERCOLATION THROUGH SOIL AND EVAPORATION FROM SURFACE.

Authority	Material	Duration of Experiment	Percolation per cent.	Evaporation per cent.
Dalton . .	Earth . . . . . / Surface grass . . .	3 years	25·0	75·0
Dickinson .	Gravelly loam . . / Surface grass . .	8 ,,	42·5	57·5
Maurice . .	Earth	2 ,,	39·0	61·0
Gasparin .	Earth	2 ,,	20·0	80·0
Rister . .	Impervious subsoil . / Sand, cropped . .	2 ,,	30·0	70·0
	Mean—	—	31·3	68·7
Greaves . .	Loam, gravel, and sand, turfed	22 ,,	26·6	73·4
	Sand	14 ,,	83·2	16·8
Laws & Gilbert	Loam, clay, subsoil, built in 20″ deep . .	5 ,,	36·8	63·2
	Loam, clay, subsoil, built in 40″ deep . .	5 ,,	36·0	64·0
	Loam, clay, subsoil, built in 60″ deep . .	5 ,,	28·6	71

In hot climates, the relative power of various soils to retain heat would alter these proportions: for instance, the evaporation in such cases would be large from sand if unprotected by herbage.

The presence or absence of vegetation exercises an important influence on percolation. When vegetation is rapid, as in the case of growing crops in the spring, it arrests percolation. Dr. Ehermeyer found that at Salzburg, percolation was 53 per cent. less through turf than through bare earth in the month of June, and that the difference was least in January. When the ground is covered with forests, the moisture is retained nearer the surface.

Apart from its effect on the moisture of the soil, vegetation has an influence of its own on the healthiness of a site. Plants in respiration absorb oxygen and throw off carbonic acid, but the action of the cells in which the green matter termed chlorophyll is formed, which gives colour to vegetation, is to absorb carbonic acid and to eliminate oxygen. This action is due to the sun's rays. Vegetation is thus beneficial, but when placed near dwellings it should always be vigorous, healthy, and green; fallen leaves and decayed vegetation should be rapidly removed, like other refuse, from the vicinity of dwellings.

When the rainfall has penetrated from twelve inches to two feet into the ground, the loss from evaporation is comparatively small; but it varies with the nature of the soil. In the chalk formation, water will rise by capillary attraction from the level at which the chalk is saturated to a considerable height above that point; while a bed of sand will be dry at the height of about a foot above the water standing in it.

So long as there is water sufficiently near the surface of the soil to keep it moist by attraction, evaporation will continue. Clay and similarly retentive soils do not give off vapour as copiously as free open soils; therefore a given quantity of moisture will occupy a longer period in passing off these soils than is the case with free soils under similar conditions.

The capacity of soils to retain water varies greatly. Impermeable granite or marble will hold about a pint of water per cubic yard. Open gravel will hold from 10 to 15 per cent. of its own weight when dry; pure sand will hold forty or fifty gallons, or about 17 per cent. of its weight when dry, and the ordinary red sandstone rock twenty-seven gallons per cubic yard, or from 7 to 8 per cent. of its weight when dry. London clay will hold 50 per cent. of its own weight when dry.

The following is the result of some experiments made by Mr. Baldwin Latham in 1879:—

Soil	Weight of Water absorbed Per cent.
Open gravel	9 to 13
Light sandy soils	23 to 36
Yellow marl subsoil	25·9
Loamy soil	43
Stiff land and clay soils	43·3 to 57·6
Gravelly surface soil	48
Sandy and peaty soils	61·5 to 80
Peat	103

The conditions of two localities may thus vary greatly, although there may be an apparent general similarity in the soils.

Under-draining facilitates the passage of the water from the surface into the ground. The discharge of underdrains in a free soil of chalk, gravel, and sand, was found, by Mr. Bailey Denton, to be 2¾ times as rapid as that from underdrains in a clay soil, the drains in the clay being 25 feet apart, and those in the free soil placed at irregular intervals widely apart. Hence the rate at which a soil allows of the percolation of water regulates the distance apart at which underdrains should be placed for the purpose of lowering the subsoil water in land. In free soils, a single drain will lower the water from a large area; in clay soils numerous drains are necessary. The discharge from open soils is more regular than from clay, although clay soils often give out a large proportion of the rainfall immediately after it occurs, especially in summer or after a dry period, when the ground near the drain is opened out by cracks, through which the rainfall passes straight to the drain. Barometric pressure may affect the discharge from drainage outlets; an increased discharge has been observed to follow a fall in the barometer without any fall of rain on the surface.

A smaller evaporation and greater percolation takes place in drained lands, and a drained field will consequently have a temperature as much as 6° or 7° Fahr. higher than an adjacent undrained field. The cause is obvious. To convert water into vapour absorbs 960° Fahrenheit of heat from its vicinity; thus each cubic foot of water evaporated will lower the temperature of something like 3,000,000 cubic feet of air 1°. The lower the water in the soil the less the evaporation, and the warmer the adjacent air.

At all places above the sea level where the strata are porous, the portion of water which is not evaporated flows away either over the surface or underneath the surface.

For instance, a vast proportion of the rain which falls in the valley of the Thames flows away through the ground under and beside the bed of the river.

If, by reason of the disposition of the strata, the water cannot flow away, it remains a stagnant pool.

The air does not cease where the ground begins, but air permeates the ground and occupies every space not filled by solid matter or by water. Thus, it is the same thing to build on a dry gravelly soil, where the interstices between the stones are naturally somewhat large, as to build over a stratum of air. The air moves in and out of the soil in proportion to barometric pressure, and with reference to the wind. If there is much water in the soil, the air carries with it watery vapours, and is cold, and such a site is called damp.

A site with a high-water level is, as a rule, more unhealthy than a site with a low-water level; but a site with a fluctuating water level is most unhealthy.

The soil contains much organic matter. Where the soil is filled with water the decomposition of this organic matter is arrested; but when the water retires, decomposition goes on at an accelerated rate. Moreover, whilst the water is present it maintains an equable temperature. When the water is drying up, not only is the air above the soil moister, but there are greater alternations of temperature, which of itself is a frequent cause of fever. Not that all fever attacks are due to malaria; but when malaria has done its work, any sudden change or lowering of temperature, with moist air, will reproduce the fever.

India affords many instances of this. In the Punjab the mortality from fever deaths in each of three consecutive years—1872-74—when food was cheap, and when there was no extraordinary occurrence to affect the ordinary relations between fever and rainfall, the fever deaths only began to rise after the rainfall had attained its maximum and had begun to decrease; and the deaths from fever attained their maximum soon after the rainy season came to an end, during the drying up of the ground, after which they decreased.

The Civil Surgeon at Sylhet in Assam says: 'Looking back to my notes for the last six years, I find it has invariably happened that as soon as the country becomes dry cholera makes its appearance, and remains till the inundations set in. During the rains the district is practically converted into an archipelago, and epidemic cholera is rarely heard of. But with the drying up of the water come reports of cholera from every direction. They are almost simultaneous from every point of the compass. It springs up like a plant of the season.'

The exciting cause of the fever or cholera in this district is the decay of the organic matter present in and on the soil, which is arrested so long as the ground is covered by water, but when the water retires decay goes on.

It is within the power of the engineer to mitigate this cause of disease, for he can remove the decaying organic matter, or he can control the water level in the soil and remedy the evils of a wet site by the construction of necessary works.

There is a considerable quantity of carbonic acid in the soil; and it is an evidence that some decomposition of organic matter has gone on there. It varies at different depths; it has been found to vary greatly even in localities in close proximity. The processes going on in the soil in these several places are therefore probably very different. Each will have its influence on the ground air. One evil arising from a foul subsoil is very apparent. In cold weather the temperature of a house is warmer than that of the outer air. If a house, or barrack, or hospital, is built on soil containing deleterious matters, the impure air will be drawn into the rooms by the action of the warmer air of the house. The sanitary constructor, therefore, takes measures to check the passage of air between the house and the ground under and around it. The fact of this continual free passage of air in and out of the ground makes it important that not only should the ground lived on be free from water, but that it should also be free from impurities. It would be just as healthy—indeed, probably far healthier, to live over a pigsty than over a site in which refuse has been buried, or into which sewer water has penetrated, or over a soil filled with decaying organic matter. It is certain that fever prevails in many of the newly built houses round our great cities, simply because the builders, having bought a piece of land with gravel and sand upon it, have excavated and sold the sand and gravel, and have then allowed the town refuse to be brought there and deposited at so much a load; and when the excavations have been thus filled up, they have built houses, which for many years afterwards are mere dens of fever. Thus, before building on any ground, its nature should be carefully examined.

But in proportion as there is a free movement of air in the soil, so is the process of decay, and consequently the removal of decaying matter, more rapid. Louis Créteur, in his work, 'Hygiene in the Battle-field,' gives his experience in disinfecting the pits where dead were buried near Sédan. The bodies were buried in chalk, quarry rubble, sand, argillite, slate, marl, or clay soils, and the work of disinfection lasted from the beginning of March till the end of June. In rubble the decay had taken place fully, but in clay the bodies were surprisingly well kept, and even after a very long time the features could be identified. And to show you how slow the progress of decomposition may be, the Sanitary Commissioner for the Government of Bombay, in a recent report, mentions that in that city, thirty-one years after a part had been filled with town sweepings, pieces of hay, straw, &c., were distinguishable 5½ feet below the surface.

It is desirable to keep the permanent level of water in the soil where habitations are placed as low as possible; that is to say, to drain it, so as to allow the air to have free play in the soil. But where the ground water cannot be maintained permanently at a low level, then keep it at an even level.

The effect of the water level on the healthiness or unhealthiness of a site is to some extent dependent on the question as to whether the underground water is moving, or held in by impervious strata in a stagnant underground lake; because, if the water is moving, it will carry away with it organic matter or impurities in the soil, and then wash it and cleanse it; but if stagnant, and merely carried away by evaporation, it will leave the organic matter to putrefy.

Stagnant water in the soil is injurious to health; marshes, or irrigation carried on without adequate oultets, which thus produces artificially the conditions of a marsh, tend to the production of malaria. This would prove dangerous in any climate, but is especially so in hot climates.

The presence or absence of moisture determines very much the degree of healthiness of sites. The water level of every camping-ground should be examined by digging holes; but a correct idea can be obtained as to where water is nearest the surface from observing where the vegetation is greenest, where midges prevail in the daytime, and where frogs appear soonest at nightfall.

These considerations show the importance of forming a deep open area round a house, and carrying it below the level of the basement floor. Between the floor of any inhabited room and the ground there should always be ventilation to the outer air. Similarly, a trench should always be dug round a tent. Apart from the advantage which this affords of draining off the water, the sides of the trench enable the atmospheric air to permeate freely to the ground immediately under the tent, especially where the tent stands on a gravelly soil.

The effect of these local conditions on health may, however, be much influenced by the manner in which the site is occupied. For instance, granitic and other impermeable formations are termed healthy because the impurities, instead of passing into the soil, are carried off rapidly by rainfall; but if filth is allowed to accumulate they will be unhealthy.

Thus, during the first visitation of cholera, one of the places which suffered most severely, owing to its filthy local condition, was Megavissey, on the granite formation in Cornwall.

There was much sickness and mortality in 1859–60 at Hong Kong. The peninsula of Kowloon was selected as a sanatorium. It was of granite formation, freely exposed to the winds; it was reputed to possess every quality for health. Huts were built, and the troops were moved into them. They suffered severely from fever. This arose from the disturbance in a tropical climate of the surface soil impregnated with decaying organic matter. Until soil of that nature has been opened and oxygenised, it is in the highest degree deleterious.

Brushwood is a source of danger near camps in a hot climate, but the immediate result of the removal of brushwood has been found to cause fever, owing to the disturbance of decaying organic matter occasioned thereby.

Sand or gravel soils are, however, only healthy if kept entirely free from sewage and decaying organic matter, and from excess of water. If this is not seen to, then expect typhoid fever from foul subsoil air and polluted well-water. Moreover, sand is easily polluted, because the polluted matter on the surface percolates freely into sand with the aid of rain-water.

On the other hand, in hot countries, sands are objectionable from their heat, unless they are covered with grass. They do not allow the heat to pass through, but radiate it slowly, and the air is hot over them day and night.

A clay soil prevents the percolation of rainfall; the air over it is therefore damper. A clay soil cannot be easily polluted by sewage-water like sand, and in some cases fever has been observed to stop on passing from gravel to clay.

On the other hand, the Indian experience has sometimes shown that fever death-rates are highest in alluvial clay soils and water-logged ground, whilst the general death-rate was highest on porous wet soils, but porous wet soils possess no advantage in the way of escape from fever if they be deluged with water periodically.

Pervious beds, such as sand and gravel, interlaced with impervious beds, such as clay or shale, have the great disadvantage of sweating out water at the outcrop; this is a frequent cause of fever in dwellings situated at the outcrop. See Fig. 2, Plate I.

A wet hill-slope should always on this account be avoided, if at all practicable, but if it must be used, then it must be efficiently drained.

The following instance will explain this. Fig. 3, Plate I., shows the slope of the ground falling towards the plain of Balaclava. The formation is rock below and above, traversed by a belt of clay and shale. The 79th Highlanders were placed on the clay, and, as the material was soft, their huts were placed on terraces cut out of the hill-side, and were thus embedded in the ground, and the floors, consequently, were always damp. There was no roof ventilation. This regiment had half the men down with fever. The 42nd Highlanders were placed on the rock, and as it was hard they did not cut into the rock, but preferred building their huts on projecting terraces, so that they were quite dry, and air circulated freely round. This regiment did not suffer from fever.

The huts on the clay were subsequently altered as shown in Fig. 4 and Fig. 5, Plate I., so as to allow of a clear circulation of air round the huts. Drainage and roof ventilation were provided, as shown in the sketch, and fever no longer prevailed.

In connection with this, it should be mentioned that where, from circumstances, tents and buildings must be placed on the side of a hill, a plateau should be formed to receive them, and a broad space be left between the hill and the tents or buildings. A trench should also be cut to carry off the moisture between the tent and plateau, and no accumulation of refuse should be allowed between the hill and the tent or building. See Fig. 6, Plate I.

Although the general features of a site may be unhealthy, when it is absolutely necessary, for any reasons, military, political, or otherwise, that it should be occupied, you will have seen from my remarks that much may be done to remedy its unhealthiness.

For instance, if temporary occupation only is contemplated, probably cutting off the water which may flow from higher levels, or the adoption of measures already mentioned, such as digging trenches round tents or huts, would be all that could be done; but if the ground is to be permanently occupied, not only the area to be built on, but an area extending to probably 100 yards round it on every side, should be thoroughly underdrained, and the mouths of the drains so arranged as to allow the aëration of the soil as well as the removal of the subsoil water. Dwellings should be raised above the level of the ground, and provided with ventilated air-spaces underneath.

It is, however, not sufficient to devise and execute the works for rendering a site healthy. It is necessary to keep a watchful eye upon these works after they are made. For instance, it is not sufficient to make the drains. All drainage cuts are liable to become injured, if open, by vegetation, and in all cases by decay, by atmospheric causes, and by other means. If not properly maintained and cleared out, the evils they are created to remove will recur.

Thus at Bona, in Algeria, from which, as already mentioned, in consequence of drainage works, the fever disappeared, the drains were left exposed to atmospheric influences; they became partially obstructed, the discharge irregular, and finally did not allow the water to reach the outfall; the result was a violent outbreak of fever at Bona, attended with great loss of life, both civil and military. An inquiry took place, the drainage was rectified, and since then Bona has been healthy.

General Conclusions as to Conditions Necessary in a Healthy Site.

Let me sum up now what are the conditions to be aimed at in a healthy site.

The local climate should be healthy; the soil should be dry and porous; it should be protected from the north and east by shelter at a sufficient distance to prevent stagnation of air or damp, otherwise the shelter from cold and unhealthy winds, which is an evil recurring only at intervals, will be purchased by loss of healthiness at other times. The ground should fall in all directions, to facilitate drainage; it should not be on a steep slope, for high ground rising near a building stagnates the air just as a wall stagnates it; the natural drainage outlets should be sufficient and available. There should be nothing to prevent a perfectly free circulation of air over the district; there should be no nuisances, damp ravines, muddy creeks or ditches, undrained or marshy ground close to the site, or in such a position that the prevailing winds would blow the effluvia over it.

It sometimes happens that the immediate vicinity of a marsh, or other local cause of disease, is safer than an elevated and distant position to leeward. There have been cases where a belt of trees or a slightly rising ground between the marsh and the building site seems to have effectually prevented any bad effects from its vicinity. Elevated sites situated on the margin or at the heads of steep ravines, up which malaria may be carried by air currents flowing upwards from the low country, are apt to become unhealthy at particular seasons. Such ravines, moreover, from want of care, are often made receptacles for decaying matter and filth, and become dangerous nuisances. In tropical climates these ravines convey malaria, and occasionally aggravated remittent or even yellow fever is experienced, at an elevation which would be otherwise exempt from the action of tropical malaria. This was one of the causes which contributed to the prevalence of yellow fever in the New Castle Barracks in Jamaica, which had been placed on an elevated site from 3,500 to 4,000 feet above the sea level, situated on the crest of a spur of land falling rapidly from the Blue Mountains southwards towards the deep damp valleys and ravines, filled with tropical vegetation, which connect the range with the lower country.

A main object to be attained in laying out the ground for a site for a barrack or a camp is the rapid and effectual removal of all water from the habitations themselves and from the ground in their vicinity, so that there shall be no stagnation in or near the site. Therefore the site should be thoroughly underdrained, except possibly in a case where the ground is so elevated and porous as to ensure that water never remains in it; and if there is higher ground adjacent, the water from the higher ground should be carefully cut off by underground catchwater drains, and led away from the vicinity of the site.

It is no doubt impossible always to procure a perfect site for building, but it will be necessary in the construction of buildings upon a given site to discount any departure from these qualifications by additional sanitary precautions in the building—*i.e.* by increased expenditure.

To test the healthiness of a site, an inquiry into the rate of sickness and mortality in the district will afford valuable information. But care should be taken not to be guided by the mortality alone. The nature of the diseases, and the facility, or otherwise, with which convalescences and recoveries take place, must also be taken into account.

I have now exhausted the time at my disposal by the explanation of certain preliminary questions which it is necessary that you should consider when you are called upon to provide for the location of a body of troops in a healthy locality.

A skilled sanitary officer will be a man of many expedients, derived from close and intelligent observation, and in his works he will strive to save labour. Every country has its character impressed on its surface contours, and these the geologist and engineer will read at a glance. Wide and flat areas will indicate, as a rule, a soft subsoil; a steep gradient will indicate a subsoil of some hard material, such as gravel; rock will generally show above the surface; where there are mountains, there will usually be at the base mounds of material —particles weathered from the rock and admirably suited for road-forming.

This was the case in the Crimea on the margin of the road from Balaclava to the front. In the lower part of the valley this road, during the first winter, was worn into almost impassable mud by the wheel traffic. To repair this road the Royal Engineers were blasting rock at a distance to break into road material, when at the foot of the mountain, and close to the road, there were thousands of tons of stone ready broken—that is, the 'talus' weathered and washed down during untold years from the mountain.

If this material had been used from the first to maintain the road to the front in proper order, there need have been no railway; much suffering would have been prevented, and many lives would have been saved.

This rapid *résumé* is only sufficient to suggest to you points for observation.

The selection of a healthy site for a camp or a barrack will depend upon your own power of applying the sanitary knowledge you have acquired to the particular case.

I trust that the remarks I have made to-day will impress upon you the extent of the field of knowledge which this branch of your profession alone requires you to traverse.

LECTURE II.

PURE AIR.

In my first lecture I endeavoured to explain to you the general principles which should govern the selection of a site for a camp or for permanent buildings, were conditions of health alone to be considered.

If for military reasons it has been necessary to take a site which presents unsatisfactory sanitary conditions, then the arrangements adopted in the construction of the buildings must be such as to discount the unsatisfactory features and reduce their effect to a minimum.

The conditions which you have to secure are summed up in the words—pure air and pure water, and to secure these the principal consideration is the speedy removal of all refuse matter.

Causes of Impurity in Air.

What are the conditions which regulate the purity of the outer air?

1st. There are causes at work owing to the existence of plants, animals, and men, by which the surrounding air is being constantly filled with impurities; and

2nd. Nature has provided means by which the purity of the air is being continually renewed.

Every analysis of air shows the presence in varying proportions of carbonic acid, vapour of water, organic matter, ammonia, suspended matter.

Organic Matter.

Organic matter and gases from decaying vegetation are constantly passing into the air, but the various processes connected with life, and especially human life, and occupation, are among the most fertile causes of the pollution of air in the vicinity of habitations. The quantity of organic matter in outside air varies considerably, within certain limits, from day to day and from hour to hour on the same day. It is least in fine weather, it increases in dull weather, it is greatest in fogs. It is washed out of the air by means of rain.

Dr. Russell's experiments in London show that city air contains twice as much impurity as suburban air, but that the impurities are the same in character, and that in country air the impurities were much less; and on Dartmoor the air was uncontaminated either by the products of combustion or by the decomposition of animal or vegetable substances.

Let us now consider how we affect the purity of air by our presence in a room.

What takes place is as follows:—Putrefying organic matter is thrown off from the human body in the process of breathing and transpiring:—

1. The oxygen is diminished.
2. The carbonic acid is increased.
3. A large amount of watery vapour is produced.
4. There is an evolution of ammonia and organic matter.
5. A considerable amount of suspended matter is set free, consisting of epithelium, and molecular and cellular matter, in a more or less active condition of putrefaction. At the same time, portions of epithelium are constantly being given off from the skin, and even pus cells from suppurating surfaces—as, for instance, with surgical cases in hospitals.

Putrefaction.

Putrefaction is the process which nature employs to make the matter which has formed part of an organic structure again available for the support of life. And as the investigation into the action of ferments or putrefaction has an important bearing upon practical hygiene, it is desirable that I should briefly allude to the present state of the theories on this subject.

Animals or vegetables, whilst they are in the condition which we call alive, are continually employed in working up into the solid matter of which their bodies are composed, gases taken from the atmosphere, or nitrogenous and saline substances which are dissolved in water. For instance, if you take some seeds of mustard and cress, and put them on a piece of flannel in a plate with water, and place the plate in the sunlight near your window, you will soon have a luxuriant crop of mustard and cress, derived from a combination of the salts dissolved in the water and the gases in the air, assisted by the sunlight. Thus it is possible, by means of air, and the gaseous elements it contains—by means of water, and the elements contained in rain—to create and develop the smallest blade of grass as well as the largest oak.

An oak, a blade of grass, an animal that lives by eating grass—as, for instance, a sheep—or a carnivorous animal that lives by eating the sheep—as, for instance, a lion—or, indeed, each one of you here present, were all originally water, carbonic acid, salts of ammonia, and soluble mineral substances. But when once these substances have been converted into the oak or the blade of grass, or into the sheep, or the lion, or the man—that is to say, into organic matter which can be handled, this new matter is as it were paralysed, and incapable of contributing to the nourishment of a new vegetable life; and if it were to remain perpetually in this state—if its elements were never to pass back into the atmosphere, or into the water which circulates around the globe—the atmosphere would soon be deprived of the elements it contains, out of which organisms are produced; water would be deprived of its nutritious matter, and life would become impossible on the surface of the globe.

As a means of enabling life to go on continuously in the world, nature has provided minute microscopic beings, which we are barely beginning to know, but which have always existed side by side with us in the larger world of animals and plants with which we have always been familiar, which, at the moment when life has ceased in a plant or an animal, begin to redistribute its component parts back into the air and the water.

Putrefaction, whilst it is one of the purifying agencies of nature, produces vapours or gases injurious to health, which, however, are counteracted by thorough oxidation; and when organic matter is thrown off from the body a current of air may either carry it away, oxidising or burning it up, as it were.

Ammonia.

Ammonia is present wherever there is organic matter. It comes from all living organisms, and is equally necessary to build them up. It is therefore present wherever plants or animals grow or decay. As it is volatile, some of it is launched into the air on its escape from combination, and it is always found in the air. As it is soluble in water, it is found wherever we find water on the surface of the earth, or in the air, and probably in all natural waters, even the deepest and most purified. As a part of the atmosphere, it touches all substances, and can be found on many; it is in reality universally on the surface of the earth in the presence of men and animals, attached more or less to the surface of all objects, but especially to all found within human habitations, and the habitations of all animals. Thus a room that has a smell indicating recent residence will, in a certain time, have its objects covered with organic matter, and this will be indicated by ammonia on the surface of objects.

Hence ammonia, being more readily observed than organic matter itself, may be taken as a test, and the amount will be a measure of the impurity.

It is probable that the chief cause of the presence of ammonia on surfaces in houses and near habitations is the direct decomposition of organic matter on the spot. In towns the air is filled with the impurities which it is the practice to retain in and about the houses, on the street surfaces, and on open spaces within and around the city area.

The whole subsoil of our cities used to be perforated with cesspits, which were generally porous, and were preferred to be so, because it rendered frequent emptyings unnecessary.

The subsoil of all large Indian cities has been saturated with the filth of generations, just as the subsoil of large cities in ancient times had been saturated. From this saturation these ancient cities became foci of disease, and were abandoned.

Oxygen.

The air of mountains and great plains contains more oxygen than that of cities, where the air is being breathed, and where putrefaction may be supposed to exist. Dr. Angus Smith has found that a diminution of oxygen and an increase of carbonic acid is decidedly apparent in crowded rooms, theatres, cowhouses, and stables, and near middens, in Manchester. The diminution is no doubt small. The average quantity of oxygen in pure air amounts to 21 parts out of 100.

In impure places, such for instance as in a sleeping room where the windows had been shut all night, or in a lecture theatre after a lecture, or in a close stable, the oxygen has been found to be reduced to as little as 20 parts in 100. That is to say, a man breathing pure air obtains, and he requires, 2,164 grains of oxygen per hour. In bad air he would, if breathing at the same rate, get little over 2,000 grains of oxygen an hour, that is, a loss of about 8 per cent.; and this diminished quantity of oxygen is replaced with other, and in almost all cases pernicious matters, and although the quantity is no doubt small, it becomes appreciable from the large amount of air we inhale, viz., from 1,000 to 2,000 gallons of air daily.

A current of air either carries away the organic matter with it, decomposing it and turning it into gases, or, if it were not possible for the oxygen alone to do this, it might happen that the oxygen destroys those minute forms which have been shown to be concomitant with putrefaction and decay. Moreover, besides any poisonous action which these substances may possess, if the air is loaded with impurities, the lungs get clogged, and their power of absorbing the oxygen that is present in the air is diminished. An individual breathing this impure air must, therefore, do less work; or, if he does the same amount of work, it is at a greater expense to his system.

Mr. Romanes mentioned on a recent occasion that he had found, in examining after death the lungs and air-tubes of persons who had lived in the densely-inhabited parts of London, that they were coated in many places with soot and carbon, and thus able to act much less efficiently than the lungs of people who had breathed clear air.

Carbonic Acid.

Carbonic acid (CO_2) is slightly in excess in town air; in crowded unventilated rooms and theatres the excess is very apparent, and even in the open country an appreciable variation in the quantity present has been produced by the proximity of a flock of sheep.

In normal air in the open country it varies from ·29 to ·32 per 1,000 parts. In cities it sometimes amounts to ·42 per 1,000 parts; in a long-continued fog in the city of London as much as 1·41 parts per 1,000 of air have been observed; in crowded theatres as much as 3·2 has been found. This air is oppressive; for this accumulation of CO_2 implies an accumulation also of many other impurities. On the other hand, over vats in breweries and distilleries as much as 2·5 and 3·0 per 1,000 has been obtained without any oppressive effects. The difference is this. In the case of the air of crowded rooms there is present with the CO_2 organic matters thrown off from the body; this organic matter is highly poisonous, and it is as an approximate measure of the amount of organic impurity created by the processes of life in the air of inhabited rooms, rather than on account of its own effects, that the determination of the amount of CO_2 is especially useful.

I may here mention a standard case of the effect of bad air, viz., the well-known case 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 morning 123 corpses were taken out, and 23 beings who could scarcely be said to be alive.

These were deaths caused by breathing over again air which had been previously breathed, without any addition of fresh air to dilute it.

Of the other impurities in air carbon oxide (CO_1) is eminently poisonous. Less than 0·5 per cent. has produced poisonous symptoms, and 1 per cent. rapidly produces fatal results. This gas is formed by the imperfect combustion of carbon.

Other Impurities.

There are various suspended matters in air which produce disease from mechanical causes, such as the dust which in Egypt produces a sort of ophthalmia. Bronchitis and lung disease prevail in many factories, arising from the inhalation by the workmen of the dust of coal, sand, and steel, or of particles of cotton or hemp. Stonemasons suffer from inhalation of stone dust. The Guards suffered largely about eighteen years ago from lung disease; one of the contributing causes was assumed to be the quantity of pipeclay they inhaled in the process of cleaning their white cloth fatigue jackets. House-painters suffer from the dust of white-lead; though in this, as in many cases, the persons suffer as much from swallowing particles, in consequence of not washing off the dirt from their hands before eating. In factories cotton dust was at one time a dangerous source of disease, because, when inhaled in breathing, it clogged the lungs and led to illness and death; but in all well-conducted factories, arrangements are now made for drawing the dust away by a fan as soon as it is generated. In towns the suspended matters in air which are of most importance consist of the dust from refuse, chiefly organic matter from horse-dung and the imperfectly consumed particles of coal.

London air contains an enormous quantity of soot and suspended organic matter, independently of the sewer and other emanations, and of the ammonia given out by the manure of the enormous number of horses in London. It is noteworthy that the mud from a paved street in London was found on analysis to contain nearly 90 per cent. of horses' dung; the mud on a wood pavement consists almost entirely of horse-dung. London air contains also about nineteen grains of sulphurous acid in a cubic yard of air. These impurities are all materially increased during fogs.

The influence of smoky and otherwise polluted town air on health is to some extent illustrated by the fact that the death-rate of twenty-three manufacturing towns, selected chiefly for their smoky character, averaged 21·9 per 1,000 in 1880, whilst the rural districts in the counties of Wilts, Dorset, and Devon, excluding large towns, averaged 17·7 per 1,000, and the deaths from the principal zymotic diseases in the towns were more than double those in the rural districts.

Causes of Fogs.

Atmospheric air always contains more or less aqueous vapour, either in an invisible state or in the form of clouds, fogs, and mists. Vapour exists in the atmosphere at all temperatures, even below the freezing point of water; and as the point of saturation of air rises more rapidly than the temperature, air is dry or moist, not in proportion to the water it contains, but to its temperature; that is to say, in proportion as it is more or less removed from the point of saturation.

Recent experiments show that the conversion of this aqueous vapour into visible fog arises from the presence of particles of foreign matter floating in the air, upon which a deposition of the aqueous vapour takes place. The vapour of water injected into air from which all particles have been strained out, is not visible; whereas, as soon as foreign matter, such as dust, or smoke, or fumes, and especially fumes of sulphur, are introduced, the aqueous vapour condenses on the particles and becomes visible as fog. Some kinds of dust, such as salt and ammonia, have so great an affinity for water, that they determine the condensation of vapour in unsaturated air, whilst other kinds of dust only form nuclei when the air is supersaturated; and dry fogs are produced by those dust particles whose affinity for water vapour enables them to condense vapour in unsaturated air. This accounts for the greater prevalence of fog and haze in towns. And in towns where the streets are paved with stone, asphalte, or wood, and even where the surface is of macadam composed of granite, the chief part of the mud and dust consists of horse manure, which continually gives off the fumes of ammonia; and these, when mixed with fumes of sulphur, have a great power of condensing aqueous vapour, and give rise to a very fine-textured dry fog.

Dr. Frankland and Dr. Russell have shown that the tarry matter which arises from the combustion of coal coats over the water resulting from the aqueous vapour thus condensed upon the particles of dust, and considerably delays their re-evaporation; consequently, whilst on the one hand the atmosphere of large towns is more favourable to the development of fog, on the other hand fogs prevailing over large towns are more persistent in their character than in the open country.

The conclusions which may be drawn from these experiments are—

1st. That when water vapour condenses in the atmosphere, it always does so on some solid nucleus;

2nd. That the dust particles in the air form the nuclei on which it condenses;

3rd. If there was no dust in the air there would be no fogs, no clouds, no mists, and probably no rain; but when the air got into the condition in which rain falls—that is, burdened with supersaturated vapour—it would convert everything on the surface of the earth into a condenser, on which it would deposit itself. Every blade of grass and every branch of tree would drip with moisture deposited by the passing air; our dresses would become wet and dripping, and umbrellas useless. But our miseries would not end here; the inside of our houses would become wet, the walls and every object in the room would run with moisture.

This dust pervades the air everywhere. The haze in the air on a summer's day is caused by dust, which is probably largely composed of the pollen of flowers. This dust appears chiefly to occupy the lower strata of air. For instance, in the valleys on the south or Italian side of the Alps, a blue haze mellows the view; but this is passed through after a little hill-climbing, and the atmosphere becomes clearer. But the theory is not inconsistent with the formation of the loftiest clouds, because dust does not pervade the lower region only of the atmosphere.

Mr. Langley was making observations in 1882 on the spectrum of the sun on Mount Whitney, which is situated in the United States of America about 300 miles north of the Mexican frontier, and about 200 miles from the Pacific Ocean. When at a height of 13,000 feet above the sea, he observed dust in the atmosphere between him and the sun. He computed that this dust was at a height of from 1,000 to 1,500 feet above the elevation at which he was placed; that is to say, at a total height of from 14,000 to 15,000 feet above the sea. He considered that it came from the west in the plains of China.

These several conclusions are well illustrated by a fact of everyday experience. A heavy fall of rain washes the particles of dust out of the air, and after rain the fog is often removed, and the air of a town is much clearer.

This dust consists partly of inorganic matter, and partly of the organisms or germs which I have already mentioned in connection with putrefaction.

Dr. Tyndall has shown us, by passing a ray of light through a space otherwise dark, that all air is more or less filled with dust; and that this dust contains germs of forms of bacteria, which are always ready to spring into life when a congenial medium for their development is at hand.

He shows that if the air of a room be left absolutely undisturbed for some time, this dust is more rapidly deposited than in moving air; and consequently that in a sheltered and quiescent position in a room, flasks filled with various infusions favourable to their development, but in which all germs had been destroyed by repeated boiling, developed organisms more rapidly than those placed in the more open parts of the room.

Dr. Tyndall has also shown by similar experiments that these sterilized infusions did not develop organisms when exposed to the clear mountain air on the Bel Alp, in Switzerland, whilst the air of a hayloft near the glacier developed organisms in ninety per cent. of the flasks containing sterilized infusions.

Recent observations at the Montsouris Observatory at Paris show that the air taken from the centre of Paris, and especially air from the vicinity of sewers, produced bacteria in greater quantities than air taken from the more open country. It also appeared that whilst the numbers of bacteria were comparatively small from air collected during wet weather, they increased as the soil became drier, but decreased again under the influence of bright, sunshiny weather.

Of those various organisms some are productive of what we term putrefaction; it is alleged that others may be productive of disease; but some may possibly afford nourishment.

Their absence from pure air, and the fact that sunshine and movement of air appear to be inimical to their development, agrees with the accepted doctrine that sunshine and a moving atmosphere are elements of health.

Having briefly mentioned some of the causes of the pollution of the air, we will now see in what way nature acts to remove the impurities.

Movement of Air.

This purification is effected partly by the property which gases possess of diffusing themselves through each others' masses, partly by the action of sunlight, and partly by the continual movement of the atmosphere, by which its solvent properties are brought into play.

We can hardly estimate the importance of the law of the diffusion of gases. Animals and vegetables, as we have already shown, are constantly pouring out certain gases essential to the life and growth of the other; and yet if these gases were allowed to stagnate where they are formed, they would not only injure but destroy both the animal and the vegetable kingdom. But by this law of diffusion these poisons are rapidly diffused through the atmosphere; and on account of this law, it is only by the most delicate analysis, and for a short time, that any differences in the constitution of the atmosphere can be detected.

The rays of the sun, with the assistance of vegetation, favour the dissociation of the carbon and oxygen, which united form carbonic oxide and carbonic acid. But the ruling agency in the purification of the air from the causes of pollution which I have described above is the movement of the atmosphere. You all know the laws which govern this; but it will be convenient to allude briefly to their sanitary aspect.

The molecules of air are but feebly attracted to each other, and small increases of temperature or slight diminutions of pressure separate the particles from one another, and thus one cubic foot of expanded air weighs less than a cubic foot of normal air. Similarly, small decreases of temperature bring the particles nearly together, and make the cubic foot of cold air heavier than the standard above mentioned. The expansion and the contraction are equal for equal increments or decrements of temperature. The increase of volume amounts to 0·375, or about three-eighths of the original bulk, in the process of being heated from the freezing to the boiling point of water, or a little more than $\frac{1}{491}$ for every degree of Fahrenheit.

Calculations upon the movement of air are based upon this law.

The dilatation of air by heat and its contraction by cold are expressed by the formula $V_1 = (1 + a\,t)\,V$.

When V = Volume at 32° and the barometer at 30°.

,, V_1 = Volume at the temperature of t degrees above 32°.

,, a = Co-efficient derived from experiments of proportion of increase of volumes of air in each degree of elevation of temperature $= \frac{1}{491}$ for each degree of Fahrenheit. When temperature is decreasing the formula is $V = (1 - a\,t)\,V$.

Therefore when the temperature of air and the space it occupies increases, its density, that is, its weight per cubic foot, decreases in the ratio expressed in the following formula, assuming barometric pressure constant.

$$d = \frac{d_1}{1 + a\,t}$$

But you must also bear in mind that the presence of vapour of water in the air renders it lighter than dry air; and the following table shows the density of dry and saturated air at different temperatures.

WEIGHT OF AIR PER CUBIC FOOT UNDER 30 INCHES PRESSURE OF MERCURY.

Temperature Fahrenheit	Dry air	Air saturated with vapour
0°	606·37	606·03
32°	566·85	565·58
60°	536·28	532·84
100°	497·93	486·65

It follows that as warmed air expands it ascends, and as cooled air contracts it falls. It also follows that as the warmed air ascends the colder air around rushes in to fill its place.

In this room, as air is warmed by your bodies it ascends; it comes against the glass of the windows, cools, and falls down.

If, on the other hand, you carry a vertical tube from the ceiling of this room up to the outer air, the warmed air will flow up the tube and its place will be taken by the colder, heavier air passing into the room through any available openings from below. The rate at which the heated air will thus flow out depends on the height of the flue containing the column of heated air.

Thus, 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_1, then the velocity at which the warmer air ascends will be that which would be acquired by a body falling from C to B.

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

If V = velocity in feet per second.

H = height of shaft.

t = temperature in shaft.

t_1 = temperature out of doors.

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

The theoretical equation becomes $V = 8{\cdot}024 \sqrt{H a (t - t_1)}$.

But the actual movement of air in the flue is much reduced by friction.

Although other forces may have a limited influence, alterations of temperature are the great and efficient causes of the disturbance of equilibrium of the atmosphere; the solar heat warms the earth, which in its turn communicates heat to the air, and an upward current is immediately established. The alternation of day and night, and the revolution of the seasons, cause winds of a greater or less duration and extent.

Ozone.

This continual movement of air brings into play its solvent properties, and causes the products of vegetable and animal waste to be continually removed from the air by oxidation. Much of this oxidation is probably due to the action of ozone, and would not be effected by ordinary or inactive oxygen.

There is great variety of opinion as to the atmospheric conditions which produce ozone. Ozone is rarely found in the air of large towns, unless in a suburb when the wind is blowing from the country. An experiment made a short time ago at the end of the pier at Brighton showed the presence of ozone when the wind was blowing off the sea; but no ozone was present when the wind blew directly over the town, and it is only under the rarest and most exceptional conditions that it is found in the air of the largest and best ventilated apartments. It is, in fact, rapidly destroyed in consequence of its action upon impurities, which are present in the air of localities where large bodies of men have fixed their habitations. The permanent absence of ozone from the air of a locality may, however, be regarded as a proof that the air is adulterated air. But, on the other hand, no connection has yet been proved to exist between the amount of ozone in the atmosphere and the occurrence of epidemic and other forms of disease. Its absence from the air of towns, and of large rooms even in the country, is probably the chief cause of the difference which every one feels when he breathes the air of a town, or of an apartment however spacious, and afterwards inhales the fresh or ozone-containing air of the open country.

Density of Population.

The movement of the air is stated in the Registrar-General's reports to be about twelve miles an hour on an average, or rather more than seventeen feet per second. It will rarely be much below six feet per second. The atmosphere is thus never stagnant.

It follows from these considerations that if buildings are so arranged on a given site as to allow of a free circulation of air on all sides, the natural continual movement of the atmosphere will tend to prevent any accumulation of impurities in the air which surrounds them. It has been established that propinquity alone is a cause of an increased death-rate, unless special care is taken to provide for the sanitation of a population in proportion to the increase of its density; consequently, the number of persons which can be safely located on a given space will depend upon the arrangements made for circulation of air.

Let us consider what results from the presence of a large number of persons on a given area.

If a site is occupied by a dense crowd, and if there is no movement of air, it is quite intelligible that a person should be (and indeed cases have occurred where persons in the middle of the crowd have been) suffocated by absence of air to breathe. If there are lanes in the crowd where air may circulate, this effect would not occur.

An acre contains 43,560 square feet. If 1,000 persons are located on an acre, each person would occupy a space of little over 7 feet by 6 feet. If the people were lodged in one-story buildings, the buildings would necessarily occupy the whole site;

no circulation of air would be possible, nor would there be any means of disposing of the refuse from the occupants (see Fig. 1, Plate II.).

On the other hand, if this number of persons were to be placed in buildings six stories high, the area of the buildings would only occupy little over one-fifth of the acre, and therefore a free circulation of air would be possible all round the buildings, and arrangements could be easily made for the disposal of refuse matter. Thus, if a large population is to be placed on a given limited area, the only way in which this can be done, with a due regard to health, is to place them in lofty buildings with air spaces between.

This is exemplified by a comparison between the degrees of healthiness which prevail in crowded districts of London, and those which prevail in the model lodging-houses.

The crowded district of St. Giles, in London, with a population of about 250 per acre, had a death rate in 1880 of about 26 per 1,000, whilst in certain model lodging-houses, where no refuse was allowed to accumulate in or near the buildings, and where there was free circulation of air all round, although the density of inhabitants per acre was as much as 860 and 1,140 persons, they only showed death-rates of from 14 to 16 per 1,000.

Some of the model lodging-houses are as healthy as a healthy country district. Why is this? Because impurities are not allowed to be retained in the open area round them; and the numerous stories in these buildings, whilst affording accommodation for a dense population on a limited area, are provided with free through ventilation, and allow of ample space all around for the circulation of air.

Therefore you may regard it as an axiom that when sanitary conditions are carefully maintained, when all putrefactive matter is removed, and free circulation of air allowed, and certain other conditions of construction observed, the density of population within limits need not be a cause of inferior health.

There is therefore no reason why barracks and military buildings should not be eminently healthy.

Conditions of Health in a Camp.

Let us consider these facts with reference to a camp.

The Quartermaster-General's instructions for camping, issued at the commencement of the Crimean War, authorized densities of population on the camp surface equal to 542, 543, and 1,037 per acre. The lowest of these densities is double that of the most densely populated district in England. It includes not only the ground actually covered by tents, but all the open spaces in the camp. The ground actually covered by tents in these plans of encampment gave a density of population equal to 1,632 per acre, or 26 square feet (*i.e.* 6·6 × 4 feet) to each occupant.

A camp is a temporary town, without paving or proper drainage.

It is only by paving and drainage that the deleterious influence of surface overcrowding in towns can be reduced to a minimum. But paving and drainage cannot be carried out to a sufficient extent in camps so as to enable the surface to be crowded during any length of time with safety to health ; and with a large body of men a too close proximity of tents may be, and certainly has been, a common cause of camp diseases. Therefore as large an extent of space should be given as the nature of the ground or of the service will admit.

Assuming an acre, and twelve men to a tent, as our units of comparison, the following table will give the surface area per tent for different densities of population per acre.

No. of square yards per tent	No. of tents per square mile	No. of troops per acre, assuming 12 men per tent
50	61,953	1,161
100	30,976	580
200	15,488	290
400	7,744	145
800	3,872	72
1,000	3,092	58

The number of troops to be placed on a given area must be determined by local circumstances, but the above table will be useful in enabling a correct judgment to be formed as regards one very important element in the sanitary state of camps, namely, density of population.

The manner of arranging tents is of importance to health, as well as to cleanliness.

Tents should if possible be arranged in short single lines; and the tents in line should be separated from each other by a space at the very least equal to a diameter and a half of a tent, and the farther the lines can be conveniently placed from each other the better. These are all matters which are necessarily more or less subject to military considerations, and therefore my object in pointing them out is to give you a sanitary standard at which to aim, rather than to suggest an absolute rule.

The main consideration in a camp, if it is to occupy the site for any length of time, is to make arrangements for preserving a pure water supply, and for the deposit of all refuse in specified places, and to cause all refuse to be removed daily, if not at more frequent intervals, either to a distance or to where it can be buried or, under certain circumstances, burned.

The chief dangers of camps arise from permitting refuse to remain in and about them. The experience of the Indian Government in the regulation of pilgrimages affords a useful illustration of camp hygiene.

Pilgrimages and fairs in India were formerly important foci of disease. These large assemblages are attended by hundreds of thousands of persons. They remain encamped for many days in crowded huts. The adjacent ground and watercourses become a mass of every sort of filth, and, as a consequence, a large fair or a pilgrimage generally formed the precursor of an outbreak of epidemic disease.

The Indian Government have now placed pilgrimages and fairs under sanitary regulation. Surface cleanliness and a pure water supply are enforced. I will give one instance of the results. In Oudh, at Masickpur, a fair of 125,000 persons was held whilst cholera was very severe in the district. Good water was supplied and strict sanitary supervision maintained. The result was an entire absence of cholera at the fair.

Conditions of Health in a Barrack.

The construction of barracks, however, is a matter over which the engineer has a more complete control than over the location and arrangement of a camp.

The general locality of a barrack is no doubt settled by military or political considerations; but the actual site within such general locality, and the arrangement of buildings on the site, are matters which fall more immediately within the province of the engineer to determine.

The health of a barrack is dependent on free moving, pure air, outside and inside its walls; anything which interferes with this first condition of health is injurious.

If a barrack is placed in a town, the health of the soldier is governed by the same conditions as those of the civil population around him. Thus the barracks in the manufacturing towns show a death-rate of 10·88 per 1,000, as compared with a death-rate of 6·98 per 1,000 at Aldershot.

If, however, political or military necessities require that barracks should be placed in towns and fortresses, additional precautions must be taken to render them as little unhealthy as possible. The broad principles to be observed in the construction of buildings intended for a number of men are that there shall be as few obstacles as possible to the movement of air round and through the building. Therefore the barrack enclosure should be sufficient to allow of ample space between the enclosure wall and the inhabited buildings, and between the buildings themselves.

In the next place, sources of impure air should not be permitted near the inhabited buildings; the surface of the ground round the buildings should be impermeable, otherwise it soon forms a reservoir of impurities.

Receptacles for refuse, such as ash-pits, manure-pits, &c., should be as small in size and as few in number as possible within the barrack enclosure, and they should be so placed that the air in their vicinity should not stagnate.

During the recent Egyptian campaign in the hospital at Cairo, the failure to remove the excreta from the vicinity of the building was the cause of ordinary fever cases merging into typhoid fever.

In the design of a barrack, the first consideration is, how can the ground at the disposal of the engineer be best utilized, so as to secure pure flowing air and sunlight over every part of the building?

Fig. 2, Plate II., shows an example of a ground plan of a comparatively modern barrack where the arrangement does not admit of proper circulation of air. And Fig. 3, Plate II., shows a plan of an old barrack, built probably some fifty years ago, which is well laid out, so as to afford free circulation of air round all the buildings.

The conditions which you should bear in mind in designing a building which is to be inhabited, and especially one like a barrack which is to be occupied by a large number of men, may be summed up as follows:—

Buildings should be arranged in the simplest manner.

Squares with closed angles should be as far as possible avoided. The great object to be aimed at is to have free external ventilation all round the buildings; in temperate and cold climates to have as much sunlight as possible, and to avoid a purely northern exposure for living rooms. These conditions are essential to health. Free access of sunlight to a square is best obtained by placing two opposite angles of the square north and south.

If the administrative conditions allow of it, the simplest arrangement for such buildings is in a single line, lying north and south if possible, to allow the sun to shine on both sides of the range every day. The line may be divided into separate blocks for facility of passing across it at different points.

It is this principle which has guided recent hospital construction on the block system.

If the buildings are in parallel lines, the height of a building must be regulated with respect to its surroundings.

The distance apart of dwellings should, if possible, at least equal the height of the dwelling, so as to ensure adequate light and air in the lower floors; but it would be preferable, if space allows, for the dwellings to be apart a distance of one and a half times the height from the floors of the lowest inhabited rooms to the eaves, and in hospitals twice the height should be insisted on.

The space between the buildings should be covered with some material affording an impervious and even surface, easily cleaned, such as asphalte, to prevent impurities from sinking into the ground; and this surface should be kept scrupulously clean. The internal form of a building to be occupied by large numbers of persons next demands attention.

Impurity of Air in Confined Spaces.

The conditions which govern the internal arrangement depend on the causes of impurity to which their occupation exposes them.

In discussing the general causes of impurity in air, I have told you that the main cause of impurity in *breathed* air is the organic impurity it contains.

The presence of CO_2 has generally been accepted as a test of the amount of this impurity, although CO_2 may be present in a quantity not injurious in itself. With respect to these questions, however, it must be observed that in recent experiments it appears to have been shown that a relation of organic matter to carbonic acid in outside air showed a high carbonic acid accompanied by a high organic matter, and *vice versâ*. This, however, is by no means invariably the case. Moreover, the organic matter in outside air has a far wider range of variations than carbonic acid ; for whereas the carbonic acid seldom passes beyond the limits of 2 to 6 vols. per 10,000, the organic matter has been found to vary in some cases from a quantity too small to estimate to as much as will require for oxidation about 16 vols. of oxygen per 1,000,000 vols. of air. Notwithstanding this, however, on the whole the test of CO_2 present in the air may be fairly accepted as a test of other impurities.

In judging of the amount of impurity which may be allowed in an inhabited air-space, the sense of smell, when carefully educated, affords the best indication of the relative purity and impurity of the air.

The accompanying table, obtained from results of experiments communicated by Dr. De Chaumont to the Royal Society, shows the conclusions at which he arrived from a very large number of observations on the air of barracks and hospitals.

The method employed in judging of the quality of the air was to enter directly from the open air into the room in which the air was to be judged, after having been at least fifteen minutes in the open air. It will be seen how closely the state of the room, as detected by the sense of smell, agrees with that which would be expected from the carbonic acid as shown by analysis.

Sense of Smell	Temperature		Vapour		Carbonic Acid per 1,000 Volumes	
	In Air-space	Excess over Outer Air	In Air-space	Excess over Outer Air	In Room	Excess over Outer Air
Fresh	62·85	5·38	4·629	0·344	0·5999	0·1830
A little smell	62·85	8·00	4·823	0·687	0·8004	0·3894
Close or disagreeable smell. .	64·67	12·91	4·909	1·072	1·0027	0·6322
Very close, or offensive and oppressive smell	65·15	13·87	5·078	1·409	1·2335	0·8432
Extremely close, when the sense of smell can no longer differentiate	65·05	13·19	5·194	1·319	1·2818	0·8817

In these experiments Dr. De Chaumont takes ·0002 of carbonic acid per cubic foot as the standard of impurity, in addition to ·0004 carbonic acid per cubic foot as the normal amount of CO_2 in the outer air.

The experiments were made in barracks and in hospitals, and a result came out from the experiments confirmatory of the opinion that, in the case of sick men, more air is required to keep the air-space pure to the senses than is necessary in the case of men in health. It appeared that, in barracks, the mean amount of respiratory carbonic acid, when the air was pure to the senses, was ·196 per 1,000 volumes, but in hospitals it was only ·157; or, in other words, whilst in the hospitals the air would have smelt somewhat impure when the CO_2 was ·157, in the barracks with that amount it was fresh.

On these grounds it would therefore appear that if it be assumed that the standard for impurity for healthy persons may be regulated by allowing an excess of ·0002 grains per cubic foot of CO_2 over that in the outer air, it would be desirable to limit the excess in the case of sick to ·00015 grains per cubic foot.

In addition to the proportion of carbonic acid, and of the impurities of which its presence affords a rough test, there are conditions of temperature and humidity necessary for good ventilation.

The dry-bulb thermometer in this climate in our sitting-rooms ought to read from 58° F. to 65° F., and ought not, if possible, to fall much below 60° F. At night a cooler temperature is desirable.

The wet bulb ought to read 55° F. to 61° F.—that is to say, in this country the difference between the two thermometers ought not to be less than 4° F. or more than 8° F. A greater degree of dryness in the air, provided the supply of air be ample, is not, however, found objectionable, and, indeed, the sensation of cold appears to be largely influenced by the presence of moisture rather than of actual temperature.

In the open air, in healthy weather, the difference between the wet and dry bulb is often 8° or 9°, or more. The difference is of course increased in hot and dry climates. Vapour ought not to exceed 4·7 grains per cubic foot at a temperature of 63°, or 5·0 grains at a temperature of 65° F.

The limit of humidity is 75 per cent. or under.

When the outer air is saturated, as in wet weather, the reduction of the humidity in a room will depend on the increase of temperature of the air admitted.

Impurity of Air from Artificial Light.

An important cause of the impurity of air in houses after dark arises from the use of artificial light.

All artificial sources of light depend upon the development of light during incandescence. For the illumination of our streets and houses at night we have hitherto chiefly made use of ordinary coal gas, which is a combination of carbon and hydrogen. When this burns its elements unite with the oxygen of the air; it undergoes partial decomposition, and evolves heat. Carbon is separated in the solid state, and floats in a finely divided and incandescent state in the interior of the burning vapour, and this constitutes the flame. The combustion of the particles of carbon takes place at the border of the flame, where they are first brought into contact with the oxygen of the air; but if the supply of oxygen be insufficient in quantity, they escape in a partially unburnt condition in the form of smoke.

The brightness of the flame is owing to these solid incandescent particles, for the burning gas itself possesses only a feeble illuminating power.

The flames of candles and lamps, whether the substance burned be tallow or wax, rape oil or petroleum, do not differ essentially from that of an ordinary gas-burner. The same hydrocarbon gas which is the essential constituent of common gas is the source of light in them.

The wick is a small gas factory.

The flames of candles and of lamps all owe their luminosity to the incandescence of particles of carbon floating in them; and the electric light similarly owes its brilliancy to the incandescence of the carbon: the reason why one description of candle or lamp is more smoky than another is because the supply of air in the smoky one is not sufficient to produce adequate combustion.

Effect caused on the air of a room by combustion is firstly to diminish the oxygen, and secondly to increase the carbonic acid, and further to produce water and ammonia. If the combustion is imperfect, the effect is also to create carbonic oxide and soot, as well as to disperse into the room any impurities which the material which is used for illumination contains besides the carbon and hydrogen which are necessary for purposes of illumination.

Hence, as regards the contamination of the air of a room, it may be accepted as an axiom that the more imperfect the combustion in any source of artificial light, the more deleterious the effect on the air of the room.

Each cubic foot of gas burnt per hour has generally been assumed, upon an average, to vitiate as much air as would be rendered impure by the respiration of an individual. But the degree of purity of the gas has an important bearing upon this question. With very pure gas and perfect combustion the amount of organic matter in the air is not appreciably increased. In such cases any injurious effect of the gas is chiefly due to sulphurous acid.

Effect of Shape and Size of Rooms on Diffusion of Air.

The unit upon which all inhabited dwellings depend is the room; and it is upon the conditions which govern the purity of air in the room that the size and shape of our rooms and the arrangement of barracks, hospitals, and houses must depend.

Stagnation in the movement of the air in an inhabited room would lead to rapid putrefaction of the emanations given out by its occupants.

Vitiated air does not necessarily mix with the whole air of the room with rapidity. Anyone may satisfy himself of this by comparing the upper part of a heated room with the lower, or by examining outlets for the escape of air.

CO_2, when first thrown out in the process of breathing, is warmer, and ascends to the ceiling, although its specific gravity when cool is greater than that of air. The organic emanations diffuse themselves more slowly, and without absolute uniformity, and are deposited on the cool walls, ceilings, floors, and furniture, where they may be easily collected if desired.

It would be desirable, if it were practicable, to remove the exhalations with such rapidity as to prevent deposition, and to permit as little admixture as possible with the air of the room; but this is not practicable.

Principles of Ventilation.

In considering, theoretically, the condition of a room in which sources of impurity exist, and which is furnished with any kind of ventilating arrangements, the two *extreme* suppositions (both inadmissible) are—

(1) That all exhalations are *immediately* removed completely out of contact of the persons in it, so that the occupants of the room are in the same condition as to purity of air as if they were out of doors in a brisk wind.

(2) That the ventilation is so unequal that the spaces immediately surrounding the persons do not get ventilated at all, and that the occupants of the room practically live in an air which may become saturated with noxious matter.

The actual state of things must be something between these two.

Now, supposing this ideal condition to subsist, it is perfectly easy to show that the degree of purity of the air would ultimately depend in no way on the size of the room, but solely on these two things, viz. (*a*) the rate at which emanations are produced; (*b*) the rate at which fresh air is admitted.

For example, suppose a man produces six units of carbonic acid per hour, and fresh air contains ·004 such units per cubic foot, if it is required to maintain a room (of whatever size), constantly occupied by one man, in such a condition that the units of carbonic acid in a cubic foot shall never exceed ·006, then—

$$A = \frac{6}{\cdot006 - \cdot004} = 3000\,;$$

that is, 3,000 cubic feet of fresh air must be supplied per hour.

As another method of calculation in considering the question of purity of air in an enclosed space, you may take into consideration the sources of vapour inside the room. Every man gives off from the lungs and skin each hour enough to raise the humidity from 70 per cent. to complete saturation in 500 cubic feet at 60° F., and to raise it to 82 per cent. in 1,500 cubic feet. Now to reduce this amount to 73 per cent. would take 3,000 cubic feet of air saturated at 50° F. But the vapour given off by the body is not the only source of humidity. Humidity may arise from the combustion of lights, or the vapour of liquids used in the room.

According to this theoretical assumption of temperature and moisture, a room containing an air-space of 1,000 cubic feet, occupied by one individual, would require to be supplied with 3,000 cubic feet per hour, in order to maintain it in a proper condition of purity and humidity.

The size of the room does not affect the permanent condition of the air; but everything else being the same, the larger the room is, the longer it will be (after beginning to be occupied) before it attains sensibly its final or permanent condition of impurity.

The advantage of large space is—First, that the large room is longer in reaching the state of normal impurity than the small room. For instance, the following table shows the time required to bring air to the standard of admissible impurity—viz., 0·2 per 1,000 of CO_2 above the amount of 0·4 per 1,000 in fresh air in different sized rooms.

One man in	10,000	cubic feet,	3 hours 20 minutes.
"	1,000	"	20 "
"	200	"	4 "
"	30	"	36 seconds.

Secondly, that the inflow and outflow of air necessary to maintain the standard of impurity is less perceptible in a large than in a small room, for the chief difficulty of ventilation is the draughts it causes.

If, therefore, you consider the fresh air which enters and the impure air which flows out of a room to pass through openings of a defined size only, about 3,000 cubic feet of air per occupant would satisfy theoretical requirements.

But in our climate, a careful practical examination of the condition of barrack-rooms, judged of by the test of smell, shows that arrangements which appear to provide for a volume of air much less in amount than that obtained by calculation will keep the room in a fair condition.

These results have pointed to about 1,200 cubic feet of air admitted per hour in barrack-rooms occupied by persons in health. This need not be set down to errors in calculation or in theory.

There are many data which cannot be brought into the theoretical calculation.

For instance, the carbonic acid disappears in a newly-plastered or lime-washed room, and could be recovered from the lime; therefore a newly cleaned lime-whited room will present different conditions from a long occupied dirty room. Washing with quicklime destroys fungi in dirty walls, as also does sulphurous acid fumigation. Now air has the same property, especially dry air, and hence opening windows acts directly on the subsequent state of the air. Therefore an enormous effect is produced on all the elements of the above calculation if the windows of a room are kept open for several hours a day, instead of being closed. Besides this, 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 ordinary wall materials admit of a greater or less change of air through the material itself, depending upon the extent to which the material is porous.

Porosity of Materials.

The porosity of a material is shown by its power to absorb water. The following is the percentage of its own weight of water which each of the materials mentioned below has been found to absorb :—

Bricks.	Per cent.	Stones.	Per cent.
Malm cutters	22	Good granite	½
Malm bright stock	22	Indifferent granite	1
Malm seconds	20	Bad specimen granite	3
Brown paviors	17	Trap and basalt	a trace
Hard paviors	9½	Sandstone—	
Common grey stock	10½	Craigleith	8
Hard "	7½	Parkspring	8
Washed hard stocks	4½	Mansfield	10·4
Staffordshire—		Hassock (very bad quality)	20
Common blue	6·5	Limestone—	
Dressed "	2·3	Marble	a trace
Brown glazed brick	8·6	Portland	13·5
		Ancaster	16·6
		Bath	17
		Chilmark	8·6
		Kent rag	1⅓
		Ransome artificial stone	12

From this it appears that brick and stone walls, being always more or less porous, must admit, as already mentioned, of a considerable spontaneous change of air when dry.

The ceiling affords a ready instance of porosity ; an old ceiling is blackened where the plaster has nothing over it to check the passage of air, whilst under the joists where the air has not passed so freely, it is less black. On breaking the plaster, it will be found 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 amount of moisture given out in breathing, 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. In the absence of sufficient ventilation, when impervious walls are colder than the air, moisture condenses on the walls.

Effect of Shape of Building on Change of Air.

The shape of the building is important, because that in a room with outside windows there is more spontaneous change of air. The accompanying sketch (Fig. 1, Plate III.) of barrack-rooms at Edinburgh Castle shows rooms in which the aëration of the room is rendered difficult from the form of the building. As a contrast is annexed a sketch of a barrack unit, properly arranged to assist aëration. See Fig. 1a, Plate III.

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 of air from and the inflow of air into a confined space are in constant operation. A sleeping room is very warm when occupied at night; a rapid fall of temperature occurs outside, and at once a considerable movement of air takes place.

Cubic Space and Floor Space.

It will be evident from these various considerations, that in allotting the number of occupants to a room, especially a sleeping room, the occupants should be so placed that there should be adequate space between them. It is not more than forty years since, in the West Indies, the men slept in hammocks touching each other, only twenty-three inches of lateral space being allowed for each man. At the same time, in England, the men slept in beds placed in two tiers, like berths in a ship; and not infrequently each bed held four men. When it is added that neither in the West Indies nor in the home service was such a thing as an opening for ventilation ever thought of, the state of the air can be imagined.

There had been a great change in the conditions of the occupation of barrack-rooms between 1840 and the Crimean War, but that there remained at that time much to be done is evidenced by the fact that out of every 100 deaths in the English army in the three years ending 1861, more than one-third were due to lung disease, and two-fifths to lung disease and typhoid combined, whilst in the French army one half the number of deaths were due to these diseases. These diseases specially indicate impure air.

The condition which limits the number of men to be placed in a barrack-room is the floor space which ought to be allotted to each.

A floor space of from fifty to sixty superficial feet has been accepted as sufficient in this climate for barrack-rooms. In warm climates, or where the local conditions of healthiness of site or the character or plan of the buildings require it, as much as eighty or 100 superficial feet per man have been given.

There is no advantage in mere height in a room unless combined with means for removing heated air from the upper part. Indeed a lofty room with a space above the tops of the windows or of the ventilating openings, to which space air loaded with emanations can ascend, remain stagnant, cool, and then fall down, is a positive disadvantage.

But in order to allow of comfortable ventilation, the height of the room must to some extent depend upon its width. With barrack-rooms of about twenty to twenty-two feet wide a height of twelve feet need not be exceeded. If, however, the height of the room be less than twelve feet, the floor space per occupant ought to be increased. In this way there is a mutual interdependence between the floor space and the cubic space. For instance, the cubic space for soldiers in barrack-rooms occupied by day and night was fixed by the Royal Commission of 1858 at 600 cubic feet per man. Therefore, if fifty superficial feet be allowed per occupant, in a room twenty feet wide and twelve feet high, with beds on each side, a linear bed space will be afforded of five feet per occupant: if the height of the room were only ten feet, then the linear bed space would become six feet per occupant. With rooms higher than twelve feet, it would be unadvisable to diminish the floor space, and therefore it is the floor space rather than the cubic space which should limit the number of occupants in a room. In no case should there be more than two rows of beds between the opposite windows. This rule holds good in all climates, but more especially in hot climates.

Light.

There is one other condition of health required in the design of a room with which I will conclude.

An abundance of light, and direct sunshine, is always necessary for maintaining purity of air in a room; and in this country the window area should not afford less than 1 square foot of surface to every 60 cubic feet of content of the room.

In the early part of this century a tax was put upon windows —that is, on light. This tax was removed less than forty years ago, but during its continuance it acted so disastrously on healthy architecture that the country has not yet recovered from its effects.

Dr. Richardson observes: 'Pure light is as essential to health as pure food and drink. We are but just beginning to understand its vital value. We have long known that those who are immured in dark places become blanched and feeble. We are beginning to know more than this. We are learning that by the action of light some of the poisonous organic products which produce disease are decomposed or rendered inactive.'

You may accept as an axiom that a dark house is an unhealthy house, an ill-aired house, and a dirty house.

From these remarks I trust I have impressed upon you that the unceasing movement of the air around us, by virtue of the oxygen it contains, is constanty acting to remove impurities from the atmosphere; and that by reason of the same natural forces —viz., difference of temperature, the air in our houses is similarly constantly striving to follow the same laws as the outer atmosphere. And by the continual movement of the air in and out of our rooms, due to this difference of temperature, the impurities which we diffuse from our bodies are being constantly removed to a greater or less degree, according to circumstances.

If our dwellings are to be healthy we must not obstruct nature. And in my next lecture I propose to explain to you how we can best apply the general principles which regulate the ventilation and warming of our rooms, so as to assist nature in her efforts to render the air pure.

LECTURE III.

VENTILATION AND WARMING.

I PROPOSE to draw your attention in this lecture to some points connected with the ventilation and warming of buildings.

In my last lecture I showed you how the processes of life vitiate the air by throwing off organic matter from the person, and that this is eminently dangerous under certain conditions.

The following very striking illustration of the effects which may arise from the perspiration of a human being is worth notice.

Dr. Beddoes mentions, a great many years ago, a case where the perspiration which had penetrated the soldiers' bedding was a source of fever.

One man of the Horse Artillery at Woolwich was admitted into the hospital with a suspicious fever; next day another. This excited inquiry. It was found that they came from two separate barrack-rooms. These were followed by other men, in all amounting to eight, three of whom came from a separate room, the rest from the same rooms. All the rooms whence the infected men came were found to have entirely different bedding from the rest of the barracks. The Horse Artillery being in those days a corps in constant readiness for service, and whose appointments were always complete, had, for convenience of carriage, hammock bedding. The hammocks were rolled up tightly every morning the moment the men rose, and they were unloosed when they got into them at night. At this time it happened that there had been so much and so constant rain that this bedding had not been aired or opened for a single day for at least two months. The hammocks, with their bedding, were examined, and the moment they were opened a very peculiar nauseating smell was perceptible. Immediate steps were taken to alter the bedding, and no further mischief took place.

Here an infectious fever evidently arose from the confinement of the effluvia (or fumes, vapours, exhalations) given out each night from a man's own person for a term of about two months.

Movement of Atmosphere.

In my last lecture I explained to you that if it were not for the supply of fresh air and the removal of foul air from a room, its occupants would soon die; that out of doors the movement of the air removes the impurities as soon as generated; that therefore in an occupied room it is essential to obtain a continual movement and change of air; and that, in order to allow this change of air to take place without inconvenience to the occupants, a certain floor-space is necessary for each individual sleeping in a room, combined with a certain height of room.

The rate of movement of the atmosphere is very rarely below 6 feet a second, and even at that rate between 3,000 and 4,000 cubic feet of air would flow in every minute over the space occupied by a human body out of doors, or nearly 200,000 cubic feet of air in an hour.

A current of air flowing through a room at 6 feet per second would be unpleasant to the occupants of the room; and 1,200 cubic feet per hour per occupant of a room has been fixed upon as affording an adequate change in a barrack-room.

The comfort of ventilation depends upon letting the air flow into a room at such a temperature, with such a velocity, and in such a position, as will prevent the inmates from feeling any sensation of cold or draught.

Air flowing against the body, at, or even somewhat above, the temperature of the air of a room, will cause an unpleasant sensation of cold, from the fact that, as it removes the moisture of the body, it causes evaporation.

In order to prevent a sensible current of air against the body, the velocity of the air as it flows in and out of a room, as measured at the openings for admission or exit, should not exceed one foot, or at most two feet, per second, because a low velocity is favourable to the uniform diffusion of the incoming air through the air of the room.

The part of the room at which the air is admitted is important.

Air should never, as a rule, be introduced at or close to the floor level.

The air, if introduced at that part, unless at a temperature very much above the temperature of the air of the room, would produce a sensation of cold to the feet. It may be regarded as an axiom in ventilation and warming, that the feet should be kept warm and the head be kept cool.

The Romans appear to have understood this matter, and warmed the floors of their buildings. Moreover, orifices at the floor level are liable to be fouled with sweepings and dirt.

The orifices at which air is admitted should be above the level of the heads of persons occupying the room; the current of inflowing air should be directed towards the ceiling, and should either be as much subdivided as possible by means of numerous openings, or be admitted through openings conical in shape, with the base of the cone towards the room, by which means the air of the entering current is very rapidly dispersed.

Air admitted near the ceiling very soon ceases to exist as a distinct current, and will be found at a very short distance from the inlet to have mingled with the general mass of the air, and to have attained the temperature of the room, partly owing to the larger mass of air in the room with which the inflowing current mingles, partly to the action of gravity when the inflowing air is colder than the air in the room.

A change of air in a room is constantly going on by means of the movement of the air produced by variations of temperature, or by the action of the winds.

In every room in which there is an opening at the upper part, out of which the air warmed by the bodies of the occupants can pass, and an opening either level with it or below it, through which fresh air can flow in, ventilation by difference of temperature will operate.

If, in an ordinary sash window, the top sash be 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. Hence, in an ordinary room, provided with a fire place, but unprovided with special inlets for fresh air, a very simple inlet may be contrived 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. Or a piece of wood may be fitted to the bottom of the lower sash so as to increase its depth, and prevent the window being closed completely, thus leaving a permanent opening at the junction between the upper and lower sashes, without leaving any room for admission of air and draught at the bottom of the lower sash. The panes of windows are sometimes used for openings for air. One method is simply to cut holes in the pane of glass, and to fix another piece of glass in the pane, arranged on the principle of the hit-and-miss ventilator, by which the openings can be closed or opened at will.

In cottages there is often seen a tin whirligig inserted instead of a pane: this revolves with the admission of air, and breaks up and throws the current towards the ceiling. In window-panes the best forms of ventilators are those which direct the current of air towards the ceiling, such as hopper ventilators, or Moore's louvred panes; but all ventilators of this nature in windows are makeshifts adapted to rooms with a small number of occupants. In rooms containing many persons, such as barrack-rooms, it is absolutely necessary to adopt ventilation independent of the window openings, reserving these for light, and for effecting a thorough change of air in the room at occasional times.

Systematic ventilation in military buildings is generally effected either by taking advantage of the ordinary currents of the atmosphere, or else by generating heat so as to cause movement of air. Ventilation by direct propulsion of the air by fans or pumps, either to draw the air into extraction shafts or to force it into the room, may also be resorted to, but the limits of this lecture will prevent me from entering into this part of the subject.

The simplest form in which advantage can be taken of the atmospheric currents is as follows.

If a room has two outer walls on opposite sides, and if an opening be made in each wall, and if the wind blows against one of the walls, there will be an increase of pressure against that wall, and a diminution of pressure against the wall opposite; consequently air will be forced in through the inlet on the side against which the wind blows, and be extracted on the other side. In order to utilise this effect of wind pressure, Sir Joshua Jebb ventilated barrack-rooms by hollow beams (see Fig. 2, Plate III.) carried across the rooms from one outside wall to the other, communicating with the open air at both ends, and also provided with openings into the room, but having a wooden partition placed across in the centre of the beam, so as to compel it to act both as an inlet and an outlet when the wind is blowing against either outer wall.

This action becomes more efficient if the beam be dispensed with, and the openings in the opposite walls retained (see Fig. 3, Plate III.); the most convenient form for such openings is the Sheringham ventilator, or the conical ventilator above mentioned.

The Sheringham ventilator consists of an iron air-brick or box inserted close to the ceiling of the room (see Fig. 4, Plate III.), and affording a direct communication with the external air. The current of inflowing air is directed by the hopper form of valve upwards towards the ceiling. The inside area is somewhat larger than the outside area in consequence of the latter being closed with a grating, and thus the air enters the room at a less velocity than that at which it passes the outer surface of the wall.

Where a room has two outside walls and is provided with openings on both sides, this inflow and outflow of air is almost certain to go on continuously, in consequence of the movement of the outer air, which is rarely at rest.

Where rooms have only one outer wall, other conditions prevail.

Velocity of Air in Flues.

The movement of the atmosphere is equally effective in producing movement in a vertical tube.

If a tube or shaft be carried up from a room or enclosed space to a point above, where the top is exposed to the free movement of the atmosphere, an upward current will prevail in the shaft so long as there is a movement in the atmosphere, because the atmospheric current, in its passage over the top of the tube, relieves to a certain extent the pressure which prevails when the atmosphere is at rest, and thus causes the air in the tube to rise.

This is the natural law of which advantage is taken in the case of the shafts carried from the ceilings of barrack-rooms to above the roof.

The movement is of course unequal in its action. It is powerful when the wind is high. In calm weather it is very small; but in this country, as already mentioned, the average velocity of the atmosphere is above 17 feet per second, and is rarely quite at rest.

It is very difficult to measure the relation which the current in a tube or shaft caused by this method of extraction bears to the velocity of the wind.

The friction in small tubes forms a very perceptible element of retardation. Experiments made with tubes three inches in diameter tend to show that the velocity obtained in the tube was about two-fifths of that of the wind; larger diameters, on the other hand, produce better results.

There are, however, many conflicting elements to be considered.

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. It is often from this cause that chimneys are found to smoke in windy weather, especially when they are so constructed as to allow of a sluggish draught.

The form of the top of the upright tube or shaft has an influence on the current in these cases. Thus, when the air which impinges on the flue is caused to slope upwards or sideways from the opening, it will frequently be found to prevent a reverse action or a down-draught.

Some experiments on this subject recently made by Lord Rayleigh in the Cavendish Laboratory at Cambridge, show that a current impinging on the top of the flue in a downward direction, at an angle of 30° or upwards, checks the draught; a current across the top of the flue, forming a less angle with the horizon than 30°, increases the draught; and the most advantageous effect is produced when the current strikes upwards at an angle of 30°.

Moreover, 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 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.

In consequence of the numerous causes of disturbance enumerated above, this method of extraction could not be relied on to act on all occasions with certainty as an extraction shaft, but it can be relied on to ensure in one way or other, and to a certain extent, a continual change of air.

This method of ventilation is convenient in this climate, and it is sufficient in buildings such as barracks in which it is convenient that each room be treated as a separate unit.

But if a regulated outflow of air for the space to be ventilated is required, resort must be had to extraction by mechanical means, such as heat or fans.

You are aware that the movement of air or gases in a heated flue depends upon the following considerations:—

(1) Upon the difference of temperature of the air inside the flue as compared with that outside.

(2) Upon the area of the flue.

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

The volume of outflowing air which is obtained by calculation according to the formula I mentioned in my last lecture is diminished by the resistance from friction in the flue or shaft, which 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 sometimes 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.

Péclet, in his treatise on the application of heat, has given a formula to include some of these resistances, viz.:—

$$V^2 = \frac{2gHa(t - t_1)D}{D + 2gHK}.$$

When D = diameter of chimney.

,, K = co-efficient of resistance, which varies with different chimneys.

Péclet determined the resistance for—

Pottery chimneys	= ·0127.
Sheet iron chimneys	= ·005.
Cast iron chimneys	= ·0025.

But other experiments, published by Mr. Wyman, showed a variation between this formula and experiment of from 15 to 20 per cent.

In devising a system of ventilation, formulæ afford approximate data for calculating the sizes of flues; but 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 is 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. It is, however, somewhat difficult to obtain correct results, because so many eddies accompany the flow of air in a tube, which further are aggravated by the introduction of measuring apparatus.

The velocity of the air may be measured in various ways. It may be measured by puffs of vapour of turpentine, or by balloons filled with hydrogen and weighted to be of the exact specific gravity of air, the time occupied by the puff of vapour or balloon in passing along a measured length being accurately ascertained.

For low velocities, it is worth noting that a sheet of light tracing-paper, moved through the air at two 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°
·40	64°

In other cases, where the flow of the air is more rapid, an anemometer may be resorted to. An ordinary form of anemometer is that of vanes fixed to a spindle, the revolutions of which are recorded by a counter. The vanes are turned by the direct action of the current of air, and the number of revolutions which are recorded by the counter gives the velocity. Of course, the value of these revolutions 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, and ascertaining the number of revolutions made by the vanes at different velocities, and thus obtaining the equation for the particular instrument. Another method of ascertaining the value of the revolutions is to move the instrument itself through stagnant air at given velocities. It is necessary to measure the effects of various velocities, because the number of revolutions corresponding to a given volume of air when the current of air is moving slowly does not necessarily correspond with the number of revolutions required to measure the same volume of air when the current of air is rapid. The currents prevailing in the room when the measurement takes place have also an appreciable effect on the movement of the vanes. And, moreover, the vanes will only begin to move after the current of air has attained a certain strength, and this form of measurement is therefore not applicable to very low velocities.

The most convenient apparatus for the purpose of measuring the relation between the motion of the vanes and the rate of the flow of air is a graduated vessel constructed on the principle of the ordinary gas-holder, from which a known quantity of air can be drawn in or expelled at will through a channel of convenient dimensions in connection with it, provided proper precautions be taken to protect the mouth of the channel from eddies in the room.

Fletcher's Anemometer is another very convenient form for measuring the speed of air in heated flues. The instrument consists of two parts: the first part of two metal tubes of about three-tenths of an inch internal diameter, open throughout, and of any length; the second part, of a manometer, or pressure-gauge. Of these tubes, the end of one is straight and plain, while that of the other is bent to a right angle. When in use, these tubes are placed parallel to each other, and so that their ends are exposed to the current of air to be measured (see Fig. 5, Plate III.). 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 one over that in the straight one. The manometer used is a simple U tube of glass set vertically, containing ether, fitted with vernier scales, by which the difference of level of the surfaces of the ether in the two limbs can be measured to $\frac{1}{1000}$th 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 connection between the tubes in the chimney and the glass U tube may be conveniently made by means of india-rubber tubing.

Temperature of Air.

My remarks hitherto have related mainly to the extraction of air, and its renewal directly from the outer air. But in cold weather an adequate change of air for purposes of ventilation requires that the air supplied should be warmer than that of the outside air.

For purposes of comfort and health, in this climate, the day temperature of a room should be maintained at something between 58° and 65°. The night temperature should not be so high, but it is not desirable that the night temperature should fall below 40°. It should, however, be noted that the quantity of oxygen present in a cubic foot of heated air is less than that in a cubic foot of cold air. Thus a cubic foot of dry air at 32° weighs 566·85 grains, and if the proportion of nitrogen and oxygen be assumed to be by weight 77 and 23 per cent., and the slight amount of carbonic acid be neglected, there will be in a cubic foot—

436·475	grains of nitrogen.
130·375	,, oxygen.
566·850	

As a man draws, on an average, when tranquil, 16·6 cubic feet per hour into his lungs, he will thus receive $130{\cdot}375 \times 16{\cdot}6 = 2164{\cdot}2$ grains of oxygen per hour.

At a temperature of 80° the foot of air weighs 516·38 grains, and is made up by weight of—

397·61	grains of nitrogen.
118·77	„ oxygen.
516·38	

Therefore, in an hour, if a man withdraws 16·6 cubic feet, he will receive $118{\cdot}77 \times 16{\cdot}6 = 1971{\cdot}6$ grains of oxygen per hour. Or, in other words, in an hour he would receive 192·6 grains less oxygen in his lungs with warmed than with cold air. This explains the exhilarating effects of the cold clear air of a frosty morning.

Methods of Warming.

In order to warm our houses we generally resort to one of three methods:—

1. The open fireplace.
2. Close stoves, or hot-water pipes, or steam pipes, in the room.
3. Warmed air brought by flues from a centrally placed calorigen.

The laws which regulate the generation and the distribution of heat are familiar to you; and I only propose to bring to your notice a few points connected with them which bear especially on ventilation.

There are several modes of warming. In the first place, the heat conditions which prevail between the air and the walls or objects in a room are different in each case.

Sometimes we attribute to a current of air a sensation of cold which comes from another cause.

We hear often, 'I don't like sitting near this window, or close to this wall,' and so on; 'there is always a slight draught coming from there.'

We fancy that we feel in the draught the motion of a wind, but it is mostly the result of a loss of heat from the warm body on one side by radiation towards the adjacent cold surface. People generally imagine in such a case that the wind is passing through the wall. But the velocity of such a wind would be too small to be felt as air in motion, and a piece of carpet fixed to the suspected wall, which checks the radiation of heat from the body to the wall, does away with the supposed draught. In this case the walls of the room are unduly cold as compared with the body of the occupant of the room.

You will now see how the various methods of warming bear upon this.

Radiant heat from a flame or from an incandescent body passes through air without warming it. It warms the bodies upon which the rays impinge. Therefore, an open fire with a bright flame conveys warmth to the walls of the room, whilst its rays leave the air to be breathed cool; and there is no doubt that the perfection of ventilation would be to have cool air to breathe, but to be surrounded with warm walls, floors, and furniture, so as not to feel ourselves parting with our heat to surrounding objects. Besides this, the open fire enables each occupant of a room, by selecting his position, to regulate according to his wishes the amount of heat he desires to obtain from it.

On the other hand, stoves or pipes warm the air in contact with them, and give out a proportion of radiant heat, which passes to the walls of a room, dependent upon the degree of heat to which they are warmed. Thus, with hot-water pipes, the temperature of which rarely exceeds from 120° to 150°, the larger proportion of the heat is employed to warm the air, and the walls and furniture of the room being only warmed by means of the contact of the air, are thus necessarily somewhat cooler than the air itself.

The warmed air is less pleasant and invigorating to breathe than cold air; it leaves the walls colder than the air of the room, and the heat of the body is radiated to the colder walls; and to avoid this cause of discomfort the temperature of the warmed air is frequently raised beyond what is either comfortable or healthy for breathing, and thus discomfort in one form or the other can with difficulty be avoided.

On the other hand, when stoves or pipes are heated to a high temperature, the heat is partly communicated to the adjacent air, but the larger part acts as radiant heat to warm the surfaces adjacent.

This will be best explained by imagining a stove-pipe heated at the end nearest the stove to a dull-red heat of 1230° F., and of sufficient length to allow the heat to be diminished to 150° at the further end. It would then be found that at the stove end of the flue-pipe 92 per cent. of the total heat emitted by the pipe is given out by radiation to the walls and only 8 per cent. to the air; but at the exit end the heat is nearly equally divided, the walls receiving 55 and the air 45 per cent. Taking the whole length of such a pipe, the walls would receive 74 per cent. and the air 26 per cent. of the heat emitted. But with a flue-pipe heated to lower temperatures the air would receive more than half the heat. When, therefore, the object is to heat the walls of the room rather than the air, which is sometimes the case, the temperature of the pipes should be high.

Thus the character of the heat we desire to obtain must decide the form of heating and the temperature to be maintained.

To ensure comfort it is essential to combine warmth in the walls and floors with cool air to breathe, as, for instance, air at a temperature not exceeding 54° to 64°.

It is on this account, as well as because it is so efficient as an engine of ventilation, that the open fire continues to be so highly prized in this country.

I will now briefly allude to the mode of action of each of the methods of warming.

Open Fire.

The open fire, if it be looked upon as a mere heating agent, is somewhat wasteful. One pound of coal is far more than sufficient, if all the heat of combustion is utilized, to raise the temperature of a room, twenty feet square and twelve feet high, to ten degrees above the temperature of the outer air. If the air of the room were not carried away up the chimney, and the walls were composed of non-conducting materials, the consumption of fuel to maintain this temperature would be very small.

But the principle of the ordinary open fireplace is that the coal shall be placed in a grate, to which air is admitted from the bottom and sides to aid in the combustion of the coal; and with an ordinary fireplace, for a room of twenty feet square and twelve feet high, the consumption may be assumed at about 8lbs. of coal an hour.

Eight pounds of coal may be assumed to require for its perfect combustion, 1,280 cubic feet of atmospheric air; but in the best constructed furnaces or stoves at least twice the volume of air which theory demands for perfect combustion is carried up a chimney; and with the open fire, it will be found that at a very low computation of the velocity of the gases in an ordinary chimney flue, the air would pass up the chimney at a rate of from 4 to 6 feet per second, or at from 14,000 to 20,000 cubic feet per hour; and with the chimneys in ordinary use, a velocity often prevails giving an outflow of air of from 25,000 to 30,000 cubic feet per hour.

The open fire, on that account, is a most efficient engine of ventilation, and the fuel which it consumes beyond what is required for warming is in reality a contribution towards the ventilation of a room.

This air comes into the room cold, and when it is beginning to be warmed it is drawn away up the chimney, and its place filled by fresh cold air.

A room 20 feet square and 12 feet high contains 4,800 cubic feet of space. In such a room, with a good fire, the air would be removed four or five times an hour with a moderate draught in the chimney, and six or eight times with a blazing fire. The atmosphere of the room is thus being cooled down rapidly by the continued influx of cold air to supply the place of the warmer air drawn up the chimney; and General Morin estimated that, of the heat generated by fuel in an ordinary open fireplace about one-eighth only is utilized in the room, and very much passes away through the brickwork of the fireplace and through the chimney walls in addition to that carried away in the heated air up the chimney. The very means adopted to heat the room tends to produce draughts, because the stronger the direct radiation, or rather, the brighter the flame in open fireplaces, the stronger must be the draught of the fire and the abstraction of heat.

A fireplace is powerful enough to draw into the room all the air it wants; and for this purpose will use indiscriminately all other openings, whether inlets or outlets, if necessary.

The large volume of fresh air thus 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.

The only way to prevent discomfort from this large volume of cold air is to adopt means for bringing in fresh air moderately warmed at convenient places, to supply that removed by the chimney.

The place for introducing the air depends on the action of the currents in the room produced by the action of the fire.

The way in which an ordinary open fireplace 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 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 fireplace (see Fig. 1, Plate IV.).

It follows from this, that with an open fireplace in a room, the best position in which to deliver the fresh air required to take the place of that which has passed up the chimney, is above the projecting chimney-piece, and at any convenient point in the chimney breast, between the chimney-piece and the top of the room, for the air thus falls into the warmer upward current, and mixes with the air of the room, without perceptible disturbance.

The open fireplace thus presents special advantages for securing efficient ventilation by means of the circulation of air which it creates. It makes the room in which it is in use independent of other means of extraction of air, unless the room is very crowded, or beyond the size for which the fireplace is calculated.

Warmed air may be supplied from other sources, but the simplest plan is to utilise some of the waste heat which, in the case of an ordinary open fireplace, passes away unused up the chimney.

The ventilating fireplace was designed with the object of utilizing spare heat, and of providing such adequate means of ventilating the soldiers' rooms in cold weather, when the windows are shut, as would not be liable to be deranged, and would make the ventilating and warming arrangements in each room self-dependent (see Fig. 2, Plate IV.).

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.

The ventilating grate has certain features for promoting the full combustion of the fuel. The bottom is partly solid, of two fire-lumps, with an intermediate cast-iron fire-grating, which occupies about one-third of the bottom of the grate; by this means, whilst the draught is checked by the solid part of the bottom of the grate, and the consumption of fuel reduced, a sufficient supply of air is obtained for combustion through the grating to secure a cheerful fire. A clear space, half an inch deep, is formed between the back piece of fire-lump and the iron back of the grate, through which a supply of air passes from the ash-pit under the grate, and through a slit in the fire-lump, on to the upper part of the back of the fire. The air thus brought into contact with the heated coal is received at a high temperature in consequence of passing through the heated fire-lump, and is forced into contact with the gases from the coal by means of the piece of fire-lump which projects over the fire at the back of the grate; and thus a more perfect combustion of the fuel is effected than with an ordinary grate, and the creation of smoke is prevented; in fact, with care, almost perfect combustion of the fuel, and consequent utilization of the heat, can be obtained (see Figs. 4, 5, and 6, Plate IV.).

Whilst the incandescent fuel and flame are kept away from actual contact with the iron back of the stove, the heated gases from combustion are compelled, by the form of the back of the grate and the iron part of the smoke-flue, to impinge upon a large heating surface, so that as much heat as possible may be extracted from the gases before they pass into the chimney; the heat thus extracted is employed to warm air taken directly from the outer air. The air is warmed by the iron back of the stove and smoke-flue, upon both of which several broad flanges are cast, so as to obtain a large surface of metal to give off the heat. This giving-off surface (amounting in the case of No. 1 grate to about eighteen square feet), is sufficient to prevent the fire from ever rendering the back of the grate so hot as to injure the air which it is employed to heat. The fresh air, after it has been warmed, is passed into the room near the ceiling by the flue shown in Fig. 3, Plate IV.

The ventilating fireplace thus retains the advantage of giving out radiant heat; and it provides ventilation without draughts by admitting air moderately warmed into the room at a convenient point, to replace the air which is removed by the chimney.

Thus with the open fireplace the warming and ventilation of each room may be kept distinct from that of the remainder of the building.

Heated Air.

In the case of other methods, the warming of the building is generally treated as a whole; and whilst extraction shafts are necessary for removing foul air, the fresh warmed air is either brought by flues from a stove in the basement, or the heat is conveyed into the several rooms by hot water or steam pipes.

When heat is conveyed to the room by means of warmed air alone, supplied from a stove in the basement, the walls must necessarily be somewhat cooler than the air which warms them, and therefore this mode of heating is not comfortable unless supplemented with some form of radiant heat.

The supply of warmed air alone is thus not a comfortable method of warming unless used in connection with an open fire-place. If, however, it be used alone, the only way in which this method of warming can be applied so as to be comfortable is to bring in the warmed air through hollow spaces in all the outside walls, so that the walls would be warmed by the air before it enters the room; and thus the radiation from the bodies of the occupants to walls colder than the air of the room would be prevented. But this would be uneconomical, because so large a portion of the heat would pass away unutilized to the outer air through the outer surface of the wall.

Hot Water Pipes—Low Pressure.

The next mode of warming to which I will refer is by hot water pipes. The efficiency of the hot water as an engine of heating depends upon the heated water reaching the coils of pipes where the heat is to be utilized in as hot a condition as possible.

The velocity of flow in the pipes will depend upon the difference of temperature between the water as it leaves the boiler and the temperature at which it passes down the return pipe back into the boiler; and partly upon the height to which the heated water has to rise.

It follows, therefore, that the upward flow of the heated and expanded water as it passes from the boiler should be as direct as possible, and be so protected as to lose as little heat as possible between the boiler and the place where the heat is to be utilized.

On the other hand, the return pipe, which brings back the water to the boiler after the heat has been utilized in the coils employed in warming the air may be unprotected, but it should be passed in to the bottom of the boiler as directly, and in as uniform a line from the place where the heat has been used as possible.

When the water circulates through the pipes by virtue of the difference of temperature of the flow and return currents only, it is impossible to count upon a greater mean temperature in the pipes than from 160° to 180°, because above that temperature the water in the boiler begins to boil, and causes an overflow of the supply cistern and escape of steam at the air pipes. In order to obtain a sufficient velocity of circulation for long distances, or with small differences of level, a forced circulation may be resorted to, as has been done by Messrs. Easton and Anderson at the County Lunatic Asylum at Banstead.

There two pipes are laid side by side, one of which communicates with the boilers and is termed the flow pipe; the other, termed the return pipe, is connected with the feed cistern for the boilers, which cistern is situated above the level of the boilers.

Both pipes are connected with the various coils to which the heated water is desired to be conveyed, by valves which can be opened or closed at will. An Archimedean screw pump is fixed on the return pipe near the point where the pipe ascends into the cistern. This pump is always kept at work. When the communications between the flow and the return pipes are closed, the screw simply slips through the water; as soon as any communication is opened, the screw draws the water along the pipe, and forces it into the cistern, thus ensuring a constant circulation.

In the ordinary system of heating by hot water the temperature of the pipes can be reduced if desired, and this plan thus gives the power of regulating the range of temperature, to meet the various changes in the external atmosphere.

But with low temperatures the greater part of the heat is employed in warming the air, and a very small proportion acts as radiant heat to warm the walls.

Hot Water Pipes—High Pressure.

By heating water under considerable pressure a much higher temperature may be obtained than from low pressure hot water pipes, probably from 260° to 280°.

Pipes heated by hot water under pressure convey heat to the air with greater rapidity than pipes heated by hot water at low pressures.

And in addition to the increased direct effect which pipes heated to a high temperature by water under pressure have in heating the air, is the collateral advantage of the consequent radiation of a larger proportion of heat to the walls of a room than takes place with pipes heated under ordinary pressures.

The most convenient form of applying this method is Perkins's system, by which the water is heated under considerable pressure.

In its simplest form the apparatus consists of a continuous or endless iron tube of about one inch diameter, closed in all parts and filled with water. The joints are screw joints connected within a socket forming a right and left hand screw. About one-sixth part of the tube is coiled in any suitable form and placed in the furnace, forming the heating surface, and the other five-sixths are heated by the circulation of the water which flows from the top of this coil, and after having been cooled in its progress through the building, returns to the bottom of the coil to be reheated. At the highest point to which the pipes are led an expansion tube is provided, also closed, but into which the heated water and vapour can rise, and thus regulate the pressure in the pipes.

As these pipes are absolutely closed, so that there can be no evaporation, they will, when once fitted and in operation, go on for years without any alteration being necessary.

This system is an approach to steam in the temperature which obtains in the pipes, but it is free from the necessity of supplying water to the boiler, or of having safety valves, and it rarely requires attention.

Steam Heating.

Steam pipes for heating present many advantages. In the first place steam is easily led to great distances. In the next place, as steam heated pipes are hotter than hot water pipes, their effect in warming the air in contact with them is also greater; and therefore, when heating is required on a large scale, it will be found that it is more economical to use steam pipes than hot water pipes; besides which, the pipes may be smaller, and thus in both ways expense is saved.

Highly heated steam pipes, moreover, radiate a large portion of their heat to the walls and furniture of a room.

Heating by steam is universal in the United States, and the usual system may be described as follows:—

The steam is conveyed from the basement along pipes to the room or passage where it is wanted to be used, and there it is passed into a cluster or coil of pipes called a radiator, which gives an enlarged heating surface.

The cause producing the circulation throughout the pipes of the warming apparatus is solely the difference of pressure which results from the more or less rapid condensation of the steam in contact with the radiating surfaces; a partial vacuum of greater or less amount is thereby formed within the radiating portions of the apparatus, and the column of steam or of water equivalent to this diminution of pressure constitutes the effective head producing the flow of steam from the boiler, while the return current of condensed water is determined by the downward inclination of the pipes for the return course. Therefore the flow pipe should be carried in as direct a line as possible from the boiler to the highest point; all the coils for heating should be placed on the return pipe, which should be laid in a uniformly descending line back to the boiler, so arranged as to prevent the lodgment of any condensed water on its way there; because if condensed water lodges in the pipes most unpleasant and startling noises result. It is a source of economy in steam heating that the condensed water should flow back to the boiler.

This is what is called closed circulation, with separate supply and return mains, both of which extend to the furthest distance to which the heat has to be distributed.

It is, however, possible to carry the steam and bring back the condensed water by means of a single main, which answers at once for both the supply and the return, either with or without a longitudinal partition inside it for separating the outward current of steam supply from the return current of condensed water.

If more convenient the return of the condensed water to the boilers may be dispensed with, and the steam may be applied in what is called the system of *open circulation*, where a supply main conveys the steam to the radiating surfaces, whence a return main conducts the condensed water either into an open tank for feeding the boiler, or into a drain to run to waste, or for use as hot water for domestic purposes, the boiler being then fed from some other source. In either case suitable traps have to be provided on the return main, for preserving the steam-pressure within the supply main and radiators. In places where the water contains lime or other matter liable to form a deposit the return of the condensed water to the boiler is preferable.

Steam heating no doubt possesses some disadvantages, but much of the bad name which steam heating has acquired is due to the want of a proper system of ventilation in connection with its use.

The heat given out is very great, and becomes often oppressive. Under the ordinary arrangements for steam heating, the temperature of the pipes cannot be regulated as with hot water. This latter objection is met to some extent by separating the coils into parts, which can be put in operation consecutively.

In the New York Hospital the incoming air is warmed by coils of steam pipes, and generally to a considerable temperature; but in order to prevent the warmed air entering the wards at too high a temperature, this hot air is mixed with cold air to the extent necessary to moderate its temperature before it is allowed to flow into the wards.

But whatever may be its disadvantages, steam heating possesses the great advantage of being easily distributed; and from its use in distributing heat to considerable distances, great economy and convenience result.

The fires can be concentrated in one spot, by which a considerable saving can be made, both in labour and fuel. It is this saving in labour which has led the Americans to adopt a plan in several towns for consuming the fuel at a central source of supply, and sending thence the heat itself to supply the several houses in connection with it; and the system thus dispenses with the necessity for consuming the fuel in each individual house.

Loss of Heat.

Having thus briefly alluded to the methods of providing heat, I would call to your attention the importance of preventing the loss of heat from buildings.

The warmth of a house is largely influenced by the materials and arrangements adopted in the construction of the building.

There are many points connected with this question which deserve your careful attention.

Dryness is an element of health, therefore let me in the first place allude to damp walls.

Damp in walls is considered to be a cause of fever, especially in warm climates. A damp wall, whilst it checks the passage of the air, is cold, and consequently occasions a rapid radiation of heat from persons sitting within its influence.

Damp walls, besides being unhealthy, are uneconomical. They cause a great absorption of heat by the evaporation of the moisture from the surface. New walls are always damp. The quantity of water which will be contained in a new wall is very remarkable. Suppose that 100,000 bricks are used for a building, each weighing seven pounds; a good brick can suck up from 10 to 20 per cent. of its weight in water, but assume 7 per cent. as what gets into it by the manipulations of the bricklayer. Also assume that the same amount of water is contained in the mortar, a quantity certainly much understated; the mortar forms about one-fifth of the walls; thus nearly 100,000 pounds of water, equal to 10,000 gallons, may be assumed to be put in the walls in the process of building, and of which much must be removed from the walls of the house before it becomes habitable. This water must be removed by evaporation into and by the air, and assuming the average temperature to be 50° Fahr. and the average hygrometric condition of air to be 75 per cent. of complete saturation, it will be found that it would require 700,000,000 cubic feet of air to pass through the building to dry it.

The heat generated in rooms passes away in cold weather through the floor, ceiling, and walls and windows into the open air or adjacent colder parts of the house, and the heat of the house is similarly constantly passing away into the open air through the walls and the windows and the roof.

The loss of heat by walls varies in a direct ratio with the conducting power of the material of the walls, and with the difference of temperature between the inner and the outer surface of the wall, and it varies inversely with the thickness of the wall.

Therefore hollow walls and double windows prevent a loss of heat.

It will be useful to recall to your recollection why they are serviceable in retaining heat.

The rate at which radiation goes on from a warmer body to the colder air, depends on the difference of temperature between the radiant and the recipient. Therefore in the case of the solid wall or single window, the heat of the warm room radiates directly to the cold outer air.

Hollow Walls and Double Windows.

In the case of the hollow wall or double window, the hollow space necessarily acquires a degree of heat intermediate between that of the warm room and the cold outer air; and the rate of radiation from the warm room will be in proportion to the difference of temperature between the room and the comparatively warm air space, instead of between the temperature of the room and the cold outer air.

For this reason, the loss of heat through the roof will depend upon whether the rooms are ceiled, and upon the form and nature of the roof covering. If there is a lath and plaster ceiling to the upper rooms, and an air space between the ceiling and the roof, closed from the outer air, so as to prevent any rapid circulation of air, and if the roof be formed in the most approved manner in this country, viz., with closed boards covered with felt under the slates or tiles, the loss of heat in winter, and the effect of heat in summer, in raising the inner temperature, will be comparatively small.

If there is no ceiling, and if the roof be not carefully constructed, as above mentioned, the loss of heat in the rooms directly under the roof will be very considerable, and the room will be very uncomfortable.

The air in contact with metal or thin glass exposed to cooling influences is under the most favourable condition for being cooled. Each layer as it is cooled falls down and is replaced by warm air, which undergoes the same process. This renders a space covered with a metal or glass roof without intermediate ceiling very difficult to warm. Therefore in halls or rooms lighted by a glass roof, or staircases lighted by skylights, it is essential for preserving the heat that there should be a second glass ceiling below the one exposed to the outer air; and in cold weather it may be advisable to adopt special means to warm the intermediate space, if an equable temperature is sought to be maintained in the room at all times.

In very hot weather, when it is desired to cool down the temperature of an iron or glass roof, it may be watered by jets from 8 or 9 o'clock in the morning till about 5 o'clock in the evening.

The practice of limewhiting the roof, which is largely resorted to in some places, is a great protection against heat.

The loss of heat with double windows is much less than that with single windows, and they have the advantage not only of transmitting less heat, but, from the temperature of the inside glass being greater, less radiant heat is absorbed from the occupants of the room. Péclet found that the loss of heat in double windows increased somewhat with the distance apart of the inner and outer glass, owing probably to the greater facility for currents of air in the wider space between the glass.

Thus you will see how largely the choice of materials and the methods of construction influence the retention of heat. For instance, iron is a good conductor of heat, and you will thus easily understand why an iron building is so fearfully cold in cold weather, and why wood, which is a bad conductor of heat, makes a comfortable house in the coldest climates.

I trust I have made clear to you that economy in warming is largely dependent upon the methods of construction as well as upon the quantity of firing supplied to a house.

Comfort and health depend largely upon the maintenance of warmth. You will find that, as a rule, the occupant of a room will prefer what is comfortable and unhealthy to what is healthy but uncomfortable. If, therefore, you desire to ensure adequate ventilation in a house, a hospital, a barrack, or a hut, you must adopt such methods as will combine warmth with the use of fresh air. Unless you do so, you may rest assured that the best contrived ventilation will result in failure.

LECTURE IV.

OBSERVATIONS ON WATER SUPPLY.

As the question of Water Supply in its engineering aspect has been dealt with in other lectures, it is only necessary here to draw attention to some practical points which should be borne in mind in arranging for a pure supply of water for troops under circumstances of temporary occupation, or on the march.

One of the chief dangers of camps arises from the pollution of the water supply by refuse.

A large part of the sickness in the Egyptian campaign was due to the drinking water obtained by the troops. At Ramleh the water for the camps and buildings occupying the sloping and low-lying ground was all drawn from wells; water-latrines were used; the consequence was that the wells were, directly in some cases, indirectly in all, probably the receptacles of soakage.

To this a part of the enteric fever which prevailed was ascribed.

In other cases the water came from canals, into which the dead bodies of animals had been thrown.

A man probably requires two quarts of water in his food per day. That means 500 to 600 gallons for 1,000 men, not far short of half a ton weight; or if the water had to be evaporated, probably 80 lbs. of coal would be required daily for the purpose.

Horses and cattle drink far more.

You will thus see how much forethought is necessary in regard to the provision of water for an army marching through countries where water is scarce.

Examination of Samples.

In the case of permanent occupation the source of supply would necessarily be submitted to careful chemical examination; the few remarks which I shall make on water are chiefly to call attention to some points which should be borne in mind in selecting a source of supply on emergencies.

The microscope affords the readiest means of cursory examination, on account of the facility with which the presence of organisms and solid organic and inorganic matter can be detected by it.

A simple test is to collect water in a clean bottle, to be kept stoppered, and allowed to stand for a day or two, exposed to light but not to evaporation, to see whether vegetation or putrefaction is developed. It should be in a temperature suited to vegetation.

The presence of substances capable of putrefaction is indicated by the disengagement of sulphuretted hydrogen, and by the animalcules.

Water that will not bear the test of standing should in most cases be rejected at once. If no other water can be obtained, it ought to be used before putrefaction has set in, but this is a great risk; the next best method is to wait until after putrefaction has terminated. To ascertain the nature of its organic matter, a small quantity of the water should be boiled down and the residue burnt, weighing before and after burning to obtain the amount of combustible and volatile matter. With practice and attention to the smell, it is possible to detect humous or peaty acids, nitrogen, organic substances, or nitrates, and to ascertain their amount to a useful degree of accuracy.

Condition of Wholesome Water.

Generally speaking, in a locality that is clean, water that is free from colour, taste, and smell is wholesome.

Pure water should have no sweet, or salt, or other decided taste, and should be odourless. It should be clear and colourless if looked at through a tube 2 feet in length. In some cases, however, a water may possess a decided colour, such as the water of Loch Katrine, and yet be perfectly fit to drink; but nevertheless, yellowish and brownish, and greenish yellow tints are always to be regarded with suspicion.

The mere existence of organic matter, either in solution or in suspension, is no proof of impurity. If water contains the fresh juices of inoffensive plants, it would not be unwholesome. But these juices may putrefy. Hence organic matter, though at a given time harmless, may at any moment become extremely dangerous, and so long as a water is polluted to any appreciable extent with organic matter it should be condemned.

It is important to know whether organic matter comes from animals or vegetables. The presence of common salt will in many cases, with proper precaution, be found to be a nearly certain guide, for it is largely consumed in the food of men and animals.

It is the constant accompaniment of the animal living, or decomposing after death.

Of course this test must be used with caution, because near the sea the spray is driven many miles inland, and in many districts, where deposits of salt exist, wells and springs are saline. Chlorides are also given out from manufactures. But water containing chlorides to a great extent ought not to be used without careful examination as to the source; one grain per gallon should be a cause of suspicion.

The absence of chlorides may be taken as conclusive against the presence of decomposed animal matter or excreta.

Rain Water.

Theoretically the purest natural water is obviously rain water, collected in the open country, inasmuch as it has merely passed through pure air. Rain falling in towns takes up impurities from the air, such as sulphates, chlorides, ammonia, and organic matter.

Dr. Russell's experiments, made in the city of London and the suburbs, show that city rain contains twice as much impurity as that collected at the suburban stations, but that the impurities at all the stations are in the same proportion. Dilut the city rain with very nearly an equal bulk of water, and you have the rain of the suburbs.

Summer rain, both in town and country, is more impure than winter rain, probably owing to the decomposition of animal and vegetable matter, volatile sulphur compounds being eliminated and afterwards oxidised.

It is worthy of note that London rain, when collected at once, is never acid; but if the rain be collected in an open vessel, which is left exposed for a considerable length of time, then the water will always be acid. This acidity, however, arises, not from acid washed directly out of the air, but from acid washed out of the soot which is always abundantly present in London air.

Rain water that has percolated through strata, or through surface soil more or less contaminated, becomes charged with some of the substances contained in the strata or soils; it is very difficult to collect rain water in a pure condition, as the surfaces on which it falls, when in the vicinity of habitations, are liable to so many sources of impurity—as, for instance, droppings of birds, soot, ammonia from the decomposition of organic matter, and much else.

Moreover, rain water is insipid, and not agreeable to drink unless aërated in the ground. In parts of Italy it is the custom, after collecting the rain water, to leave it in underground cemented tanks for a year at least before use, to allow it to imbibe carbonic acid gas.

Some of these difficulties would be met in the case of permanent occupations, where porous strata exist, where sufficient ground can be set apart, and where military labour is available, by excavating an area, of a size to hold a sufficient supply calculated on the minimum rainfall to a depth of 5 or 6 feet, and paving the bottom of the excavation with tiles or impervious material, such as puddle, cement, or asphalte, sloped down towards one corner, and lining the sides with puddle, and then filling in the whole again with the porous material of the ground. A pump could be fixed in the lowest corner.

The surface should be covered with grass or shrubs, and kept free from impurities. By these means a valuable reservoir would be formed, which would act also partially as a filter bed.

Water from Springs, Rivers, and Marshes.

It may, however, be generally assumed that, when you can get it, the best source of supply is from pure springs. This will be more or less hard, from the salts the water has imbibed in the ground. Soft water is no doubt more economical of soap, but a moderately hard water is probably best for health. Indeed, water with a small amount of sulphate of lime brews the best beer and makes the best tea.

Springs should be away from and, if possible, at a higher level than the camping-ground, so that they may not become polluted by refuse.

River water and lake water, if otherwise pure, rank next in wholesomeness, although river water may not always be free from sediment.

In the Egyptian campaign, Surgeon-General Marston observed:—'It was difficult to make the troops believe that a muddy water like that from the Nile was preferable to clear water from the polluted wells.'

River water is, however, very liable to pollution from impurities on the banks; and although it is undoubtedly true that sewage or other contamination will be removed by plants and animal life in the water, and by the aëration of the water due to the flow of the river, yet for all that, if sewage has been poured into the river higher up, it would be safer to reject the river as a source of supply if other sources of supply were accessible.

Marsh water is never wholesome, and should under all circumstances be avoided, even if free from taste and smell.

Well Water.

As a rule, deep well water would rank after pure river water in wholesomeness.

Shallow wells, especially if the ground is to be occupied for a length of time, are not safe as water sources.

Except where the occupation of the camp is of the most temporary character, the surface of the ground round wells should be protected for as far round as can be managed, and if possible sloped away from the edges of the well, which should be raised, so as to prevent any water from the immediate surface flowing back into the well.

Although a surface supply is not desirable, yet in camps and for temporary occupation it may often be necessary to resort to a surface supply.

Norton's tubes, which are easily applied, are very useful for ascertaining the quantity of subsoil water, and for drawing the supply, for a time at least, free from surface pollution.

When these are not at hand, and where brushwood is obtainable, a simple way of making a shallow well is to make a large gabion 4 or 5 feet in diameter, some 10 or 12 feet long, and then dig the well and drop this gabion into it, taking care to let its upper end project a foot or two above the ground, so as to support a bank of earth all round the edge of the well; this forms a temporary casing which answers its immediate object.

For a permanent supply, surface wells in porous strata should be lined with puddle behind the steyning to the full depth, or in wells beyond 12 to 15 feet in depth, then to that depth at least, so as to ensure complete filtration through the soil of the surface water which passes into the well.

The surface round the well should also be puddled, sloped away from the well, and paved.

The distance to which this preparation of the surface should be carried round the well depends on the depth of the well: with a deep well, in which there would be a considerable depth of soil through which the surface water would have to pass before it reached the well, an extensive surface covering would not be necessary; whilst with a shallow well you could, by extending the area of surface puddling, materially extend the amount of filtration to which the surface water would be subjected before it reached the well.

The tube lining of the well should be carried up to at least 2 feet above the surface, so as to prevent surface impurities from falling in. The well should be covered as a protection against dead leaves, &c.

For keeping well water clean, it is preferable that it should be drawn by a pump. In the use of buckets impurities frequently fall in. If not a pump, then an iron chain and bucket, because they can be kept cleaner than rope and wood.

Observations on Filtration.

It is always safer to filter water, provided you keep the filter clean.

The efficiency of a material for filtering depends generally upon the extent of surface it offers to the water passing through. Sand offers a large surface. It is estimated that a cubic yard of sand would contain an area of surface in the particles of about 2,500 square yards.

Charcoal similarly is made up of surfaces.

Iron acts in a somewhat different way. Thus iron filings will remove impurities by the effect of the oxidation of the iron on decomposable substances in the water; and spongy iron, which has a large extent of surface, exercises a similar cleansing effect so long as its pores are open.

The effects of the treatment of water by iron may be classed under three heads:—

1. The organic matter is altered in its chemical nature, and the albuminoid ammonia is reduced to from one-half to one-fifth of its original amount.

2. A reaction analogous to that in Clark's softening process appears in many cases to go on. The iron oxide which is produced by combining with some of the carbonic acid which holds the carbonates of lime and magnesia in solution in the water,

causes some precipitation of these to take place, and hence an appreciable amount of softening generally results.

3. Treatment with iron appears to destroy or remove much of the infusorial life.

For filters on a large scale sand is the simplest material.

It has considerable purifying power when first used, but it clogs rapidly. The sediment stops mainly on the surface, and thus diminishes its filtering power. This can be restored for a certain time by scraping off a small film of the top surface of the sand, and washing and replacing it.

In the Egyptian campaign filters were made out of disused meat tins, by perforating the bottom with a hole, putting thereupon a layer of muslin, and then clean sand (2 or 3 inches deep), drawing down the tin lid (previously punched with some holes) into contact with the sand, and then suspending the tin at the top by a string for dipping into the water.

In the Crimean War the Turkish troops sometimes resorted to the following plan.

They selected a site near their camp where the surface was clean, and dug a hole and placed in it a barrel, in the bottom of which holes had been bored, so as to ensure that water from the deepest part of the hole should alone come into the barrel. If they wanted further filtration, they got a smaller barrel and bored holes in the sides as high as was desired, and they then placed the smaller barrel in the larger one, ramming sand in below and all round, so as to bring its top to the level of the first barrel, and thus forming an upward filter of sand, through which the water passed.

By degrees any filter will become foul by retaining in itself the impurities which were in the water ; and the water passing through a foul filter is sometimes more dangerously polluted than it was before it entered the filter.

Filters must, therefore, be frequently and thoroughly cleansed by washing the material of which they are composed, and by exposing them to the air, so as to cause any remaining impurities to be oxidised.

A filter with sponges to arrest the sediment, so arranged that the sponge can be frequently cleaned, and a porous filtering medium so arranged as to have a free exposure to the air when water is not actually passing through, would appear to be the form of filter which should be sought for.

Pollution of Water Supply.

When you have got a good water supply, you must watch it with the greatest care. It is so liable to be polluted in very various ways by organic matter.

Wells and springs will be polluted if animal filth or decaying matter be deposited near them ; cisterns, by dirt falling into them.

But the methods of pollution may be very occult—as, for instance, from the leakage from cesspools, or soakage from drains in proximity to a well or tank.

There was an interesting case which occurred at Croydon.

Croydon has been drained effectually, and the water supply is obtained from springs at some distance in the chalk.

In the dry seasons the supply was excellent; in wet seasons fever was found to prevail, which was attributed to the water. The cause of this was explained by the fact that in dry seasons the level of the water was far below any subsoil contamination; but that in a wet season the water level of the underground river rose up to the level of cesspits, which were not impervious, and to other sources of contamination, and thus became contaminated with the contents.

In houses, water stored in cisterns may be polluted by foul air coming up the waste-pipe into the cistern, and even from the vicinity of decaying matter; for water has a great affinity for imbibing gases, especially when cold, and it gives them out again when warmed.

Lead and zinc poisoning may also arise from the pipes through which water is conveyed, or the cisterns in which it is stored, especially in the case of very pure waters.

In the water supply of an army on the march, a most important feature is the distribution of water.

Sir Charles Wilson, in his very graphic story of the march from Korti, gives plenty of illustrations of the importance of watching over the water supply.

The distribution of water in camps should invariably be placed under inspection, and under the charge of some person who must be responsible for not allowing waste or pollution. With this object the general dipping of buckets into a well should be prevented.

If a pump is not fixed, one man must be made responsible for raising the water out of the well. He pours the water into a box or reservoir in front provided with taps, out of which all who come for water must draw without confusion or fouling of the well with dirty buckets.

In a camp of any degree of permanence the surface of the ground near places where water is obtained ought, if possible, to be paved, or else it will soon become a mass of mud. This is especially desirable with horse-troughs.

In making troughs for watering horses, care must be taken to supply each trough independently of the neighbouring troughs, and not to let the overflow of the first fill the second, and so on; because the water of a trough becomes fouled by the horses drinking in it, and consequently the overflow from the upper troughs conveys nothing but polluted water into the lower ones.

Sewage.

The retention of refuse matter in and about dwellings is one of the most frequent causes of disease.

This system of retaining the sewage under our houses has not been given up for much more than forty years.

I well remember when each house had its cesspit, which, when the ground was favourable (that is porous), was formed without any walls, and the liquid was allowed to drain away; and thus these cesspits tended to pollute the whole subsoil of a city and to destroy the purity of the wells.

The town of Memphis, in Tennessee, affords a striking illustration of the effect of porous cesspits on the pollution of the soil. The town stands close to the Mississippi River, on a bluff of clay resting on sands. The privy pits in Memphis were so deep as to reach this sand substratum, through which the water of the river finds its way at every great rise, so that in many places the rise of the Mississippi would be actually gauged by the rise of the excreta, which, when the river falls, were drawn after the water through the soil; and the privy vaults or pits were purposely made deep enough to reach this sand, as a sure means of dispensing with the labour of the night-soiler.

In the fifty years of its existence, this town has suffered from 22 epidemic visitations of yellow fever, cholera, dengue, erysipelas, puerperal fever, and small-pox. In 1878 half the population died of yellow fever. In non-epidemic years the mortality was rarely so low as 35 per 1,000. A drainage system was introduced in 1879–80.

The effect of impurities accumulated in porous cesspits upon the air of Munich, and the death-rate of the population, affords another striking illustration. At Munich, the whole excreta of the population were originally received into porous cesspits; and the whole soil under the town was saturated with emanations, and consequently the air of the town was polluted. This state of affairs was begun to be improved by cementing the sides and bottoms of the cesspits, so as to render them water-tight; subsequently the cesspits were abolished and sewerage provided. The following table shows the effect on the health of the population of these successive alterations. The enteric fever mortality per 1,000 of inhabitants for quinquennial periods was as under :—

1854 to 1859, when there were absolutely no regulations for keeping the soil clean	24·2
1860 to 1865, when reforms were begun by cementing the sides and bottoms of the porous cesspits	16·8
1866 to 1873, when there was partial sewerage	13·3
1876 to 1880, when the sewerage was complete	8·7

Similarly, at Frankfort-on-the-Main, the deaths from enteric fever per 10,000 deaths were—

1854 to 1859, when there was no sewerage	8·7
1875 to 1880, when the sewerage was complete	2·4

At Dantzig, the figures present some more striking characteristics; the deaths from enteric fever per 100,000 living were as follow—

1865 to 1869, when there was no sewerage and no proper water-supply	108
1871 to 1875, after the introduction of water-supply	90
1876 to 1880, after the introduction of sewerage	18

These results illustrate the effect of purifying the air of towns by the rapid abstraction of refuse matter, so as to prevent it from remaining and putrefying in and upon the ground.

Removal of Waste Water.

Wherever you introduce a supply of water to a house or town, you must at the same time provide some method of removing that water after it has been made foul.

A theoretically perfect system of getting rid of all waste water, excreta, and indeed all other refuse, so far as possible contamination is concerned, would be one where a large volume of rapidly flowing water received the whole refuse and carried it away to a large river not used for drinking purposes, and thence to deep water in the sea. But this is not often attainable, and would be singularly wasteful.

An ordinary household of, say, six persons, enjoying a proper water supply, will consume for all purposes about 20 gallons per head per diem, or a total daily quantity of 120 gallons, which must necessarily be fouled in its use, and pass away from the house laden with dangerous impurities. If earth-closets are used instead of water-closets, a certain quantity of water, perhaps as much as four or five gallons per head, may be saved; but there will still be 15 gallons of water fouled with grease, soapsuds, vegetable refuse, and other materials of a highly putrescible kind, which must necessarily pass away and be disposed of at the outfall. Whatever, therefore, may be the system adopted with reference to the excreta, there will always be a large amount of liquid refuse to be dealt with which is liable to putrefy.

The Rivers Pollution Commissioners, in their first report, after a careful comparison of thirty-one towns, in fifteen of which the midden system prevailed, while sixteen were water-closet towns, came to the conclusion that it mattered little, as regards the degree of pollution in the sewer water, whether a system of interception of the excreta was practised or not.

Therefore, as in every town some system of sewers for the removal of foul water is absolutely necessary, this water in flowing away would carry the excreta without any extra outlay.

I will give you, from a recent experience, an instance in point.

I was asked last year by the municipality of the town of Cannes, in France, to advise as to a system of drainage.

The fæcal matter is there received into cesspits or into *tinettes* (metal cans), and is removed by contract by a company who convert the contents into manure. The charge for the removal of the fæcal matter was four francs per cubic metre, and this amounted, on a population of 20,000 inhabitants, to 100,000 francs a year. The water actually used for domestic purposes amounted to between 30 and 40 gallons per person per day, of which less than 2 gallons per person would be required in the water-closets. Thus the drain actually necessary to remove the domestic water would equally suffice to remove the excreta; and if the water-closet drainage were turned into this drain, instead of being retained in cesspits, the community would avoid an expenditure of 100,000 francs a year for the removal of excreta. This sum, if capitalised at five per cent., is equal to 2,000,000 francs, a sum more than sufficient to drain the whole commune of Cannes efficiently and completely.

Consequently, in providing on any large scale for the removal of the domestic water it would be more economical, where possible, to arrange at the same time for removing the excreta, than to institute a separate service for this part of the refuse.

With the water-carriage system, that is the use of water-closets, you necessarily still have to provide for removing ashes, refuse, and manure.

Removal of Rainfall with Sewage.

In designing a system of sewers, the first question which arises is whether you will remove the rainfall with the foul water.

This question has been much discussed on theoretical grounds. Theoretically it is advisable to exclude from the sewers everything which tends to form a deposit, and refuse from road surfaces is very liable to cause deposit. But you cannot lay down a strict rule. In the case of a detached house or of a barrack, or of a small collection of houses, the conditions are very different from those in large or moderate-sized towns. In the case of detached houses and barracks, it is frequently found advisable to save the water which falls on roofs, and to use it for washing and other purposes requiring soft water. When, however, the ground is closely occupied by houses, the rain-water, as it falls, is fouled by soot, and it moreover takes up many other impurities from the atmosphere. For instance, rain-water collected in London will frequently be found very acid from the sulphurous acid in the air, arising from the combustion of coal.

In a town area, whilst the soot and the impurities of the atmosphere, which the rain-water takes up in falling, frequently render it unfit for domestic purposes, that which falls on streets and yards is made quite foul by the large quantities of horse-dung and other impurities which are the chief constituents of the street dust in towns. Indeed, experiments made by Professor Way some years ago on the rain-water which passed into sewers, showed that whilst a small part of the solid matter from paved streets consisted of granite, the bulk was horse-dung; and he showed that the value, as manure, of street-water taken in rainy weather on its way to the sewers was as great, or even greater, than the ordinary contents of the dry weather sewage. The mud on a wood pavement is almost entirely formed of horse-dung.

It is on these grounds generally necessary to provide in town drainage, as far as possible, for the removal of the foul street and yard water, as well as the house sewage proper.

On the other hand, the sand and grit which surface-water from macadamised roads and yards carries into the sewers always cause deposits; and if a sewer carried foul house-water alone, without sand, any deposits in the drain would be much more easily dealt with.

The question of removal of rainfall is, however, dependent on (1st) the nature of the locality, (2nd) on the habits of the people, and (3rd) on the climate.

1st. On the locality; for instance, at Memphis, where water-courses traverse the town at such intervals as to allow the rain water to flow readily away, the rain water is turned into the watercourses, and the sewers are reserved for waste-water from houses alone.

In cases where the position of the outlet is such that levels do not allow of the sewage gravitating to the outlet, but it requires to be lifted in order to obtain a sufficient fall, it will be advisable, as far as possible, to exclude all surface-water which can be got rid of otherwise, so as to reduce the expense of pumping.

2nd. On the habits of the people; as, for instance, on the methods adopted for street cleansing. If the streets are carefully swept, and the refuse removed before rain falls on it, the street-water will be much less impure. But in some foreign towns, in consequence of an abundant water supply, the following system is in use:—The dry refuse from houses is placed in the street every morning, in a small heap in front of each house; a cart comes round and removes this, but some small part is generally left on the street. The street is then washed, and the washings, which consist of very foul water, flow away through the sewers.

3rd. On the climate; as, for instance, in countries such as parts of India, where rain falls at rare intervals, the occasional pollution of a stream by street-washings would not have the same importance as where rain is more continuous; and the construction of a large sewer of a capacity sufficient to remove the occasional rainfall which would rarely be required, would present other evils. The small amount of dry-weather flow of sewage would necessarily only form a trickling and stagnating stream in a sewer calculated to remove the maximum volume of rainfall; a sewer large enough for this latter purpose would form a great reservoir for sewer gas.

In England, where the rainfall is more evenly distributed, a rainfall of one inch in twenty-four hours is not very unfrequently registered. But when this volume falls, it generally does so in a smaller portion of the twenty-four hours. I have known several cases where half-an-inch has fallen in an hour; but this heavy rate of rainfall usually only prevails over a limited area.

Therefore, when we speak of providing for rainfall, we do not mean the whole rainfall.

The nature of the area which has to be drained regulates the proportion of rainfall to be removed. In a town area, closely built over, the rain-water will run off rapidly into the drains; in a suburban area, that which falls on garden ground will pass off more slowly.

The provision for rainfall has been assumed in London at one-quarter of an inch of rainfall to be carried off in twenty-four hours, for the urban districts, and one-eighth of an inch in twenty-four hours, for the suburban districts. But that this amount was not sufficient has been shown by the continual floods which occur in the low-lying parts of London.

Most cases of flooding in sewers arise from the assumption that the rainfall will be distributed over a longer period of time than always occurs, so that when the calculated rainfall for twenty-four hours falls in three hours, the sewer is taxed far beyond its capacity, and serious mischief to property and danger to health accrue.

A remarkable instance of this occurred in 1878. An epidemic of diphtheria broke out in the parishes of Hampstead and Marylebone. At one point of the sewerage system of those districts, and in the centre of the infected area, two sewers, about six feet in diameter each (draining a large area), were carried by a double junction into a sewer only 4 feet 10 inches in diameter, which latter sewer subsequently expanded to 7 feet in diameter. The effect of this contraction was to permanently interfere with the regular flow of the contributory sewers, and to create deposits of foul matter in them, causing a general pollution of the air in the district. During heavy rains the sewers became choked, and two floods occurred in the year 1878.

These sewers were rectified by the Metropolitan Board of Works, but when the works were in course of being executed, many months after the original epidemic had subsided, several cases of diphtheria again occurred in the immediate neighbourhood of the portions of the sewers which were then opened for purposes of alteration, confirming the opinion that the polluted condition of the sewers in this district was a factor in regard to the epidemic.

If the sewage is provided for separately from the rainfall, it still remains necessary to make provision for the latter. In the case of the city of Memphis, United States, before mentioned, the position of the town favoured the escape of rain-water. The town chiefly occupied high ridges intersected by streams, so that there was nowhere any great distance for the rain-water to travel to reach the bed of a natural stream, and consequently open gutters were sufficient.

Each case must be considered on its own merits.

Flow of Sewage.

The sewage proper of a town or village consists of waste water and excreta from the houses, besides water used for manufacturing purposes, and the volume may range from 100 to 250 gallons per day per house.

The flow of sewage is not uniform throughout the day. It varies with different places, according to the habits of the people. In London, in the short sewers leading into the main outfall sewers, half the total flow of dry-weather sewage passes off in the six hours between 9 a.m. and 3 p.m., whereas the maximum flow at the outfalls themselves occurs between 11 a.m. and 8 p.m., whilst only twenty-one per cent. flows off between 2 a.m. and 9 a.m.

The volume of maximum flow regulates the size of the sewer so far as sewage is concerned, to which the proportion of rainfall (if any), which it may be proposed to remove with the sewage, must be added.

A perfect sewer is one in which there is no deposit. Sewer gases are the result of putrefaction. If the sewage flows continuously and rapidly away there will not be time for putrefaction, but where deposits occur, putrefaction takes place.

The absence of deposit depends on—(1), the form and construction of the sewer; (2), on the volume and velocity of the flow of sewage; and (3), on preventing materials capable of forming deposits from entering the sewer.

Form and Construction of Sewers.

The accompanying diagrams show you what were the old forms, Fig. 7, Plate IV., and what are the modern forms, Figs. 8 and 9, Plate IV., of sewers for towns.

You will see that the old form of sewer with a comparatively flat bottom was eminently favourable to deposits, with the varying depths of sewage to which a sewer is exposed, and it used to be an axiom in sewer construction that sewers should be everywhere accessible by men for purposes of cleansing by hand.

The modern form of sewer is egg-shaped, in order that the depth of sewage may be as great as possible during the time of minimum flow.

It is now the rule that no system of sewers should be considered satisfactory if the engineer is not able to examine the sewer and keep it free from deposit along its whole length, without the necessity of excavating one cubic foot of earth, or removing one brick or drain pipe.

In order to accomplish this, all sewers should be laid in straight lines from point to point, both in plan and in gradient.

At every change of direction, and at every junction with another sewer, means of examining the sewer should be formed. This is effected by means of man-holes and intermediate lamp-holes, see Fig. 10, Plate IV. A lamp lowered into the sewer through a lamp-hole would be visible to a person in the man-hole, and any intermediate obstructions could thus be discovered.

Flushing, or mechanical means, such as long rods or a rope or chain passed from man-hole to man-hole, will serve to remove even heavy road grit sediment, if the invert of the sewer is true, smooth, and struck to a radius not greater than nine inches; no egg-shaped sewer, however large, need have an invert of greater radius than nine inches.

Junctions with lateral sewers or with house-drains should never be laid at right angles, but always so rounded as to deliver in the direction of the flow, and as a sewer, when once laid, should never be broken into, provision must be made, when originally constructing a sewer, for all lateral connections with subsidiary drains from houses, or other sources ever likely to drain into it.

In the construction of the sewer the greatest care must be taken to secure good workmanship. If sewers and drains of small dimensions are to work efficiently, they must be true in form, have smooth surfaces, and be laid absolutely true in line and gradient, because inequalities are liable to produce deposit. The joints in brickwork of sewers, as well as the joints of drain-pipes must also be true, smooth, and water-tight.

Leakage of water from sewers invariably leads to deposit. Therefore sewers and earthenware pipes must not be porous. Sewers should either be cemented inside or lined with glazed bricks or cement. Drain-pipes ought to be of glazed stoneware, and the joints should be of cement, and be water-tight, so that the sewage may not escape from the drain into the subsoil, nor pass from the subsoil into the drain.

In order that the joints of drain-pipes may be smooth, the cement must be prevented from entering the drain-pipes whilst making the joint. In order to secure this, after the pipes are placed in position, a layer of tarred hemp should be forced into the sockets before making the joint with cement; this will also serve to retain the centres of the pipes in true position.

Where the ground does not afford a firm foundation, cast-iron pipes ought to be used. Where cast-iron pipes are used, they should have socket joints turned and bored.

In cases where drain-pipes have to be carried long distances by land, cast-iron pipes may be cheapest, because cast-iron pipes may be worked full and under pressure; and therefore a six-inch cast-iron drain may serve in place of an earthenware drain of nine inches.

Velocity of Flow.

The velocity of course depends upon the inclination of the sewer, its form, and the depth of the sewage flowing in it.

As the flow of sewage is not uniform, it may happen, especially when surface water passes into the drain, that silt is deposited; therefore the velocity should, at the time of maximum dry weather discharge, at least be such as to remove silt or other obstructions.

The velocity of flow of water which will move materials is regulated by the following considerations:—(1.) For objects of the same character, the velocity required to start them increases with the mass of the object; (2.) For different objects, the velocity required increases with the specific gravity; (3.) According as the object assumes a form approaching a sphere, the less velocity does it take to move it; whereas a flat object, like slate, requires a considerable current before it becomes disturbed from its position; (4.) The object moves at a less rate than the current, but when the velocity of current increases after an object is in motion, the velocity of such object increases in a progressive ratio.

A velocity which will start an object will (when constantly maintained, and no accidental circumstance occurs to prevent it) never allow such object to deposit in the stream.

A velocity of from 2 feet to 2 feet 6 inches per second, with a continuous flow, will remove all objects of the nature of those likely to be found in sewers ; but if the flow is intermittent, or if a part of the sewer remains occasionally stagnant, a velocity of 3 feet would be advisable during a portion, at least, of the period of maximum flow.

Sewage should not be allowed to acquire a velocity of more than 4 feet per second; a velocity of 6 feet per second will move grit and other solids along the sewer invert, with a cutting action rapidly destructive of the material of the sewer.

The rules for calculating the velocity of flow according to given depths, in sewers of various sizes and inclinations, are of course familiar to you; but it is convenient to recollect that a main sewer 24 inches in diameter, and having a fall of 1 in 1,000, flowing a little more than half full, will convey about 2,000,000 gallons in 24 hours, or about 650,000 gallons in eight hours, and this, at 50 gallons per head each day, will provide for the sewage of a population of say 12,000; and as circular sewers have a capacity in proportion to the squares of their diameters, a sewer of three feet in diameter will serve for a population of 28,000, and so on. Where the fall is greater than 1 in 1,000, the delivering velocity will be quickened.

For barracks and hospitals drain-pipes of 9 inches, of 6 inches, and 4 inches diameter, will be of ample dimensions for populations up to 1,000; but of course with small-sized drains the fall to be obtained becomes a material consideration.

Preventing Deposit entering the Sewer.

Gullies and other inlet connections with the surface and subsoil or other water should be formed so as to prevent silt and sediment of all sorts as much as possible from being admitted into the drains. To effect this, the form of the gully and catch-pit is of importance. Gullies ought to be small and numerous, rather than large and open.

The bottom of the catch-pit (Fig. 11, Plate IV.) should be at a considerable depth below the point of overflow into the sewer, and it should be of large size in relation to the water which flows into it, and of such form at the bottom that a rush of water entering the gully in time of storm is not liable to stir up the deposit and carry it away. In some sandy districts, in order to intercept the sand carried down a steep road in time of storm, a special catch-pit into which the sand may fall before it reaches the ordinary gully has sometimes been provided. This arrangement is shown in Fig. 12, Plate IV.

Another plan is to furnish each gully with a sediment box which may be easily removed and emptied.

Gullies are liable to become untrapped from leakage or from evaporation, therefore, to ensure the integrity of the traps, they should have the water constantly renewed in dry weather. This is readily done in the summer months by the ordinary water carts, or else a special supply of water could be provided.

All gullies must be regularly scavenged, not less frequently than once every six or ten days, as matters of a decomposable character are often passed into them which decay and give off an offensive effluvium if left too long in the gully. After every storm the deposit in a gully should invariably be removed from the catch-pit in order to prevent its being washed into the sewer.

Gullies for stables should be constructed with good-sized catch-pits, in order to prevent, as far as possible, the matters entering the sewers and choking them. Gratings covering gullies ought to be arranged with their bars at right angles to the traffic, or otherwise narrow-wheeled vehicles are liable to get injured in the openings between the bars of the gratings.

For the same reason, openings into sewers or drains made for purposes of ventilation should not be direct, but should be made over a catch-pit provided with a lateral opening to the drain or sewer, so that road-grit or dirt may not fall directly into the sewer.

The accompanying diagrams show gullies and ventilators intended to prevent the road-grit from falling into the sewer. (Figs. 1 and 2, Plate V.)

Flushing.

When, from circumstances, the velocity necessary to maintain the sewer clear cannot be secured either from want of fall or otherwise, it is necessary to resort to arrangements for flushing the sewers. This means accumulating water on a given point in a sewer and suddenly releasing it.

The most effectual method of flushing is to provide tanks independent of the sewer at given intervals. Where the conditions admit of it the most convenient tank is Mr. Roger Field's self-acting flush tank. The syphon is so constructed as to be put in action by a very small constant flow of water. This is effected by making the discharging limb of the syphon in such a way that when a small quantity of water flows over the bend, it falls clear of the sides, instead of running down along the sides of the discharging limb. (See Figs. 3 and 4, Plate V.)

By this arrangement the water as it drops carries away the air in the discharging limb, and thereby starts the syphon. The longer limb of the syphon must of course be dipped into water below the tank.

In the case of the drainage of the town of Memphis (Tennessee), in the United States, which I have already mentioned, the population of which is about 60,000, no rain-water, either from the surface of the ground or from the roofs of houses, is admitted to the sewers. The sewers serve solely for the removal of the waste water of houses, manufacturing establishments, stables, &c., and under no circumstances is the pipe connecting a house of whatever size with the sewer allowed to be more than 4 inches in diameter.

The sewers in the side streets are 6 inches diameter. The main sewer is only 20 inches diameter at the outfall into the Mississippi.

The 4 inch house drain was adopted in order to exclude matter which might clog the 6 inch street drain; and by that means to throw the responsibility of excluding rubbish or grease upon the householder, as he alone will suffer inconvenience from his neglect.

In order to ensure that the street drains are kept free from deposit, at the head of each sewer there is built a flush tank, having a capacity of about 112 gallons. This tank is built of mason work under the surface of the ground, but above the level of the head of the sewer. It is supplied by a constant stream of water from the public water-supply, barely sufficient to fill it once in twenty-four hours. It is furnished with Field's automatic syphon, which is brought into operation when the tank is filled to the top of its outlet pipe; the whole amount of water in the tank is then discharged rapidly (in from 35 to 40 seconds), and rushes down the sewer with a force sufficient to carry before it every substance, of whatever character, the 4 inch pipe may have been capable of admitting.

The flushing stream, according to the observations made at Memphis, fills the sewer more than half full 900 feet from the tank. This distance must, of course, depend on the fall of the sewer. Each tank has only the dead end of its own sewer to flush.

It is thus immaterial whether all the flush tanks go off at once or irregularly.

This flush tank is one of the essential features of this system of drainage.

I annex some other experiments showing the effect of the flow in a sewer of one of Mr. Roger Field's automatic flush tanks, containing 9,000 gallons.

Operation of Field's Flush Tank.

Diameter of Sewer	Gradient of Sewer	Distance from Tank	Depth of Sewer before Flush	Greatest height during Flush	Rise during Flush	Time on reaching each point	Speed per min. during Flush
Inches	Steep	Yards	Inches	Inches	Inches	Minutes	Feet per sec.
18	—	—	—	—	—	—	3
24 by 30	$\frac{1}{600}$	135	$1\frac{1}{8}$	9	$7\frac{1}{8}$	$1\frac{1}{2}$	3·5
		315	$2\frac{1}{16}$	$10\frac{3}{4}$	$8\frac{11}{16}$	—	3·2
30 by 39	$\frac{1}{800}$	1072	$7\frac{3}{4}$	14	$6\frac{1}{4}$	$18\frac{1}{2}$	2·5
		1879	8	12	4	37	2·2
30 by 39	$\frac{1}{1545}$	2730	$7\frac{3}{4}$	9	$1\frac{1}{4}$	59	1·8
		3445	$15\frac{3}{4}$	$16\frac{3}{4}$	1	$78\frac{1}{2}$	1·6

The effect was to bring down a quantity of black sludge on each occasion of flushing to the outfall, within a distance of two miles.

In large sewers other methods of flushing are resorted to.

In the large sewers in Paris and Brussels a movable flushing apparatus is provided. The sewer has a footpath on each side, along which a truck is arranged to run as on a railway, as shown in Fig. 5, Plate V. The truck is provided with a board of the exact section of the sewer, which can be raised or lowered by a screw apparatus fitted to the truck. When the board is lowered, the water in the sewer is dammed back. Two small doors are provided in the board near the bottom, and by opening these when the sewage is dammed back, a strong current of water is passed through so as to wash away any accumulation of *débris*. The truck can be moved on to any spot where the action is required.

The sewers at Paris are carried under the Seine from one bank to another by means of pipes laid in the form of an inverted syphon (Fig. 6, Plate V.) Each pipe is about one metre in diameter; to clean this out a wooden ball of a diameter a little less than that of the tube is periodically caused to roll through the pipe. It delays the flow, and thus accumulates a head of water behind it sufficient to force away any impediment from the bottom of the syphon.

Ventilation of Sewers.

Intimately connected with the question of deposit in sewers, is that of sewer ventilation.

Ventilation of sewers prevents stagnation or concentration of sewage gases within them.

In unventilated sewers the concentrated gas may become deadly, whilst in fully ventilated sewers, with continued flow, without deposit, the sewer air is purer than that of stables, or even than that of a public room when fully occupied.

Ventilation requires both inlets and outlets. There are two systems in force for securing this ventilation.

One is to use the soil-pipes of the houses as the upcast shaft for the sewers.

At Memphis (Tennessee), which I have already mentioned; at Worthing, in this country; and in some other towns, the soil-pipe of the house is connected directly with the sewer, and is carried thence at its full size of four inches to above the roof of the house. Thus every house assists in the sewer ventilation.

It is quite possible that in a newly-drained town, where the sewers and house-drains are all of the newest and most careful construction, this plan may not entail danger. But unless the sewers are so constructed that deposit in them is impossible, there should never be any air connection between the house-drain and the sewer. I would therefore always advocate placing an intercepting trap between the house-drain and sewer, so that each house shall be rendered independent of the faults of its neighbours. It is quite certain that adequate sewer ventilation can be afforded by making numerous openings from the sewers to the external air, which will bring about and maintain dilution and dispersion of sewage gas so soon as generated; but there will be much less chance of the sewer gas being generated if deposit be not allowed to accumulate in the sewer. These ventilating openings should be provided for all sewers at intervals not greater than 100 yards; that is to say, not fewer than eighteen fixed openings for ventilation should exist on each mile of main sewer; but if a sewer is liable to deposit, it is impossible to say what amount of ventilation would suffice.

If sewer air at any sewer ventilator, or at any other point, should be offensive, it is an evidence that additional means for prevention of deposit and for ventilation of this sewer are required, and should, as soon as possible, be supplied.

The upper, or 'dead ends,' of all sewers and drains should have means provided for full ventilation continued beyond the junction of the last house-drain, combined with means of flushing. (Fig. 1, Plate VI.) Similarly, for detached houses, drains should never end at the house which has to be drained, but should be continued beyond and above to some higher point or ventilating shaft where means for full and permanent ventilation and flushing can be provided, so as effectively to relieve the house from any chance of sewage gas contamination.

Sewers in Steep Ground.

It is not always possible to avoid the construction of a sewer down a steep hill.

In such cases the sewer should terminate at its upper end in a ventilating opening, and the sewer should be divided by steps or falls (Fig. 2, Plate IV.); at each step a ventilating chamber should be provided with a flap-valve at the discharging end of the sewer, to compel the gases to pass through the ventilating shaft, instead of being drawn up the sewer.

When sewers discharge above the water level, their mouths should be protected to prevent the wind blowing in.

When the outlet is in a tide-way, or in a river subject to varying levels, the following plan will answer. The main sewer discharges between high and low water, but in order to prevent nuisance from the sewage running over the surface at low water, an iron pipe is led from the bottom of the main sewer to discharge below low water. (See Fig. 3, Plate VI.)

When the area to be drained is situated on hilly ground, intercepting sewers are employed to carry off the water from the higher levels independently of the lower levels. This is necessary in order to prevent inconvenience to the lower districts; and also to save expense of pumping in those cases where the lower districts are at so low a level as to require the sewage to be lifted in order to reach the outfall.

Gibraltar afforded a striking instance of the inconvenience caused by the water of the upper levels flowing into the lower levels. The town is at the foot of a rock—part is situated on the steep side of the rock, and part on a flat piece of land which is separated from the sea by the fortifications.

The sewers were carried down the steep streets which ran from the upper part of the town across the flat portion of the town, and through the line wall into the sea. One of the main sewers commenced at a height of about 128 feet above high-water mark, and reached the sea-level after a course of about 1,000 feet.

Another commenced at a height of 264 feet, and descended to the sea-level after a course of about 1,500 feet, 500 feet of the lower end being nearly horizontal. A third had a fall of 264 feet in 2,200 feet. A fourth discharged its water into a nearly horizontal main, after a fall of 232 feet in 1,550 feet. (Fig. 4, Plate VI.)

Therefore the rainfall on the surface of the town, and on the roofs of the houses, together with the deluge of surface water which descended from the highly inclined slopes of the rock above, ran with extreme rapidity from all the higher levels into the lower and flatter districts, where it used to burst the sewers, saturate the subsoil, and interfere with the efficient drainage of all the lower parts of the town.

The rapid current down the steep part became a slow stream in the flat portion, deposited a large sediment, and in dry weather became a source of intolerable nuisance. This has now been remedied by an intercepting sewer, which carries the water from the upper part of the town to the sea, independently of the lower levels.

The lower districts of London used to suffer from periodical flooding in consequence of the water from the high districts coming down upon the lower districts. In the case of London, there was the aggravation of the sewers delivering through the low level districts only at low water; and consequently when it was decided to exclude the sewage from the river, it became necessary to lift all the sewage which reached the low-lying districts to a sufficient height to enable it to flow away to the outfall near Barking. It was therefore necessary to make intercepting sewers to take the sewage of the high level districts and convey this part away by gravitation, and prevent it passing into the low-level sewers.

Fig. 5, Plate VI. shows the line of the intercepting sewers now laid down in London, by which the water which falls on the upper districts is carried off by gravitation, whilst the sewage carried by the sewers in the lower levels has to be pumped in order to flow away to the outfall.

Purification of Sewage.

When sewage has been brought to an outfall, the very important problem remains, what to do with it.

As in the case of air rendered impure by the operations of man, so in the case of sewage, nature is always at work to remove the impurity. Thus, however foul the water of a river may be rendered by turning sewage into it, the water will become gradually purer in its course.

Take the case of Paris. Above Paris the Seine presents a satisfactory appearance. The sewers of Paris discharge into the river black fœtid streams covered with layers of greasy matter which accumulates on the sides of the river. These streams transport particles of organic matter and *débris*, which are deposited as gray and black mud on the banks, or else form shoals. This mud is the seat of an active fermentation, throwing up innumerable bubbles of gas which burst at the surface of the water, the bubbles attaining sometimes in hot weather a diameter of 1½ metres (nearly 5 feet), dragging up the black mud with them to the surface; fish and plants cannot exist. But as the river leaves these sources of pollution, it gradually improves. From Epinay to Argenteuil the water is still of a deep colour, mud has disappeared, fish make their appearance. Below Bezons a most abundant vegetation clothes both banks, and large sheets of water plants partly impede the course of the river. At Meulan all visible sign of pollution has disappeared, and the river is chemically pure.

The diminution of oxygen is very remarkable; and it is this removal of the oxygen from the water by the sewage which is a frequent cause of sewage killing the fish in a river.

The conditions which regulate the purification depend on the volume of the river as compared with the volume of sewage, and the distance of flow.

In England, in consequence of the dense population, the rivers cannot be devoted to this purpose. Nor, indeed, does the sea always afford a satisfactory means of getting rid of sewage.

Matters which would remain suspended for many days in fresh water would be readily precipitated in a few hours when the water is saline; consequently where the sewage is poured into the sea in front of a town, unless there be strong tidal currents the foul particles are not carried away, but are precipitated and mingled with the sand and mud of the beach.

On this account the foreshores of many watering places are polluted by the deposition of sewage.

It follows, therefore, that some means must be taken in the case of every town to get rid of the danger to health consequent upon the existence of sewage.

Crude sewage ought not to be allowed to be turned into rivers or into the sea in this country. It must be purified.

When you desire to purify sewage the main point to be observed is that the sewage should be disposed of, if practicable, on the day of its production.

It is not desirable to retain it at all in tanks if it can be avoided, because decomposition will go on in them; in some cases, however, tanks are necessary.

Tanks may be necessary, as in the case of London sewage, to retain the flow when on the seashore or in a tidal estuary, until ebb-tide sets in.

Sewage is sometimes retained in tanks and treated with lime or chemicals to promote the deposition of the grosser particles.

But tanks cannot properly filter sewage: they can only store it for mechanical deposition, or for chemical treatment and deposition.

Sewage tanks ought therefore to be of simple construction, and should be open. With ordinary care, and if emptied and cleaned frequently, they need not cause any nuisance injurious to health; and the sediment, when emptied from the tanks, should be disinfected, and removed as rapidly as practicable. When any manufacture of manure for sale out of the sediment is carried on, care must, of course, be taken to prevent nuisance.

With these preliminary observations, I will now pass to the processes for purifying sewage.

In all these processes it will be found that the treatment entails a certain loss of head, and on that account it rarely happens that the town is sufficiently elevated to enable you to dispense with lifting the sewage in whole or in part, therefore when the rainfall is received with the sewage, the pumps have a very varying duty to perform, and you will easily understand why the exclusion of rain water from the sewer is so sought after.

The processes for purifying sewage fall under three classes:—

1st. Irrigation of land.

2nd. Downward filtration through a small area of adequate thickness of earth.

3rd. Deposition of the solid matter brought about by mixing the sewage with some foreign ingredient, which assists the precipitation, the effluent being then more or less fit to turn into a stream.

Irrigation.

In the application of sewage to land there are certain general principles which you should bear in mind.

Thoroughly drained land has the property of converting the nitrogenous organic matters in sewage into nitrates. These, however, are not stored up in the soil for utilization when required, but such as are not quickly absorbed by vegetation pass through the ground beyond the reach of the plant roots. In other words, the fertility of land is not increased by applying larger volumes of sewage than the growing crops on it can assimilate at once.

Hence, however well land may act as a purifier of sewage for sanitary purposes, it can only be relied on to utilize the manurial constituents of the sewage according to the requirements of the crops for the time being assimilating them, and any excess of the supply of manure over the demand by the crops is not stored up for subsequent use, but is wasted, and passes off in the subsoil drainage, either partially or wholly purified, according to the nature of the land, and of its preparation to filter and oxidise the sewage passed through it. Therefore, except in so far as the particular crop which is on the land at the time of irrigation is concerned, land is not made more fertile by filtering the sewage of a thousand people through an acre than it is if the sewage of a hundred only is applied.

In order to ensure that the purifying action of the soil shall not be destroyed, the soil must be allowed sufficient time after the application of sewage to become thoroughly aërated.

If the sewage be applied too often, not only does the nitrification often completely stop, but the soil entirely ceases to allow percolation, and becomes clogged.

Provided that sufficient time be allowed between the application of the sewage (four to eight days), and that the quantity of sewage be not in excess of the power of the soil to deal with, and does not tend to become saturated, it does not appear that the soil loses its power, even unaided by vegetation.

The areas which have been found in practice to answer are, for broad irrigation, about one statute acre to each hundred of population of a fully water-closeted town.

Sewage-farm irrigation, to be successful, requires special management.

One-twentieth only of any sewage farm should as a rule ever be under sewage at one time. Sewage should be applied to growing crops, because the readiest purifiers are the roots of plants.

Loamy, porous soil is the best for sewage irrigation, from a sanitary point of view. Where the land is of a stiff, clayey nature, it requires to be broken up and deep drained.

In laying the drains, special care is necessary to ensure their protection from the direct passage of the sewage and surface-water into them through cracks and open spaces. In clay soil cracks are so difficult to prevent that clay soil is a very undesirable one to employ.

The cleanest and cheapest mode of dealing with sewage is to apply the crude sewage direct, either by gravitation or by pumping, and so at once to distribute it in thin films over the land; the trouble, nuisance, and costs of tanking, screening, and filtering are then avoided, and the land is benefited by having the whole of the fresh sewage, sludge and fluid, incorporated with the soil; but this requires a great extent of land.

In preparing land to receive sewage the greatest economy should be used. Costly brick or earthenware carriers need not be made; but main carriers can be constructed in concrete, whilst tributary carriers can be formed with a spade or be ploughed into shape. Main carriers should be in level lengths, as any required fall can be obtained by vertical steps. The lay of the land necessarily determines the arrangements for distributing the sewage over the surface.

On sloping ground a series of catchwater drains may be necessary, following the contours of the ground. The sewage passes along the upper carrier, and then overflows over the space between it and the catchwater drain next below it, and so on to the bottom of the hill.

The position of the catchwater drains must depend upon the configuration of the ground.

In flatter ground the land should be laid out in ridge and furrow form, which is done easily with the plough. The carrier runs along the ridge, and the gutter is placed in the furrow with a deep underdrain. The width between the furrows varies according to the porosity of the soil, and may be anything between 30 and 150 feet, the inclination of the slope between the ridge and furrow varying between 1 in 25 and 1 in 150.

On some sewage farms more money has been expended per acre in surface forming and levelling than the first cost of the land, in this way more than doubling the rent without giving an equivalent benefit to the land. In some other cases nothing has been done to the land but to bring the sewage and flood it on in a slovenly way—growing weeds rather than grass. Both extremes are to be avoided.

The character of the effluent will depend upon the care with which the sewage is applied.

Thus Dr. Frankland found nearly 70 per cent. of the nitrogen originally in the sewage escaping in the effluent water from the Lodge Farm, Barking, when the sewage was not being properly applied to the land. On the other hand, Colonel Hope states that on his farm at Romford, during a whole year, only 10·69 per cent. escaped in the effluent, as the most careful supervision was exercised.

As regards the results of sewage farming I may instance the evidence of Mr. Brundell, who has the management of the Doncaster Sewage Farm. He stated that during nine years he has never applied any other manure than sewage; that last year the crops were the heaviest that have been produced, and the land remains just as capable of receiving the sewage as it ever was, and does not 'tire.'

Filtration through Land.

Sewage can be purified by simple filtration, provided it passes through a sufficient thickness of material. The purifying action of a filter is one of oxidation, dependent therefore upon the numerous surfaces which the pores of the filtering material present, and upon the presence of air in these pores.

Dr. Frankland made some experiments as to the filtration of London sewage through 15 feet of sand and chalk, and he found that a very satisfactory purification was effected when the sewage treated amounted to 5·6 gallons per cubic yard in 24 hours, the organic matter being converted chiefly into carbonic acid, water, and nitric acid.

It follows, therefore, that if a large area cannot be obtained for broad irrigation, a skilful manipulation of a much smaller area will enable a large volume of sewage to be purified on it.

Mr. Bailey Denton defines intermittent filtration as 'the concentration of sewage at *regulated intervals* on as few acres of land as will absorb and cleanse it without preventing the production of vegetation.'

He expresses the opinion that the sewage of 1,000 persons can be applied to an acre of such soils as are most suitably constituted, and of 250 persons to those soils which are least suitably constituted.

The following points have to be kept in view to obtain efficient filtration.

The filtration area must be laid out in plots carefully separated from one another, so that some plots may be at rest whilst others are in use.

The drains for removing the filtered sewage should be sufficiently deep to afford effective aëration to a depth of 6 feet. To secure this, the drains should be somewhat deeper—say a foot, if possible. Then under every square yard of surface there will exist two cubic yards of aërated filtering material, giving nearly 10,000 cubic yards per acre. Every cubic yard has a cleansing power varying from 4 to 12·4 gallons of sewage per diem.

A single acre drained so as to give 6 feet of aërated soil will purify 'sewage proper' in quantities varying from a minimum of 40,000 gallons up to a maximum of 124,000 gallons.

Where the depth of drainage is reduced to less than 6 feet, the superficial extent must be increased in proportion as the depth of underdrainage is diminished, in order to secure the necessary quantity of filtering material for purification.

The filtering area must be allowed from six to twelve hours, or even more, rest between each application of the sewage, for aëration; and this alternation will not suffice if the effluent water does not flow freely off from the bottom of the filter. When this takes place, atmospheric air follows the last part of each dose of sewage as it sinks through the filtering material, and so oxidises the organic matter retained in its pores.

Precipitation of Sewage.

The object of precipitation or chemical treatment is to remove in a solid, dry, or semi-dry state the putrescible constituents of the sewage, and to render the filtrate or effluent water sufficiently pure to pass into streams.

I do not think that any chemical system of sewage purification has yet produced a really pure effluent, but by some of the various methods in use, an effluent water can be produced which could be passed into large rivers, or indeed into any rivers, where the highest degree of purity is not required; and where a still purer effluent is necessary, that is to say, one which has to be admitted into a stream of which the water may be required for use, the effluent should be passed from the precipitating tanks through a small area of land serving as a filter, by which the remainder of the impurities, which precipitation by the addition of chemicals cannot remove, may be abstracted.

There are two points connected with the effluent from precipitation processes which ought to be borne in mind. In the first place, we must not have an alkaline effluent, because wherever there is alkalinity there is a tendency to putrefaction. Where we can keep the effluent acid we are safe, and if it be neutral the carbonic acid of the atmosphere will make it safe. Another point, proved many years ago by Professor Heisch, is that we must not have phosphoric acid in the effluent, or there will be a tendency to produce the low confervoid growth commonly called sewage fungus. That is a great difficulty with any process which employs any phosphate in it.

The simplest of the precipitation processes is the lime process, in which cream of lime is mixed with the fresh sewage, and after some hours' deposition in tanks an effluent more or less clarified is allowed to pass away.

This process, which is simple and cheap, does not, however, satisfy the conditions of purification required for allowing the effluent to pass into fresh-water streams; and moreover, it creates a large amount of sludge composed of carbonate of lime and non-nitrogenous organic matter, which is not sufficiently valuable as manure to bear any distant carriage.

Moreover, an objection to the use of lime arises where the effluent passes into a river containing fish, as free lime is most injurious to fish. Where it is used under these circumstances great care must be taken that free lime does not escape. Fig. 1, Plate VII. shows a form of tank for mixing sewage with either lime or other chemical, and allowing it to deposit. The chemical preparation is added to the sewage at the sewage inlet, and the mixture is passed gradually from one tank to the next, the effluent flowing away at the outlet, while the sludge is run off from the bottom of the tank at intervals into the sludge channel.

The late General Scott, Royal Engineers, invented a process by which the sewage is used to make cement, to remove some of the difficulties of the lime process. General Scott's process is in use at Burnley.

The sewage, on reaching the works, is passed through two small tanks (catchpits), where the grosser matters, such as pebbles, sand, &c., sink to the bottom.

These tanks are cleaned out alternately about once a week. The sewage is then strained through iron gratings, with bars about ¾ inch apart, which arrest the rags, shavings, cotton waste, and other articles likely to choke the pumps.

The necessary quantity of milk of lime, and clay proportioned to the strength and quality of the sewage, is then added, and the limed sewage, which becomes thoroughly precipitated, is passed into one of two series of tanks, where the precipitate is deposited in the form of sludge. Each series of tanks is divided into three compartments, the two first, at Burnley, being each 50 feet by 40 feet, and the third or final compartment 100 feet by 40 feet. The bulk of the sludge is deposited in the two first tanks, and the third, through which it passes more slowly, arrests only the very light suspended matters. The effluent then flows into the river.

The sewage takes about four hours to pass through the tanks. When a sufficient quantity of sludge has been collected, it is pumped from the tanks into filtering beds, where, after eight or nine days, it parts with the greater part of the moisture, and contains on an average only 65 per cent. of water. The sludge should then be sampled to test the amount of lime it contains, and if necessary a further small quantity is added to bring up the amount to that required for a good cement. This addition is, however, rarely needed, as practice soon enables those in charge to proportion the lime with sufficient nicety in the precipitation of the sewage.

The sludge is dried, and finally burnt in kilns similar to those used for burning Portland cement. The resulting clinker is ground up, and produces what is described as an excellent hydraulic cement, having a composition similar to that of Portland cement.

The cost of drying is 7*s.* per ton. The coke for burning in kilns is 1*s.* 4*d.* per ton. Labour, grinding, and bagging, 15*s.* per ton.

The tensile strength after fourteen days is stated to be 400 to 500 lbs. per $1\frac{1}{2}$ inch square, and after two months to become 800 to 900 lbs.

The demand for the cement produced is greater than the works can supply.

The present total expenditure per week for labour and materials in purifying the sewage of Burnley and converting the resultant sludge into cement is stated to be 25*l.*, and the total cement produced averages $13\frac{1}{4}$ tons a week, which sells for 36*s.* per ton. The cost to the town is about 7·2 per head of the population.

The A. B. C. process of sewage purification is the one which seems to have attained the greatest prominence, and by its means an effluent, sufficiently satisfactory to be placed in a running stream whose volume is from fifteen to twenty times the bulk of the effluent, seems to be produced from chemicals alone, unaided by land, and without nuisance.

The A. B. C. process consists of using alum, blood, clay, and charcoal. The following are the ingredients employed :—

		Proportion.
A.	Crude alum cake, containing 47 per cent. of sulphate of alumina	2
B.	Blood	$\frac{1}{24}$
C.	Clay, containing 35 per cent. of moisture	4
	Charcoal, containing 40 per cent. of moisture	3

The charcoal aids the deodorizing properties of the sulphate of alumina, whilst the clay, in a state of fine subdivision, offers a large surface for the absorption of impurities which are carried down with the precipitate.

The blood is essentially a liquid highly charged with albumen; albumen is instantly coagulated in the presence of alum, and in the same way as this ready coagulability of albumen is utilised in fining wine and coffee, so it is made use of in this process by joining with and assisting the alumina in its precipitation.

The blood, clay, and charcoal, after being ground together in a pug mill, with sufficient water to enable them to flow, form the first ingredients, which are mixed with the sewage. The alum is next added in a dissolved state. The sewage thus treated flows along a salmon-ladder mixer into brick tanks, which are worked in pairs, the effluent from one passing to a second for further precipitation before it is discharged into the river. The effluent water is clear and practically inodorous.

The sludge is partially dried by filter presses, and further by artificial heat or exposure to the air, when it is ground into a powder (which contains about 14 per cent. of moisture), and bagged for sale.

A very large proportion of this sludge or manure consists of the ingredients added to the sewage. This process can be seen in use at Aylesbury and at other places.

There are numerous other methods of sewage precipitation in use in various places, but the same general principles govern all; and this brief account of the processes which are in use for dealing with sewage will give you some idea of the importance and difficulties of the problem.

General Results.

You will see that no one system of sewage disposal can be adopted universally, but that each locality will require to be treated according to the facilities which it presents.

You may conclude that one or other of the processes based upon subsidence and precipitation, if combined with filtration through land, will always furnish an effluent sufficiently purified to be discharged into streams or rivers, provided always that they are of adequate size to effect a sufficient amount of dilution. Where land can be obtained at a reasonable price, with favourable gradients, and with soil of a suitable quality, a sewage farm, properly conducted, is the best method of disposing of water-carried sewage.

As a rule, no profit can be derived from sewage utilisation; but for health's sake, without regard to commercial profits, sewage and excreta must be got rid of at any cost.

LECTURE V.

THE DISPOSAL OF REFUSE.

The refuse which has to be dealt with, whether in houses, in towns, in barracks, or in camps, falls under the heads of—

1. Ashes.
2. Kitchen refuse.
3. Stable manure.
4. Solid or liquid ejections.
5. Rain water and domestic waste water, including water for personal ablution, kitchen washing-up, washings of passages, stables, yards, and pavements.

Refuse in Camps.

The disposal of such matters in camps deserves notice first. In a camp you have the simplest form of dealing with them; for a camp is a town without paving or drainage, where the evils of surface pollution are intensified if not prevented. The water used for domestic purposes in a camp is very limited, as it is all carried by hand from the source of supply. In a temporary camp waste water and liquid ejections are absorbed by the ground. Comparatively little harm can result from the surface pollution caused by the refuse water from cooking and washing in the case of a merely temporary occupation, provided care be taken to prevent any pollution whatever of the ground in the neighbourhood of wells, springs, or places whence the water is obtained. The places in which cooking is carried on should have a pit or trench for slops.

For the disposal of offal, burning is best; but it should be done in a close furnace, with a chimney of sufficient height to ensure thorough combustion, or else burning may give rise to much nuisance; burying at a safe distance is often advisable. If buried, some disinfectant should be added to the soil; but where the occupation is permanent, the pollution of the subsoil thus caused would be dangerous.

If there is not time to bury an animal, then bury the viscera and make a fire of any rubbish inside the animal's trunk; or if that cannot be done, stab the animal's body in several places to give free exit to gases and entrance to air.

In certain soils and certain conditions of locality and weather it may be necessary to take precautions in a camp, however temporary, to facilitate the rapid flowing away of rain water. And however temporary the occupation of a camp, there should always be places provided for latrines and for the deposit of horse-dung and other solid refuse. A camp unprovided with latrines would always be in a state of danger from epidemic disease.

One of the most frequent causes of an unhealthy condition of the air of a camp in former times has arisen, either from neglect to provide latrines, so that the ground outside the camp becomes covered with filth, or constructing the latrines too shallow, and exposing too large a surface to rain, sun, and air.

The Quartermaster-General's regulations provide against these contingencies; but it is advisable here to recapitulate the general principles which should govern camp latrines, because it is of the greatest importance to health that they should be so arranged and managed that no smell from them should ever reach the men's tents. This can be ensured by very simple precautions:—

(1.) The latrines should be placed to leeward, with respect to prevailing winds, and at as great a distance from the tents as is compatible with convenience.

(2.) They should be dug narrow and deep, and their contents covered over every evening with at least a foot of fresh earth. A certain bulk and thickness of earth are required to absorb the putrescent gas, otherwise it will disperse itself and pollute the air to a considerable distance round.

(3.) When the latrine is filled to within two feet six inches or three feet of the surface, earth should be thrown into it, and heaped over it like a grave to mark its site.

(4.) Great care should be taken not to place latrines near existing wells, nor to dig wells near where latrines have been placed. The necessity of these precautions to prevent wells becoming polluted is obvious.

Screens made out of any available material are, of course, required for latrines.

These arrangements apply to a temporary camp, and are only admissible under such conditions.

A deep trench saves labour, and places the refuse in the most immediately safe position, but a buried mass of refuse will take a long time to decay; it should not be disturbed, and will taint the adjacent soil for a long time. Whilst, therefore, this is of little consequence in a merely temporary encampment, and so far as the soldiers are concerned, it might entail serious evils in localities continuously inhabited, and where a very prolonged occupation was contemplated such a plan might not be advisable.

Around many Indian villages it has been the universal custom of the people to foul the fields, roads, streets, and water-courses. No doubt the sunshine diminishes the evils of this surface pollution, but it is represented as being very serious to health and offensive to decency. Consequently, in order to check the evils of this surface pollution the following plan of trench has been adopted in Indian villages, as a more permanent arrangement than that above described for camp use.

Long trenches are dug, at about one foot or less in depth, at a spot set apart, about 200 or 300 yards from dwellings. Matting screens are placed round for decency. Each day the trench which has received the excreta of the preceding day is filled up, the excreta being covered with fresh earth obtained by digging a new trench adjoining, which, when it has been used, is treated in the same manner. Thus the trenches are gradually extended, until sufficient ground has been utilised, when they are ploughed up, and the site used for cultivation.

The Indian plough does not penetrate more than eight inches, consequently, if the trench is too deep the lower stratum is left unmixed with earth, forming a permanent cesspool, and becomes a source of future trouble.

It is to be observed, however, that in the wet season these trenches cannot be used; and in sandy soil they do not answer.

This system, although it is preferable to what formerly prevailed, viz., the surface defilement of the ground all round villages, and of the adjacent water-courses, is fraught with danger, unless subsequent cultivation of the site be strictly enforced, because it would otherwise retain large and increasing masses of putrefying matter in the soil, in a condition somewhat unfavourable to rapid absorption.

These arrangements are applicable only to very rough life or very poor communities.

Refuse in Barracks.

Having thus drawn your attention to the main principles to be observed in dealing with refuse in cases of temporary occupation, we will now pass on to consider the conditions to be observed when the occupation is more permanent, as in barracks, houses, towns, &c.

The question of the removal of kitchen refuse, manure, &c., from barracks first calls for notice.

The first principle to be observed in removing the solid refuse from all habitations is that every decomposable substance should be taken away at once. This principle applies especially in warm climates. That is to say, you should regard it as an axiom in sanitation that all refuse should be removed daily out of inhabited buildings.

As having a bearing upon this question, it is curious to consider the effect which the habit of accumulating refuse in and around habitations had upon former generations. So late as the reign of Henry VIII., we read in a letter from Erasmus to the king's physician, upon an outbreak of sweating sickness, that 'Englishmen never consider the aspect of the doors and windows; their chambers are built in such a way as to admit of no ventilation. A great part of the walls of the houses is occupied by glass casements, which admit light but exclude air, yet they let in the draught through holes and corners, in which pestilential filth often stagnates. The floors are in general laid with white clay, and are covered with rushes, but so imperfectly that the bottom layer is left undisturbed, sometimes for twenty years, harbouring expectorations, vomiting, the leakage of dogs and men, all droppings, scraps of fish, and other abominations not fit to be mentioned. When the weather changes a vapour is exhaled from the floors thus covered, which is very detrimental to health.'

The result of this method of living was that in the time of Henry VIII. the sweating sickness appeared more than once. It is stated that in 1516 it carried off 12,000 persons in ten or twelve days; and that those struck with the disease were carried off in the course of a few hours. No remedies were effectual, and the most opposite treatments were equally unsuccessful. The only preventive was moving into fresh, pure air, and separating the households.

We have made much progress since then; but even last year the Royal Commission on the Sanitary State of Dublin reported that in some houses in that city the ashpits were large enough to hold the refuse of not months but years, and were consequently never really emptied, because the contractors would take what was easiest from the top and leave the putrefying mass at the bottom.

The daily removal of refuse entails the necessity of, first, some receptacle to hold it till removed; this, however, should be as small as circumstances permit, and of non-absorbent material, and secondly, a place for the deposit of the refuse in cases where it cannot be finally disposed of at once; and therefore, whilst the removal of the refuse out of the inhabited building should be imperative, the disposal of the refuse outside may be arranged for in various ways to suit local convenience. In open situations, exposed to cool winds, there is less danger of injury to health from decomposing matters than there would be in hot, moist, or close positions. In the country, generally, there is less risk of injury than in the close parts of towns. These considerations show that the same stringency as to the choice of a place in which to deposit refuse is not necessarily required everywhere. Position by itself affords a certain degree of protection from nuisance. There is less risk from a dung-heap to the leeward than to the windward of a barrack. The amount of decomposing matter usually produced is also another point to be considered. A small daily product is not, of course, so injurious as a large product. Even the manner of accumulating decomposing substances influences their effect on health.

The receptacles in which refuse is temporarily placed, such as ash-pits and manure-pits, should never be below the level of the ground.

If a deep pit is dug in the ground, into which the refuse is thrown in the intervals between times of removal, rain and surface-water will mix with the refuse, and hasten its decomposition, and generally the lowest part of the filth will not be removed, but will be left to fester and taint the whole surrounding atmosphere.

I could mention many barracks where I found large, deep dung-pits and ash-pits, uncovered, with uneven bottoms, which, when I had them emptied to the bottom, I found that it was evident the lower strata had been left for a long time, and was in such a putrefying state as to accelerate the putrefaction of all new refuse added at the top.

In all places where the occupation is permanent, that is to say in the case of barracks, hospitals, houses, and towns, the following conditions should be attended to in arranging places of temporary deposit, previous to the final disposal of the refuse:—

(1.) That the places of deposit be sufficiently removed from inhabited buildings to prevent any smell being perceived by the occupants.

(2.) That the places of deposit be as small as possible consistently with arrangements for the final disposal of the refuse. That they be above the level of the ground—never dug out of the ground. The floor of the ash-pit or dung-pit should be at least six inches above the surface-level.

(3.) That the floor be paved with square setts, or flagged, or asphalted, and drained, so as to be capable of thorough cleaning when the refuse is removed.

(4.) That ash-pits be covered.

(5.) That a space should be paved in front, so as to provide that the traffic which takes place in depositing the refuse, or in removing it, shall not produce a polluted surface.

In towns, those parts of the refuse which cannot be utilized for manure or otherwise are burned. But this is an operation which, if done unskilfully, without a properly constructed kiln, may give rise to nuisance. There are several forms of kiln.

The following is a general description of Fryer's Destructor, which is in use at Ealing:—

The materials to be consumed are tilted from the carts in which they are brought on to a screen, which is kept moving up and down by a cogged wheel kept in motion by a steam engine. The fine ashes fall through the screen, the coarser material being jerked forward on the top of the Destructor.

This is simply a close furnace fed with the refuse through holes in the top. The heat from the combustion is passed round a tubular boiler, and thence up a tall chimney. The boiler supplies steam sufficient to work a steam engine, which at Ealing is employed to perform various operations in connection with purification of the sewage.

I mention this appliance because, although the refuse from barracks can generally be got rid of by contract on favourable terms, cases do arise where it might be necessary for the engineer officer to provide for the complete disposal of all refuse, and in such cases some arrangement for the destruction of what could not be utilized would be required.

Disposal of Excreta.

The next question is the removal of solid or liquid ejections, and the removal of domestic water from all dwellings where the occupation is permanent.

The disposal of excreta is not necessarily connected with that of the domestic water; but the same preliminary condition governs both, viz.: the immediate and complete removal from the house of all foul and effete matter directly it is produced.

The immediate removal of excreta can be attained, in connection with the removal of domestic water, by the water-closet, but it could equally be attained without drains, if desired. The earth-closet or the pail system or the French system of *tinettes* are severally methods of immediate removal which are safe.

Cesspools in a house do not fulfil this condition of immediate removal. They serve for the retention of excremental and other matters.

I showed you in my last lecture how the existence of cesspools in towns and under houses had been a cause of disease.

In a porous soil it endangers the purity of the wells.

The Indian cities afford numerous examples of subsoil pollution. The Delhi ulcer was traced to the pollution of the wells from the contaminated subsoil; and the soil in many cities and villages is loaded with nitre and salt, the chemical results of animal and vegetable refuse left to decay for many generations, from the presence of which the well water is impure.

In the town of Ahmedabad, in India, the general death-rate is permanently 53 per 1,000; and the children under one year die at the rate of 333 per 1,000 born, or one out of every three. This is owing to the whole town being perforated with filth wells, into which all refuse has been thrown for generations, and to the water being drawn from wells situated in the soil thus perforated, the air above these sources of impurity and the water in the soil being equally polluted.

There are many factories of saltpetre in India whose supplies are derived from the polluted subsoil; and during the great French wars, when England blockaded all the seaports of Europe, the first Napoleon obtained saltpetre for gunpowder from the cesspits in Paris.

Cesspools are inadmissible where complete removal can be effected.

Cesspits may, however, be a necessity in some special cases, as, for instance, in detached houses or a small detached barrack. Where they cannot be avoided, the following conditions as to their use should be enforced:—

1st. A cesspit should never be located under a dwelling. It should be placed outside, and as far removed from the immediate neighbourhood of the dwelling as circumstances will allow.

2nd. It should be formed of impervious material so as to permit of no leakage.

3rd. It should be ventilated.

4th. No overflow should be permitted from it.

5th. When full it should be thoroughly emptied and cleaned out; for the matter left at the bottom of a cesspit is liable to be in a highly putrescible condition.

6th. Direct communication with the house should be cut off by means of a ventilated trap placed on the pipe leading from the water closet to the cesspit, and an air current should be carried up to above the roof of the house, and open at the top.

Where a cesspit is unavoidable, perhaps the best and least offensive system for emptying it is the pneumatic system.

The pneumatic system acts as follows:—A large air-tight cylinder on wheels, or what answers equally, a series of air-tight barrels connected together by tubes about three inches diameter, placed on a cart, is brought as near to the cesspit as is convenient; a tube of about the same diameter is led from the stop-cock on the cylinder or nearest barrel to the cesspit; the air is then exhausted in the barrels or cylinder either by means of an air-pump, or by means of injected steam, which on condensation forms a vacuum; the stop-cock is then opened and the contents of the cesspit are drawn through the tube by the atmospheric pressure into the cylinder or barrels.

A plan which is practically an extension of this system has been introduced by Captain Liernur in Holland.

He removes the fæcal matter from water-closets and the products of kitchen sinks by pneumatic agency. He places large air-tight tanks in a suitable part of the town, to which he leads pipes from all the houses. He creates a vacuum in the tanks, and thus sucks into one centre the fæcal matter from all the houses.

The substitutes for the cesspit which have been tried, and which retain the principle of the hand removal of excreta, may be generally classed as follows:—

The first was the combination of the privy with an ashpit above the surface of the ground, the ashes and excreta being mixed together, and both being removed periodically.

The next improvement was the provision of a movable receptacle. Of this type the simplest arrangement is a box placed under the seat, which is taken out periodically, the contents emptied into the scavenger's cart, and the box replaced.

The difficulty of cleansing the angles of the boxes led to the adoption of oval or round pails, and the removal of the pail and its contents to the scavenger's yard. The pail is placed under the seat and removed at stated intervals, or when full, and replaced by a clean pail.

In Marseilles and Nice a somewhat similar system is in use. They employ cylindrical metal vessels called *tinettes*, furnished with a lid which closes hermetically, each capable of holding eleven gallons. The household is furnished with three or four of these vessels, and when one is full the lid is closed hermetically, the vessel thus remaining in a harmless condition in the house till taken away by the authorities and replaced by a clean one. The contents are converted into manure.

In this country the question of the offensiveness of the open pail was endeavoured to be met by the daily use of some form of deodorising material.

In the north of England the arrangement generally is that the ashes shall be passed through a shoot, on which they are sifted—the finer fall into the pail to deodorise it, the coarser pass into a box, whence they can be taken to be again burned; whilst a separate shoot is provided for kitchen refuse which falls into another pail adjacent.

Probably the best known contrivance for deodorising the excreta is the dry-earth system as applied in the earth-closet, in which advantage is taken of the deodorising properties of earth.

Dry earth is a good deodoriser: 1½ lb. of dry earth of good garden ground or clay will deodorise each excretion. A larger quantity is required of sand or gravel. If the earth after use is dried, it can be applied again, and it is stated that the deodorising powers of earth are not destroyed until it has been used ten or twelve times.

This system requires close attention, or the dry-earth closet will get out of order; as compared with water-closets, it is cheaper in first construction, and is not liable to injury by frost; and it has this advantage over any form of cesspit that it necessitates the daily removal of refuse.

The cost of the dry-earth system per 1,000 persons may be assumed as follows:—

Cost of closets, say	£500	
Expense of ovens, carts, horses, &c.	250	
Total capital	£750 @ 5% =	£37 10*s*. Interest.

Wages of two men and a boy per week	£1 12*s*.
Keep of horses, stables, &c.	18
Fuel for drying earth 1*s*. 6*d*. per ton dried daily	1 10
Cost of earth and repairs, &c.	14
Weekly expenses	£4 14

Yearly expenses	£247 0	= 4*s*. 11*d*. per ton per annum.
Interest	37 10	
	£284 10*s*.	

against which should be put the value of the manure. But the value of manure is simply a question of carriage. If the manure is highly concentrated, like guano, it can stand a high carriage. If the manuring elements are diffused through a large bulk of passive substances, the cost of the carriage of the extra, or non-manuring elements, absorbs all profit. If a town, therefore, by adding deodorants to the contents of pails, produces a large quantity of manure, containing much besides the actual manuring elements—such as is generally the case with dry earth—as soon as the districts immediately around have been fully supplied, a point is quickly reached at which it is impossible to continue to find purchasers.

The dry-earth system is applicable to separate houses, provided the closets be outside the house, or to institutions where much attention can be given to it, but it is inapplicable to large towns, from the practical difficulties connected with procuring, carting, and storing the dry earth, and the impossibility of using it inside a house without its being offensive.

With the idea that if the solid part of the excreta could be separated from the liquid and kept comparatively dry, the offensiveness would be much diminished and deodorisation be unnecessary; a method for getting rid of the liquid portion by what is termed the Goux system has been in use at Halifax.

This system consists in lining the pail with a composition formed from the ashes and all the dry refuse which can be conveniently collected, together with some clay to give it adhesion. The lining is adjusted and kept in position by means of a core or mould (Fig. 3, Plate VII.), which is allowed to remain in the pails until just before they are about to be placed under the seat; the core is then withdrawn, and the pail is left ready for use (Fig. 2, Plate VII.)

The liquid which passes into the pail soaks into this lining which thus forms the deodorising medium.

The proportion of absorbents, in a lining 3 inches thick, to the central space in a tub of the above dimensions would be about two to one; but unless the absorbents are dry, this proportion would be insufficient to produce a dry mass in the tubs when used for a week, and experience has shown that after being in use for several days the absorbing power of the lining is already exceeded, and the whole contents have remained liquid.

There would appear to be little gain by the use of the Goux lining as regards freedom from nuisance, and though it removes the risk of splashing and does away with much of the unsightliness of the contents, the absorbent, inasmuch as it adds extra weight which has to be carried to and from the houses, is rather a disadvantage than otherwise from the manurial point of view.

The simple pail system, which is in use in various ways in the northern towns of England, and in the permanent camps to some extent at least, and of which the French tinette is a very much improved form, is more economically convenient than the dry-earth system or the Goux or other deodorising system, where a large amount of removal of refuse has to be accomplished; because by the pail system the liquid and solid ejections may be collected with a very small, or even without any, admixture of foreign substances; and, according to theory, the manurial value of dejections per head per annum ought to be from 8*s.* to 10*s.*

The great superiority, in a sanitary point of view, of all the pail or pan systems over the best forms of the old cesspits, or even the middens, is due to the fact that the interval of collection is reduced to a minimum, the changing or emptying of the receptacles being sometimes effected daily, and the period never exceeding a week.

The excrementitious matter is removed without soaking in the ground or putrefying in the midst of a population.

Waste Water.

These plans for the removal of excreta do not deal with the equally important refuse liquid, viz., the waste water from washing, stables, &c.

But it is necessary to have drains for the purpose of removing the waste water, and it would save the expense of carting away the solid refuse if you allow this waste water to carry away the excreta at the same time.

In any case you must have drains for removing the fouled water. Down these drains it is evident that much of the liquid excreta will be poured; and thus you must take precautions to prevent the gases of decomposition, which the drains are liable to contain, from passing into your houses.

I have already explained the difficulties of getting rid of sewage on a large scale.

There is a method which you might find useful on a small scale, to which I will now draw your attention, as it is applicable to detached houses or small barracks, viz., the plan of applying the domestic water to land through underground drains, or what is called subsoil irrigation.

This system affords peculiar facilities for disposing of sewage matter without nuisance.

There are many cases where open irrigation in close contiguity to mansions or dwellings might be exceedingly objectionable, and in such cases subsoil irrigation supplies a means of dealing with a very difficult question.

This system was applied some years ago by Mr. Waring in Newport in the United States. It has recently been introduced into this country.

The system is briefly as follows:—

The water from the house is carried through a water-tight drain to the ground where the irrigation is to be applied. It is there passed through ordinary drain-pipes, placed one foot below the surface, with open joints, by means of which it percolates into the soil. Land drains, four feet deep, should be laid intermediately between the subsoil drains to remove the water from the soil.

The difficulty of subsoil irrigation is to prevent deposits, which choke the drains, and if the foul domestic water is allowed to trickle through the drains as it passes away from the house it soon chokes the drains. It is therefore necessary to pass it in flushes through the drains, and this can be best managed by running the water from the house into one of Field's automatic flush tanks, which runs off in a body when full.

Disconnection of House Drains.

When you have water-closets and drainage, the great object to be attained in house drainage is to prevent the sewer gas from passing from the main sewer into the house drains. It was the custom to place a flap at the junction of the house drain with the sewer, but this flap is useless for preventing sewer gas from passing up the house drain. The plan was therefore adopted of placing a water-trap under the w.c. basin, on the sink, &c., in direct communication with the drain. The capacity of water to absorb sewer gas is very great, consequently the water in the trap would absorb this gas. When the water became warm from increase of temperature it would give out the gas into the house; when it cooled down at night it would again absorb more gas from the soil-pipe; and frequent change of temperature would cause it to give out and re-absorb the gas continually.

These objections have led to the present recognised system, viz. (1st) to place a water-trap on the drain to cut off the sewer gases from the foot of the soil-pipe; and next, to place an opening to the outer air on the soil-pipe between the trap and the house, and thus to secure efficient disconnection between the sewer and the house (Figs. 4 and 5, Plate VII.)

It is, moreover, necessary to produce a movement of air and ventilation in the house drain-pipes to aërate the pipe and to oxidise any putrescible products which may be in it. To do this we must ensure that a current of air shall be continually passing through the drains; both an inlet and an outlet for fresh air must be provided in the portions of the house drain which are cut off from the main sewer, for without an inlet and outlet there can be no efficient ventilation. This outlet may be formed by prolonging the soil-pipe at its full diameter, and with an open top, to above the roof, in a position away from windows, sky-lights, or chimneys. And an inlet may be obtained by an opening into the house drain, on the dwelling side of and close to the trap, through the disconnecting man-hole or branch-pipe before mentioned, or, where necessary, by carrying up the inlet by means of a ventilating pipe to above the roof (Fig. 7, Plate VII.) The inlet should be equal in area to the drain-pipe, and not in any case less than four inches in diameter.

If it were not for appearance, and the difficulty of conveying the excreta without lodgments, an open gutter might be preferable to a closed pipe.

Condition of House Drainage.

This arrangement is based on the principle that there should be no deposit in the house drains. Therefore the utmost care should be taken to lay the house drains in straight lines, both in plan and gradient, and to give the adequate inclination; and, in addition to this precaution, the following conditions should be observed in house drains:—

(1.) As to material of pipes.

House drains should be made either of glazed stoneware pipes or fireclay pipes with cement joints, or preferably of cast-iron pipes jointed with carefully-made lead joints, or with turned joints and bored sockets, or connected by means of planed flanges.

I say preferably of cast iron, and the pipes must all be carefully tested by a high water pressure.

In New York the iron soil-pipe, with joints made with lead, is now required by the municipal regulations. It is a stronger pipe than a rain-water pipe. The latter will often be found to have holes. A lead joint cannot be made properly in a weak pipe, therefore the lead joint is to some extent a guarantee of soundness.

Lead pipes will be eaten away by water containing free oxygen without carbonic acid, therefore pure rain-water injures lead pipes. An excess of carbonic acid in water will also eat away lead.

You will find that in many cases pin-holes appear in a soil-pipe, and, when inside a house, that allows sewer gas to pass into the house.

Moreover, lead is a soft material. It is subject to indentations, to injury from nails, to sagging. A cast-iron pipe, when coated with sewage-matter, does not appear to be much subject to decay; and if of sufficient substance, it is not liable to injury. When once well fixed it has no tendency to move. I would, therefore, advocate cast-iron in lieu of lead soil-pipes.

In fixing the soil-pipe which is to receive a w.c. the trap should form part of the fixed pipe; so that if there is any sinking the down pipe will not sink away from the trap, but the iron pipe should be supported like a column on a solid base.

It is, however, not sufficient to provide good material. There is nothing which is more important in a sanitary point of view than good workmanship in house drainage.

In this matter, it is on details that all depends. Just consider: the drain-pipes, under the best conditions of aëration, contain elements of danger; and those pipes are composed of a number of parts, at the point of junction of any one of which the poison may escape into the house.

You thus perceive how necessary it is first to reduce the poison to a minimum by cutting off the sewer gas, which might otherwise pass from the street sewer to the house drain; and in the next place to be most careful in the workmanship of every part of your house drains and soil-pipes. Reduce your danger where you can by putting your pipes outside. But you cannot always do that—for instance, at New York and in Canada they would freeze.

(1.) Every drain-pipe in house drainage should be proved to be water-tight after being fixed by plugging up the lower end of the drain-pipe and filling it with water.

In no case should a soil-pipe be built up inside a wall. It should be so placed as to be always accessible.

If the pipes are to be placed inside a house, properly formed chases rendered inside should be formed when the wall is built; the practice of shaking the wall by cutting chases in it for pipes is most objectionable.

(2.) The pipes should be generally four inches diameter. In no instance need a drain-pipe inside a house exceed six inches in diameter.

(3.) Every drain of a house or building should be laid with true gradients, in no case less than $\frac{1}{100}$, but much steeper would be preferable. When from circumstances the drain is laid at a smaller inclination, a flush tank should be provided at the upper end. Drain-pipes should be laid in straight lines from point to point. At every change of direction there should be reserved a means of access to the drain, so as to allow of looking through the drain from one point to the next point.

(4.) No drain should be constructed so as to pass under a dwelling-house, except in particular cases when absolutely necessary. In such cases the pipes should be of cast-iron, and the length of drain laid under the house should be laid perfectly straight; a means of access should be provided at each end; it should have a free air-current passing through it from end to end, and a flush tank should be placed at the upper end.

(5.) Every house drain should be arranged so as to be capable of being flushed, and kept at all times free from deposit.

(6.) No house drain should terminate in a dead end; each branch should terminate in a suitable opening, so as to afford a current of air through the drain, either from the opening already mentioned in the intercepting chamber or otherwise if desirable, and no pipe or opening should be used for ventilation unless the same be carried upwards without angles or horizontal lengths, and with tight joints. The size of such pipes or openings should be fully equal to that of the drain-pipe ventilated.

(7.) The upper extremities of ventilating pipes should be at a distance from any windows or openings, so that there will be no danger of the escape of the foul air into the interior of the house from such pipes.

The soil-pipe should terminate at its lower end in a properly ventilated disconnecting trap, so that a current of air would be constantly maintained through the pipe.

(8.) No rain-water pipe and no overflow or waste-pipe from any cistern or rain-water tank, or from any sink (other than a slop-sink for urine), or from any bath or lavatory, should pass directly to the soil-pipe; but every such pipe should be disconnected therefrom, by passing through the wall to the outside of the house, and discharging with an end open to the air and over a trapped gully.

Waste Water Fittings.

I would now draw your attention to some points of detail in the fittings for carrying away waste water.

First, with regard to lavatories. As already mentioned, every waste-pipe from a sink should deliver in the open air; but it should have an opening at its upper end as well as at its lower end to permit a current of air to pass through it, and it should be trapped close to the sink so as to prevent the air being drawn through it into the house; otherwise you may have an offensive smell from it.

I will give you an instance. At University College Hospital there are some fire tanks on the several landings. The water flows in every day, and some flows away through the waste-pipes. These pipes, which carry away nothing but fresh London water to empty in the yard, got most offensive simply from the decomposition of the sediment left in them by the London water passing through them day after day.

A small waste-pipe from a bath or a basin is a great inconvenience, as it makes it a very difficult operation to cleanse the basin or bath. They should be of a size to empty rapidly—for a bath 2 inches, a basin 1½ inch.

There are other points connected with fittings to which I would call your attention.

The great inventive powers which have been applied to the w.c. pan are an evidence of how unsatisfactory they all are.

Many kinds of water-closet apparatus and of so-called 'traps' have a tendency to retain foul matter in the house, and therefore in reality partake more or less of the nature of small cesspools; and nuisances are frequently attributed to the ingress of 'sewer-gas' which have nothing whatever to do with the sewers, but arise from foul air generated in the house drains and internal fittings.

The old form was always made with what is called a D trap.

Avoid the D trap. It is simply a small cesspool which cannot be cleaned out.

Any trap in which refuse remains is an objectionable cesspool.

It is a receptacle for putrescible matter.

The trap for basins and closets least liable to retain refuse, in its simplest form, is a bent lead pipe. If properly made such a trap is always smooth and without corners.

The depth of dip of a trap should depend on the frequency of use of the trap. It varies from ½ in. to 3½ in.

When a trap is rarely used the dip should be deeper than when frequently used, to allow of evaporation.

In the selection of a w.c. pan, the object to be attained is to take that form in which all the parts of the trap can be easily examined and cleaned, in which both the pan and the trap will be washed clean by the water at each discharge, and, if it is a valve closet, in which the lever movement of the handle will not allow of the passage of sewer gas.

If you place several w.c.'s on the same soil-pipe you must make provision for a supply of air to the junction pipe leading from the trap of each w.c. to the soil-pipe, close to the trap and independent of the soil-pipe itself; otherwise the rush of water down the soil-pipe from one of the w.c.'s may unsyphon others in its rush down the pipe. This is shown in Fig. 7, Plate VII.

Where a large number of w.c.'s are required, as is the case in barracks, they should be so placed as not to create offence, and yet they ought not to be too far removed from the barrack rooms. They should be thoroughly ventilated and light in every part, as light means cleanliness. The annexed drawing shows a convenient form of w.c., invented by Messrs. Bowes, Scott, & Read, for soldiers' w.c.'s, which is automatically cleansed by a Field's Flush Tank (Fig. 8, Plate VII.)

There should be a w.c. and urinal attached to every barrack room, for night use; the latter should preferably be a receptacle containing about two gallons of water, capable of being automatically flushed at specified intervals, but arranged to be thoroughly cleansed every morning, as it is only by thorough daily cleansing that such apparatus can be kept free from smell. Every night-urinal should be provided with a water tap over it for ablutionary purposes.

Ablution Necessary to Health.

Lastly, I will say a few words upon ablution rooms. Before doing so, I will quote an instance from one of Mr. Chadwick's publications of the effect of ablutions on health:—

'In one orphan institution, where the death-rate was twelve in the thousand, a cleansing of the place, the removal of cesspits and foul drains, the air cleansing was effected, the death-rate was reduced to eight in the thousand; and next a cleansing of the person was effected by a constant ablution with tepid water, and then a reduction by another third, or to four in a thousand, was achieved. Other experiments tend to establish the value of personal cleanliness as a preventive factor at one-third.'

Mr. Chadwick also mentions the case of a general in India, whose army was hemmed in and put upon short rations, and who encouraged his men to bathe daily; he said that by that means he kept his men in as good condition and force as another division of the army that was on full rations but unwashed.

It is, therefore, essential that convenient means of personal ablution should be given to every soldier, and it would be still better if he were compelled to make use of such means.

The following are some of the conditions which should be observed in the provision of ablution accommodation.

(1.) The access from the barrack room should be sufficiently sheltered to enable the men to leave their rooms to wash without incurring the risk of disease from damp and cold. The ablution room should be cut off from the barrack room by a separate and distinct ventilation, so that while there is a covered communication between them, damp air from the ablution room may be prevented from entering the barrack room.

The floor and wall coverings and ablution table should be of material impervious to wet, and every arrangement should be made to assist the rapid flowing away of water which is spilt.

The room should have abundant light, and be well ventilated.

The washing utensils should be such as to enable the men to wash wholly or in part every day without necessarily taking a bath. There should consequently be a supply of warm water, and a particular form of prevalent disease might be checked by special arrangements to allow the soldiers to wash themselves on returning to their barracks in the evening.

The room should, therefore, be furnished with sitting accommodation and means of hanging up clothes, as well as screens behind which the men may wash if they desire.

With respect to baths, the following points should be noted. Fire-clay baths are very clean, and if they are required for use with warm water, for several people consecutively, they will be found very advantageous, because when once heated, the fire-clay retains the heat for a long time ; but if only one warm bath is required, then the fire-clay bath is uneconomical, because in order to warm up the great mass of fire-clay in the first instance a great deal of heat has to be expended, and the hot water first put in is rapidly cooled down. For such occasional use a copper bath or a French block tin bath is preferable.

Importance of maintaining Conditions of Health.

I have shown you how to provide healthy sites for barracks and camps, and a pure water supply, and I have explained to you the principles upon which your buildings should be constructed and your camps laid out with a view to health ; I have also explained the conditions which govern the removal of refuse, so as to maintain the purity of air and of water in and around dwellings.

I would, in conclusion, impress upon you the importance of continued watchfulness to prevent any departure from conditions of health.

You may select the most healthy site, or, if you must occupy a comparatively unhealthy site, you may devise the best means for remedying its defects; you may build the best and most healthy structures, fitted with the best appliances; but unless you maintain them in a healthy condition, your care will have been useless.

Indeed, in a camp, however careful you may be to cleanse it, the surface of the ground must become polluted in time.

Therefore, after a temporary camp has been occupied for some time, the site should be abandoned for a new one ; and in any case, if disease breaks out in a camp, the best course is to move the soldiers at once to new ground.

When cholera has broken out in a regiment, it has frequently been at once stopped by moving the regiment on to fresh camping-ground a few miles from the site originally occupied.

Necessity of Sanitary Administration in an Army.

These remarks will show you the paramount importance of having some sanitary organisation in each section of an army, whose business it is to look after the practical sanitation of the troops, if the condition of health of the troops is always to be cared for.

The medical and sanitary officer attached to the Egyptian campaign repeatedly urged the want of a Sanitary Police to effect the measures which he reported to be necessary; and Lord Morley's Committee, which reported upon the medical organisation in the Egyptian War, states:—

'What is wanted is a large and well-organised body for executive conservancy work in connection with the Quartermaster-General's Department. Nothing short of this would have answered in Egypt.'

Careful organisation and forethought will effect much, but not all. It is of still more importance that each officer and man in the army should recognise the necessity of sanitary measures.

I mentioned in my first lecture that army sanitation included certain conditions personal to the men—such, for instance, as cooking, diet, dress, exercise, recreation, and general habits.

These matters all have a bearing upon the prevention of disease, and a general appreciation of the influence they exercise is necessary to those who are charged with devising constructional arrangements for securing the health of the soldier. They are, however, somewhat beyond the scope of these lectures, and I will only allude to one or two points connected with them.

Cooking and Diet.

The economy of the soldier's diet, and the extent to which it can be varied, will much depend upon constructional arrangements.

The main consideration in a cooking apparatus for barracks is to obtain the means of boiling, roasting, frying, and baking, with great economy of fuel.

The complete combustion of the fuel, which means a bright flame, is essential to economy of fuel; and therefore in any cooking apparatus the fire must be arranged to allow of rapid draught as well as of complete regulation of the fire by means of dampers and doors.

As regards boiling, in recent soup-kitchens great economy of fuel has been obtained by exposing only the lower part of the boiler to the flame, and preventing any loss of heat through the sides and cover by means of a packing of silicate cotton.

I merely mention this as an illustration of what may be done by carefully considering the means of producing heat and of preventing the waste of that heat when produced. I would only add that with the large numbers for whom cooking is required in barracks, the consumption of coal need not exceed from ½ oz. to 1½ oz. of coal per head, and ought certainly to be less than the latter amount; but, considering that from the varying occupation of barracks, the numbers to be cooked for must vary, any cooking apparatus constructed should be capable of being used with economy for any varying number of men the barrack is likely to accommodate.

Under a careful system of army hygiene, diet would be suited to climate and duties. The present system is not elastic.

The single meat meal in the middle of the day is bad enough in any climate; but in a hot climate what can be more absurd than to give the soldier a heavy meat meal just before the hottest part of the day? Indeed, formerly in India the soldier was by regulation forbidden to leave his barracks, and required to lie down on his bed after his meal. It was treating him like a boa constrictor. Is it astonishing that soldiers' livers were disordered?

This has been altered now so far as going to bed is concerned.

The French system of dividing the meat meal into two—morning and evening—is much more rational, and indeed the heavier portion ought to be taken in the evening; and it is very probable that a radical change in this respect of the arrangement for soldiers' meals might be the means of checking to some extent the vice of drunkenness.

The question of drink is very important.

In England we give beer-money, and the soldier buys what he wants; but on foreign service and in India facilities are given for purchase of spirits.

Spirits in hot climates without hard work prepare the way for disease, but no doubt on service spirits may be occasionally necessary, therefore the rule should be to issue them only by medical order. This system was endeavoured to be enforced in the Egyptian campaign, and it is understood to be the rule in the French army.

Necessity of adapting Clothing to Climate.

At stations where the alternations of temperature are very considerable, there will be a great liability to fever, which may be counteracted by care in the clothing as well as in the diet.

Between the years 1830 and 1845, the annual mortality among troops in Bengal was nearly 30 per 10,000 from apoplexy alone; in particular instances the mortality from this disease was as high as 500 per 10,000, while the deaths from the same disease in England were less than 2 in 10,000. This resulted from the defective form of head-dress, or chako, then worn; and, moreover, excessive heat produces moral depression, even among the best troops in the service.

For this reason the dress should be adapted to the climate, seasons, and duties; and in dress as in a house, heating and ventilation are important items.

Dress has been materially altered since those days when the high army mortality occurred in India; and the present dress used in hot climates is better adapted to the climates.

Whilst dress should be close-fitting for convenience, it should not be too tight to impede circulation or muscular action.

In India the evaporation from the surface of the body is great, and it is alleged that dysentery and liver disease are frequently produced by chills. Hence a slow-conducting medium next the skin is absolutely necessary.

Pure wool is superior to all other textiles as a non-conductor of heat and absorber and distributor of moisture—in cold weather preventing the heat of the body, but not its exhalations, from going out, and similarly in hot weather the heat of the atmosphere from coming in. Hence flannel moderates the evaporation from the surface of the body. Moreover, the temperature of the skin in hot and dry weather is found to be lower under flannel with a cotton dress over it than under cotton alone. But cotton, though inferior to wool, is superior to linen as a non-conductor; but it is a very poor absorbent, while linen is a rapid conductor, attracts moisture, and has a very low radiating power.

In regard to colour, white is the best protector against heat; the relation which other colours bear to white in this respect is in the following order—light grey, yellow, light red or pink, blue and black.

Observations on Physical Exercises.

Again, exercise has a most important influence on health. Your body is constantly undergoing change; bit by bit, atom by atom, it is being pulled down; bit by bit, atom by atom, it is built up again, and the new is fashioned by, and is adapted for, the circumstances under which it is built.

This process goes on constantly, so that after a time a new creature is produced—new at all points in organ and limb, but newest in the parts most directly under the influence of the circumstances under which the changes are wrought.

Let us take for illustration the human hand. In men following widely different callings it can scarcely be recognised as the same organ, yet at one period of life it might have been more difficult still to perceive any difference; occupation has changed it, occupation has fashioned it, moulding the hand which followed the occupation fittingly to its use.

The hand of a man whose occupation has been to wield the pen or pencil is slim and delicate as a woman's, the skin soft, the bones slender, the muscles small, and the joints round and mobile. The hand of a man whose whole occupation is manual labour, where force and tenacity of grip are the sole requirements, is nearly twice the size of the first, though from its bulk and breadth it scarcely seems so long; the skin is rough and horny, the bones are short and thick, the muscles, when contracted, angular and hard as the bones, and the joints furrowed up and rigid, and stiff and slow in action, but with a closing force like the opposing parts of metallic machinery. The time was when both hands were the same; the time was when either could have been made to take the condition and aspect of the other. They have been moulded under the influence of occupation each to its particular use. The same thing takes place with every other part of the body. The exercise which is difficult when first tried becomes easy when practice in it has fitted the body to perform it.

To give you an idea of the amount of daily work which it is desirable to perform, Dr. Parkes lays it down that every healthy man ought, if possible, to take a daily amount of exercise in some way which shall not be less than 150 tons lifted a foot, equivalent to a walk of about nine miles. As an illustration, I may mention that the work done per man in rowing one mile at racing speed is 18·56 foot tons, and the work done by one of the crew, weighing 158 lbs. (11 st. 4 lbs.), in racing costume, walking one mile, would be 18·62 foot tons.

Lord Herbert of Lea introduced systematic training in gymnastics into the army, and as a means of physical training and of keeping all parts of the body in due exercise it is most important to health.

But the question of preservation of health is not limited to conditions which admit of precise physiological demonstration. Constitution is affected by mental as well as physical attributes. In certain circumstances a man is brought face to face with problems which demand instant solution, in which a wrong decision would be productive of disaster to himself and his companions. That is where *presence of mind* or *nerve* is required.

Some persons by temperament possess more presence of mind than others. But it can be strengthened and increased by education. Like muscular power, it can be developed by exercise. Every occasion in which promptitude of decision is called out and successfully applied, under sudden and exciting circumstances, the chances are increased that the same result will follow another time. In proportion to the frequency with which such instances are encountered will be the formation of this most distinct and valuable habit. Those moments of life in which the strongest forces of a man are revealed in one instantaneous effort, and in which mind, will, and muscle combine in a flash, as it were, of associated impulse to carry him successfully through the ordeal that faces him, are worth days of ordinary living, and become a source of spontaneous and unconscious influence, the recollection of which serves to stimulate to stronger action in grappling with many a difficulty of ordinary life.

In a battle or campaign the safety of the individual or of the army may depend on the courage and rapidity of decision with which such problems are faced. May it not be due to the fact that these qualities are frequently called into play in each individual in the active operations of a campaign that rapid marches, made under constant expectation of attack, are often attended with little apparent sickness at the time.

We cannot provide opportunities for exercise of this quality by artificial means. Their exercise consists in their arising unexpectedly. We can only educate 'nerve' and 'presence of mind' by encouraging exercises in which such occasions are likely to arise of themselves.

Conclusion.

I have had much pleasure in giving to my old brother officers, in these lectures, the result of my experience in sanitary science. In doing so I desired especially to impress on you, who are just entering your profession, the importance of giving effect to those principles of sanitary science which were left very much in abeyance in army sanitation until after the Crimean War.

In the ten years succeeding that war, the impetus given by the late Lord Herbert of Lea to the sanitary improvement of the army bore fruit in the improvements in barracks and military hospitals and other measures of sanitary procedure in the army.

At that time army sanitation was ahead of the sanitation of the country generally. The occasional opportunities which I have had since the close of my connection with the War Office of looking into the progress which has been made in those matters in recent years makes me fear that latterly army sanitation has not kept pace with the advance in sanitary knowledge which has been going on in the country generally.

It is no doubt the function of the medical officer to advise upon the measures required for securing the health of the troops, but the practical application of very important branches of the subject, viz., those connected with the lodging of troops, the supply of water, and the disposal of refuse, rest upon the Royal Engineer. They are embodied in the words, pure earth, pure air, pure water.

The fate of a campaign may sometimes depend upon the ability with which the engineer officer is able to apply these principles with rapidity and in an effective manner to meet the particular case. It is well to remember that in the field rough and ready measures taken at once, adapted to temporary use, will often serve more effectually than elaborate schemes which require time; and in the application of these principles to barracks and permanent buildings, provided the various details which I have pointed out are carefully attended to, you will often find that there is an economical as well as an expensive way of attaining the same object.

I have endeavoured to explain, by general illustrations, the principles on which sanitary science rests, rather than to fetter you with dogmatic rules.

In the application of these principles your goal of to-day should be your starting-post for to-morrow; and I trust that if you have thoroughly appreciated those principles, the sanitary barrack and camp of the future will be as far in advance of those of to-day as those of to-day are in advance of those of the pre-Crimean period.

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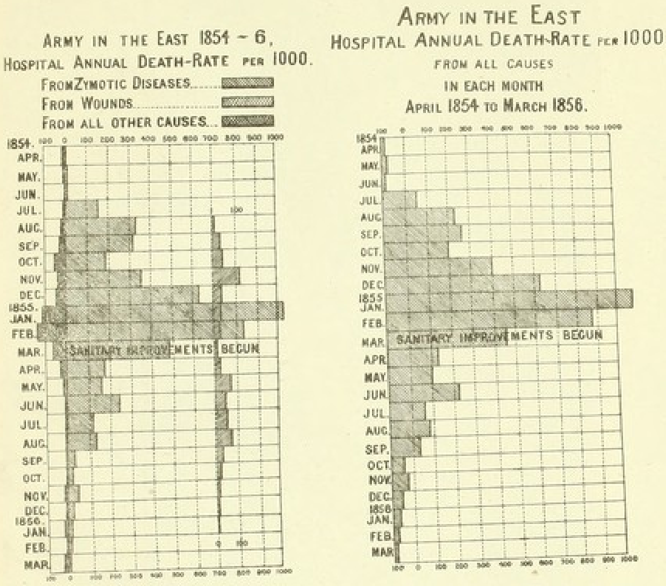
PLATE.I.

Fig. 1 (Page 4)



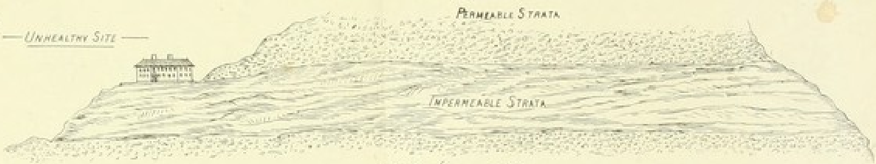


Fig. 2 (Page 23)

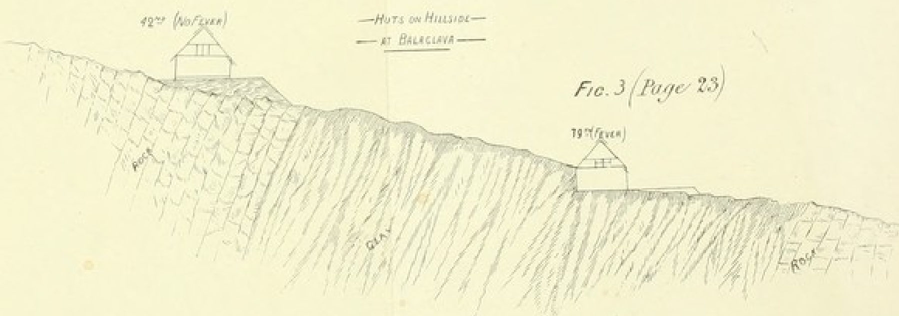


Fig. 3 (Page 23)

Fig. 4 (Page 23)

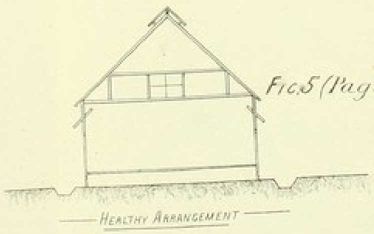


Fig. 5 (Page 23)

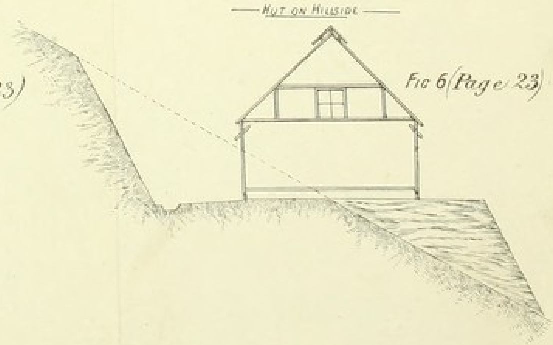
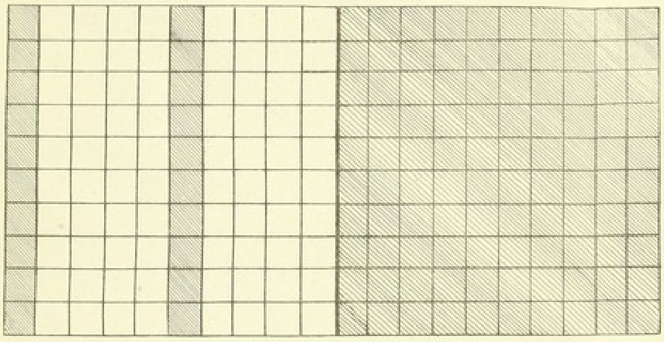


Fig. 6 (Page 23)

1000 Persons Per Acre

In 6-Story Buildings — Fig. 1 (Page 31) — In 1-Story Buildings



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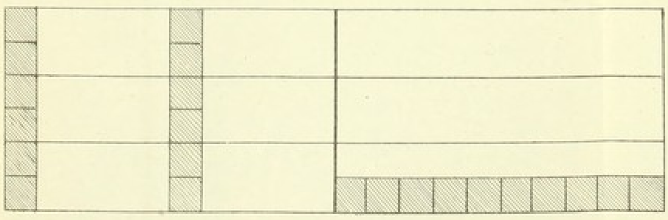


Royal Barracks Dublin.
(Crowded Arrangement.)

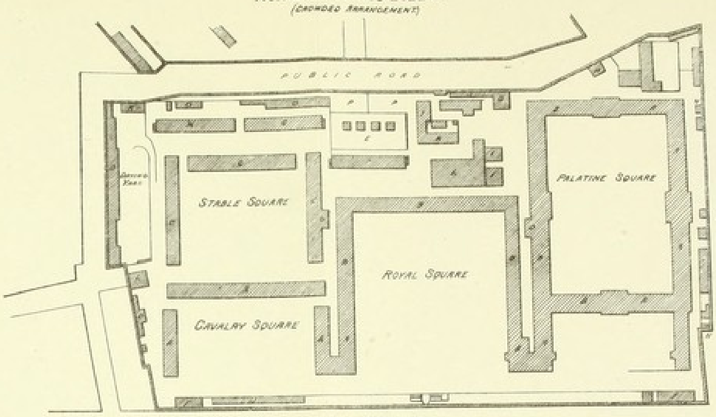


Fig 2 (Page 40)

A. Officers Qrs.
B. Soldiers Qrs.
C. " " over Stables.
D. Officers Stables.
E. Magazine.
F. Guardhouses.
G. Ablution Houses.
H. Wash Houses.
I. Cook Houses.
K. Canteen.
L. Riding School.
M. Granary over Stables.
N. Officers Privies.
O. Mens Privies.
P. Ball Courts.

Naas Barracks
(Well Arranged)

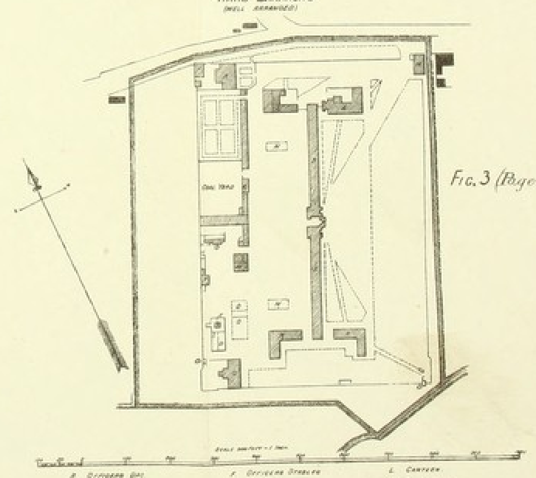


Fig. 3 (Page 40)

A. Officers Qrs.
B. Soldiers Qrs.
C. Hospital and Dead House.
D. Prison.
E. Magazine.
F. Officers Stables.
G. Priviess.
H. Wash House and Cook House.
I. Ablution House and Stores.
K. Engine House.
L. Canteen.
M. Guard House.
N. Fire Tanks.
O. Ball Court.

Fig. 1 (Page 46)

— Barracks at Edinburgh Castle —

— Badly Arranged —

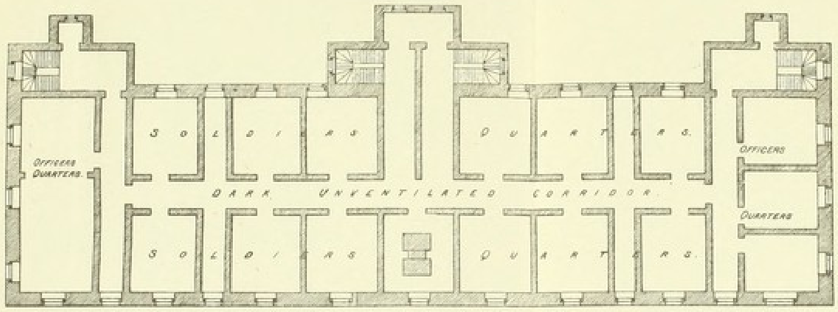
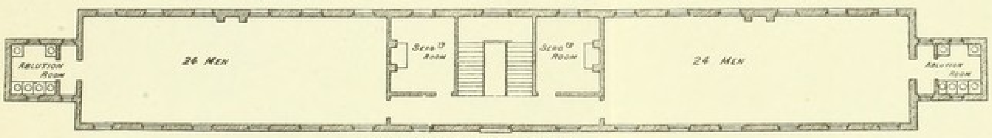


Fig. 1A (Page 46)



— Barrack Unit Properly Arranged —

Fig. 2 (Page 52)

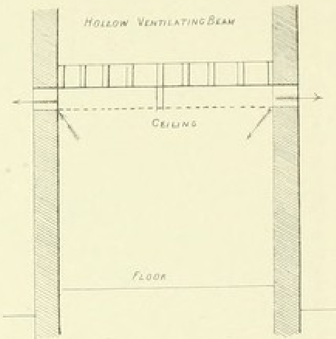


Fig. 3 (Page 52)

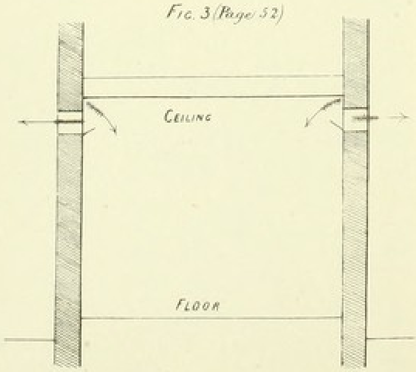


Fig. 4 (Page 52)

Sherringham's.

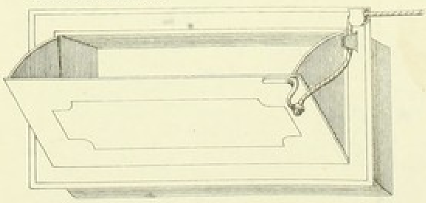


Fig. 5 (Page 56)

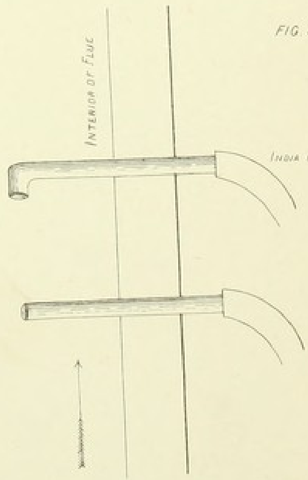
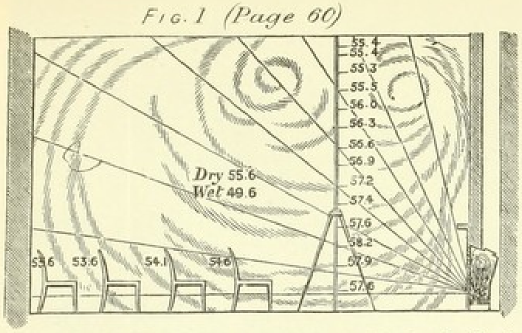
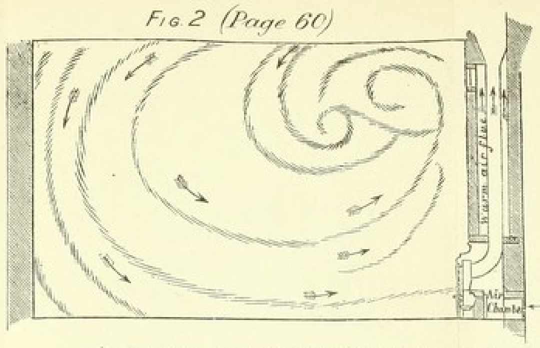


Fig. 1 (Page 60)



Sketch of Experiment made by Mr. Campbell in 1857 showing the movement of currents of air in a room with an open fireplace.

Fig. 2 (Page 60)



Section of a room with a ventilating grate and warm-air flue, showing action of fire in producing circulation of air.

Fig. 3 (Page 61)

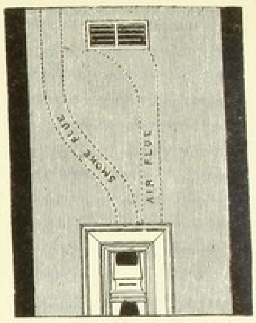
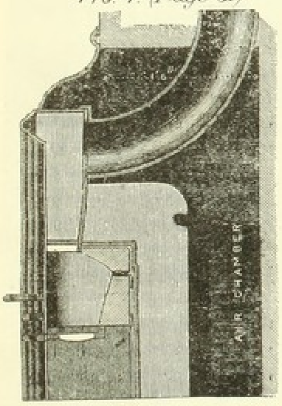


Fig. 4. (Page 61)



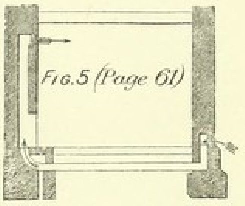


Fig. 5 (Page 61)

Fig. 6 (Page 61)

Old Form

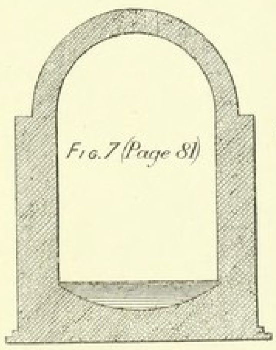


Fig. 7 (Page 81)

Brickwork

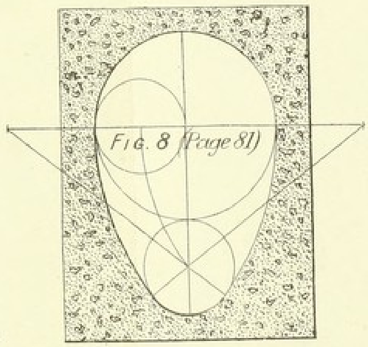


Fig. 8 (Page 81)

Concrete

Improved Form

Fig. 9 (Page 81)

Brickwork

Stoneware Invert.

Manhole Fig. 10 (Page 81) Lamphole

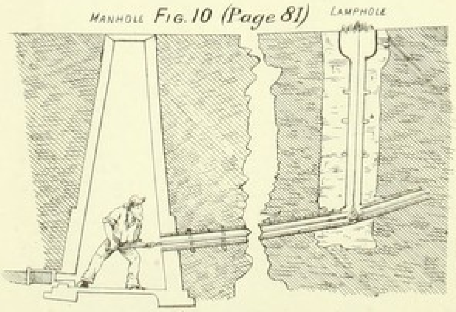
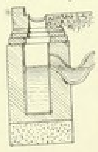


Fig. 11 (Page 83)



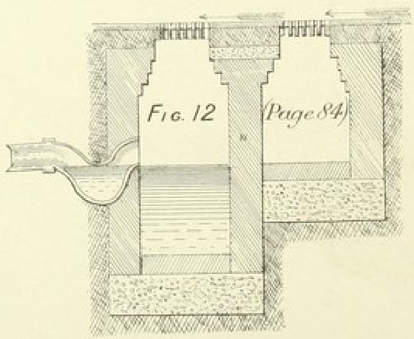


Fig. 12 (Page 84)

Fig 1 (Page 84)

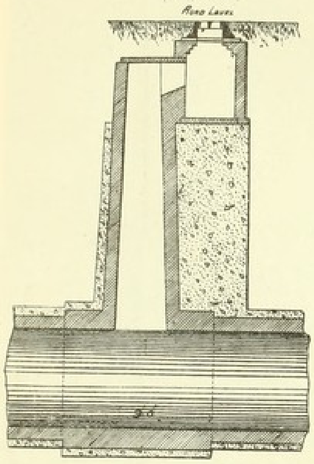


Fig. 2 (Page 84)

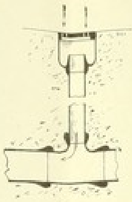
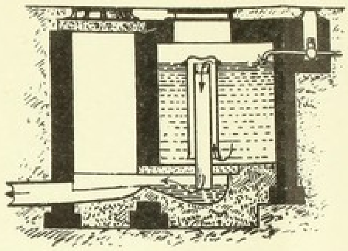


Fig. 3 (Page 84)



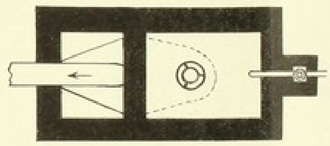
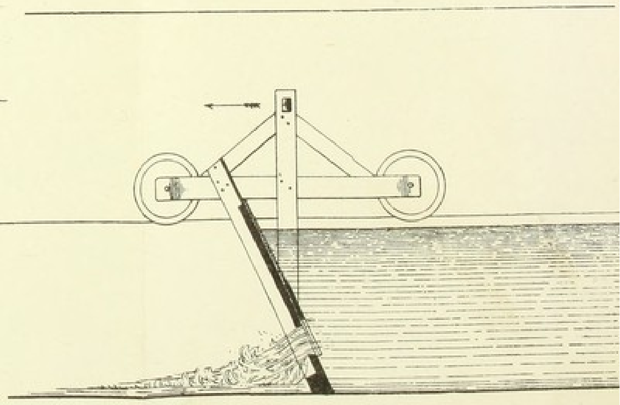
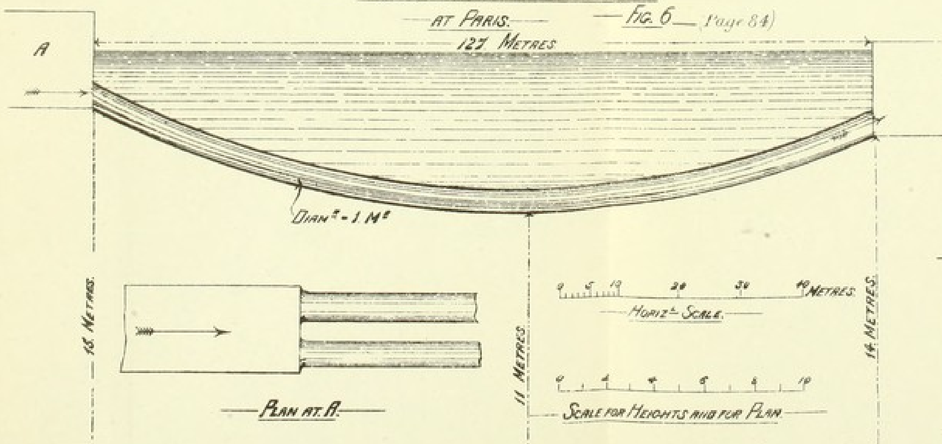


Fig. 5 (Page 86)



Sewage Syphons under the Seine at Paris. Fig. 6 (Page 84)



PLAT

Fig. 1 (Page 87)

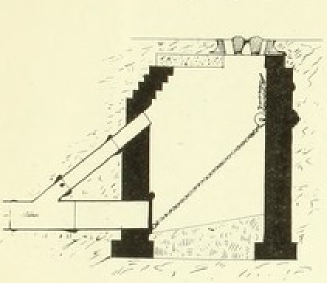


Fig. 2 (Page 87)

VENTILATOR

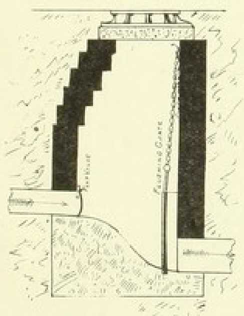
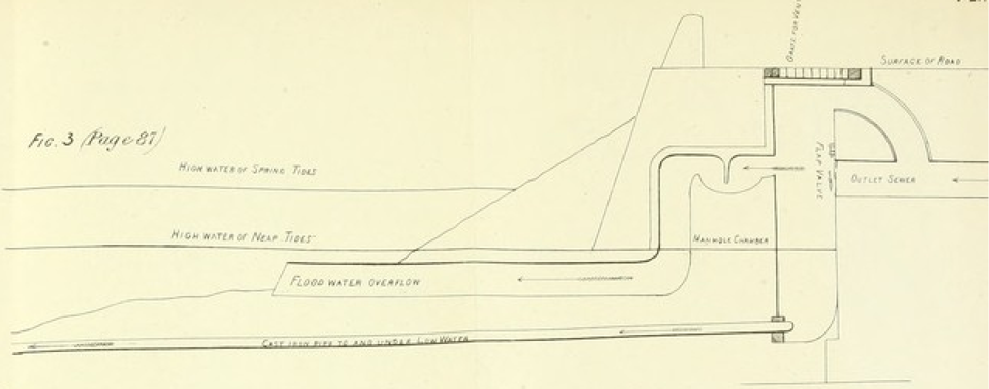


Fig. 3 (Page 87)



— SEWERS AT GIBRALTAR —

Fig. 4 (Page 88)

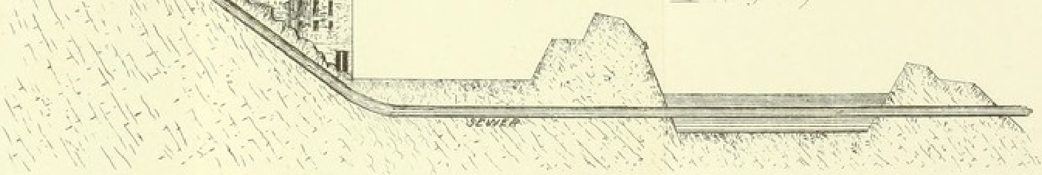
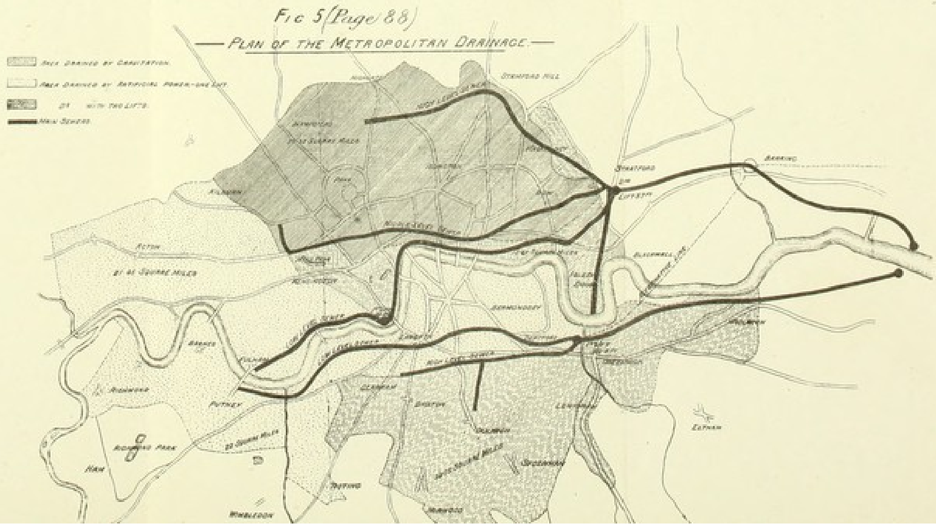


Fig. 5 (Page 88)

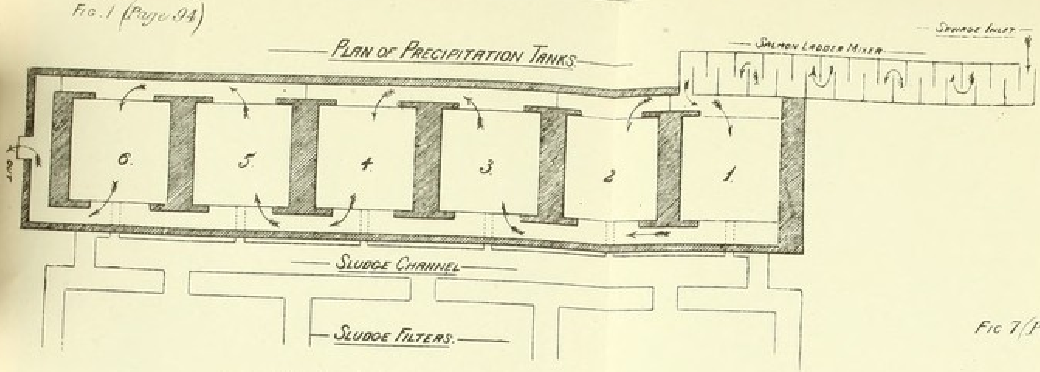
— PLAN OF THE METROPOLITAN DRAINAGE. —



Treatment of Sewage by Precipitation

Fig. 1 (Page 94)

Plan of Precipitation Tanks.



Note. Tanks 1 & 2 are worked alternately.

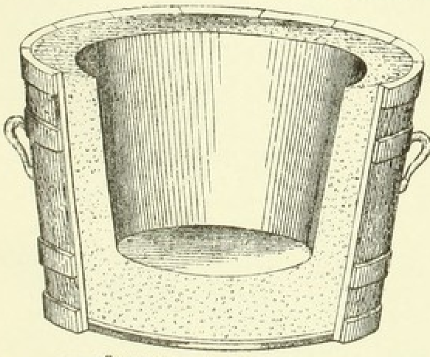


Fig 2 (Page 105)

Absorbent Receptacle.

Lined Pail used for "Goux" System.

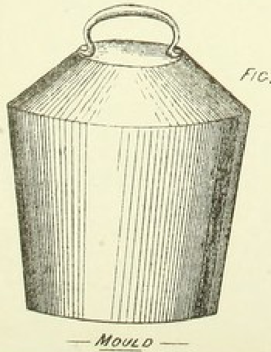


Fig. 3 (Page 105)

Mould

Interception Chamber

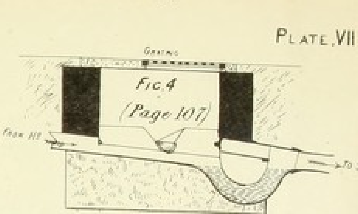


Fig. 4 (Page 107)

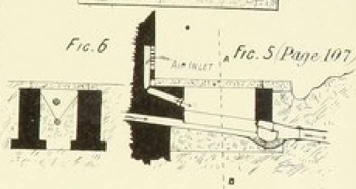


Fig. 6

Fig. 5 (Page 107)

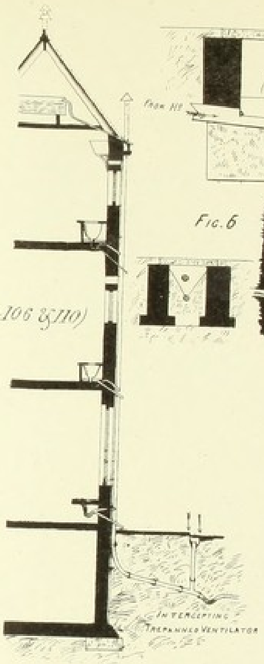


Fig 7 (Page 106 & 110)

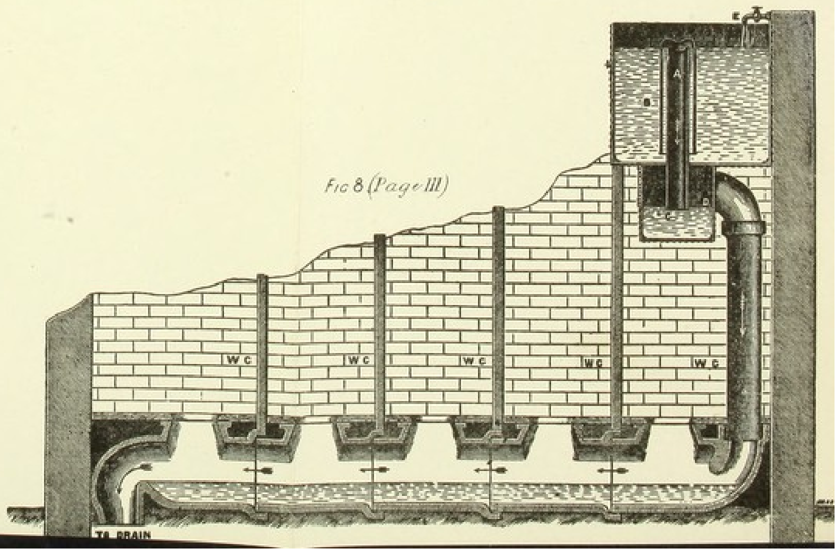


Fig 8 (Page 111)