HEALTHY HOSPITALS

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HEALTHY HOSPITALS

OBSERVATIONS ON SOME POINTS CONNECTED WITH HOSPITAL CONSTRUCTION

BY

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PREFACE

THE object which I have had in publishing these notes on Hospital Construction is to place on record those principles which ought invariably to be followed in every good hospital, and to point out those conditions of construction which according to recent practice represent the minimum standard required to be followed in building a new hospital.

These notes do not embody the detailed requirements of hospitals for special diseases, which may entail in some cases separation of patients, in others special curative adjuncts. They are limited to explaining the general principles upon which healthy construction must be based.

Fortunately the tendency of the modern hospital architect is not to be content to accept the dicta of his predecessor, but to endeavour always to improve upon former practice; and a great development in new methods of hospital construction has been the result. This tendency has however the drawback, that it has not invariably added to the hygienic perfection of the structure; indeed in some recent palatial buildings it has been very detrimental, and it has in every case added to the expense of hospital construction. It seems therefore desirable to bring the fundamental principles which should govern hospital construction prominently before the hospital architect as well as before those who are concerned with proposals for new hospitals.

If simplicity of design is the main object which the architect keeps in view in following out these principles, the cost per bed of new hospitals would certainly be much smaller than has been the case in many of those which have been recently constructed. This question possesses especial importance at the present time, because the prosecution of sanitary measures and the development of sanitary progress, consequent upon the institution of County Councils over the country, render it probable that a large number of new hospitals for infectious cases and others may ere long have to be constructed.

In pursuing this object it has been necessary to consult a large number of authorities, both English and foreign. Among these authorities may be specially mentioned Dr. Mouat and Saxon Snell, Tollet, Leroux, Surgeon-General Billings, Burdett, and Herr V. Kohler, Pistor, Böhm, and many others. As it would have been inconvenient to refer in the text to every book from which information has been sought, it has been thought preferable to append a list of many of the principal works which have been referred to in the compilation of these notes.

DOUGLAS GALTON.

12 CHESTER STREET,
GROSVENOR PLACE, LONDON.
August, 1893.

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HEALTHY HOSPITALS.

CHAPTER I.

PRELIMINARY.

HOSPITALS for the reception of sick and injured date from very early times. The Buddhist religion, which overspread India 400 years before the Christian era, gave rise to numerous conventual establishments, containing many thousand monks; these were in some cases practically Universities. In them Science, Medicine, Philosophy, and Law were taught, as well as Theology. Great Public hospitals were established in every city which afforded facilities for continuous study. Discoveries of celebrated drugs and remedies as well as the power of treating difficult surgical operations with boldness and skill resulted from this experience.

Military hospitals appear to have been first established for the Roman armies in the time of Trajan.

At Delos we read of a Lying-in hospital. St. Jerome mentions a hospital built by the Roman matron Fabiola 360 years after Christ, and the Emperor Valens is said to have richly endowed a hospital at Cæsarea about 370 years after Christ. In the ninth century there were twenty-four hospitals in Rome. These hospitals seem to have been under the Deacons supervised by the Bishops. In Paris the Hôtel Dieu dates from the Merovingian Kings, and in 660 it received from Archambaud, Count of Paris, the gift of his Palace and Chapel, and was further enlarged by the architect Adam, under King Philip Augustus II, in 1198.

In 1153 there were established hospitals at Chartres and Angers in the form of a cross. At Ourscamp about the same time a hall was built to accommodate 100 sick and injured persons, which was 144 feet long, 64 feet wide, and 33 feet high, affording 92 superficial feet per bed.

Margaret of Burgundy established a hospital at Tonnère, nursed by Sisters of Mercy, where the beds were placed along the sides of the Hall each in its own compartment surrounded with curtains.

The appearance of the plague in France in 1360 caused a great addition to the hospitals. Those for isolation purposes were generally situated outside the towns, and were subsequently used as lodgings by strangers who came to the towns after the gates were closed at night.

In this country St. Bartholomew's Hospital was founded in 1125. The principal existing hospitals in England date however from periods between 1700 and the middle of the present century; but many hospitals of the last and of the beginning of this century have been entirely rebuilt during the last twenty or twenty-five years; it may be further observed that a great development has taken place during recent years in Cottage hospitals for Villages and in Isolation hospitals for infectious diseases.

It is not, however, intended here to give a history of the progress of hospital construction since early times. That will be found in M. Tollet's beautiful book, Mr. Burdett's comprehensive work, and in other publications. We desire only to show in a succinct manner what are the principles of hospital construction which have been developed in late years by the careful consideration that has been given to the causes of disease, their prevention and cure. But before proceeding to discuss this question we may recall a few of the considerations which have led to the present form of hospitals.

The shape and disposition of wards which have been arrived at in recent years were worked out after experience had shown the importance of these forms, rather than as a consequence of a preconceived theory.

The fact is that our present system of hospital construction mainly owes its rise, in this country at least, to the experience derived from the wars of the last and present century, where large numbers of sick and wounded were collected together in extemporised hospitals. Dr. Brocklesby had shown as early as 1758, and Sir John Pringle and other military surgeons later on, that hospital huts and tents, in which the patients were exposed to unfavourable conditions from cold and wet, produced more numerous and rapid recoveries from wounds during these wars, and from the diseases incidental to camps, than the permanent hospital buildings then in use.

But it was mainly in consequence of the experience of the Crimean War, the American War of Secession, and the Franco-German War of 1870–71, that physicians and surgeons generally became impressed with the importance of so arranging the buildings for sick and wounded that they should be constantly under the favourable influence of fresh air and cleanliness.

There is abundant evidence that the agglomeration of sick and wounded men into the permanent buildings used as hospitals during these wars was very destructive of life, while it was seen that wounded recovered best when scattered among cottages, attended almost entirely by the people, notwithstanding that they were often indifferently fed; and it was found far better to place wounded men, as a rule, in detached buildings, or even under a canvas roof, or any similar shelter sloping from a barrack or church wall, than to take them inside the building even in cold weather.

In some of the reports on the reconstruction of the Hôtel Dieu in Paris made before the breaking out of the Revolution, the objection to massing together large numbers of patients in one building was strongly urged, and instances were given in official reports of the evil influences of the sick upon each other. Cases were quoted in which persons whose beds were placed not far from wards which contained patients ill with putrid fever, did not get cured at all, or were cured with great difficulty.

No doubt many of the early hospitals were of the pavilion form of construction, so far as placing windows on opposite sides is concerned, but a very large number of beds were placed in several rows in one long room or gallery, and under one roof.

In this country the earliest specimen of a hospital on a pavilion system, with a limited number of patients in each pavilion building, appears to have been built for sailors, at Stonehouse, near Plymouth, by an architect named Rovehead, between the years 1756–64. In this building the ends of the pavilions were united by a covered corridor to protect persons passing from one pavilion to the other.

This hospital was based on the principle of limiting the number under one roof, and was a practical protest against the plan then largely prevalent, chiefly on the Continent, of agglomerating a large number of sick or injured in one large hall. But it did not embody the cross ventilation of our present pavilion construction.

This form was not, however, followed generally in this country, and the corridor system with rooms, each containing a limited number of sick, opening out of a common corridor, arranged apparently with the object of facilitating the interchange of vitiated air, appears for a long time to have been preferred—a system which culminated in Netley in 1856.

This was not the case in France. In that country the excellent work of M. Tollet shows that the pavilion principle, as now understood, was suggested as far back as 1750, with wards limited to about thirty-four beds in each.

In the American War of Secession long wooden huts, erected for receiving the sick and wounded, were resorted to instead of existing brick buildings.

The Lower General Hospital of Philadelphia consisted of a series of one-storied huts disposed round an interior area, in which the offices and abodes of the administration were situated.

The site was a high and airy plateau, on which fifty huts afforded accommodation for 500 patients. These huts were arranged like spokes of a wheel around a central corridor, and open freely to the air, but closed and warmed in winter by stoves; this corridor afforded, at all seasons, a pleasant lounge for the convalescent patients.

A tramroad ran round the corridor, on which waggons brought the food and supplies to the end of each hut-ward without delay.

A telegraph connected the huts and the kitchen with the director's office and other parts of the administration.

A branch from the railroad permitted the railway cars, in which the patients had been laid near the battle-field, to discharge their freight at the door of the hospital; thus the patients suffered only one change, from the railway to their beds.

It was upon this model that the German temporary hospitals were organised during the Franco-German war. In this war the want of suitable hospitals led to the erection of a large number of buildings of wood, as well as to the use of tents. Neuwied, Frankfort, Mannheim, Heidelberg, Darmstadt, and Aachen afforded some very good examples of extemporised hut hospitals.

In all these the arrangement aimed at was to give the patient as much fresh air as possible. The sides were in many cases capable of being entirely opened, and were kept open till late in the autumn. Along the ridge a very large space was devoted to the admission of air. Where the sides were continuous, and there were windows, a large opening for fresh air was reserved along the eaves, and frequently also along the floor. The floor was always raised from two to four feet off the ground.

Some surgeons, in addition to the arrangements for securing fresh air in the huts, caused many of their patients to be carried in their beds by day into the adjoining meadow, and would willingly have kept the wounded in the open air through the winter, but the nurses could not stand the cold.

These hospitals, although crowded with wounded, presented scarcely any cases of pyæmia or hospital disease so long as they were permeated by fresh air. But curiously enough, as soon as the winter set in with severity, the advantages of fresh air were ignored, the sides and even the windows were nailed up, leaving only one or two moveable ventilators at the top of the building, and a nurse employed in one of them said,—'The air was so utterly foul and corrupt, that a feeling of nausea came over me each time I entered them'; and during the winter hospital diseases made their appearance.

There is no question but that the experience of the advantages of fresh air in hospital wards, gained during these wars, has led the medical profession to approve of the present pavilion system of hospital construction.

There does not appear to be any very definite view as to the extent of hospital accommodation which is necessary to be provided in proportion to the population. According to Mr. Burdett and other authorities, there should be one bed to every 1,000 inhabitants for general diseases and surgical cases. The whole hospital accommodation of London, exclusive of Infectious hospitals, may be said to afford about one bed to every 800 inhabitants. In some counties the proportion is only one bed to 2000 inhabitants, and in others, if we include the workhouse infirmary, it approaches within measurable distance of Mr. Burdett's standard. Of course this provision refers to an *average*; and in a village of say 500 or 1,000 inhabitants, if a cottage hospital were provided, three or four beds at least would be necessary.

It is quite certain that many persons, even of the fairly well-to-do class, would have much better chances of recovery from either sickness or injury in a well-administered hospital than in their own homes. This is especially the case with the less well-to-do. For infectious or contagious diseases, where early separation of the sick from the healthy is of paramount importance, a hospital is a necessity. In the case of small-pox and scarlet fever, unless provision for isolation is sufficient to permit of the earliest cases being weeded out at once, the prime object of an Infectious hospital is not attained. In the case of Infectious hospitals the ratio given by Mr. Netten Radcliffe as desirable was about twenty beds for a population of 25,000. In twenty-seven important towns, having a total population of nearly 4,500,000, there are twenty infectious beds to each 29,000 persons. This seems too small in the event of epidemics. As a matter of fact London at the present time has nearly 4600 beds in the hospitals of the Metropolitan Asylums Board. This, on Mr. Netten Radcliffe's calculation, should be sufficient for a population of 5,700,000, which is more than the population of the Metropolitan area. But the hospitals of the Metropolitan Asylums Board are overcrowded when an accession of scarlet fever occurs, accompanied by that of any other disease, as for instance in the autumn of 1892, when there was at the same time much diphtheria, and provision was also required to be made in anticipation of cholera. From this experience it may be inferred that a larger proportion of beds, either by temporary provision or otherwise, is necessary to meet such an emergency. It would, however, be costly to provide, and to keep up permanently, sufficient accommodation to meet the occasional contingency of epidemics.

The reasonable course would seem to be, that the permanent provision should suffice for an average number of two or three simultaneous infections, and that this should be supplemented by temporary arrangements in case of need. Late authorities have proposed that infectious accommodation should be provided in the proportion of ten beds per 10,000 of population, with arrangements framed to admit of three different infections in both sexes.

The case of cholera involves other considerations. It is worthy of note that the removal of the patients to hospital does not find favour with those who have had experience in the treatment of this disease. The act of removal is attended by fatigue, which during an attack of cholera appears to reduce the probabilities of recovery. In such cases it might be preferable to leave the patient in his own home, and to make provision elsewhere for the healthy occupants of the house.

It may, however, be observed that both cholera and enteric fever might, with proper precautions, be treated in General hospitals, in isolation wards, a course which would not be advisable in the case of scarlet fever and small-pox.

CHAPTER II.

DEFINING A HOSPITAL.

A HOSPITAL is not only a place for the reception and cure of the sick poor ; it has, so far as the community is concerned, another very important function.

It is the technical school in which the medical student must learn his profession, and it is an experimental workshop in which the matured physician or surgeon carries on scientific research.

As a place for the reception and cure of the sick or injured, who do not possess facilities for being nursed at home, the hospital should be so arranged as to possess conditions more favourable for recovery than such persons could otherwise command in their own homes.

The care of the sick and injured, which in the time of the Egyptians, Greeks and Romans, seems to have been connected with the religion of the people, has in these later days, especially in this country, been mainly the attribute of the charitable.

Our principal institutions, where they do not possess endowments, such as are possessed by St. Bartholomew's, St. Thomas's, and Guy's Hospitals, have necessarily to depend for their maintenance upon the contributions of the public. Our Infectious hospitals and Poor Law infirmaries, on the other hand, are built and maintained out of the rates. These institutions in London have not hitherto been adapted to the very important objects which a hospital fulfils in educating the medical student.

It must be remembered that in other professions the student can pursue his studies largely in his library, but for the medical student the patients are the books out of which he has to read at the bedside, and hence it is of essential importance to the community that every hospital should be available for study. It is, however, true that recently, in consequence of the absorption of all infectious cases into the Metropolitan Asylums Board and the impossibility therefore of students having the opportunity of studying these diseases outside, some small provision has been made for students in these hospitals.

In towns of moderate size an individual interest is taken in the hospital or infirmary, and the county population surrounding the town, which is in a position to derive advantage from the hospital, willingly contributes to its maintenance. But London has in a great measure outgrown this feeling of individual interest. The supporters of many of the hospitals now necessarily often reside far from them. The poor in their immediate vicinity have not the means or inclination to give substantial support. The new Workhouse infirmaries and the Asylums Board hospitals are gradually impressing on the poorer classes the feeling that they ought to be treated for illness at the expense of the community.

The necessities of the hospitals grow daily with the growing population, but the funds do not proportionately increase. Hence important questions arise as to their future maintenance.

Some influential persons have advocated that the subscriptions for hospitals should all be collected by a central federated committee, by whom they should be distributed to the several hospitals. Such a system would probably soon dry up all that remains of individual effort, and the only solution of the question then would be for all the cost of the hospitals to be borne on the rates, and for the parochial authorities to partly recoup themselves by charging a reasonable sum to every patient who could afford it.

In Paris, when in the Revolution of 1789 the charitable and other endowments shared the same fate as our monasteries under Henry VIII, the State had ultimately to make some provision for the sick poor. And at the present day all the hospitals are under the direction and control of an Administrative Council, subject to the Prefect of Paris and ultimately to the Minister of the Interior, while the necessary funds are supplemented annually by votes in the budget, a legal power being given to assess patients admitted to a proportion of the cost of maintenance apportioned to their means.

In Sweden the hospitals are managed by separate governing bodies, as in London, but submitted to a State control so far as necessary to insure a certain unity of system and administration, and especially as regards finance and accountability. A scale of charges is also established, and *all pay something except the really poor*. The first class pay a substantial sum, as now in our paying hospitals; the second pay less, but still a remunerative sum.

Without entering further into these questions it may be admitted that it certainly would seem desirable that those patients who can afford it should contribute to their treatment when in hospital.

This principle is endeavoured to be enforced in our Infectious hospitals in London. They are built and maintained out of the rates; the cost of each patient is charged to the parish whence he comes, and the parochial authorities call on those patients, who can afford it, to repay them their contribution. The argument for payment in these Infectious hospitals is not, however, so strong as in other hospitals, because they are established as a protection to the community rather than for the advantage of the affected individual; and enforced payment tends to discourage resort to them. Whether, however, the Hospital is supported by voluntary effort, or whether it is supported by the rates, the necessity for economy in management is apparent, and it follows as an important feature of hospital construction that the building should be so arranged as to enable a small staff of medical men, nurses, and assistants to minister to the wants of a large number of sick. This can only be done by bringing many sick together in one establishment, and, except in special cases, placing several sick in one room.

The attention which has been given of late years to the management of sick and injured persons, in connection with the investigations which have taken place into the causation of disease, have led to a considerable development of the practical application of hygienic principles to hospital construction.

These general principles of construction may be assumed to be similar under all circumstances. That is to say, in every hospital it is necessary that the building be so arranged that it shall stand on a pure soil; that it shall be supplied with pure water; that it shall be permeated with pure air; and that its cleanliness shall be ensured by abundance of light.

There must, however, be a division between certain classes of patients. For instance, it may be desirable to keep in separate classes—

(1) Contagious and infectious diseases, possibly including phthisis.

(2) Ordinary sick.

(3) Injured or wounded.

(4) Aged sick poor.

(5) Lunatics and imbecile.

(6) Pregnant women, who are not suffering from disease in the ordinary sense.

(7) Convalescents.

And there are further subdivisions which are necessary as regards infectious and contagious diseases.

It is noteworthy that the Infectious or Contagious hospital was at one time a necessary adjunct to every small community.

With the diminution in the number of the violent outbreaks of such diseases, consequent upon the improved habits of cleanliness in the population, these lazar or pest houses fell into disuse, and it is only now that we are awakening to the necessity of again making such establishments an appendage of every Sanitary Authority, and, unlike the case of general hospitals, charging the cost of their construction and maintenance to the rates.

In these hospitals small-pox should be separated from scarlet fever and diphtheria. Some forms of ophthalmic disease require separation. Subdivisions may also be necessary in the case of the sick admitted to General hospitals. For instance—the temperature to be maintained for those suffering from bronchitis and pulmonary complaints may differ from that for other cases of sickness, and so forth.

Hence the class or character of disease to be treated may require a special application of these general principles ; and this has led to the adoption of separate hospitals, suited to various classes of patients, and various categories of disease.

Existing hospitals may be said to fall under the following general heads :—

A. Those connected with treatment and cure of disease, each of which may be assumed to require special arrangements.

(1) General Hospitals, with a medical and surgical side, with which must be grouped the small Cottage hospitals, which have attained a certain extension, in recent years, both in this country and elsewhere.
(2) Children's hospitals with a similar division of medical and surgical cases.
(3) Infection hospitals.
(4) Lying-in hospitals.
(5) Convalescent hospitals.
(6) Seaside hospitals for treatment of lymphatic and scrofula patients.

(7) Special hospitals for surgical treatment—as ophthalmic, orthopœdic, dental, and otherwise.

In connection with these it may be desirable to mention dispensaries, either provident or otherwise, and assistance to be rendered where patients are treated at home.

Workhouse infirmaries have also received extended development in late years, but these are mainly for paupers and charged to the rates; whilst Military and Naval hospitals are a necessary appendage to every garrison and naval port; and Field hospitals the necessary accompaniment of every army.

B. Those hospitals which are more in the nature of permanent refuges:—

(1) For Incurables.

(2) Imbecile Asylums.

(3) Lunatic Asylums.

It is beyond the province of this book to discuss the detailed construction of all these various institutions, but there are certain general considerations which affect all hospitals, and it is to these principles that it is now proposed to direct attention.

The first object of a hospital, as has been already mentioned, apart from its function as a teaching institution, is to enable the sick to recover in the shortest possible time.

In a treatise on hospital nursing, Miss Nightingale observes that—'Sickness or disease is Nature's way of getting rid of the effects of conditions which have interfered with health. It is Nature's attempt to cure; we must help her.'

In addition, therefore, to being supplied with the most complete curative appliances, the hospital should furnish all those conditions which are wanted to enable Nature to set up her restorative processes, and to put the patient in a condition to recover.

These conditions are summed up by Sir John Simon, the former Medical Officer of Health to the Privy Council, in the following apt words:—'A healthy hospital is one which does not by any fault of its own aggravate ever so little the recovery of persons who are properly its inmates. The faults by which a hospital fails to attain to the best results for its medical and surgical treatment may be of two kinds—either it is an inherent fault as of site and construction, or else it is a fault of keeping, as dirtiness or overcrowding, or neglect of ventilation.'

There are in existence many hospital buildings which, although they are not well calculated by their form to allow of the free permeation of fresh air, and to which light does not readily penetrate to all parts, yet show a record of favourable recoveries, owing to the larger floor space which is allotted to patients in the wards, to the judicious use which is constantly made of such means of aëration as exist, and to the scrupulous cleanliness which is maintained in every part of the building.

Cleanliness and fresh air do not so much give life as they are life itself to the patient. Cleanliness—clean air, clean water, clean surroundings—and a fresh atmosphere everywhere are the true safeguards against 'infection'; segregation by ample floor and cubic space, ample ramparts of fresh atmosphere, rather than segregation by walls and divisions. You cannot lock-in or lock-out the infectious poison. You *can* air it out, diffuse it, and clean it away. In order to facilitate the maintenance of healthy conditions in a hospital the form of the building should be such as to ensure the provision and proper application of

(1) Fresh air, with the necessary warmth and coolness.

(2) Ample light, including the penetration of sunshine to every part.

(3) Purification of floors and walls.

(4) Means of personal cleanliness.

(5) Adequate bed and bedding maintained absolutely clean, and adequately prepared food and drink.

(6) Attendance.

The constructional arrangements which bear on these various matters may be conveniently summed up under the following heads :—

(1) The soil on which the hospital stands should be clean, that is to say, the soil should neither emit, nor should it be exposed to any injurious emanations.

(2) The surrounding air should be pure, and there should be no appreciable difference in purity between the air inside and that outside the building.

(3) The pure air supplied to the wards, corridors, and offices should be capable of being warmed to any required extent.

(4) The water supplied for use should be pure, and after use it should be removed with its impurities to a distance from the hospital.

(5) Perfect cleanliness should prevail within and around the building.

In respect of the importance of cleanliness, the following extract from the report of Sir John Simon deserves notice :— 'That which makes the healthiest house, makes likewise the healthiest hospital ; the same fastidious and universal cleanliness, the same never-ceasing vigilance against the thousand forms in which dirt may disguise itself in air, and soil and water, in walls and floors and ceilings, in dress and bedding and furniture, in pots and pans and pails, in sinks and drains and dustbins. It is but the same principle of management, but with immeasurably greater vigilance and skill ; for the establishment which has to be kept in such exquisite perfection of cleanliness is an establishment which never rests from fouling itself ; nor are there any products of its foulness —not even the least odorous of such products—which ought not to be regarded as poisonous.'

The number of the inmates in a hospital—the number collected under one roof—the shape of the hospital buildings, and their distribution in regard to each other, and the methods of administration, all materially affect the preservation of the purity of the air. The best index to the relative efficiency with which this purity is maintained in different hospitals would probably be an equation in which the mortality and the length of time required for recovery of patients would form the chief factors.

But the facts of medical science are complex in their nature and liable to be influenced by an infinite number of collateral and minor considerations. Attempts therefore to compare large hospitals with small, to show the superiority of one form of construction over another, based on results derived from their mortality as at present ascertained, or on the average length of time cases are under treatment, are as yet too deficient in scientific accuracy to afford reliable data for the solution of this problem.

As has been already mentioned, we meet with hospitals converted from ordinary houses, where a scrupulous attention to cleanliness and the maintenance of a large floor space in the wards have produced satisfactory results. Other statistics have been adduced to show that the small cottage hospitals have produced fewer deaths and more rapid recoveries than larger town hospitals; but those statistics did not sufficiently bring into comparison the nature of the cases treated in each hospital, the form of the wards, the degree of cleanliness and of excellence of maintenance and nursing in each hospital.

As a general rule, however, it is quite certain that those hospitals in which the external architectural design had been the first care of the architect and the free circulation of air a secondary consideration, have produced results in deaths and in difficulty of cure far exceeding those which take place in hospitals where the architect has endeavoured, in the first instance, to arrange a plan which will secure free permeation of fresh air and an absence of dark corners as the normal condition of the building.

With these preliminary remarks we will proceed to consider the conditions which should regulate—

(1) The site of the proposed hospital.

(2) The form of the rooms in which the sick are to be placed and nursed, so as to ensure purity of air and convenience of nursing; because these rooms form the principal units of hospital construction.

(3) The distribution of these units, and of the other necessary accessories, which when combined constitute the hospital.

As a preliminary to these questions it will be convenient to mention what are the several parts of which a hospital may be said to be composed, bearing in mind that simplicity of design should be one of the aims of the hospital architect, and that any useless multiplication of administrative offices can only lead to complication of administration, confusion of the departments, and needless expense.

The several parts of a hospital may be classed as follows:—

I. Those connected with the admission and treatment of the sick.

(1) Rooms for reception and examination and for discharge of patients.
(2) The wards and their appurtenances.
(3) Baths for treatment, including medicated, Turkish, vapour, electric, &c.
(4) Operation room and its adjuncts.
(5) Dispensary and drug store.
(6) Splint store and workshop.
(7) Mortuary and its adjuncts.
(8) Out-patients' waiting room and the various rooms for their examination and treatment; where an out-patients' department exists.

II. Connected with boarding and clothing of patients.

(1) Kitchen with its adjuncts.
(2) Stores of food, fuel, linen, patients' clothes.

(3) Laundry.
(4) Disinfection.
(5) Destruction of refuse.
(6) Servants' accommodation, male and female bedrooms, dining rooms, sitting rooms, &c.

III. Connected with nursing accommodation.

(1) Nurses' rooms or Nurses' home with bedrooms, dining room, sitting room, library and lecture room.
(2) Probationers' rooms in connection with training school.

IV. Connected with Medical Education.

(1) Post-mortem room.
(2) Preparation room and laboratory.
(3) Museum and library.
(4) Lecture room.
(5) Students' waiting rooms and Cloak rooms.

V. Connected with General Supervision.

(1) Accommodation for meetings of Governing body, and for Secretary, Accountant, the keeping of Registers, &c.
(2) Rooms for Medical Staff, resident and non-resident.
(3) Apartments of Matron, or Superintendent of female staff connected with service of hospital.
(4) Arrangements for controlling ingress to and egress from Hospital.

The wards are the units which govern the general shape of a hospital, and the shape of the wards is therefore the first point to be settled.

The form and size of the wards depend upon the air-space required for each individual patient placed in the ward, and upon the way in which this air-space is distributed round him. This air-space is governed by the questions involved in the renewal of air, and these are affected by the methods adopted for the introduction of fresh air and the arrangements for warming the wards.

These questions are so vital to the form of the wards that it will be desirable to consider them before discussing the shape of the wards.

They may be described under the following heads :—

(1) Conditions which vitiate the air in an occupied room.

(2) Quantity of air necessary to mitigate these conditions.

(3) Movement of air—

(*a*) by natural means,

(*β*) by artificial appliances.

(4) Conditions which regulate the warming of air.

But in the first place we must consider the conditions which regulate the choice of the site on which the hospital should stand.

CHAPTER III.

SITE.

THE site to be selected for a hospital depends upon various considerations, and cannot be determined merely by its physical condition.

On the one hand, in order that the curative art may be carried on under the most favourable circumstances and without disturbing causes, it is necessary that the hospital building, in which the patients are lodged, should be furnished with the most complete appliances, and that it should be placed in the most favourable hygienic conditions. If these latter conditions are to be fully ensured, the hospital should be in the open country, and if health considerations alone are to prevail, no hospital would probably be located in a town. But, on the other hand, a hospital must be so placed that it will be conveniently available for the reception of the sick poor, and in the case of accidents, and of many diseases such as enteric fever, scarlet fever, pneumonia, cholera, &c., it is of importance that the distance which the patient has to be conveyed shall be as short as possible.

The hospital should also be easily accessible to the physicians and surgeons, both to enable them to prosecute the study of their profession, and to give clinical instruction to the Medical Students. The leading physicians and surgeons of a town necessarily reside near the more crowded localities.

These conditions would require that hospitals should be placed in centres of population. Consequently, one of the principal considerations in determining the position of a site for a General hospital is proximity.

Other classes of hospitals, including Cottage hospitals, for comparatively scattered rural populations, Asylums, or hospitals where the treatment is for special diseases, are not similarly fettered.

In the case of Isolation hospitals for small-pox and fevers, whilst it is desirable that the patients should not be transported to great distances by road, yet it is of importance that, where it can be avoided, they should not be treated in centres of population; besides which these institutions are always objected to, mainly on grounds of sentiment, as disagreeable neighbours. Hence, when the size of a town admits of it, they are placed in the open country. But in London, the great distances to be traversed render this impossible, in the case of those infectious diseases which would especially suffer from a long land-journey.

Convalescent hospitals are placed in the open country, or by the sea-side. In England there are such hospitals, both for adults and for children, at Margate, Hastings, and other sea-side places; whilst in France and Italy there are numerous Marine hospitals, where children of lymphatic nature, or those suffering from scrofula, rickets, or tuberculosis, are treated. Indeed, the municipality of Paris has for many years had a hospital of 1,100 beds at Berck-sur-Mer, in the Pas de Calais.

The asylums for imbeciles or lunatics are similarly placed in the open country.

The consideration of proximity must, however, be controlled to a great extent by physical conditions, and therefore in selecting a site for a hospital it is essential, where the conditions admit of it, to test the healthiness of a proposed site, by enquiry into the rate of mortality in the district; as well as the prevalence of sickness, and the nature of the diseases. Whenever this information can be satisfactorily obtained, it would afford a ready and effectual means of ascertaining the suitableness of a site for the sick. On the assumption that the choice of a site is unfettered, except by hygienic requirements, the qualities of a site most favourable to a hospital may be described to be a situation in the open country, upon a clean, porous, and dry soil, with free circulation of air round it, but sheltered from the north and east; raised above the plain, with the ground falling from the hospital in all directions, so as to facilitate drainage.

The elevation of a site above the surrounding country is very important. Observations taken in Switzerland have shown that a milder and more equable climate prevailed at a few hundred feet above the valleys than at the bottom, where the vegetation of the hillsides would not thrive.

In the British Isles, during a frost of long duration in 1879, at certain stations on hills, which were 200 and 300 feet above the adjacent valleys, the minimum cold registered during the winter was 17° Fahr., when in the valleys the absolute cold registered as low a minimum as 1·1° and 2°.

The general conclusion shown by these and many other observations is, that at a height about equal to that of the upper rooms in a high house a more equable and drier climate prevails than at lower levels; drier than at the seaside, and with a daily range not much greater, and much less cold on the coldest and foggy nights than down below.

Hence, in ordinary circumstances, delicate persons should not sleep on a ground floor; and living near the top of a high house, or on the ridge of a hill, might be of great benefit in many cases of lung and throat diseases, and in cases where night air has a bad effect.

But the selection of an elevated site requires care. For though elevated positions are generally healthy, yet in cases where they are exposed to winds blowing over marshes or malarial ground, their very elevation may be a source of danger.

On the other hand, in the case of buildings placed at a slight elevation above a marsh, the evil effect of the marsh has sometimes been obviated by the interposition of a belt of high trees which have shielded the buildings from the influence of the wind blowing over it.

The site selected for a hospital should not receive the drainage of any higher ground.

The supply of water must be ample and good.

It is an error to build a hospital on a steep slope. No doubt, by forming a plateau for the structure, and adopting a system of catch-water drainage, the water from the higher ground may be more or less cut off from the building; but the higher ground, especially if it be near to the building and steep, and if it rise to a considerable height above the hospital, will stagnate the air just as a wall stagnates it. Shelter from cold, or from unhealthy winds, be it by means of a range of hills, or walls, or houses, or trees, should always be at a sufficient distance to prevent stagnation of air and damp, otherwise the shelter from an evil recurring only at intervals may be purchased by sacrifice of healthiness at all times.

The level of water in the subsoil regulates the amount of ground air.

Ground air has a most important influence on the healthiness of a site. It is desirable to have clear ideas upon this subject.

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. The particles of soil may be compared to a pile of shot with the interspaces, where the circumferences of the shot do not touch, filled with air, or which would be filled with water if the ground on which the shot are standing were submerged.

Thus, if you build on a dry, gravelly soil, where the interstices between the stones are naturally somewhat large, you practically build over a large stratum of air. This 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 we say such a site is damp.

There is a considerable quantity of carbonic acid in the ground, and there are even considerable variations in the amount of carbonic acid present in the soil of localities in close proximity to one another; the amount has been found to be doubled in a distance of 50 yards with apparently similar soil, probably depending on the organic matter which has been present or has percolated into the soil at different places.

The processes going on in the soil at these spots must have differed materially; and if such processes affect health, persons inhabiting a building over one of these sites would be exposed to different hygienic conditions from persons living over the other.

The fact of this continual free passage of air in and out of the ground makes it important that not only should the ground we live on be free from water, but more especially that it should also be free from impurities. We might just as well (indeed probably far better) live over a pigsty, than over a site in which refuse has been buried, or in which sewer water or other impurities have penetrated, or over a soil filled with decaying organic matter. Ground air has been found to contain 50 per cent. more carbonic acid than the ground water. The level of water in the soil necessarily affects the air contained therein: when the level of the water rises, the air is forced out; when it falls, air is drawn in; but in connection with this it may be observed that whilst a permanently low water level (say 15 feet) in the soil may be healthy, and a permanently high water level (say under 5 feet) may be less healthy, a fluctuating water level is very unhealthy, especially when the fluctuations are rapid.

The unhealthiness mainly shows itself when the level of the ground water falls. This probably occurs from the decay of organic matter left by the receding water, and from this cause apparently fever chiefly occurs in flooded districts when the floods have receded.

Hence it is desirable to keep the permanent level of water in the soil, where habitations are placed, as low as possible. But where the water cannot be maintained permanently at a low level, then keep it at an even level.

Of course these conditions are modified by considerations of geological formation. On clay or on impervious formations water either remains to stagnate on the surface, or if the levels allow, it passes off the surface rapidly. Porous soils, on the other hand, allow of the penetration through them of pollution in connection with water to very considerable distances. For instance, it may be mentioned that a disinfectant put into the sewers has been known to be traced—after no long interval—in wells situated at comparatively considerable distances from the sewers. It is obvious that the sewers must have been faulty. Water sinks into a sandy gravelly soil and thence it drains away when not retained by an impervious subsoil. The impurities would not be carried into the clay soil, but the sandy or gravelly soil acts as a filter to retain the impurities which surface water may bring into it, and fever has been observed to stop on passing from a sand district to a clay district. Indeed, long-continued saturation of porous sandy or gravelly soil in towns by sewage or other foul refuse appears to be the cause of much of the typhoid fever which cannot be traced to definite causes. Sir Charles Cameron has pointed out that in Dublin the chances of getting typhoid are 50 per cent. greater on the gravel than on the clay, and attributes this to the fact that the soil of Dublin has been polluted by a system of storing human excreta for centuries, and the enormous accumulation of organic matter thus formed is under certain conditions in a state to give out into the atmosphere the poison which favours disease. Similar conditions are probably the cause of much of the enteric fever in India, and it has long been known that whilst in the great cities of America, malaria was disappearing with the advance of population, it is being replaced by typhoid fever, because the ground has been allowed to be saturated for years with organic matter from the animal kingdom. Parkes tells us that cholera is unfrequent on granite, metamorphic and trap rocks, but a careful collation of facts shows that so far as cholera, or indeed other zymotic diseases are concerned, the site and the geological formation have comparatively little to do with it. These diseases occur when there is a population living in a filthy condition, where impurities are retained around, on, in or under the dwellings—or are allowed to percolate into the ground surrounding the dwellings, or into the wells rendering the water impure.

The prevalence of fever in new houses built on the outskirts of towns frequently arises from the fact, that the gravel and sand which constituted the original soil had been removed, the hole thus formed let as a shoot for rubbish, and the restored surface converted into a building site; consequently the gradual decay of the refuse evolves emanations which pass up into the houses, even through concrete.

In connection with this it may be instanced that a site which has been occupied as a market garden, or which has been highly manured, would not be safe for a building site for a hospital unless the surface soil were removed to a depth in some cases of from one to two feet, or burned.

The importance of a clean soil is apparent when it is remembered that vapour is constantly escaping day and night from the soil, especially under grass, and bringing up ground impurities with it. This vapour often becomes visible as fog in an evening over low-lying meadows, for the same reason that fog appears over a river or pond, when after a hot day the air cools down at sunset leaving the water warm.

It follows that the ground surface on which hospital wards stand should be covered, both under the buildings and between the buildings, by a coating of impervious material, as for instance asphalte, or in default of asphalte, cement concrete.

The temperature of the soil depends on its geological formation. Thus if the power of sand to absorb heat be taken at 100, the power of clay to absorb heat would be represented by 66. Moreover, sand radiates heat more slowly than clay. Therefore a sandy soil is always warmer than a clay soil. Herbage lessens the absorbing power of the soil, and in hot climates the oppressive heat of a sandy soil may be tempered if the surface be covered with grass.

The disturbance of soil impregnated with organic matter has been a source of danger in tropical and semi-tropical climates. Whilst brushwood is a source of danger in hot climates, the removal of brushwood by stirring up decaying organic matter has caused fever. Digging out foundations, or any disturbance of the soil, is almost sure to be followed by an outbreak of malarious disease; the tendency to which diminishes or altogether disappears in time as the surface of the soil hardens, or undergoes other changes from exposure to air.

The presence of superfluous and stagnant subsoil water in the vicinity of a healthy site is dangerous.

A distinct relation has been shown to prevail between phthisis and the level of ground water; that is to say, the lowering of the water level has led to a direct reduction in mortality from phthisis.

But the level of ground water is a condition which it is eminently within the power of the engineer to remove by drainage of the soil.

In India, wherever water is applied in excess for irrigation so as to become stagnated in the subsoil, there we have ague and spleen disease.

But such localities have been improved by draining away the superfluous stagnant subsoil water. To prevent such evils, drainage should be combined with irrigation works from the beginning.

These remarks are based upon the assumption, that, in the selection of a site, healthiness is the only consideration; hence it will be convenient to summarise here the conclusions to which the above considerations point.

(1) A clay soil is disadvantageous from its cold character, but it prevents the percolation of foul matter.

(2) Ground at the foot of a slope, or in deep valleys, which receives drainage from higher levels, predisposes its occupants to epidemic diseases.

(3) High positions exposed to winds blowing over newly excavated ground, or over low marshy ground, even when miles away, are in certain climates unsafe on account of fevers. But the immediate vicinity of a marsh, or other local cause of disease, which is separated by a belt of trees from the occupied site, may be safer than an elevated and distant position to leeward.

(4) 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.

(5) Ground covered with rank vegetation, especially in tropical climates, is unhealthy, and the presence of such vegetation marks the presence of subsoil water.

(6) In warm climates, muddy sea beaches, or river banks, or muddy ground subject to periodical flooding, and marsh lands covered alternately by salt and fresh water, are peculiarly hazardous to health.

(7) A porous subsoil, not encumbered with vegetation and protected from impurities, with a good fall for drainage, not receiving or retaining the water from any higher ground,

and the prevailing winds blowing over no marshy or unwholesome ground, will, as a general rule, afford the greatest amount of protection from disease of which the climate admits.

It follows, from these considerations, that a site selected for occupation should be thoroughly under-drained, except possibly where the ground is so elevated and porous as to ensure that water never remains in it; and that if there is higher ground adjacent, the water from the higher ground shall be carefully cut off by underground catch-water drains, and led away from the vicinity of the site.

The object to be attained in laying out the ground is the rapid and effectual removal of all water from the buildings themselves, and from the ground in their vicinity, so that there shall be no stagnation in or near the site. Hence a hard compact surface should be secured in the vicinity of buildings. It prevents soakage, facilitates sweeping and surface cleanliness, and diminishes the soil emanations from below.

It may be stated as a general proposition that the area in any country over which fogs appear soonest after nightfall should be avoided.

It has already been mentioned that there are many other considerations besides those dependent upon hygiene alone which influence the choice of a site for a hospital.

Amongst these, the necessity of placing the hospital in a convenient locality, accessible both to patients and medical men, is a very real difficulty, and this often compels the erection of a hospital in the midst of a population or in unfavourable surroundings.

In the open country when the site is surrounded only by fields, it is of little consequence what is the area of the land enclosed in the hospital grounds, except for the purpose of preventing encroachment. But in towns the impurity of the air of a hospital will diminish in proportion to its distance from thickly inhabited places, and under these circumstances an enlarged area ought to be provided to counterbalance the unhealthiness of a site.

In a town, however, the surrounding population often makes it either impossible or very expensive to obtain a large site. So far this consideration has reference to the maintenance of the purity of the air to be breathed by the sick. But a certain space for a hospital placed in a town is also necessary for isolating the hospital, for the sake of the population living round the hospital. Every sick person is a focus from which emanations of more or less injurious kind are being thrown off, and the accumulation of numerous cases of sickness in one locality adds to the pollution in a rapidly increasing ratio.

Whatever may be the influences which cause the vitiation of the air in and around a hospital, whether they be due to putrefaction or fermentation and to the development of germs, or living organisms, or to consequences entailed by such organisms which have not yet been accurately ascertained, it is abundantly proved that the crowding together of individuals on a limited space is favourable to the development of such causes, whilst a large surrounding air-space reduces or limits the danger arising from them.

Consequently it may be taken as certain that a larger free space around a building in which sick or injured are located is necessary, that is to say in the case of a hospital, than would be required in the case of a collection, in a given area, of persons in good health.

In the case of some infectious diseases this has been especially apparent. No doubt well-managed fever hospitals which stand on an adequate area have not been found to involve any appreciable risk to the neighbourhood; yet even with these hospitals the Local Government Board prescribe, for London fever hospitals, that no building to which the sick would have access should be placed within 40 feet of the boundary wall. But in the neighbourhood of small-pox hospitals there would appear to be a graduated intensity of infection, and it has been shown that the incidence of small-pox upon houses within a mile radius of a small-pox hospital, apart from any infection due to the conveyance of patients to the hospital, was as follows:—The total number of cases under review was 2,527. For every 100 houses in the circle of a quarter of a mile from the hospital there were 17·35 cases. In the ring between a quarter and half a mile, 9·25. In the ring between half and three-quarters of a mile, 6·16. In the ring between three-quarters and one mile there were 2·57 cases in every 100 houses.

On this account it has been considered that small-pox hospitals are not properly admissible in a populous locality; fortunately small-pox patients may under ordinary circumstances be conveyed some miles by land in well-arranged ambulances without much risk, so that in a town it is only necessary to provide for a limited number of acute cases, and these can be safely treated even among a dense population, provided arrangements be made to burn all the air which passes out of the ward in which they are placed.

Some years ago the Surgical Society of Paris appointed a committee to consider what should be the minimum area of site to be allowed for each sick person in ordinary hospitals. The Committee recommended that this minimum area should be 50 square metres, or say 60 square yards per patient.

It must be remembered that the resident population of a hospital is much more numerous than that indicated by the number of beds, as it includes nurses, servants, staff, and resident medical officers. It will probably be found not far out of the way to assume that the total resident population in a hospital amounts on the average to one-half as many again as the patients.

The proportion of space per patient mentioned above means for a hospital of 100 beds nearly $1\frac{1}{4}$ acres; 200 beds, nearly $2\frac{1}{2}$ acres; 500 beds, rather over 6 acres.

These areas, however, are only admissible in cases where the obtaining of a larger site is a matter of exceptional difficulty, and there are few town hospitals in this country which occupy areas as small or smaller than these.

For instance, the Leeds Hospital, which stands in the centre of the town, when originally constructed, occupied about 3½ acres or 56 yards per bed for 328 patients, instead of something over 4 acres, according to the standard above mentioned, but in this case the site is surrounded by streets, which brought up the area of open space between surrounding houses to very much more than the standard of 60 yards per bed before mentioned.

The Marylebone Infirmary affords little over half the above-mentioned standard area, viz. under 32 yards per patient; but at the present time there is ground quite open to the country on one side.

The old hospitals of King's College, Middlesex, and Charing Cross, cannot be cited as desirable examples of a site. University College Hospital has had the advantage of the grounds of the College opposite to it.

St. George's Hospital occupies about seven-eighths of an acre. On this area it has to accommodate 356 patients all under one roof, or at the rate of 12 square yards per patient, instead of the allowance of 60 square yards per patient recommended by the Paris Surgical Society; these, with the nurses and others living in the building, bring up the resident number to a population of 580 per acre, which is a larger population per acre than the most thickly inhabited quarter of London. In addition to which there is a medical school and a large out-patients' department crowded on to the site.

The site has, however, the benefit of a fine open space on three sides, but this advantage is very much diminished by the way in which the buildings have been agglomerated, so as to prevent the permeation of fresh air to the centre, as well as by numerous projections which impede the flow of sunshine and fresh air to the wards.

As a contrast to this hospital we may instance the Johns Hopkins Hospital which stands on an elevated site at Baltimore. It accommodates 361 patients on 14 acres, with a superficial area per bed of about 186 square yards, and every building is separate; there is ample permeation of air and sunlight round all the buildings.

We may also mention the New York Hospital, which was built in 1877. It stands on nearly an acre of ground in the centre of New York, and accommodates 180 patients, affording nearly 30 square yards per bed. It is built with five floors of wards. This hospital is, however, arranged to admit light and air to every part of the building, in addition to which the wards are supplied with carefully devised arrangements for artificial ventilation.

St. Thomas' Hospital was built to accommodate 573 patients, and the area of the site affords above 70 yards per bed, in addition to which the site faces the River Thames, which supplies a constant aeration.

The New Liverpool Hospital affords about 90 yards per patient, but there are public streets on three sides, and the grounds of the medical school on the fourth side, which give additional aeration.

The Burnley Hospital was arranged to allow 110 yards with 88 beds, and if extended to 132 beds 73 yards, but this hospital had an open space on one side.

The Bradford Hospital, in the centre of the town, with 132 beds, affords about 100 yards per bed, and the site is surrounded by buildings.

The Glasgow Western Infirmary, besides being built on an open site, affords 154 yards per bed, and the Edinburgh Royal Infirmary, also in an open situation, affords 92 yards per bed.

Of the more recent foreign hospitals, the Antwerp Hospital affords about 118 yards, and the Berlin Military Hospital above 135 yards per bed, and the Berlin Civil Hospital 190 yards per bed.

The St. Eloi Hospital at Montpelier occupies 22 acres, and accommodates 600 patients, or at the rate of nearly 180 yards per bed.

The hospital at Menil Montant (Paris) contains 726 patients and occupies a little over 13 acres, affording about 89 square yards per bed, but it stands in an open and airy situation above Mont Martre.

The conclusion to be drawn is to obtain as much open space round a general hospital as its position will admit of.

The Infectious Fever Hospitals of London afford the following areas per patient:—The Eastern Hospital at Homerton, 98·5 yards; the North-Western Hospital at Haverstock Hill, 128 yards; the Western at Fulham, 100 yards; the South-Western Hospital, 117 yards; and the South-Eastern Hospital in the Old Kent Road, 115 yards.

In these hospitals the rule is not to place a sick ward nearer than 40 feet from the enclosure wall.

In fact the minimum space laid down by the Surgical Society of Paris has only been acted on in very exceptional circumstances, and should be strictly limited to the case of small hospitals.

Good hygienic conditions are comparatively easy to obtain even in towns in hospitals of from 150 to 250 beds, but very difficult to obtain, especially in large towns, if these numbers are exceeded.

In proportion as the cases of disease are agglomerated together, so is the degree of vitiation increased; hence a hospital with few patients may be placed upon a smaller area, per patient, than a large hospital; in other words, the area of space occupied by a hospital, per patient, should be increased in proportion to the number of patients.

With a hospital of from 100 to 200 beds, 60 square yards per patient might suffice under very exceptional conditions, but with 300 to 400 beds the area should be at least 90 yards per patient, and with 500 beds and upwards, 120 to 140 square yards per patient would be required. But it may be safely laid down that, on a town site surrounded by houses, it is not desirable to afford in any hospital less than from 90 to 100 yards per patient to be accommodated; or practically a town site should not contain more than 50 beds per acre, and for fever and infectious hospitals a larger area should be provided, and the number per acre should be limited to 35, 40, or at most 45 beds per acre.

Hence it would be preferable that in the centre of cities hospitals should be erected for urgent cases only; and in any case, hospitals in the centre of towns and surrounded by dwellings should not be constructed for more than from 200 to 300 patients each, which would be sufficient for clinical purposes. Where large hospitals are built they should be installed on open sites in the country, because there the land required would be comparatively cheap, and the absence of surrounding houses renders the question of area a secondary consideration.

As regards the acquisition of sites for hospitals, it is no doubt reasonable that when a new hospital is projected the site on which it is to be placed should be a matter of private arrangement. But in the case of well-established hospitals, which are in efficient action for the public good, and conducted without any desire of gain, it would certainly appear reasonable, where their managers are anxious to enlarge their premises with a view of increasing the amount of accommodation, or of ameliorating the condition of their patients, that the power should be afforded them, under proper restrictions, of purchasing compulsorily adjacent land for such purposes.

The Metropolitan Asylums Board possesses such power under a recent Act of Parliament, and there seems to be no reason why this should not be extended to other responsible hospital authorities in the Metropolis and in other large cities.

CHAPTER IV.

CONDITIONS WHICH VITIATE THE AIR IN AN OCCUPIED ROOM.

It will be convenient in the first place to explain briefly what are the reasons on the ground of health why a certain air-space is wanted, and though in other books this subject has been treated at length, it may be convenient here to summarise the reasons for change of air.

Let us first consider how far do we obtain pure air out-of-doors. Really pure air is composed as follows, viz.

Oxygen	209·5
Nitrogen	789·3
Other Gases	·2
Parts of Air	1000

The oxygen is necessary to life, but if it were breathed pure, it would burn us away. The nitrogen is an inert gas which dilutes the oxygen and prevents it from being injurious in the process of breathing. In air out of doors in the open country, there are from 3 to 4 parts of carbonic acid gas (CO_2) in 10,000 parts of air, indeed it is sometimes as low as 2 parts; this amount will sometimes be increased by vegetation, as in a wood, or by the emanations of animals, as, for instance, in proximity to a flock of sheep.

In towns a much larger quantity will sometimes be found. Dr. Angus Smith showed an average of 3·8 in the streets in London, as compared with 3·0 in the parks, and he found that as much as 6·8 per 10,000 parts of air were present in confined streets in a fog in Manchester. Dr. Russell has found as much as 9, 11, and even 14 parts of CO_2 in 10,000 volumes of air in a dense fog in London. But on the whole it has been considered that 4 parts per 10,000 of CO_2 in outside air may be assumed to be the standard amount.

Moreover there is always dust in air, i. e. solid particles.

Dr. Langley has observed the presence of dust in air on the tops of the highest mountains. The rain washes the dust out of the air; Dr. Aitken found near his laboratory in Glasgow, that whilst during rain, a cubic centimetre of air out-of-doors contained 32,000 of these solid particles largely inorganic, in dry weather it held 130,000 particles, and in his room the air in some parts yielded nearly 6,000,000 particles. Professors Carnelley, Haldane, and Bedson have shown that the air of a room, in which much movement of persons or of articles takes place, exhibits much more dust than that of a room which is left for a long time in absolute quiescence.

This dust consists partly of inorganic matter, and partly of minute organisms. The number of organisms, e. g. bacteria and spores found by Dr. Miguel in air from the streets in Paris, averaged 3,480 per cubic metre in summer. In the vicinity of the Mont Souris Observatory they averaged only 480, whereas none were found on the top of a high mountain in the Alps. In winter the numbers found were much less than in summer. In the open country in summer the dust in the air consists largely of pollen.

This dust affords nuclei upon which the aqueous vapour in the air can settle, and this forms haze and fogs, and when the particles are over-loaded with moisture they fall down as rain.

Near the sea, where the inorganic dust contains saline particles, or in towns where it contains ammonia, its affinity for moisture is greater, and fogs are more prevalent; and where smoke from our coal fires is added, the tarry matter renders the fogs more persistent, and the sulphurous acid makes them more unpleasant.

When a person is in an open space out-of-doors, the air is perpetually flowing past him. It has been estimated that the air of the atmosphere moves at a rate of rarely less than from 5 to 7 miles per hour; the former is equivalent to 7 feet per second, but the average movement is from 20 to 24 feet per second. Now 24 feet per second means 17 miles per hour; but let us consider what the effect will be of a movement of only 7 miles an hour, or 10 feet per second. Imagine a frame about the height and width of a human body in the open air: that is to say, about 6 feet high by $1\frac{1}{2}$ foot wide, occupying an area of 9 feet. If this be multiplied by 10 feet per second for the velocity of air, it will give as the quantity of air which will pass over an individual in one second 90 cubic feet, in one minute 5400 cubic feet, and in one hour 324,000 cubic feet.

Even out-of-doors the effect of congregating large numbers of persons together may prevent the free access of fresh air to those in the middle of a crowd. As an instance of this, it has happened that on a still day, persons in the middle of a crowd have fainted for want of air. But in an occupied room the respiration of individuals, their perspiration, the burning of candles, emanations from food and all such matters, vitiate the air of rooms at a certain rate.

Every human being, in order to live, must be constantly breathing; in the act of breathing he takes in oxygen, and throws out from his lungs carbonic acid (CO_2); but he also throws off a large amount of watery vapour, organic matter and ammonia. This organic matter consists of epithelium, and molecular and cellular matter.

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

A large amount of watery vapour is also given off from the skin.

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

This watery vapour is full of the organic matter which is thrown off from the body. With persons suffering from disease, especially infectious fevers, or from wounds or sores, these emanations, as well as those from the lungs in the case of phthisis, are greater in quantity, and it is generally assumed more poisonous in quality, than from persons in health.

Hence it may be assumed that vitiation occurring in the air of occupied rooms may arise—

(1) From products of normal respiration and perspiration;

(2) From products of disease, want of cleanliness, or other abnormal conditions of the persons present in the rooms;

(3) From impurities arising from the floor, walls, &c. of the room itself.

As a rule the proportion of carbonic acid present in the air is taken as a sufficient index of vitiation. But air which, judged by the carbonic acid standard, is sufficiently pure, might be exceedingly impure when judged by the number of micro-organisms present in it, and vice versa. The carbonic acid and micro-organisms have different sources. The amount of the former depends on the number of persons or lights burning in the rooms as compared with the means of ventilation—that of the latter being determined chiefly by the conditions of the room itself and its occupants as regards cleanliness, &c.

The immediate dangers from breathing air highly vitiated by respiration appear to arise mainly from the excess of carbonic acid and deficiency of oxygen.

But the actual quantity of air impaired each minute by any one individual in a state of comparative rest is really small. About $\frac{1}{3}$ of a cubic foot of air is vitiated by breathing (inhaled and exhaled) in the one minute's time, and even this is not entirely spent for use over again. To this must be added the quantity of air vitiated by transpiration, from the person, of moisture laden with organic matter.

Ventilation would probably be perfect, if there could be removed, without admixture of other air, the volume of air exhaled in breathing, together with a layer of air next the person, and the two volumes were taken to be one cubic foot of air per person per minute, while at the same time there should be furnished the same quantity, to answer the double purpose of supplying fresh air for inhalation, and a new 'atmosphere' next the person.

But as we cannot in practice thus catch emanations from each person, they mix with the surrounding pure air, and our only remedy is to dilute this mixture with an adequate volume of outside air, so as to bring the whole to some accepted standard of impurity.

The measure of impurity of air in an occupied room has been till recently always taken from the excess of CO_2 in the occupied room over that out-of-doors, and from Professor Haldane's recent experiments, this would appear to be a safe standard to rely upon.

The estimates of sanitarians as to the amount of air required are generally based upon the observations of De Chaumont, Parkes, and others, as to the amount needed to keep an occupied room free from perceptible odour to a person entering it from the outer air, and on the percentage of carbonic acid which is found in the air of rooms in which this animal odour is barely perceptible.

When, as a product of respiration, the proportion of carbonic acid in a room is increased from the normal ratio of between 3 and 4 parts in 10,000 to between 6 and 7 parts in 10,000, a faint, musty odour is usually perceptible. Assuming that the air of an inhabited room should be just so impure as to possess this odour, the following table by Parkes shows the amount of air necessary to dilute to this standard :—

Amount of cubic space (breathing space) for one man in cubic feet.	Ratio per 1,000 of carbonic acid from respiration at the end of one hour if there has been no change of air.	Cubic feet of air necessary to dilute to standard of ·2, or including the initial carbonic acid, of ·6 per 1,000 vols. during the first hour.	Cubic feet of air necessary to dilute to the given standard every hour after the first.
100	6.00	2,900	3,000
200	3.00	2,800	3,000
300	2.00	2,700	3,000
400	1.50	2,600	3,000
500	1.20	2,500	3,000
600	1.00	2,400	3,000
700	0.85	2,300	3,000
800	0.75	2,200	3,000
900	0.66	2,100	3,000
1000	0.60	2,000	3,000

The above table refers to rooms occupied for a number of hours consecutively.

Dr. de Chaumont's experiments were made in barracks and in hospitals, and a result comes out from them 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. Thus, 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 ·196, in the barracks with that amount it was fresh.

Surgeon-General Billings, of the U. S. Army, gives a comparatively simple method of testing for CO_2 in breathed air in the appended foot-note[1].

[1] For ordinary purposes a convenient method of testing the amount of carbonic acid is the following, for which there will be needed six

Various methods have been used for measuring the organic matter in air. Dr. Angus Smith devised two methods.

According to the first of these methods, a definite quantity of the air to be examined is slowly bubbled through a dilute solution of potassium permanganate of known strength, until it is fully or considerably bleached, and the amount of undecomposed permanganate determined by oxalic acid.

In the second method a known volume of air is bubbled through distilled water, and the latter examined for free and albuminoid ammonia by Wanklyn and Chapman's process for water analysis.

These methods are, however, inapplicable in circumstances and in places where such determinations are most desirable, chiefly on the score of time and of the extent and complication of the apparatus required.

Moreover, very considerable variations in the organic matter are sometimes liable to occur within the period of determination required by Dr. Angus Smith's method.

well-stoppered bottles, containing respectively 450, 350, 300, 250, 200, and 100 cubic centimetres, a glass tube or pipette graduated, to contain exactly 15 cubic centimetres to a given mark, and a bottle of perfectly clear and transparent fresh lime-water. The bottles must be perfectly clean and dry. Having made sure that they are filled with the atmosphere which is to be examined, which can best be done by pumping into them a quantity of this air by means of one of the small handball syringes, which may be procured in any drug store, and taking care that none of your own breath is pumped in, add to the smallest bottle by means of the pipette 15 cubic centimetres of the lime-water, put in the cork, and shake the bottle. If turbidity appears, the amount of the carbonic acid will be at least 16 parts in 10,000. If no turbidity appears, treat the next sized bottle, viz. of 200 cubic centimetres, in like manner. Turbidity in this would indicate 12 parts in 10,000. If this remains clear, but turbidity is produced in the 250 cubic centimetre bottle, it makes about 10 in 10,000. The 300 cubic centimetre bottle indicates 8 parts, the 350, 7 parts, and the 450 less than 6 parts. To judge of the turbidity, mark a small piece of paper on the inside with a cross in lead pencil, and gum to the side of the bottle on the lower part. When the water becomes turbid the cross will become invisible when looked at through the water. This will enable one to judge roughly of the amount of carbonic acid in the air. For more accurate analysis, the method of Pettenkofer, as described by Parkes, should be employed.

A modification of Dr. Angus Smith's plan has been adopted by Dr. Carnelley, that is to measure the volume of oxygen required to oxidise the organic matter in a definite number of volumes of air by the reduction of potassium permanganate[1].

This method, however, does not give absolute, but only relative results. The general conclusions, however, which Dr. Carnelley obtained from a number of experiments are deserving of notice here:—

(1) As regards outside air, the quantity of organic matter varies considerably, within certain limits, from day to day, and from hour to hour on the same day.

Variations from day to day are subject to the conditions of the weather. It has been found somewhat less immediately after or during rain or snow. The highest results of all were obtained on foggy nights, e.g. 15·7, 17·0 volumes of oxygen were required to oxidise 1,000,000 volumes of air. High results were also obtained during a slight drizzling rain, accompanied by mist.

(2) A close connexion is observed between the amount of organic matter present in air and the combustion of coal. The organic matter is lowest in the middle of the night, rather higher in the morning, and considerably higher in the middle of the day, and higher still towards evening, after which it decreases.

On comparing the averages of a large number of cases it appears that a high carbonic acid is accompanied by a high organic matter, and vice versa.

But whilst the carbonic acid seldom passes beyond the limits of 2 to 6 volumes per 10,000, the organic matter varies

[1] There are some objections to this method; for instance—'it does not directly estimate the organic matter, but only measures the amount of oxygen required to oxidise either the whole, or more probably only a portion of it; and the permanganate acts upon various matters in the air, besides the organic matter, such as sulphuretted hydrogen, nitrous acid, sulphurous acid, &c. Moreover the organic matter in air is of various kinds, and consequently the permanganate will most probably be selective in its action.'

from a quantity too small to estimate to as much as will require for oxidation about 16 volumes of oxygen per 1,000,000 volumes of air.

The organic matter in air is most probably partly solid and partly gaseous; the solid—obeying a different law to that of diffusion—slowly settles down, whilst the gaseous part, unlike carbonic acid, is most likely an unstable compound or compounds, and readily undergoes oxidation.

An atmosphere which has been entirely at rest for some time is found to contain less organic matter than it did previously. This is not necessarily entirely due to the settling down of the solid organic dust, but is probably due in part to oxidation.

It may, however, be assumed that the quantity of CO_2 in breathed air will within limits, on the average, afford under ordinary circumstances a fair test of the quantity of organic matter present.

An index of the degree of impurity in the air in occupied rooms has been sought in the presence of those minute organisms which have been recently brought into prominent notice by the increased attention given to the study of bacteriology. But our knowledge of this science and of the nature of organisms is too recent to allow us to lay down any fixed rules for judging of what are the dangerous characteristics of air in wards measured by this standard.

In addition to this, there is a further difficulty with such a test. The dust and the number of organisms present in the air of any room may be enormously increased at any moment by movement of persons or materials in the room. The shaking of a counterpane, the movement of a nurse or of a patient, might seriously change the conditions exhibited by this method of test. Moreover, any test for impurity in the air of a sick ward should be such as can be made without undue delay, and the time required for the cultivation of the organisms present in the air would prevent this method of testing air from being available, except for special objects and enquiries.

In considering the vitiation of the air in its relation to ventilation, it has to be remembered that the emanations from the bodies of patients do not diffuse themselves so rapidly or uniformly as, under ordinary circumstances, is the case with carbonic acid. They hang about as the smoke of tobacco may be said to do, in corners and places where there are obstructions to the movement of the air. For instance, in some experiments made upon the air of a well-ventilated ward, it was found that whilst there were 5·8 volumes of CO_2 per 10,000 volumes of air near the patients, and 8·5 volumes in the centre of the ward, the volumes of oxygen required to bleach the organic matter in 1,000,000 volumes of air was fifteen times as much, near the patient's bed, as it was in the centre of the ward.

This may probably be accounted for by the fact that any movement, as, for instance, of the bedclothes of a patient, would largely add to the organic dust in the vicinity.

CHAPTER V.

QUANTITY OF AIR NECESSARY TO MITIGATE THESE CONDITIONS.

IF the condition of the air throughout the ward were uniform, ventilation would be comparatively simple, and whatever were the amount of the floor-space or cubic space, the whole air would attain a permanent degree of purity, or rather impurity, theoretically dependent upon the rate at which emanations are produced and the rate at which fresh air is admitted, and the question of space between the patients would be of less importance. That is to say the same supply of air will equally ventilate any space, or which is the same thing, the same supply of air is required for a small space as for a large space. Hence the question of what should be the minimum cubic space depends upon the following considerations :—

(1) An adequate floor-space.

(2) A change of atmosphere frequent enough for health, but not so frequent as to cause draughts.

(3) Sufficient space to reduce to a comparatively small amount the danger from temporarily impeded ventilation.

(1) *Adequate floor-space.* The floor-space is the important element of the cubic space; whilst it is undesirable that any ward should be less than 12 feet high, it has been generally assumed that, in hospitals, the height above 12 feet may be left out of consideration in calculating cubic space;

but this cannot be accepted as an axiom because, with a very long or wide ward, the height forms an important element (1) in the movement of the currents of air, (2) in the penetration of daylight; and whilst we may accept a height of 12 feet for a barrack room or ward of 20 to 22 feet wide, the due movement of the air in wards of 26, 28 and 30 feet require heights of 13 feet, 14 and 15 feet, and with greater widths 16 feet. Exclusive of the question of the due áeration of the space occupied by the patient, the floor space must suffice for—

(*a*) Adequate space between sides of beds, to admit of all necessary operations of nursing.

(*b*) Adequate width at foot of bed for furniture, and easy movement about the ward.

(*c*) Adequate space for students, when there is a Medical School.

The distance between beds at a low computation should not be less than from 4 feet 6 inches to 5 feet; this, with a three-foot bed, would afford a lineal bed-space of from 7 feet 6 inches to 8 feet: assuming the foot of the bed to be 7 feet from the wall, each bed-space should extend 6 feet at least beyond the bed; thus each bed would occupy a space of 8 feet × 13 feet, or 104 square feet of area, which would afford 1,300 cubic feet, with a ward 12 feet 6 inches high; 1,350 cubic feet with a ward 13 feet high; and 1,450 cubic feet with a ward 14 feet high.

Of course this floor-space would be a minimum and must be increased if there is a Medical School, or in the case of an excess of emanations from the patients, wherever the ventilation does not adequately remove such emanations.

But it must be remembered that any increase to the floor or cubic space beyond what is actually required causes unnecessary outlay in first construction, and entails a continuing excess in the charges for warming and service. And it may be assumed as an axiom that, without unduly depreciating the beneficial effect of abundant air-space, the frequency with which, and the manner in which, the air is changed, is a far more important point to be attended to in providing a purer atmosphere, than floor space or cubic space.

(2) *A change of atmosphere frequent enough for health, but not so frequent as to cause draught.* And—

(3) *Sufficient space to diminish danger from impeded ventilation.*

Let us first consider the effect of arrested ventilation. Let us suppose two occupied spaces, one of 500, and the other of 1000 cubic feet, ventilated so that the ratio of carbonic acid is ·06 per cent., and that from some cause or other the ventilation is arrested in both, the condition will then be as follows :—

Ratio of Impurity, calculated from Prof. Donkin's formula.

	1000 ft. CO_2.	500 ft. CO_2.
After 1 hour	·12 per cent.	·18 per cent.
" 2 hours	·18 " "	·30 " "
" 3 "	·24 " "	·42 " "
" 4 "	·30 " "	·54 " "
" 6 "	·42 " "	·78 " "
" 7 "	·48 " "	·90 " "

There is difference of opinion as to the amount of carbonic acid that can be borne, but when conjoined with fetid organic matter, as in the products of respiration, it is pretty generally agreed that ·3 per cent. can hardly be supported, and that at ·5 per cent. the atmosphere is unendurable.

From the foregoing table it will be seen that ·3 per cent. is reached in the case of 500 feet in two hours, but in the case of 1,000 feet in four hours, whilst ·5 per cent. would be reached in the former case in about three and a half hours, in the latter not until seven hours had elapsed.

The change of atmosphere frequent enough for health depends upon the observance of certain conditions of temperature and humidity, as well as upon the amount of impurity from CO_2 in occupied rooms.

On this account the atmospheric conditions of the country in which the hospital is to be placed have to be studied.

The comfortable warmth of air indoors is given by various authorities, as follows:—

Peclet, 'Traité de la Chaleur,' gives 59° Fahr. Morin, 'Etudes sur la Ventilation,' for nurseries, schools, &c. 59° Fahr., hospitals 61° to 64° Fahr. Tredgold, 'Principles of Warming and Ventilating,' &c., 56° to 62° Fahr. Reed, 'Illustrations of the Theory and Practice of Ventilation,' 65° Fahr. De Chaumont, 62° to 65° Fahr. for hospitals. These apply to this country, and to France; whilst in the United States Surgeon-General Billings lays it down that the temperature of 68° to 70° Fahr. is necessary.

Comfort, if not existence, depends upon a constant loss of heat from the person. The internal natural warmth of the body is about 98·6° Fahr., and this is independent of the heat of the external air, and is maintained by the food we eat and the oxygen we breathe; the personal comfort which arises from the temperature and humid condition of the air proceeds from the cooling effects which must go on with constancy and regularity, and yet not so fast as to produce the sensation of cold. The origin of the natural heat is well established. There is inhaled by each adult in comparatively still life, each three to four seconds, from 30 to 40 cubic inches of air, under such atmospheric conditions as may exist at the place. Thus there may be extreme differences of temperature ranging from − 40° to + 140° Fahr., as well as extremely variable proportions of humidity, from the point of saturation on the one hand to that of nearly an anhydrous air on the other. A portion of the oxygen of the inhaled air is consumed in the system; and the exhalation which follows each inhalation, emits about 4 per cent. of carbonic acid, and 1½ per cent. of vapour of water. Two or three grains of carbon are consumed in the system each minute, giving out 3¾ to 5¾ units of heat; the unit of heat being the equivalent of a pound of water heated 1° Fahr. It is the dispersion of this heat which establishes the sensation of comfort.

The deprivation of heat from the person is more due to evaporation from the lungs or throat, and from the skin, than from heat lost by conduction to the surrounding air or dispersed by radiation to adjacent objects. Thus the inhalation of cold vapour from fog may cause much discomfort from the rapid absorption of heat which it induces. And the hygrometric state of the air has so much effect in inducing or retarding evaporation, as to make 56° Fahr. in the west and south of England, in Ireland and in Normandy, sensibly as warm as 80° in Canada or Minnesota at the same season.

As regards *Temperature*, it may be assumed for hospitals that the dry-bulb thermometer ought to read 63° Fahr. to 65° Fahr., and should not if possible go much below 60° Fahr.

The wet-bulb ought to read 58° Fahr. to 61° Fahr. In any case the difference between the two thermometers should not be less than 4° Fahr. or more than 8° Fahr. In the open air in healthy weather it is often 8° or 9°.

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° Fahr.

The limit of humidity which can be permitted in hospitals in this country is 75° per cent. of total saturation 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.

The capacity of the air for moisture increases enormously with the temperature, and that which would saturate air at 50° Fahr. would give about 70 per cent. at 60° Fahr. Thus, at 50° Fahr. a cubic foot of air is saturated by 4·1 grains; but at 60° Fahr. it requires 5·8 grains, so that 4·1 grains would give us only 71 per cent.

The table on the next page shows the proportion of moisture required to saturate air at different temperatures:—

The Weights of Air, Vapour of Water, and Saturated Mixtures of Air and Vapour, at different Temperatures, under the ordinary Atmospheric Pressure of 29·921 inches of Mercury.

Temp. Fahr.	Volume of Dry Air at different temperatures, the vol. at 32° being 1·000.	Weight of a cubic foot of Dry Air at different Temperatures in pounds.	Elastic force of Vapour in inches of Mercury. Regnault.	Mixtures of Air Saturated with Vapour.						Cubic Feet of Vapour from one pound of Water at its own pressure in column 4.
				Elastic force of the Air in the Mixture of Air and Vapour in inches of Mercury.	Weight of a cubic foot of the mixture of Air and Vapour.			Weight of Vapour mixed with one pound of Air in pounds.	Weight of Dry Air mixed with one pound of Vapour in pounds.	
					Weight of the Air in pounds.	Weight of the Vapour in pounds.	Total Weight of Mixture in pounds.			
1	2	3	4	5	6	7	8	9	10	11
0°	·935	·0864	·044	29·877	·0863	·000079	·086379	·00092	1092·4	
32°	1·000	·0807	·181	29·740	·0802	·000304	·080504	·00379	263·81	3289
52°	1·041	·0776	·388	29·533	·0766	·000627	·077227	·00819	122·17	1595
62°	1·061	·0761	·556	29·365	·0747	·000881	·075581	·01179	84·79	1135
72°	1·082	·0747	·785	29·136	·0727	·001221	·073921	·01680	59·54	819
82°	1·102	·0733	1·092	28·829	·0706	·001667	·072267	·02361	42·35	600
102°	1·143	·0707	2·036	27·885	·0659	·002997	·068897	·04547	21·98	334
152°	1·245	·0649	7·930	21·991	·0477	·010716	·058416	·22465	4·45	93·3
212°	1·367	·0591	29·921	0·000	·0000	·036820	·036820	Infinite	·000	27·1

The diagram (Fig. 1 on page 54) shows the increase in the capacity of the air for carrying off moisture, as the temperature of the air rises. The curved lines represent 10, 20, &c. to 100 per cent. humidity; 100 per cent. being the dew point. The horizontal line of figures from 10 to 200, at the top of the diagram, indicate the grains of moisture per cubic foot of air, while the temperature of the air is given in degrees Fahr. at the left side. If therefore the outer air is at a temperature of 50°, and if the temperature inside the room be maintained at a comfortable standard, say 63° to 65°, the incoming moisture due to the condition of the outer air would never cause an excess of humidity.

In the case of an external atmosphere saturated at or above the temperature in the room, such as occurs occasionally in hot climates, it would be necessary to let in an unlimited quantity of air through every possible aperture.

The volume of air which should be provided in a room to maintain the atmosphere at a proper degree of humidity, depends upon the sources of vapour inside the room. Every man gives off from lungs and skin each hour enough to raise the humidity from 70 per cent. to complete saturation in 500 cubic feet at 60° Fahr., and to raise it to 82 per cent. in 1500 cubic feet. Now to reduce this amount to 73 per cent. would take 3,000 cubic feet of air saturated at 50° Fahr., or 2,000 at 98 per cent. But the vapour given off by the body is not the only source of humidity. Humidity may arise from the combustion of lights.

For instance, a gaslight affording 1 candle power of light, that is to say giving an amount of light equal to a sperm candle burning 120 grains per hour, will emit ·025 lbs. of watery vapour. A sperm candle would for the same amount of light give out ·02 lbs. of watery vapour, and an oil lamp ·018 lbs. Thus we shall not be far wrong in considering the effect on the air of each gas or candle light burned in the room as equivalent to that of a human body.

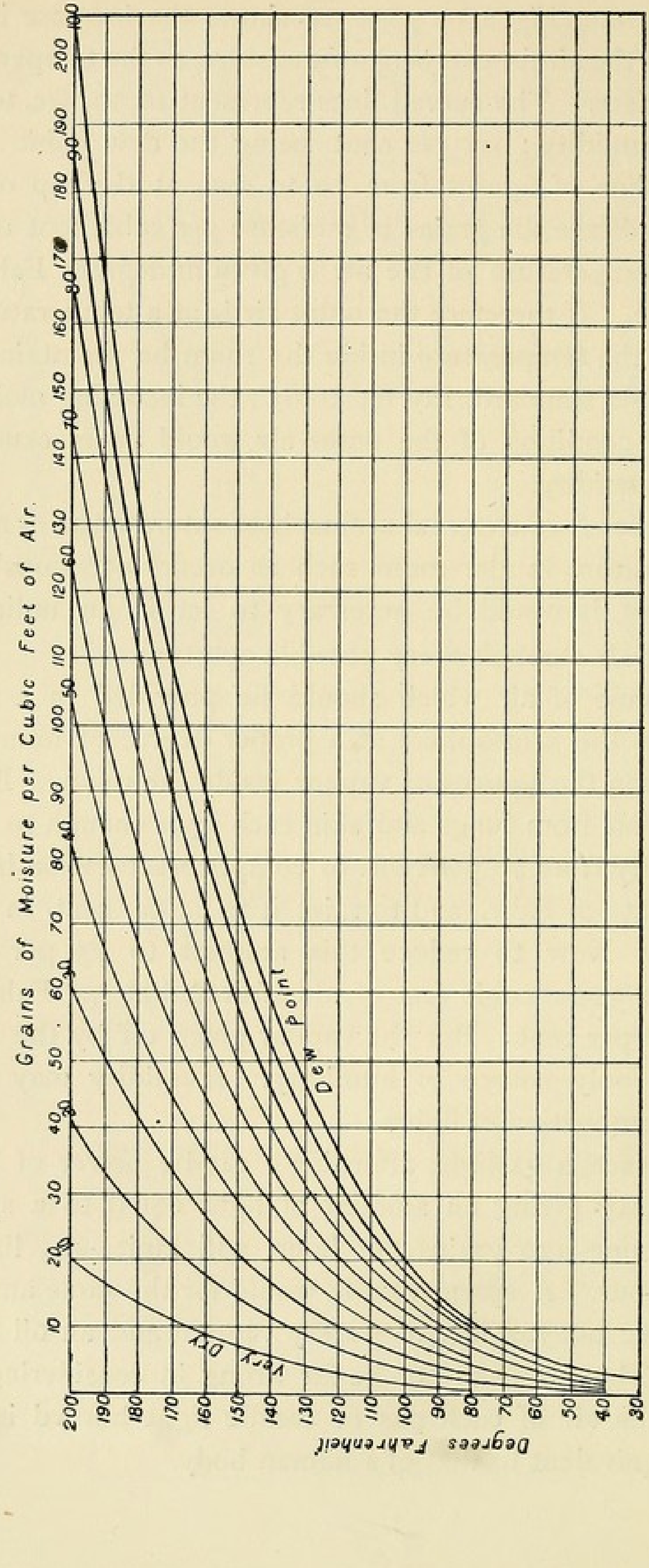

Grains of Moisture per Cubic Feet of Air.
Degrees Fahrenheit
Dew point
Very Dry

Fig. 1.

The humidity will moreover be affected by the vapour of liquids used in the room.

Upon this theoretical assumption it would appear that with an initial air-space of 1000 cubic feet occupied by one individual it would be necessary to supply 3000 cubic feet, per hour, to maintain the room in a proper condition of humidity.

As regards other impurities, if 0·2 per 1000 of CO_2 is accepted as the limit of respiratory impurity in a well-ventilated air-space, in addition to the 0·4 per 1000 in normal air, we can calculate the amount of air necessary for the purpose. For this, it is more convenient to state the ratio of CO_2 per cubic foot, so that 0·2 per 1000 would be 0·0002 per cubic foot, and calling this M, the amount of CO_2 given out by a single individual C, and the delivery of air required x, we have:

$$x = \frac{C}{M}.$$

Now, when $C = 0{\cdot}6$, and $M = 0{\cdot}0002$, we have the following:

$$x = \frac{0{\cdot}6}{0{\cdot}0002} = 3000.$$

Or, it requires 3000 cubic feet per hour to preserve the air-space in the required state of limited impurity. Upon these assumptions the theoretical calculations, based first upon humidity and secondly on carbonic acid, bring us to similar conclusions in each case. In connexion with this it is desirable to mention that experiments made in barracks showed that a much less amount of air, per head, delivered through ventilators kept the air of the room in a satisfactory condition as tested by the sense of smell; and this was attributed, partly, to the badly fitting doors and windows, and partly to porosity of walls.

The barrack-room walls were generally of brick, lime-whited without plaster.

The volume of air which will flow through ordinary brick walls and plaster is very great.

The experiments of Shultze and Marker, and of C. Lang of Munich, showed that with a brick wall of ordinary thickness, and a difference of temperature of 35° between that of the room and the outside air, very nearly 10 cubic feet of air passed through each square foot of wall surface, but the mortar in the walls was nearly equal to one-sixth of the cubic content of the wall. A wall of mud and plaster allowed a passage of 18 cubic feet of air, per hour, per square foot of wall, with a difference of temperature of 20° inside the room as compared with that outside.

These amounts would show that in the case of a closed barrack room or hospital ward at night, with a high inside temperature as compared with the temperature outside, 300 or 400 cubic feet, per occupant, per hour, might easily pass in through brick and plaster walls.

But the porosity of a material is more fully 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	·5
Malm bright stock . .	22	Bad specimen granite .	3
Brown paviors . . .	17	Sandstone—	
Hard paviors . . .	9·5	Craigleith	8
Common grey stock . .	10·5	Mansfield	10·4
Hard " " . .	7·5	Hassock (very bad quality)	20
Staffordshire—		Limestone—	
Common blue . .	6·5	Portland	13·5
Brown glazed brick . .	8·6	Ancaster	16·6
		Bath	17
		Chilmark	8·6
		Kent rag	1·75
		Ransome artificial stone .	12

From this it appears that walls of any of these materials, being always more or less porous, must admit of a continuous spontaneous change of air when dry.

An experiment made in New York, by Mr. Putman, as detailed in the note[1], showed that with every means taken to prevent porosity or cracks, the inflow through walls amounted to nearly 5,400 cubic feet per hour, in a room containing only a little over 3,000 cubic feet of air space, when the outside air was about 36° Fahr., and that inside varied from 72° to above 90° Fahr.

These facts may help to explain some matters connected with the healthiness of improvised hospitals. But with the modern system of ward walls lined with either highly glazed

[1] *Experiments on porosity of walls to air in an ordinary living room, by Mr. Putman of New York.*

The room was about 5 metres square and 3.6 metres high, having 5 windows, 2 doors, and a fire-place, with plastered walls and ceiling, and a soft pine floor.

A flue 10 metres long, from a basement furnace, furnished the rooms with hot air. The windows and doors were first made as tight as possible with rubber moldings. The fire-place was then closed by drawing the damper and pasting paper over the cracks. The brick back and jambs were oiled to render them impervious. All the woodwork was thoroughly oiled and shellacked. A good fire was lighted in the furnace, and the register opened into the room, all doors and windows being closed and locked, and the key-holes stopped up. The hot air entered almost as rapidly with the doors closed as when they stood open, and it continued to enter at the rate of 2.5 cubic metres per minute without diminution as long as the experiment was continued.

The thermometer stood at 2° C. outside. The entering hot air ranged from 40° to 55° C. The day was March 3, 1880. The pressure of the hot air from the register was sufficient only to raise a single piece of cardboard from the register. On the 5th March a coat of oil paint was applied to the walls and ceilings. This diminished the escape of air only about 5 per cent. On the 19th March four coats of oil paint had been put on the walls and ceilings, and three coats on the floor, to render them absolutely impervious to air. The escape of air was diminished only about 10 per cent. On the 25th March all the window sashes were carefully examined, and all visible cracks at the joints, at the pulleys, cord fastenings, &c., carefully caulked and puttied. The result of all this was a diminution at the utmost of but 20 per cent. in the entrance of air through a register. Each experiment was continued during more than an hour. The air entered as freely at the end as at the beginning of the hour.

bricks with cement joints, or with polished Parian cement, very little change of air can take place through the walls.

In a warm climate the natural changes of temperature, and consequent alteration of the conditions which govern the movement of air, differ widely from those in temperate and cold climates, but there other conditions step in, and open windows and other apertures for air may be largely resorted to.

Of course the admission of a definite quantity of air into a room means the removal of an equal quantity from the room.

Consequently, 3,000 cubic feet being the quantity to be removed, we must now consider how often we can change the air of a room without producing a draught. This must depend upon varying conditions of temperature.

Dr. de Chaumont's experiments led him to the conclusion that it would be difficult to effect a change of the air of a room oftener than six times in an hour under ordinary circumstances. These experiments were made in barrack rooms affording 600 cubic feet of space.

And the experiments of Pettenkofer led to a similar conclusion.

But even, with that amount of cubic space, this change would be difficult to effect without draught, unless the temperature of the incoming air was above that of the room occupied, because it must be borne in mind that this change is to go on at all times, whether windows be open or shut, although we cannot do away with the desirability or indeed the necessity of opening windows when circumstances permit. The problem is much simplified if, by giving a cubic space of 1,000 cubic feet, we limit the change of air to three times an hour, and with an increased cubic space of over 1,000 cubic feet we should require even a less frequent change. It will be recollected that Professor Faraday showed by experiments, that a velocity of two feet per second would not be perceptible, and with properly arranged inlets, no draught need be felt with a change of air of three times per hour.

The position of air inlets both in relation to their level and inclination will be alluded to in connexion with movement of air. But it will be convenient here to add a few words on the measurement of the quantity of air passing through inlets or outlets for purposes of ventilation. The only way in which actual measurements can be taken is by causing the air 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 are further 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 2 feet per second, takes up an angle of 45°, and affords a ready means of measuring that velocity; and, for smaller velocities, the angle assumed by the flame of a candle affords a fairly accurate index according to the following table:—

Velocity of flow of air. Feet per second.	Angle of inclination of flame of candle with horizon.
1.6	30°
1.0	40°
0.75	50°
0.50	60°
.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. The vanes will only begin to move after the current of air has attained a certain strength, depending upon their weight and form, and this method of measurement is therefore not applicable to very low velocities. Of course the value of the 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. On account of friction 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, where the measurement takes place, have also an appreciable effect on the movement of the vanes.

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 a size to correspond with the size of the anemometer, and so that the whole of the air will pass over the vanes, proper precautions being taken to protect the channel from eddies.

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 $\frac{3}{10}$ inch internal diameter, open throughout, and of any length; the second part, of a manometer, or pressure-guage. 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. 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[1]. The connexion between the tubes in the chimney and the glass U-tube may be conveniently made by means of india-rubber tubing.

[1] The law which governs the speed is expressed generally by the formula $v = \sqrt{p} \times 28{\cdot}55$. The corrections to be made for small variations of barometric pressure and temperature are unimportant. The corrections when required are embodied in the following formula:—

$$v = \sqrt{p \frac{h}{29{\cdot}92} \cdot \frac{519}{459+t}} \times 28{\cdot}55,$$

where p is the height of the column of liquid driven up the tube measured in inches, and v is the velocity measured in feet per second of air at a temperature of t degrees Fahr., under a pressure of h inches of mercury.

Tables of the velocities corresponding with the readings are supplied with the anemometer, and also a table of correction for temperature. See 'Healthy Dwellings,' p. 69.

CHAPTER VI.

PURIFICATION OF AIR.

THE necessity for placing hospitals in the middle of towns has introduced the double question :—

(1) Of purifying the air which is passed into the wards, for the protection of the patients.

(2) Of purifying the air which is removed from wards, placed in the centre of towns, in which a contagious or infectious disease such as small-pox is treated, for the protection of the surrounding population.

(1) *Purification of air passed into the wards.*

In large towns the fog-laden air in the winter is always injurious to patients, and it may often be said that the larger the quantity of air introduced into a ward the greater will be the fog in the ward.

In cases of bronchitis and of diseases of the respiratory organs the presence of fog is especially injurious, as is shown by a rise of mortality from these diseases in the periods of dense fog in London. Air filters of dry cloth and cotton-wool filters become easily clogged, and when clogged no longer prevent the passage of dirt. Moreover, they do not prevent the passage of fog. The system adopted in the Houses of Parliament, viz. to pass the air through a spray of water and then to filter it through dry cotton wool, does not prevent fog from penetrating into the building.

A method of purification by washing the air has been adopted at the Victoria Infirmary, Glasgow, under the design of Mr. William Key, which appears to fulfil the necessary conditions, when efficiently worked, of purification of air from smoke and fog. This plan has been in operation since the opening of the first portion of the Infirmary, April 1890. The Infirmary at that time contained 400,000 cubic feet of air-space, and it is stated that the apparatus was designed to renew this from five to nine times in an hour. The cold fresh air is drawn through the air-cleansing arrangement, by the agency of Blackman fans, which are placed between the chamber, in which the air is cleansed and then tempered by heat, and the flues through which it passes up to the wards.

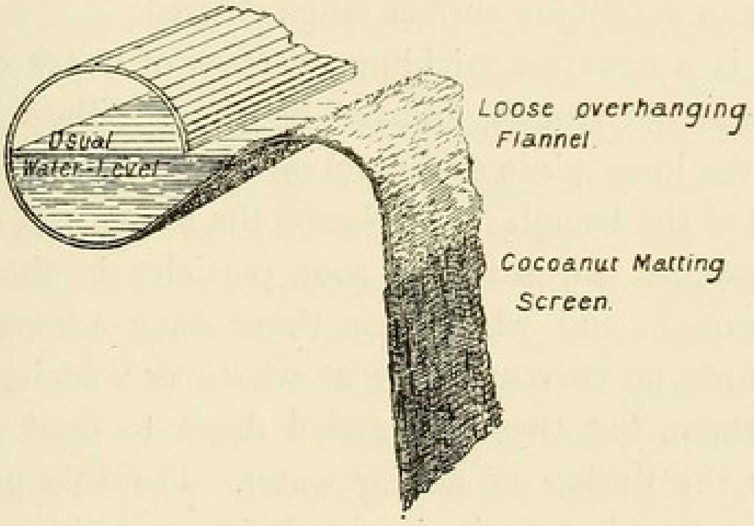


Fig. 2. Section of Water Trough.

The suction of the fans draws the fresh air down a capacious air inlet 16 feet × 4 feet, lined with white enamel bricks and open to the sky. The mouth of this inlet is placed at least 10 feet above the level of the ground, to obviate the drawing into it the dust that prevails nearer the surface.

This air from the outside is admitted to a chamber, which is divided in half by a close hanging screen. This screen is fixed to a beam near the ceiling by means of its upper side, and connected with a longitudinal trough extending along its whole length which is filled with water. The arrangement of the trough is shown in the sketch. The screen is 16 feet long and 12 feet high, thus affording nearly 200 feet of surface.

The screen consists of several thousand cords of cocoa-nut fibre or other suitable material stretched from the upper beam to another near to the floor of the air-chamber. The cords are placed so close that they touch each other; copper wires are laced through the vertical cords in horizontal rows, which being drawn tight, give the screen a flat surface, so that when finished, the screen has the appearance of coarse cloth stretched across the apartment; the rough fibrous nature of the material breaks up the entering air into very minute streams, which pass through equally all over its surface.

The screen may be formed double in order to give an extra cleansing or scrubbing surface when desired.

There is a constant trickling overflow of water down this screen from the trough, assisted by the capillary attraction through the loose piece of flannel or canvas which hangs over the edge of the trough, which keeps the screen wet. The wet surface catches the dust and soot particles in the air as it filters through, and when once these have adhered to the wetted cords, no current of air at whatever velocity can ever remove them, but they are carried down to float off at the drain by the flushes of falling water. For this purpose an automatic flushing tank is fixed in a position whereby 20 gallons of water is instantaneously discharged over the surface of the screen either once, twice, or three times an hour, as may be necessary, to flush and remove any accumulation of wetted dust, soot, or germs which may not be removed from the screen by the trickling water over its surface. This goes on automatically day and night.

The wetted surfaces of the air filtering screen is a decided improvement over any dry cloth or cotton-wool screens, because these must be frequently renewed as they become foul, and the dry process after a time will allow dust particles to pass through. The wet screen automatically flushed prevents this.

The area of the screen should be such as to allow the air to pass through at a rapidity of not more than from 2 to 4 feet per second; a lower velocity would be better, because if air is forced rapidly through a screen it cannot fail to carry dust with it; this is very apparent in using dry cotton-wool filters.

After passing the wet screen the air is warmed by coming in contact with steam-heated coils erected on a wooden platform. There are eight distinct coils in the air-chambers on this platform; the steam to each coil is admitted by means of a gun-metal wheel valve; the attendant may turn on one or more of the coils, or admit only a thin stream of steam to each, and thus increase or modify the temperature of each coil at pleasure. The coils are clustered in a space 16 feet long by 9 feet high, and formed of the best hydraulic tubes $\frac{7}{8}$ in. bore. During winter it frequently occurs that the mornings are bitterly cold, with keen frost, and provision is made for warming the air accordingly; but by eleven or twelve o'clock the sun shines forth and the air becomes warm and pleasant, to be followed in an hour or two by the air again becoming intensely cold. To meet this emergency, doors are erected between the incoming washed air and the heating coils; there are six of these doors, of which one or more can be opened or closed at will. When all are closed, the heating coils are cut off, and the incoming air prevented from coming into contact with them; or one or more only are closed, according to the temperature desired; and while this is so, there is also provided a corresponding number of bye-pass doors, which are opened under the coil platform, so as to bye-pass the air which is prevented from passing through the heating coils by the upper doors being shut; in this way the attendant can keep the temperature uniform, and make alterations as rapidly as they take place in the external air. In opening one or more bye-pass doors, and closing those in front of the coils, the cold air which passes through mixes with the warmed air from the coils as it passes through the air-propeller, and is forced inwards at the desired temperature. Thus the temperature of the air can be changed without waiting for the coils to cool down, after shutting off the steam, or withdrawing the furnace fire as is generally the case when hot-water pipes are in use to warm the incoming air; this system of tempering does not reduce the volume of air moving inwards.

It is practically a modification of the system of steam coils used for regulating the temperature in the Houses of Parliament.

One of the chief advantages of the washing screen has proved to be the facility with which it removes every vestige of fog. During the winter of 1890–91 and 1891–92 there were many days of fog of great density in Glasgow, yet within this building, so soon as this screen was passed, the air is stated to have been beautifully clear and bright.

(2) *Purifying air which is removed from wards in the case of infectious disease.*

This question was raised by the Royal Commission on Small-pox and Fever Hospitals, which reported in 1882.

They stated that 'We find in each epidemic period an excessive incidence of small-pox in the neighbourhood of the hospital as compared with that at a distance.

'Comparing epidemic with epidemic, we find that the aggregate incidence varies with the amount of hospital operations.

'Analyzing the incidence, we find that the proportion of houses invaded by small-pox decreases as they are more distant from the hospital, with a regularity strongly suggestive of a natural law.

'And examining the incidence from fortnight to fortnight, we find that the number of cases of small-pox arising in the neighbourhood varies generally with the number of acute cases under treatment in the hospital.

'In a special and carefully studied outbreak of disease, we find a large number—an unusually large number, it is said—of independent cases which cannot, after the most minute inquiry, be connected with the personal communications of the hospital, or with any other source of infection by contact, and particularly that the houses on the lines of human intercourse have not suffered more than other parts of the same neighbourhood.

'We feel that so long as it is not proved that "personal communication" is adequate to the explanation of the whole spread of small-pox, and so long as distant "atmospheric dissemination" is not shown to be in the highest degree improbable, so long it is essential that in the construction and management of small-pox hospitals, both sources of danger should be, with the utmost care, guarded against.

'It is of paramount importance that the areas of the small-pox wards, as well as their administration, should be rigorously separated from those of the fever hospitals; and further, that their construction should be such as to reduce within the smallest limits the chance of spreading infection. We fully believe that contrivances for this purpose might be devised.'

In the Appendix to that Report, Dr. Burdon-Sanderson recommended a plan by which the air of small-pox wards should be passed through a heated disinfecting chamber. But to this particular plan Surgeon-General Billings pointed out certain practical objections.

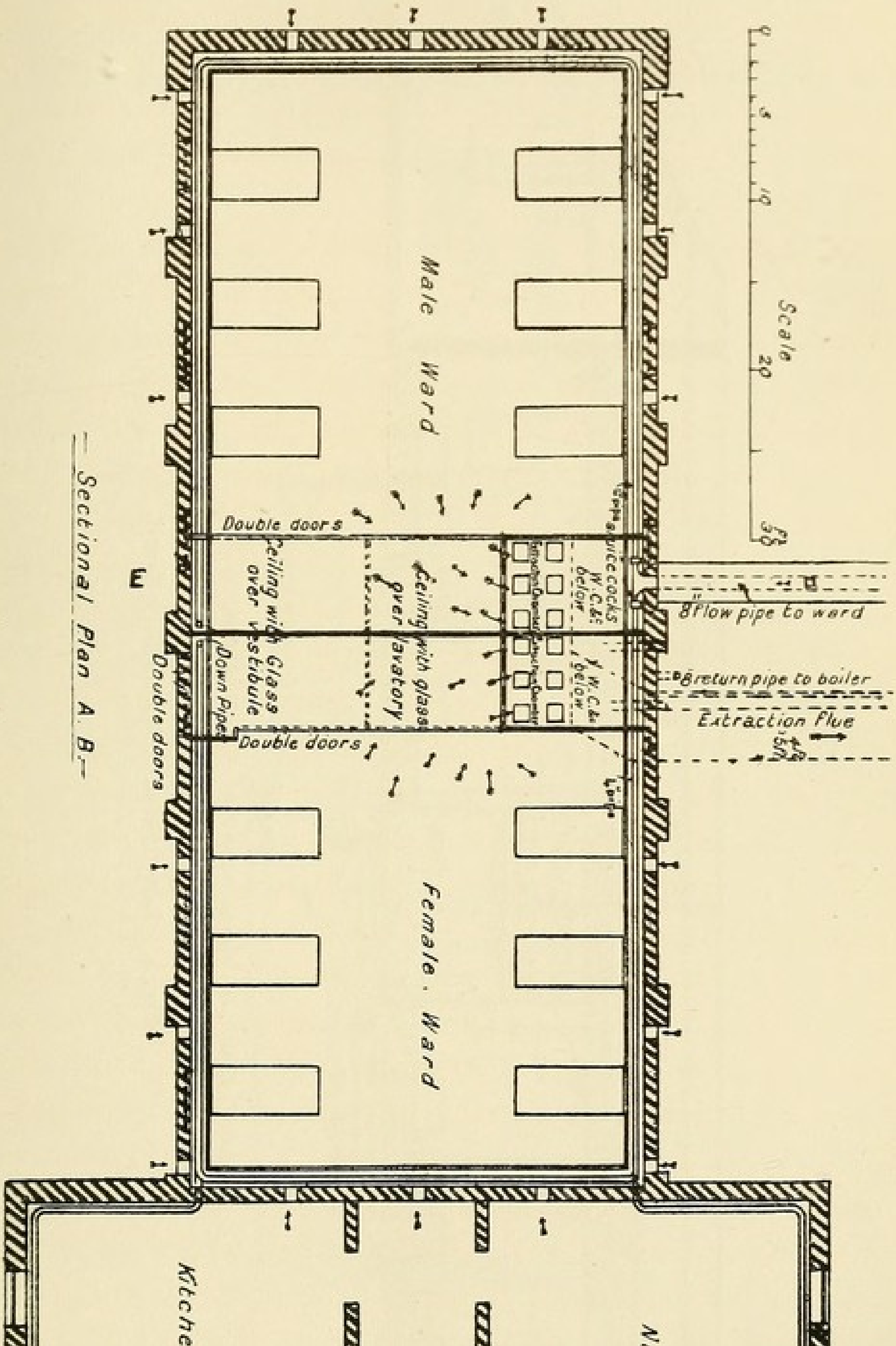
In 1888 a Committee of the Metropolitan Asylums Board drew up a plan for the effectual purification of all infected air from small-pox wards for a limited number of patients, to be applied to a ward attached to the Western Fever Hospital at Fulham. In consequence, however, of the freedom from small-pox in London resulting from the effectual isolation of individual cases by their removal to the hospital ships in the Lower Thames, the subject has remained in abeyance. As, however, this is the only serious plan which has been drawn up by a competent engineer, to effect the purification of the infected air of a hospital ward before it is passed into the atmosphere, it will be useful to explain it here. The method by which the proposal was to be carried out was placed in the hands of Mr. E. A. Cowper, C.E., of Great George Street, S.W., to design.

There was a vacant and incomplete ward, No. 6, which the Committee suggested should be connected with a furnace placed in the yard, to draw from the ward all air that passes into it; the air to be then subjected to a scorching heat in the furnace, by passing some of it through the fire, and the rest immediately over the fire into the flame and products of combustion arising from the fire.

The Committee further suggested that the waste heat should be utilized in cold weather to warm the ward itself, by means of a boiler and hot-water pipes.

These suggestions were carried into effect as follows:— In order to ensure the absolute abstraction of all vitiated air from the ward, *all air* that entered the ward was to be drawn from it, passed through or immediately over the fire by means of a tall chimney, say 100 feet high, to cause a strong draught from the ward, through flues to the fires; and in order to have these means entirely under control, the admission of external air into the ward was arranged to be connected with the hot-water pipes for warming it in winter, and was passed through a number of valves regulated by wooden slides. On occasions when there might be a high wind on one side of the building, the slides on that side would be somewhat closed, so that no excess of air could enter. The windows would all be close and air-tight. Thus the draught of the chimney would at all times tend to cause air to enter the ward, and would never allow any air to pass out of the ward except through the flue to the fire and thence up the chimney.

It was proposed to divide the building into two wards, one for six men and the other for six women; they would be entirely separate, with a room for a portable bath, and water-closets



Sectional Plan A. B.

Fig. 3.

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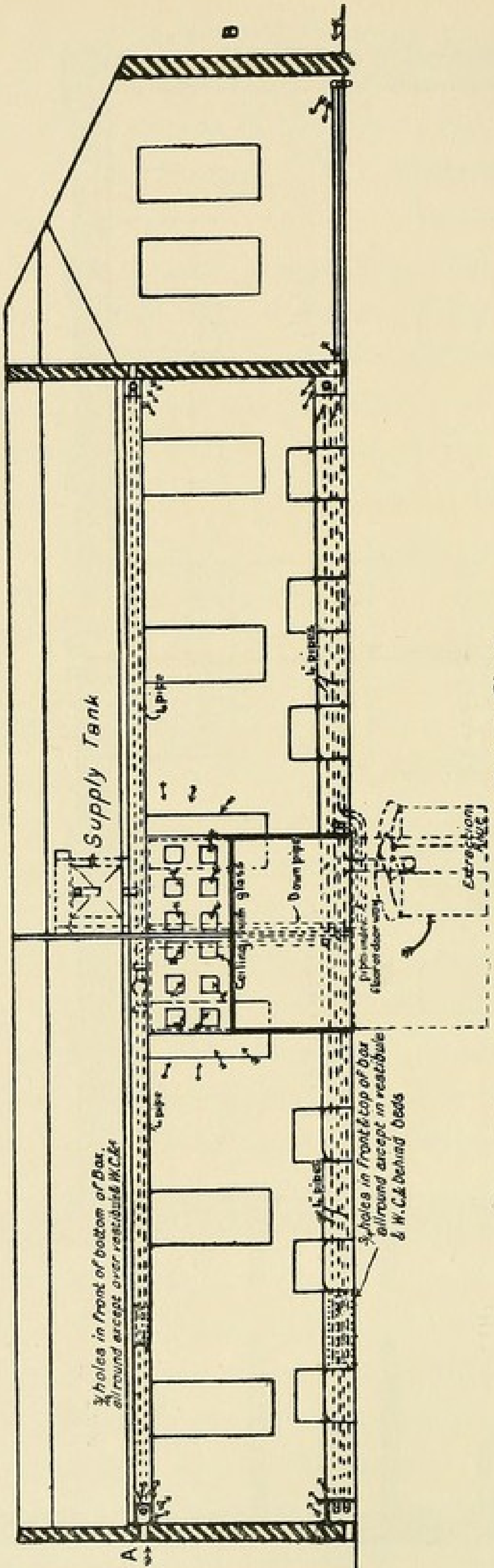
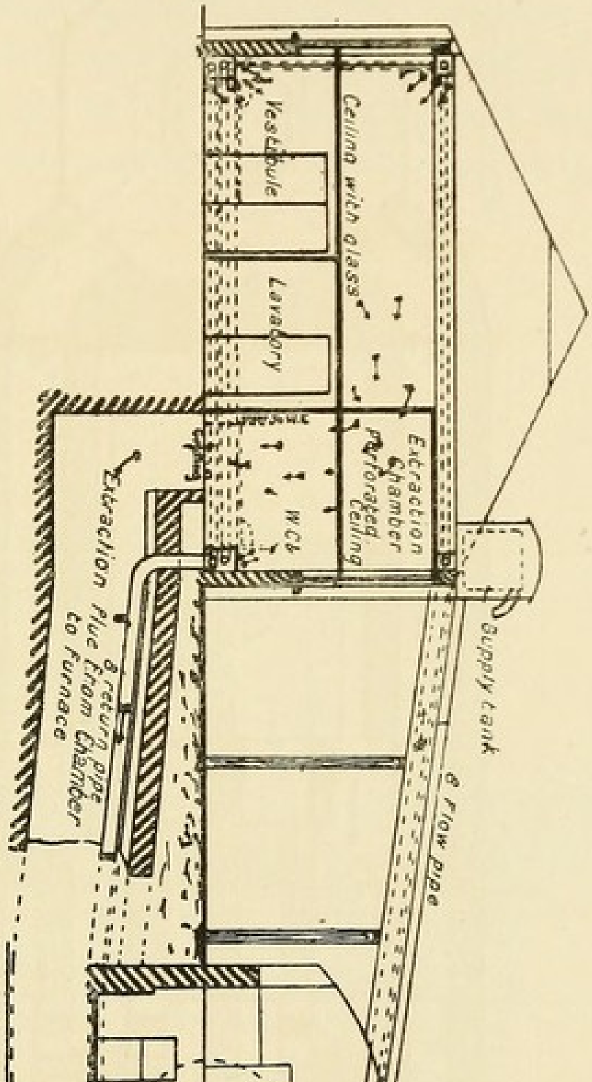


Dotted lines in Wards shew Hot Water Pipes
Sectional Elevation at C D

Fig. 4. Longitudinal section through Ward.

for each ward; the whole entered from one vestibule or entrance-hall, shut off from both wards by doors.

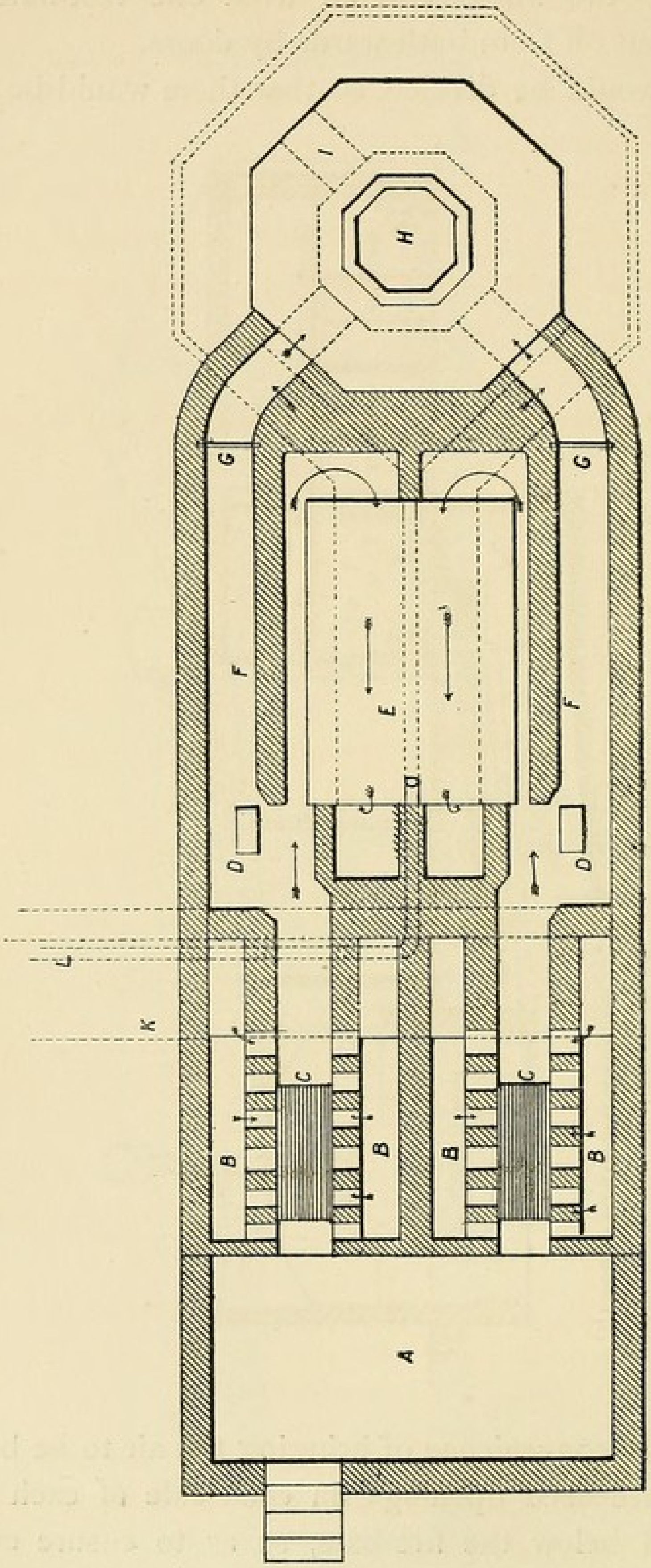
The furnace would be divided, so that there would be two



— Dotted lines shew hot water pipes in Wards.
— Sectional Elevation at E.F. —

Fig. 5. Cross section through Ward and Furnaces.

fires for the better convenience of bringing the air to be burnt through moderate-sized openings on each side of each fire, both above and below the fire-bars, so as to ensure every particle of air being thoroughly burnt or scorched; then, by

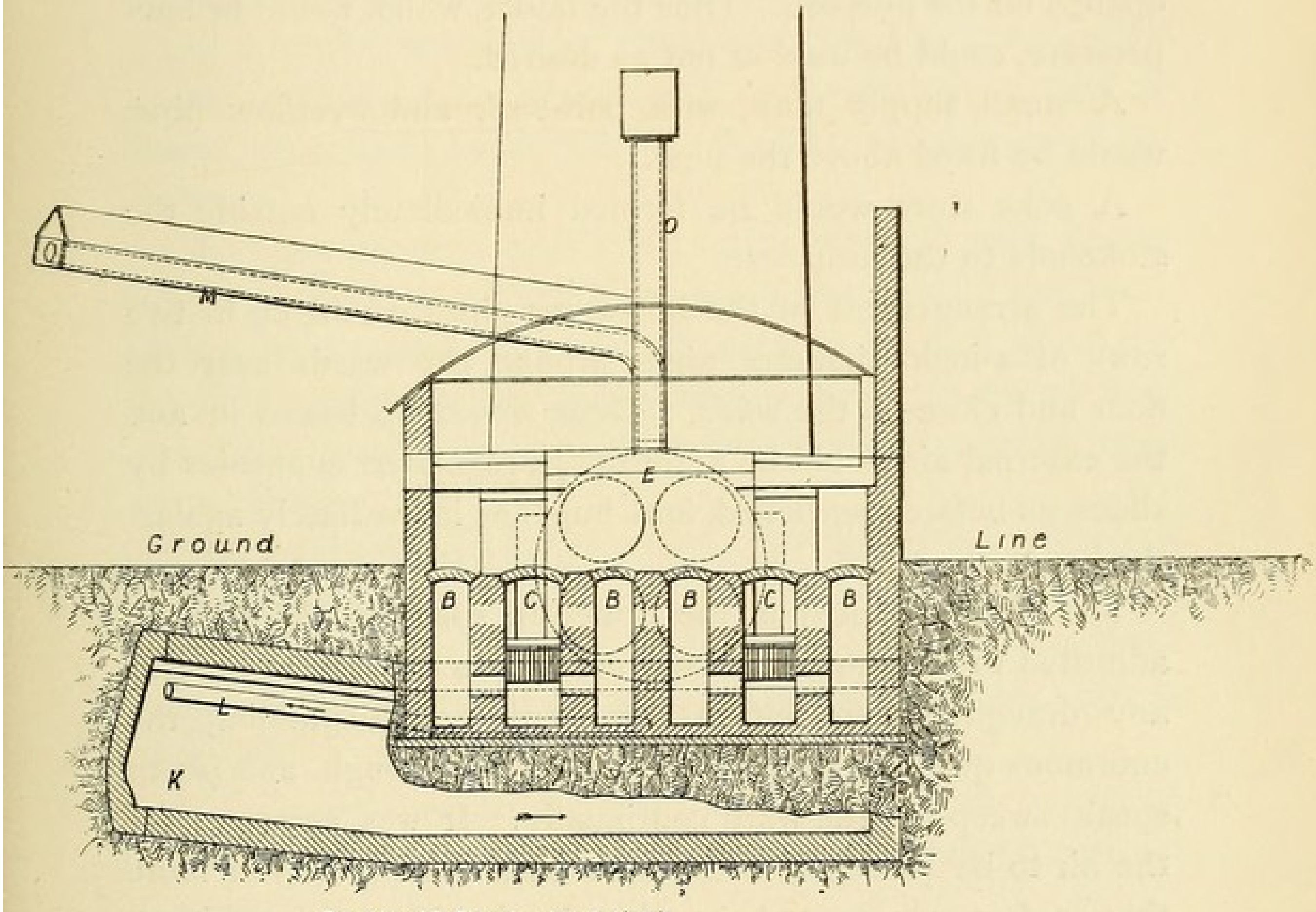


Scale 10 Feet to 1 Inch.

A. Stoke Hole.
B. Air Chamber.
C. Furnace.
D. Pyrometers.
E. Boiler.
F. Chimney Flues.
G. Dampers.
H. Chimney.
I. Opening to clear Chimney.
O. Stand Pipe.
K. Extraction Flue
L. Return Pipe.
M. Flow Pipe.

Fig. 6. Plan of Furnaces.

means of dampers both above and below the fires and an ash-pit closed in front, to prevent the outside air entering, the action of the fires and the rate of combustion could be entirely under control, there being only an inrush of outside air at the moment of adding fuel or drawing out ashes. If at any time one ward had patients in it and there were none in the other, one fire would be sufficient for that ward; and in case of any



Scale. 10 Feet to 1 Inch.

A. Stoke Hole.
B. Air Chamber.
C. Furnace.
D Pyrometers.
E. Boiler.
F. Chimney Flues.
G. Dampers.
H. Chimney.
I. Opening to clear Chimney.
K. Extraction Flue.
L. Return Pipe.
M. Flow Pipe.
O. Stand Pipe.

Fig. 7. Cross Section through Furnaces.

slight repairs to the brickwork of one of the furnaces, the other could be kept at work. There would be valves in the hot-water pipes, to shut off either ward.

The boiler would be placed immediately behind the furnace, so that the hot air and products of combustion could pass at once around the outside, and then through tubes towards the front, and back through return tubes, and through a damper to the chimney flue. When the boiler was not wanted (as in warm weather), this damper would be shut, and the products of combustion would not go round the boiler, but pass straight to the chimney through a damper in the flue, which would be opened for the purpose. Thus the boiler, which would be low-pressure, could be used or not as desired.

A small supply tank, with ball-cock and overflow pipe, would be fixed above the pipe.

A coke store would be formed immediately outside the stokehole to the furnaces.

The arrangement of the hot-water pipes would be in two rows of 4-inch diameter pipes around the wards near the floor and close to the walls. These would be boxed in, and the external air would be admitted in regulated quantities by slides, as before mentioned, and impinge immediately against the hot-water pipes.

The air so warmed in the boxed-in space would then be admitted to the ward, in such a manner as entirely to prevent any draught being felt in the ward, notwithstanding the enormous quantity of air that would pass through, and (so to speak) sweep out the ward continually. It was arranged for the air to be passed into the ward at a velocity of not more than 2 feet per second, so that it should not be felt as a draught. In order to ensure this, there would be thousands of holes of three-quarters of an inch in diameter, in the front and top of the boxed-in space (except behind the beds), thus admitting the warmed air at a limited velocity into the ward.

Hinged covers, like the lid of the box, would close the holes in the top of the boxed-in space at any given point where it was thought advisable to further limit the introduction of air.

In order effectually to sweep out any vitiated air from the ceiling or upper part of the ward, and to prevent cold down-draughts in the ward itself, another line of 4-inch hot-water pipes would run round the ward just above the windows, and be boxed-in and be provided with slides also.

The air would be extracted from the place where vitiated air would be most likely to exist, viz. from the water-closets, and the air from the ward would pass through the water-closets and away to the fires, as before mentioned.

An arrangement of levers would be applied to the external doors, to balance the pressure of the external air against them, due to the partial vacuum caused by the draught of the chimney.

There would be a vestibule or entrance-hall, with double doors to admit of a 'stretcher' being brought in, and there would be a small lavatory for each ward, and place for a portable bath besides the water-closets, all separated from the wards, from which the air would similarly be drawn away to the furnace.

The temperature to which the air would be subjected depends materially upon the rate at which the coke fires are urged, but there should be no difficulty in raising the temperature to 600° Fahrenheit or higher, so as thoroughly to burn or scorch it.

If preferred, an arrangement might be added by which super-heated steam would be thrown into the air as it reached the fire.

A ready means would be arranged of ascertaining if the air had been brought to the proper temperature by the furnaces, so as thoroughly to burn or scorch it; this would be by means of several rough pyrometers, consisting of iron tubes closed at the bottom and partly filled with lead, and fusible alloys having different fusing temperatures; then there being an iron wire loose in each tube, the fact of the alloy being melted or otherwise could be ascertained in an instant, by just pulling the wire up and down a little.

A laundry would be placed outside the ward, but within the enclosing wall, which would separate the small-pox ward from the whole of the remainder of the western hospital; there would be a 9-inch flue from the laundry to the furnaces. There would be also a small mortuary outside the ward, and entirely detached from it; this would also have a 9-inch flue to the furnaces.

A light corrugated iron roof would cover the furnaces, the boiler, and the stoke-hole.

The furnaces, chimney and flues are arranged for entirely emptying the wards of air four times an hour, which might be pushed to six times an hour. The boiler and hot-water pipes are arranged to warm the air, when changed four times an hour, in cold weather.

The cost of the disinfecting and warming apparatus was estimated at £790, exclusive of any alterations to the walls or roof of the building, partitions, &c.

CHAPTER VII.

MOVEMENT OF AIR.

THE next point for consideration is the movement of air.

Air of the composition mentioned, viz. 210 oxygen to 790 nitrogen, is a heavy body. At a temperature of 32°, and with the barometer at 29·9, the mean sea-level, dry air weighs 566 grains per cubic foot. The pressure of the atmosphere on any surface is about 14·6 lbs. to the square inch.

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. Similarly, small decreases of temperature bring the particles nearer together, and make the cubic foot of cold air heavier than the standard above mentioned. This expansion and contraction is equal, for equal increments or decrements of temperature. And the following table shows the density of air at different temperatures:—

Weight of Air per cubic foot under 30 *inches pressure of Mercury.*

Temperature. Fahrenheit.	Dry Air.	Air saturated with vapour.
	Grains.	Grains.
0°	606·37	606·03
20°	581·05	580·26
32°	566·85	565·58
40°	557·77	556·03
50°	546·82	544·36
60°	536·28	532·84
80°	516·39	509·97
100°	497·93	486·65

At 60° temperature, therefore, it may be assumed that 13,100 cubic feet of air will weigh about 1,000 lbs., and that 1 lb. of air will measure about 13·1 cubic feet, and 1 ton of 2,000 lbs. will measure 26,200 cubic feet, whilst 1 ton of 2,000 lbs. of air at 100° would measure about 28,600 cubic feet.

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 air around rushes in to fill its place. Everywhere this heating and cooling of the air is going on; the sun's rays, the proximity of a warm body, the vicinity of a cool shaded surface, all cause movements in the currents of air.

In the ventilation of hospitals we have to consider the movements of air under the heads of—

I. Movement of Air caused by difference of temperature.

(*a*) By the movement of the atmosphere.

(*b*) By the movement of Air, caused by the artificial application of Heat.

II. Movement caused by the application of mechanical appliances, viz. fans, blowers, or other such methods of propelling or extracting air.

There are, however, certain preliminary considerations which it may be well to attend to here.

The change of air in a closed space effected by suction draws in through every available opening the air required to replace that drawn out, it is therefore essential that those openings which afford only pure air should be more easily accessible than those through which impure air may arrive.

Propulsion, on the other hand, would provide only pure air, and as this comes in under some degree of pressure it would prevent the air from impure sources from passing into the closed space. In one case the air which replaces that drawn out, in the other case the air forced in, will require warmth in this climate in winter. This subject will be treated further on.

The velocities at which air should either enter a room or should pass out of the room should be equally regulated[1]; in neither case should the current, as it passes from the room or into the room, ever exceed 2 feet per second, hence the area of inlet and outlet should be so regulated.

The slow, equable and continuous movement will more effectually affect the air in the room. If incoming air is admitted through or near the ceiling, its velocity should not exceed 1 foot to 1 foot 6 inches per second.

After the air has left the room the channels may be arranged to produce an accelerated flow, gradually increasing at its departure from the propelling engine, or on its arrival at the extraction chimney to 6 feet and 7 feet per second.

This may be a convenient place to say a few words on flues, for bringing or removing air.

The position of the openings for the admission and removal of the air is a point of importance; none of these should be made through gratings in floor, as is too often the case, because they are exposed to fouling and obstruction by sweepings and rubbish from the floor.

The openings for the admission of fresh air, whether warm or cold, should be placed at such a height that no person may receive the impression of a draught. The most favourable position appears to be from six to nine or ten feet from the floor according to the height of the room, the air being directed upwards. The openings for the abstraction of the air should on the contrary be placed generally in the side wall, 3 or 4 inches above the floor level, with an upward slope at the back to prevent lodgement of dirt.

There is also the necessity of absolute cleanliness being maintained in air flues; they are naturally receptacles of dust, which is deposited either from the outer air or from the air of

[1] Movement of air of 55°–65° F. At 1½ feet per second (1 mile per hour) felt by none; at 2–2½ feet per second, felt only by a few very sensitive persons; at 3 feet, felt by most; at 3½ feet, felt by all; at 4 feet, felt as a distinct draught. *Vide* Willoughby's 'Health Officer's Pocket-Book,' 1893.

the room. The dust in an inlet flue prevents any pure air from entering the ward. This is an evil, contingent on all concealed dark passages. Freedom from dirt can only be secured in air flues by exposure to ample daylight. Indeed the actinic rays of light have been proved to be germicidal in the case of certain micro-organisms and spores.

Moreover, dust and dirt check the velocity of air in air-passages.

General Morin found that the presence of a cobweb in a flue almost entirely checked the passage of air.

The main conditions to be attended to in the design of air channels, apart from smoke flues, are that they should be as straight as possible so as to be seen through; they should have smooth sides; and they should be capable of being easily cleaned. Gratings are necessary at the openings at either end; but they facilitate the lodgment of dirt and should be easily removeable for frequent cleansing.

I. Movement of Air caused by difference of temperature.

(*a*) *Movement of Air due to the Atmosphere.*

It may be premised in the first place that, when the wind blows, there is a tendency for air to be forced into a building through openings on the side against which the wind is blowing, whilst there is an exhaust caused on the opposite side, which tends to draw air out of the building. Thus if a room has open windows, or other openings on opposite sides, the movement of the atmosphere across the building causes one opening to become an inlet and the other an outlet. Similarly, any opening, leading from the outer air into a closed space, which is either turned away from the wind, or across which the wind blows, becomes a means of extraction, dependent however to a certain extent upon the inlets through which the outflowing air can be replaced.

For instance, the windsail of a ship turned from the wind acts as an extraction shaft, whilst the windsail turned towards the wind propels air into the hold. And in the case of a chimney flue there is always a current dependent upon the movement of air across the top of the shaft of the chimney, whether it contains a fire or not, and a similar movement is caused in every flue which terminates in an opening across which the wind blows, or in an opening turned away from the wind. This acts always to create an extracting current.

This upward current will always prevail in a chimney or main air-shaft, except where there are strong counteracting influences, such as conditions interfering with the smoothness or cleanliness of the flue, which will be alluded to further on; or we may instance—

(1) In a very cold chimney on an especially warm day, with a small movement in the outside air.

(2) If the room in which the fireplace is situated is connected with a large central staircase, which itself acts as a more powerful shaft.

(3) If the room is connected with other rooms which have fireplaces in which are lighted fires, or with other parts of the building, which may themselves act as shafts to draw air down.

(4) If the chimney flue be very large, and if there are not adequate inlets to supply it with fresh air, a double current may be established within the chimney, one up and one down, and thus impede the draught.

(5) The upward current may also be occasionally checked by the fact that want of elevation of the top of the chimney with respect to adjacent buildings prevents the free movement of the atmosphere across it; or if the chimney flue terminate in an opening placed to meet the wind, air will be forced down it.

The movement of air in a vertical shaft, caused by this action, is of course unequal in its effect. 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 it 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, because there are so many conflicting elements to be considered. The formulae for calculating the velocity of wind in some of the standard anemometers are not entirely satisfactory—especially for very low velocities.

The wind, whilst it acts as an exhaust for the air which passes up 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 more powerful means of extraction.

The friction in the shaft varies inversely with the area ; and with small tubes it forms a very perceptible element of retardation.

With experiments made with tubes 3 inches in diameter the velocity obtained in the tube was about $\frac{2}{5}$ of that of the wind ; larger diameters, on the other hand, produced from $\frac{1}{2}$ to $\frac{2}{3}$ the velocity of the wind. These results were obtained in a place supplied, as conveniently as possible, with fresh air to replace that removed, in a manner independent of the movement of the atmosphere ; moreover the top of the tube was freely exposed on all sides.

The temperature inside and outside must also be considered.

If the atmosphere 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. The top of any shaft should be raised well above the ridge of the roof, to ensure clear exposure to the air, and it is desirable that the edges should be sloped upwards.

In consequence of the numerous causes of disturbance enumerated above, this method 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.

A tube or shaft with an open top acts best. It is, however, necessary to protect the top by some form of cowl, to prevent rain from entering the tube. The efficiency of the shaft or tube depends upon the area of the outlet upon which the winds acts, which blows across its top. Whatever be the shape of the cowl, if it afford only the same area of outlet as the shaft, it will delay the current more or less, dependent upon its shape. If the cowl is made to afford a larger area of outlet than the shaft or tube, the current in the shaft or tube may be increased according to the form of the cowl. What are termed air-pump cowls or exhaust cowls will be effective in proportion as they are larger than the tube or shaft. A cowl with a curved head, arranged to move round with the wind, so as always to present its back to the wind, would appear to be the form of covered top best adapted to facilitate extraction, especially if gradually enlarged at its mouth into an oval shape, with an aperture larger than the tube. But the objection to a moveable cowl is, that if by any accident it failed to turn, it would become a powerful inlet like the windsail on a ship. To obviate this Boyle's or Buchan's cowls are arranged with fixed blades, which divert the direct action of the wind, and this causes them always to assist the exhaust; and they moreover afford an area of exhaust on every side considerably larger than the area of the tube.

It may be well here to point out that where, as in a one-story ward, or a ward on the Tollet plan, the ridge is used as an outlet, the ward itself becomes the upcast shaft, and draws in the air from inlets below. If all inlets below the ridge level were, or could be closed, then the ridge ventilator would act like a Watson ventilator, and furnish an upward and a downward current.

(*b*) *Movement of air caused by the artificial application of Heat.*

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

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

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

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

If V = vel. in ft. per sec.;
H = height of shaft;
t = temperature in shaft;
t_1 = temperature out of doors;
a = the co-efficient of dilation of air which for 1° Fahr. = ·00203;

the theoretical equation for calculating velocity of air in a shaft becomes

$$V = 8{\cdot}024\sqrt{Ha(t-t_1)}.$$

But the actual movement of air is very different.

It is diminished by the resistance 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 been found to be one-half that of a clean flue.

General Morin states that the following relations between the volume and temperature of the air and the areas of the air flues have been obtained from theory and practice combined :—

$$V = C\sqrt{(T - T')H}.$$

$$Q = CA\sqrt{(T - T')H}.$$

In which—

A = sectional area of the exhausting flue ;
H = height of exhausting flue ;
T = average temperature of air in flue ;
T' = temperature of external air ;
C = co-efficient, constant for each air-flue as regards its proportions and arrangement ;
V = average velocity of air in flue ;
Q = volume of air passed per second.

The results derived from these relations are, that the velocity of the escaping current is proportional to the square root of the excess of the temperature of the heated air in the flue over the external air, and also to the square root of the height of the flue or chimney; and the volume of air extracted is consequently proportional in addition to the sectional area of the flue.

The calculations depend upon the co-efficient of resistance [1].

[1] Péclet, in his treatise on the application of heat, has given the following formula to include some of the resistances :

$$V^2 = \frac{2gaH(t - t_1)D}{D + 2gHK}; \text{ where}$$

D = diameter of shaft, circular flue, or sq. root of area of rectangular flue ;
H = height of shaft ;
K = the co-efficient of resistance ;
t = temperature of shaft ;
t_1 = outside temperature.

And he determined the co-efficient of resistance, corresponding to this formula, due to pottery chimneys to be ·0127 ; sheet-iron chimneys to be ·005 ; and cast-iron chimneys to be ·0025.

This formula gives rather too high results. Phipson suggested

$$V^2 = \frac{DH(t - t_1)}{L + 16D},$$

where L = length of evacuation channels. Hurst gives

$$V^2 = \frac{\cdot 13\, DH(t - t_1)}{D + KL},$$

where the dimensions are in feet, and K = ·02 for clean glazed earthenware flues, ·03 wood flues, ·06 sooty flues.

The difficulty of obtaining a uniform co-efficient for the resistances will be made apparent from the fact that in flues of the size of ordinary chimneys, soot or accumulations of dust on the sides seriously affect the velocity.

And in this respect the material of which the flue is composed is of importance. The ordinary open fire is a simple form of extraction, and with it a cold flue produces much more soot than a flue which has warm sides would do, apparently because the molecules which are heated rush with more force to adjacent cold surfaces than would be the case with a warm surface. It is apparently also for this reason that hot-water pipes in a room cause dust to accumulate on adjacent cold objects.

The above formula shows that the two elements of the calculation which govern the flow of air in a heated extracting shaft are difference of temperature and height. Consequently a high shaft with a moderate temperature may be as efficient as a lower shaft with a big fire. Hence an expenditure of capital in construction may economize in cost of working.

In an extraction system the size of the upcast flue from a room, as compared with the inlets for air to replace that removed, may also to some extent affect the flow of air in flues.

If the upcast flue is large, and if the inlets are not large enough to supply an adequate amount of fresh air, a double current, one up and one down, on the principle of the Watson ventilator, may be established in the upcast flues. This is a reason why chimney flues sometimes smoke when too large, and why the draught of a chimney flue is improved by contraction at the top, to prevent the formation of a double current.

An aspirating or ventilating chimney is a shaft or flue so constructed that the air in it can be heated without necessarily heating the room or rooms from which it is desired to withdraw the air, so that no discomfort need be caused by its use in warm weather.

In buildings where the architect desires to provide a centralized form of heating and ventilation, he will probably desire to unite his exhaust flues into a few or possibly one upcast shaft, because with one large chimney the friction is reduced to a minimum, the arrangements for control of the velocity can be simplified, and all risk of one aspirating shaft pulling against another is avoided. But the question as to the employment of one or more shafts must be determined by the plan of the building and the possibility of placing the shaft in a nearly central position.

When one shaft is used for a large number of rooms or halls, it may be convenient to utilize heat of the smoke-pipe from the heating apparatus to warm the ventilating shaft, but the limit to which this method of warming could be carried would be determined by the point at which it checked the draught from the furnace.

In the case of a hospital with superimposed stories, the collection of the ventilating flues from the wards into a central shaft may be effected in three different ways, premising however that the heating power ought for efficiency to be applied at a point above the entrance of all foul-air flues.

(1) All the foul-air flues from the wards may converge into a single shaft, commencing above all the rooms, in connexion with which is a furnace or coil of steam-pipe in the roof to give additional heat and ascensional force to the air. In this case the number of flues in the walls increases with the height, and the shaft begins only in the attic, and may be made of wood, if properly lined, or of galvanized iron.

(2) The foul-air flues of each story may be carried horizontally to the central shaft, which they enter at the level of the ceiling.

(3) All the foul-air flues may be carried downward below the level of the lowest ward-floor and into the central extraction-shaft at the bottom.

In this latter case the number of flues increase in the lower stories, and the lower walls must be made thicker.

The size of the upcast shaft, however, would be somewhat smaller than that in the first case, because the aspirating power of the shaft depends on the height of the heated column of air, as well as on the difference between the temperature in the shaft and that of the external air; hence the nearer to the bottom of the shaft the heat is applied, the greater will be its efficacy. The shaft in the third case would, however, be of brick, hence its size becomes an important consideration: for if the velocity of the air in it should not exceed six feet per second, the volume of air at 3,000 cubic feet per hour for about 260 persons, would be, say, 216 cubic feet per second, and the chimney must have 36 square feet of clear inside area, and as such a shaft will probably reach 100 feet in height, requiring thick walls at the bottom, it will be found necessary to provide nearly 100 square feet for it.

On the other hand, the application of heat to the central shafts can be arranged more easily and to much better advantage in this latter, the third, system, than in either of the others.

During the winter the heat needed for producing an upward current in the shaft can be obtained in most cases from the smoke-flue of the heating apparatus, while in summer a small furnace can easily be connected with the side of the base of the shaft.

With the tall shaft it will generally be found most convenient to apply the accelerating heat by means of a coil of pipes, suitably arranged for radiation in the shaft and heated by steam or hot water, or by means of an open grate placed in the shaft, as is done in the aspirating tower for the House of Commons, and in mines, or by means of a stove, heating a sheet-metal pipe passing up the chimney, or by gas jets.

The open grate is a troublesome and not an economical mode of applying heat for this purpose. The use of gas jets is expensive if the amount of air to be moved be large, but it should not be forgotten that the burning of gas for illuminating purposes gives rise to heat which can often be used advantageously for purposes of ventilation.

Good results are afforded by the plan above mentioned of heating the aspirating chimney by means of a central metal pipe, carrying the waste heat from the flues of steam boilers, &c. It has been computed that for a building four stories high, if the amount of coal necessary to heat the shaft be assumed in the first system, when the shaft commences in the attic, as 1·0, it would require ·78 in the second, and ·58 in the third, with the ventilating flues collected at the bottom of a tall shaft.

Box 'on Heat,' Billings' 'Heating and Ventilation,' and Baldwin's 'Steam Heating,' afford data for calculations. And the following formulae are here quoted as published by Mr. Trowbridge, of Columbia College, in the 'Sanitary Engineer' of New York, for calculating the heating surface by coils of steam pipes, required in ventilating flues for producing a given discharge of air.

'The formula is as follows:

$$S = \frac{WT_a}{H(T_s - T_a)} \times 1500.$$

'In this formula S represents the number of square feet in the exterior surface of the coil or cluster of steam pipes at the base of the flue; T_a is the absolute temperature of the external air—that is, the common or thermometric temperature $+ 459{\cdot}4^\circ$ (or $t^\circ + 459{\cdot}4^\circ$), in degrees Fahrenheit.

'W represents the weight of air in pounds, which is discharged in one second.

'H represents the height of the flue, and T_s is the absolute temperature of the steam in the coil, i. e. $t_s + 459{\cdot}4^\circ$.

'The constant 1500 is derived from certain constants which were employed in deducing the formula, one of which was the force of gravity, another the specific heat of air, another the rate of transfer of heat to air by coils, from Mr. C. B. Richards' experiments, and another the ratio between the theoretical velocity and the actual velocity in the flue, as influenced by friction. For ordinary and the most favourable circumstances, the actual velocity in the flue is best if it be established at about five feet per second, and it is for this actual velocity that the formula in its simplified form as above is adopted.

'Another formula, well known, and which is needed, is that for the weight of air discharged per second—to wit:

$$W = A \times D_c \times V.$$

'That is, the weight discharged is found by multiplying the cross section of the flue A by the velocity V and the density D_c of the air in the flue.'

Mr. Trowbridge states that the density of the air in the flue which will result from the proportions given by this formula will be 0·0719 pounds per cubic feet.

Hence the area of the flue for a given discharge W, will be:

$$A = \frac{W}{D_c V} = \frac{W}{0{\cdot}0719 \times 5} = \frac{W}{{\cdot}3595},$$

or $A = 3\ W$ approximately.

That is, the cross section of the flue in square feet should be three times the weight of air in lbs. discharged per second [1].

[1] An example will show the method of using these formulae for all ordinary cases.

Suppose the air of a room $30' \times 40'$ and 15 ft. from floor to ceiling is to be renewed four times every hour.

The cubic contents are

$$30' \times 40' \times 15' = 18000 \text{ cub. ft.}$$

At the ordinary temperature and pressure, this air will weigh about $\frac{8}{100}$ of a pound per cub. ft., and the weight of air discharged per hour will be

$$4 \times 18000 \times {\cdot}08 = 5760 \text{ pounds},$$

or 1.6 pounds per sec.

The required area or cross section will be

$$A = 3 \times 1{\cdot}6 = 4.8 \text{ sq. ft.}$$

If now we suppose the steam in the coil to be low-pressure steam for instance five pounds above the atmosphere, we shall have for its

It is of great importance in arranging steam and hot-water pipes for heating air in its passage to flues, or to where it is desired to utilize the heat, that the pipes should be covered with non-conducting material to prevent loss of heat, and that the pipes should not block up the flues, but should be placed in an enlargement or chamber, so that the aggregate area through and among the pipes shall not be less than the area of the flue, and preferably 20 per cent. greater, so as to ensure a moderate velocity to the air in its passage over the heated pipes.

Moreover, the pipes or heaters should be so arranged that no air will pass without coming in contact with the heated surfaces. A baffled passage, causing the filaments of air to assume a tortuous course among the pipes, is the proper one. This was the principle of the system adopted by Dr. Sylvester in warming hot air for the ventilation of asylums and hospitals more than sixty years ago, in which he used clusters of parallel

temperature Fahr. 228°, and if we assume the exterior temperature of the air to be 60°, we shall have conditions which will apply to spring or autumn weather, and the same arrangements then determined will give better results in winter or cooler weather; with these assumptions we have:

$$S = \frac{1500 \times 1.6\,(60^\circ + 459.4)}{H\{(228^\circ + 459.4) - (60^\circ + 459.4)\}}$$

or

$$S = \frac{1500 \times 1.6\,(60^\circ + 459.4)}{H\,(228^\circ - 60^\circ)}$$

$$= \frac{4.9}{H} 1500.$$

If the flue is 50 ft. high, we shall have:

$$S = \frac{1500 \times 4.9}{50} = 30 \times 4.9$$

$$= 147 \text{ sq. ft.}$$

Hence, the conditions of ventilation assumed will require an aggregate area of ventilating flue of $4\frac{8}{10}$ sq. ft. in cross section, and 147 sq. ft. of heating surface in the coil or cluster of pipes at the base.

If more than one flue is employed, which would probably be desirable, in order to have a better distribution of the inflowing air (two flues for instance), then each would have an area of $2\frac{2}{5}$ sq. ft., and each would be heated at the base by pipes having $73\frac{1}{2}$ sq. ft. of surface.

It may be thought that this amount of heating surface as given by the formula is excessive for the degree of ventilation assumed.

The reply to this objection is, that if any one expects to obtain full and sufficient ventilation without expending an appropriate amount of money, both for fixtures and for fuel, such a one is mistaken.—*Trowbridge.*

horizontal pipes in rows one above the other, and placed a baffle of thin angle-iron resting on each parallel pair of horizontal pipes, so that the incoming air was compelled to pass through the narrow space between angle-iron and pipe.

II. Movement of Air by Propulsion or direct force—such as Fans, Blowers, or some form of Air Pump.

The direct propulsion of air may be used either to extract air from or to propel air into a building.

As applied to hospital ventilation, the great utility of the fan lies in the power which it gives, in the absence of open windows, of rapidly flushing out the wards morning and evening with large quantities of air.

The various apparatus which have been used for forcing air into hospital buildings may be classed under the heads of:

1. Air Pumps;
2. Rotary Fans, Screw Fans.

In the application of these appliances, it should be mentioned that a noticeable and important defect in some systems of mechanical ventilation, is the pulsatory movement induced in the air current, and the noise consequent on the least neglect on the part of the machine attendant.

The force necessary to propel air through any passage is equal to the square of the velocity into the total surface multiplied by the co-efficient of friction, the pressure of the air being uniform.

Mr. D. P. Morrison has given as a practical formula to be used in ventilation, the following expression:

$$H = \frac{KV^2PL}{A}.$$

This formula is perfectly general and may be used for any fluid.

H = the head of pressure, in feet of air of the same density as the flowing air;

L = the length of the pipe or passage in feet;

$P =$ the perimeter of the cross section in feet;

$A =$ the area of the pipe or passage in square feet;

$V =$ the velocity in thousands of feet per minute;

$K =$ the co-efficient of friction; for which in the case of air Mr. Hawksley gives 0·03.

Taking D as the diameter for circular passages whose diameter is small in proportion to their length,

$$H = KV^2 \times \frac{4L}{D},$$

and for irregular-shaped channels,

$$H = KV^2 \times \frac{PL + 200A}{A}.$$

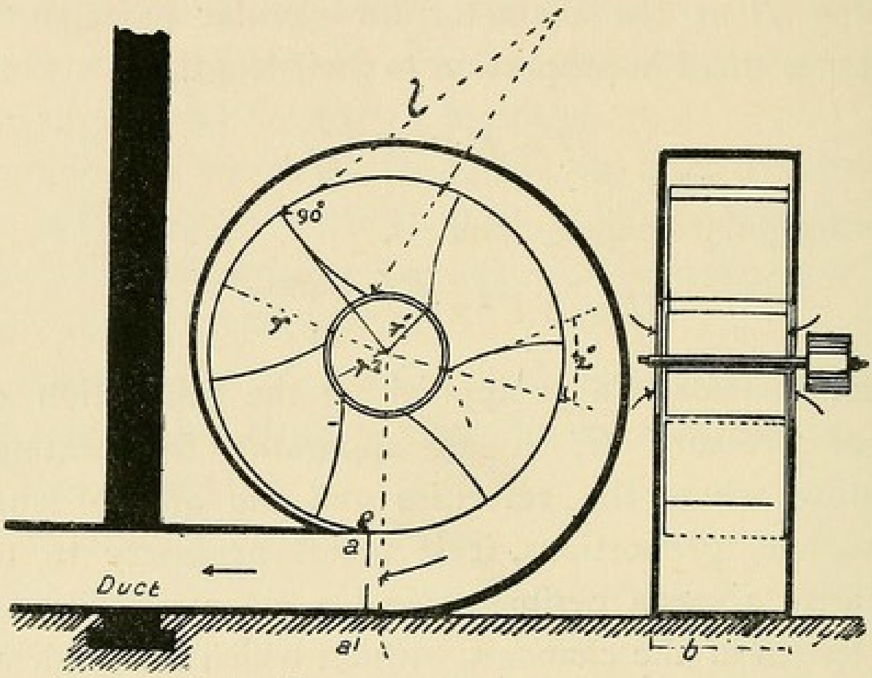
When this formula is applied for the calculation of the head of pressure H, in an apparatus for heating and ventilating, where the velocities and the area of channels have various proportions, it is found necessary to take a mean area, a mean perimeter, and a mean velocity for the whole length of the channels, without which too high a head of pressure would be given.

The pressure of 1 foot of air at 60° Fahr. under 30 inches pressure of mercury is 0·0765 lb. per square foot. The pressure of 1 inch of water is 5·2 lbs. per square foot. To reduce the pressure in feet of air to its equivalent in inches of water divide it by $\frac{0\cdot0765}{5\cdot2} = 68$. A pressure of $\frac{1}{10}$ inch of water as a measure of the pressure of the air need rarely be exceeded in hospital ventilation.

1. *Air Pumps.*

The advantage of this method of air propulsion for hospitals is that it can be arranged to furnish a carefully regulated amount of air; and, provided the size of the pump is large, the motion slow, and the pressure limited to what is necessary to send the air through the flues, it might be a convenient method. But as yet it has been chiefly adopted experimentally.

Dr. Arnott devised an air pump which would either force air into or extract air out of a hospital ward in strictly defined quantities. Dr. Arnott's plan was on the principle of a gas holder carefully balanced, from which the air was forced through the air channels into, or extracted from, the



a = height ot outlet $= \frac{V}{bc_1}$.
a_1 = distance from vertical radius to point e.
b = width of vanes $= \frac{r_2{}^2}{r_1}$ with two inlets.
c = velocity of air entering Fan (10 to 40 feet per second).
c_1 = velocity of air leaving Fan.
h = height of manometer in duct.
n = number of revolutions per minute $= \frac{2636}{r}\sqrt{h}$.
r = outer radius of vanes.
r_1 = inner radius of vanes r_2 to $2r_2$.
r_2 = radius of inlets $= \sqrt{\frac{V}{2c\pi}}$ with two inlets).
l = radius for curve of vanes $= \frac{r^2 - r_1{}^2}{2r_1 \sin z^0}$, in which the tangent $z^0 = 0{\cdot}1047 \frac{nr_1}{c}$ describes a curve from the point e to the inner periphery of vanes.
V = volume of air delivered in cubic feet per second.
Number of vanes $= 10r_1$, generally 4 to 6.

Fig. 8. Rotary Fan for Vacuum or Plenum Movement, according to Rittinger (from Schumann).

ward. This was applied more than forty years ago in the York Infirmary. A pump on a somewhat similar principle was subsequently placed in the House of Commons by Dr. Percy for propelling cooled air into the chambers during exceptionally hot weather.

Dr. Percy adopted a double acting machine consisting of a light vertical piston, carried on rollers which ran on rails. The piston was supported on double piston rods and moved in rectangular chambers 6 feet 6 inches by 8 feet, with a travel of some 10 or 12 feet.

The valves were of thin sheet india-rubber on wire seatings. The machine was driven by noiseless friction-gearing from a small vertical engine of four horse-power, and was capable, at sixteen strokes per minute, of renewing the air in the House in nine minutes.

2. *Rotary Fans and Screw Fans.*

A rotary fan, as shown in Fig. 8, consists of a certain number of tubular passages, which are rotated about a lineal axis at right angles to the direction of the passages, whereby a given volume of air is drawn into the blades at the centre and impelled by centrifugal force through the tubular passages at a determined pressure.

A screw fan of the type shown in Fig. 9 also draws in the air at the centre and distributes it at the circumference by centrifugal force.

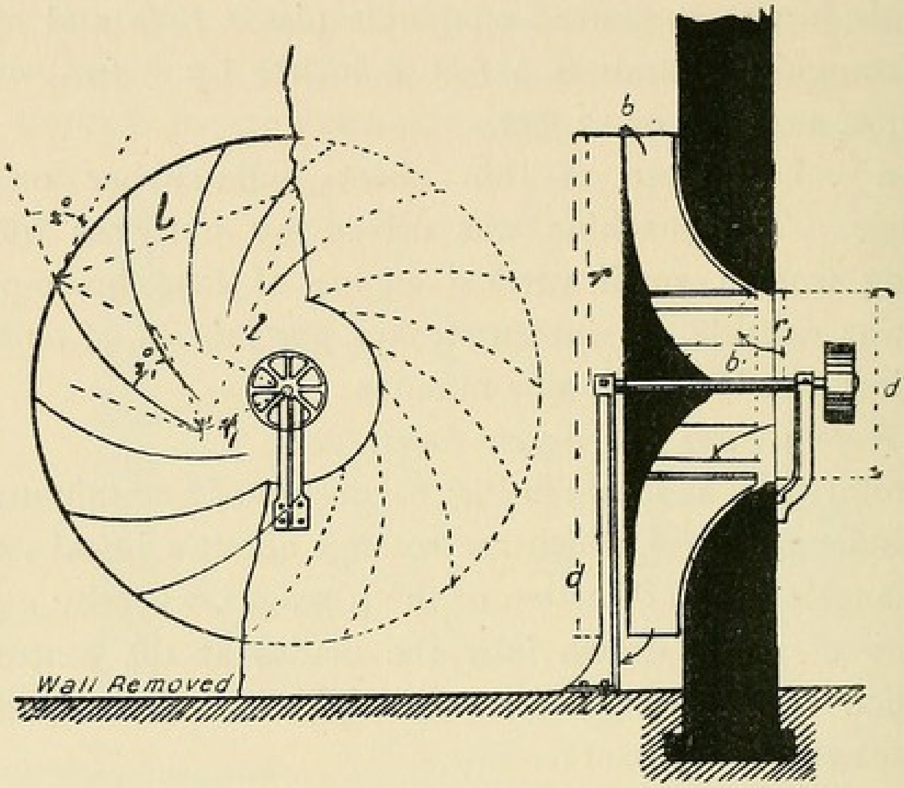
In the United States the Sturtevant fan somewhat on this pattern has obtained a large development.

The best action is obtained when the whole circumference of this fan opens into a free chamber. The effect depends upon centrifugal motion, and centrifugal motion is independent of the figure of the fan.

Hence whatever the form of the blades, whether radial or curved, nearly the same pressure is produced at similar velocities, at least so long as the volume of flow is not very great.

But in regard to the efficiency of the fan, or the ratio of the work expended in driving it, to the useful work in the air pumped, the form of the vanes has an influence.

There are two great sources of loss in a fan or centrifugal pump with straight radial vanes. In a centrifugal pump or turbine the condition of maximum efficiency is that the water should enter and pass through the wheel without any sudden



A = sectional area of air current as it leaves the Fan = $db\pi \sin z^0$.
A_1 = sectional area of air current as it enters the Fan = $d_1 b_1 \pi \sin z_1^0$.
V = volume of air in cubic feet per second delivered theoretically = nAc_1.
V_1 = volume of air in cubic feet per second delivered actually = $V\frac{k}{100}$.
b = width of Fan outside = $b_1\frac{d_1}{d}$.
b_1 = width of Fan inside = $b\frac{d}{d_1}$.
c = velocity of air entering Fan = $\frac{V_1}{A_1}$.
c_1 = velocity of air leaving Fan = $\frac{r_1 b_1}{rb} \cdot \frac{c}{\sin z^0}$.
d = outer diameter of Fan = $d_1\frac{b_1}{b}$.
d_1 = inner diameter of Fan = $d\frac{b}{b_1}$.
h = height of manometer from $\frac{1}{3}$ inch to $2\frac{1}{2}$ inches.
k = per cent. of effect from 20 to 30.
l = radius for vanes = $\frac{1}{2}d$ to $\frac{2}{3}d$.
n = No. of revolutions per second from 1 to 2.
r = outer radius of vanes.
r_1 = inner radius of vanes.
v = velocity of periphery of vanes = $dn\pi$.
z^0 and z_1^0 = angles between tangents and initial lines of vanes.
Number of vanes = $1{\cdot}5\, r_1$, generally from 6 to 16.

Fig. 9. Screw Fan for Vacuum or Plenum Movement, according to Combes (from Schumann).

change of velocity, because any sudden change of velocity or shock causes a waste of mechanical energy, by its conversion into heat. A similar effect occurs in the fan; with straight radial blades there is a sudden change of velocity at the moment the fluid enters the inner circle of the revolving blades, and another when it passes their outer tips.

Hence, in order to pass the air into the revolving wheel without wasting energy, the inner ends of the blades ought properly to be inclined to the radius at an angle whose tangent is in the direction of the motion of the air relatively to the blades; and in order to reduce the shock caused by the air, which leaves the blades at a high velocity and enters a mass of air flowing out at a comparatively low velocity, the tips of the blades have been recurved so as to give the air a backward flow relatively to the blades.

Screw fans are not more complicated to construct than the ordinary rotary fans, and they are less likely to get out of order. They appear also, when moving at a low pressure, to afford the same effective power, provided the minimum of resistance is given to the inlet and outlet of the air, and the delivery passages are of large dimensions.

The pressure attainable by any form of revolving fan is low, when considered in pounds per square inch. A pressure equivalent to a column of 7 inches or 8 inches of water is attainable only at very high speeds. A pressure or suction of 3 inches or 4 inches is nearly as large as can economically be attained in delivering a quantity of air at high velocities, when the friction of machinery, the want of adhesion of belts, and certain other considerations of friction of air on the vanes are taken into account.

Thus the largest differences of pressure are less than the ordinary atmospheric disturbances as indicated by the barometer. But, as already observed, much lower pressures may be made to suffice for ward ventilation.

Rittinger and Combes's formulae for these rotary and screw fans respectively, are referred to as applicable in calculating for the sizes of fans, and for the horse-power in proportion to the volume of air required; and according to these formulae, it would seem to require from 50 to 60 lbs. of coal per hour to propel 260 cubic feet of air per second, at a pressure of 1·2 inches of water.

The Blackman is another form of screw fan, which has attained a considerable development for ventilating purposes in recent years.

Its principle of action appears to be that of a direct screw, and it is alleged that the partially rectangular form of the blade enables it to collect air by means of its edge as well as by its face.

Hence its most efficient position would appear to be in a wall with a free space on the collecting side, the delivery for propulsion being into a channel carefully adapted to the size of the fan. Its maximum efficiency is stated to

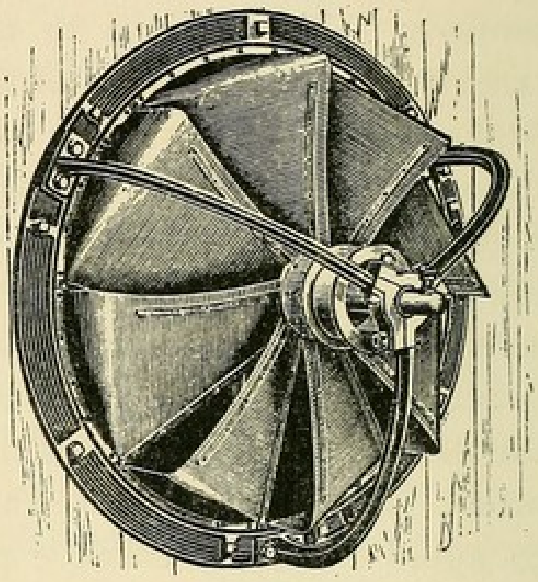


Fig. 10. Blackman Fan Elevation.

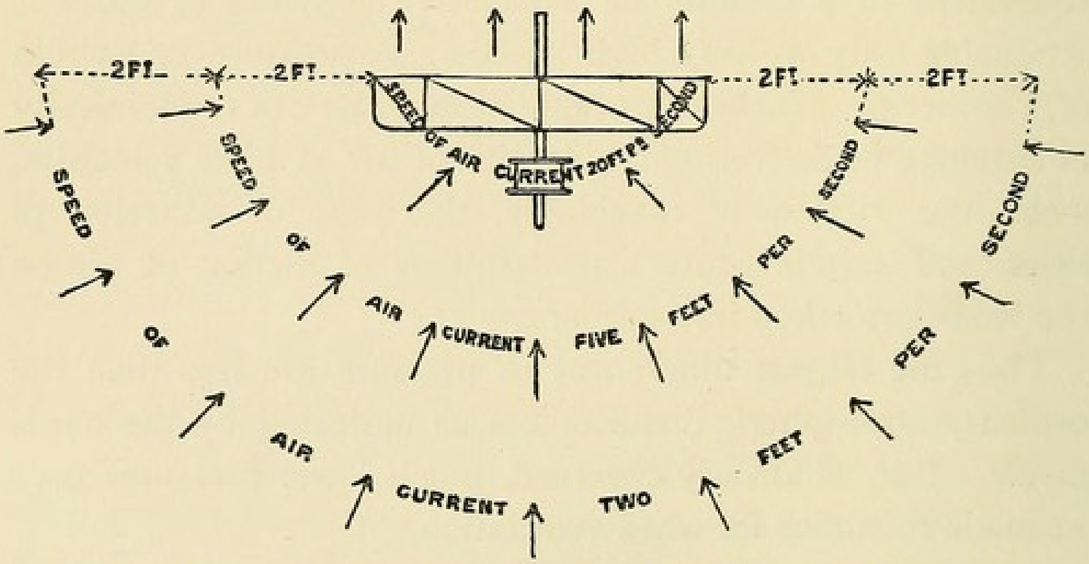


Fig. 11. Plan showing air currents in vicinity of indraught of Blackman 48-inch Fan with 500 revolutions per minute.

depend upon the delivery of air at a low pressure, as for instance from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch on the water gauge.

In its most convenient form this fan would be worked by electricity. In this case, the arrangements are such that no belting or driving gear is required. And the fan is its own motor, its periphery being the armature, its frame the field magnets, and the commutator occupying the place of the position of the usual pulley. The driving power is equally distributed all round the fan; and can be easily connected by wires to any current available.

In the case of the extraction of air from wards by fans instead of by heated flues, the observation already made as to inlets would apply. In the case of using the fan to propel air into a ward, the inlets would be similarly placed high up, and the outlets low down. The latter would not necessarily require any extracting power to be applied to them, but having regard to the various outlets through which the air from the ward might escape, some plan for extraction would preferably be combined with propulsion.

CHAPTER VIII.

WARMING.

BEFORE discussing the relative advantages and disadvantages of the different methods by which change of air can be effected in hospital buildings, it will be necessary to make some observations upon warming.

Warming is essentially connected with the provision of fresh air, inasmuch as the large volume of fresh air wanted for a hospital ward in this climate could not be supplied in cold weather without danger to patients unless the temperature of the wards can be adequately maintained.

There are different qualities of heat which depend upon the different ways in which the heat is applied, and as these differences have a very important bearing on the warming of hospital wards, it will be as well to recall them to memory in this place.

Heat is transferred from the incandescent fuel to the bodies which it warms by conduction, by convection, or by radiation.

Conduction is the transference of heat from one body to another, by means of some tangible medium which fills the whole space between the two bodies. For instance, if a poker be held with one end in the fire, the heat from the fire is transferred along the poker to the hand by conduction.

Convection is the transference of heat from one place to another by the bodily moving of heated substances.

The warming of a building by hot-water pipes is an instance of transference of heat both by conduction and convection.

The heat from the fire is, in the first place, communicated by conduction through the plates of the fire-box, from the incandescent fuel to the water in the boiler.

It is transferred by convection along the pipes which convey the water to different parts of the building, as the hot water circulates. It is again transferred by conduction to the air close to the pipes. This air, being expanded, ascends, and carries the heat with it by convection to different parts of the room.

Radiation is a form of the transference of heat which is not either conduction or convection by ordinary matter. That is to say, heat which is transmitted in a manner of which all we know for certain is that it is not convection or conduction as generally understood, is called radiant heat. Radiant heat warms to a greater or less degree the solid bodies upon which the rays impinge, but practically passes through the air without warming it.

Thus a blazing fire warms a person by the radiant heat which passes through the intermediate air to his body. In a homogeneous medium radiant heat is propagated in straight lines.

It has hitherto been assumed that it is propagated with less velocity in a dense medium than in a rare one; and that therefore on the top of a high mountain, when the air is rarefied the sun's rays are intensely hot, but when these rays are withdrawn by clouds, or at night, the cold becomes intense.

The amount of heat radiated from a body at a given temperature depends on the physical nature of the surface of the body. If a cube be made of tin and filled with hot water, and one of the sides blacked and another left bright, much more heat will be radiated from the black surface than from the bright one.

The hotter the body in proportion to an adjacent body, the greater proportionally will be the rapidity with which it emits radiant heat, and the emission of heat will be greater in direct proportion to the difference of temperature between the two bodies; as for instance is shown in the following table:—

Excess of Temperature of Radiant above that of Recipient in deg. Fahr.	Temperature of Recipient in deg. Fahr. 50°. Ratio of Heat emitted or absorbed.
432°	2·98
306°	2·13
216°	1·69
180°	1·55
126°	1·36
55°	1·15
18°	1·07

It may be here mentioned that ignited fuel has a temperature of about 2200° Fahr.; iron of a dull red 1320°, or of a red just visible 960°.

In the presence of a cold body, an adjacent warm body will rapidly lose its heat. If a person in a warm condition sits near a cold wall, the radiation from the person's body to the cold wall will cause the sensation of a draught.

This is easily tested by hanging a piece of carpet on the cold wall so as to intercept the radiation, when the feeling of draught will cease.

All these considerations have an important bearing on the application of heat to occupied rooms. But in hospitals the question of warming cannot be separated from that of ventilation. And we cannot obtain adequate ventilation combined with warming without a considerable expenditure of money.

Warming and ventilation in hospital wards is usually effected by one of the following methods:—

I. The open fireplace in each room.

II. Warmed air brought into the rooms or corridors by flues from a centrally placed calorigen or heating apparatus.

III. Close stoves, placed in the room or corridor to be warmed; or else hot-water pipes, or steam pipes heated by a boiler in some central position, and carried by the pipes thence to the places where the heat is wanted.

The heat conditions which prevail between the air and the walls or objects in a room are different in each of these cases.

But before discussing these several methods of heating it will be desirable to make a few preliminary observations on conditions which regulate the loss of heat in buildings.

In the first place: in determining the heating power required, consideration should be given to the climate of the place and to the position and subsoil of the building.

In the next place: the materials and thickness of the walls, and the area and construction of the windows, have to be considered.

The heat absorbed from a body by contact with cold air is not influenced by the nature of the surface, all materials losing the same amount, under similar conditions of temperature; nor does the form of the body affect the result materially; the loss varies only with the more or less disturbed condition of the air in contact.

But the loss of heat through walls and windows, per square foot per hour, will be partly by contact with air and partly by conduction; in this latter case, the amount transmitted varies with the material of which the wall is built, and its thickness, for similar conditions of temperature of the surfaces.

The formulae which govern this loss of heat will be found in 'Healthy Dwellings' (Oxford), Box on Heat, and other books. It suffices here to give a general idea of the value of different building materials for retaining heat, and the conducting power of the materials, or the unit of heat transmitted, per square foot per hour, by a plate 1 inch thick.

The difference of temperature between two surfaces, $t - t_1 = 1°$ Fahr., is shown by the following table:—

Iron, the units of heat transmitted are .	233
Lead	113
Marble (white coarse)	22.4
Calcareous stone	13.7
Glass	6.6
Brick-work	4.8
Plaster	3.8
Double windows with glass not less than 2 inches apart	3.6
Wood Pine parallel to fibre . . .	1.4
„ „ perpendicular to fibre . .	0.75
Stagnant Air	0.3

The latter figures show the value of panelled walls, and also the advantage of hollow walls in which no circulation of air occurs.

Loss of heat through floors:—When the floor is exposed to the external air, the loss of heat will be by conduction only, and the formulae for loss of heat through walls will apply, but when not so exposed this loss will be practically null.

Loss of heat through ceilings:—When the ceiling is composed of brick arches, concrete or joists, lathed and plastered, and covered by a good roof of slates or tiles laid on board and felt, the loss will be very small; but when the roof forms the ceiling, and is either of brick, concrete, slate, tin, glass, &c., the loss will be considerable by conduction, the same formulae applying as for walls, &c.

Loss of heat through windows:—The above table shows that the loss of heat through glass would be considerably more than through brick-work and plaster. But the proportionate loss of heat by walls, as compared with the loss of heat by windows, varies with the proportionate extent of wall exposed to the outer air; with 14-inch brick walls, and an assumed internal temperature of 60° in the room, and an outside temperature of 30°, the proportion of loss of heat from wall-surface to loss of heat from window-surface may be approximately taken to be about 1 : 2·5.

I. *The open fire.*

If there is a bright fire in the room, the rays from the flame and incandescent fuel convey warmth to the walls and furniture 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.

Unfortunately, we have never succeeded in preventing the open fire from injuring the outside atmosphere by the smoke which it emits at times.

With the open fire a proportion of the heat is used for producing a current in the chimney-flue, and does not warm the room, and hence in considering the fuel consumed in an open fire, we must remember that a portion of the fuel is being expended to assist the ventilation. Thus, for instance, with an open fireplace, a velocity will frequently prevail in the chimney of 10 feet, and in some instances of 15 feet per second; thus causing, with a flue 14 inches by 9 inches, the removal of from 30,000 to 45,000 cubic feet of air per hour. On the other hand, when the fire is low the temperature in the chimney falls, and consequently the velocity and volume of air is diminished.

Unless provision be made for replacing the air thus removed, it would find its way into the room as best it can, by crevices round doors and windows, as well as through the walls. Hence in hospital wards special means of admitting air should be provided.

Let us first consider the way in which an ordinary open fireplace acts to create circulation of air in a room with closed doors and windows.

With an open fireplace the air is drawn along the floor towards the grate, it is then warmed by the radiating heat of the fire, and part is carried up the chimney with the smoke, whilst the remainder flows upwards near the chimney-breast

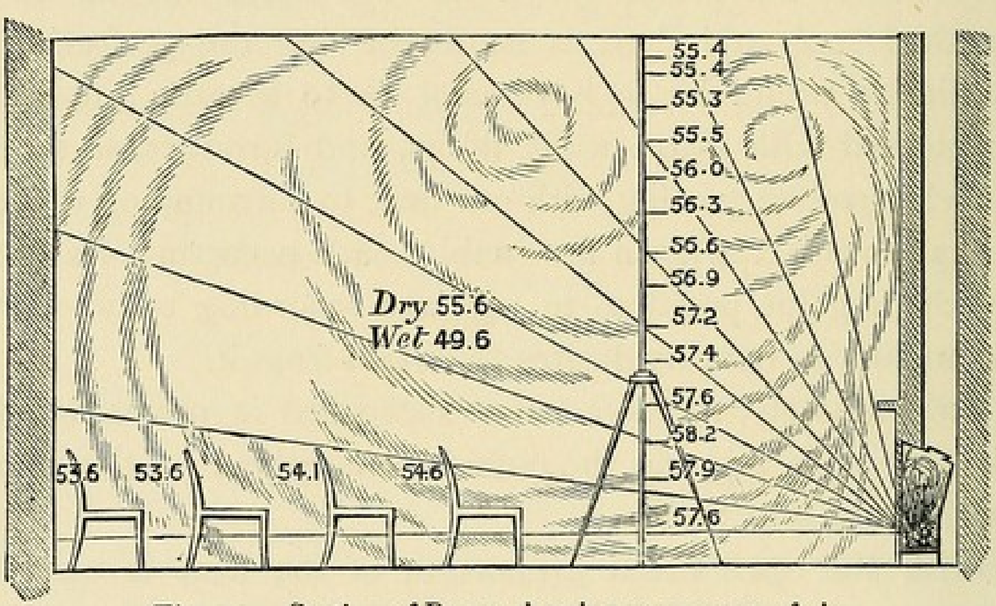


Fig. 12. Section of Room showing movement of air.

to the ceiling. 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.

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 at some convenient point in the chimney-breast, between the chimney-piece and the top of the room, for the air thus falls into the upward current, and mixes with the air of the room without perceptible disturbance.

The inventions in forms of fireplaces are very numerous.

But except as to smoke consuming appliances (which need not be entered upon here) they fall under few heads.

As already mentioned the open fire warms chiefly by means of radiant heat.

Therefore, with the simple open fire, the grate selected should in the first place be one which contributes radiant heat most effectively.

Radiant heat much depends upon a fire with flame. The material used for the sides and back which are in contact with the incandescent fuel should not absorb but should reflect heat. The height of the grate above the floor should be considered, because the fire when raised throws its rays upon the floor at a better angle for warming it than when the grate is very low or on the ground. So far as radiant heat alone is concerned it is difficult to improve upon the simple form of Rumford Grate, with splayed firebrick sides, and with the back arranged to lean slightly forwards over the fire, whilst in order to favour the draught, some air should be admitted through the bottom of the grate and the front bars should be vertical to prevent accumulation of ashes upon them.

It may, however, be advantageous for small hospitals to have a grate with hobs for convenience of administration, and Figure 13 shows a fireplace on the Rumford plan, with hobs, used by Mr. Peach, Architect. AA are fire brick-blocks, BB are glazed bricks.

In addition to radiant heat, the heating power of various descriptions of grates has been increased by an extended heating surface for warming the air which comes in contact with it. This extended surface is sometimes afforded by iron or tiled fronts, but probably the most effective form (apart from a ventilating fireplace) is by a warmed hearth such as is afforded by the radiating bars of the Sylvester grate, one of the ends of which terminates in the fire, and the other ends project like a fan into the room, and form the hearth, thus affording a large heating surface. Mr. Pridgin Teale's (the Lionel Teale) is a fireplace in a fire-clay receptacle below the level of the hearth, which latter stands about 4 or 6 inches above the floor level; this grate is an adaptation of the Sylvester

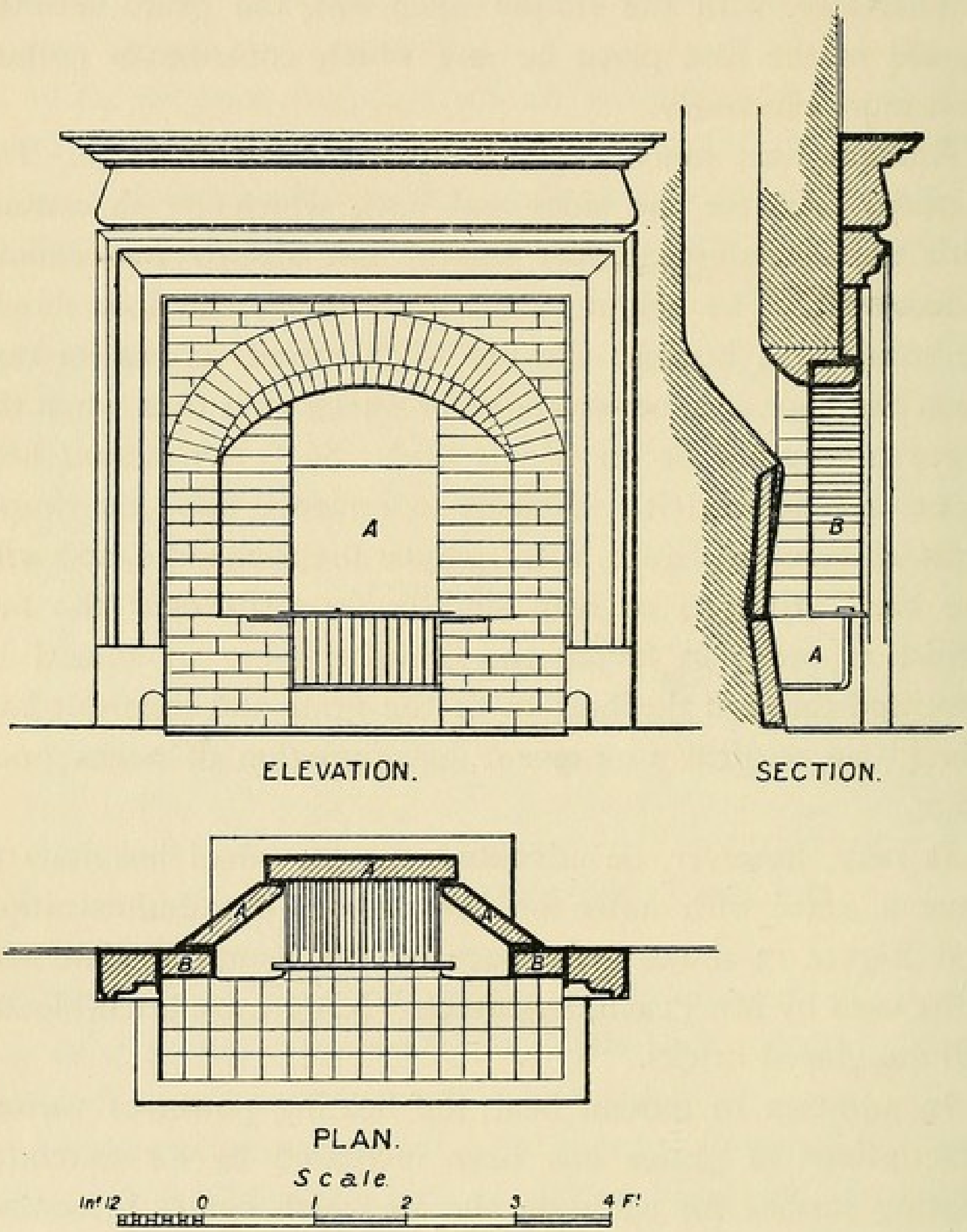


Fig. 13. Rumford Grate with hobs.

grate in that it has an iron plate carrying the hearth tiles, by means of which they are made hot, and thus the raised hearth of this grate throws out considerable heat, and is also useful as a hob.

With the open fire and the admission of cold air direct from outside, the air in different parts of the room may vary to the extent of 5° or 6° in temperature, and consequently sensations of draught may be experienced.

In all open fireplaces, with a good draught, there is a considerable portion of the heat evolved beyond that utilized for warming the room, and even beyond what is necessary for purposes of ventilation.

This may be used to warm inflowing air. The ventilating fireplace, called the Galton Grate, was designed for the War Office with this object [1].

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 ; and with this form of grate and its ventilation the temperature of a room has been found not to vary in any part to a greater extent than 1° Fahr., or at most 2°. The body of the stove is of iron, but the fire is placed in a fire-clay cradle; this prevents contact between the lighted fuel and the iron which communicates the heat to the fresh incoming air. The giving-off surface, obtained partly by the back of the grate and its flanges, and partly by the lower part of the smoke-flue, amounts to about 18 square feet.

Figure 14 shows one form of this grate.

General Morin's experiments showed that the proportion of heat utilized in the room by the use of warmed air in this grate was three times as much as that utilized by an ordinary grate.

These grates are for placing in the side walls.

Another form, in use at the Herbert Hospital, was devised to stand in the centre of the ward : the chimney *b* passes under

[1] These grates are made by Messrs. Yates and Haywood, and by Messrs. Kennard, both of Upper Thames Street, E.C.

the floor, and is placed in the centre of the flue *a*, which brings in the fresh air to be warmed by the fireplace: by utilizing this heat more than 36 superficial feet of heating surface have been obtained for warming the fresh air, beyond that afforded

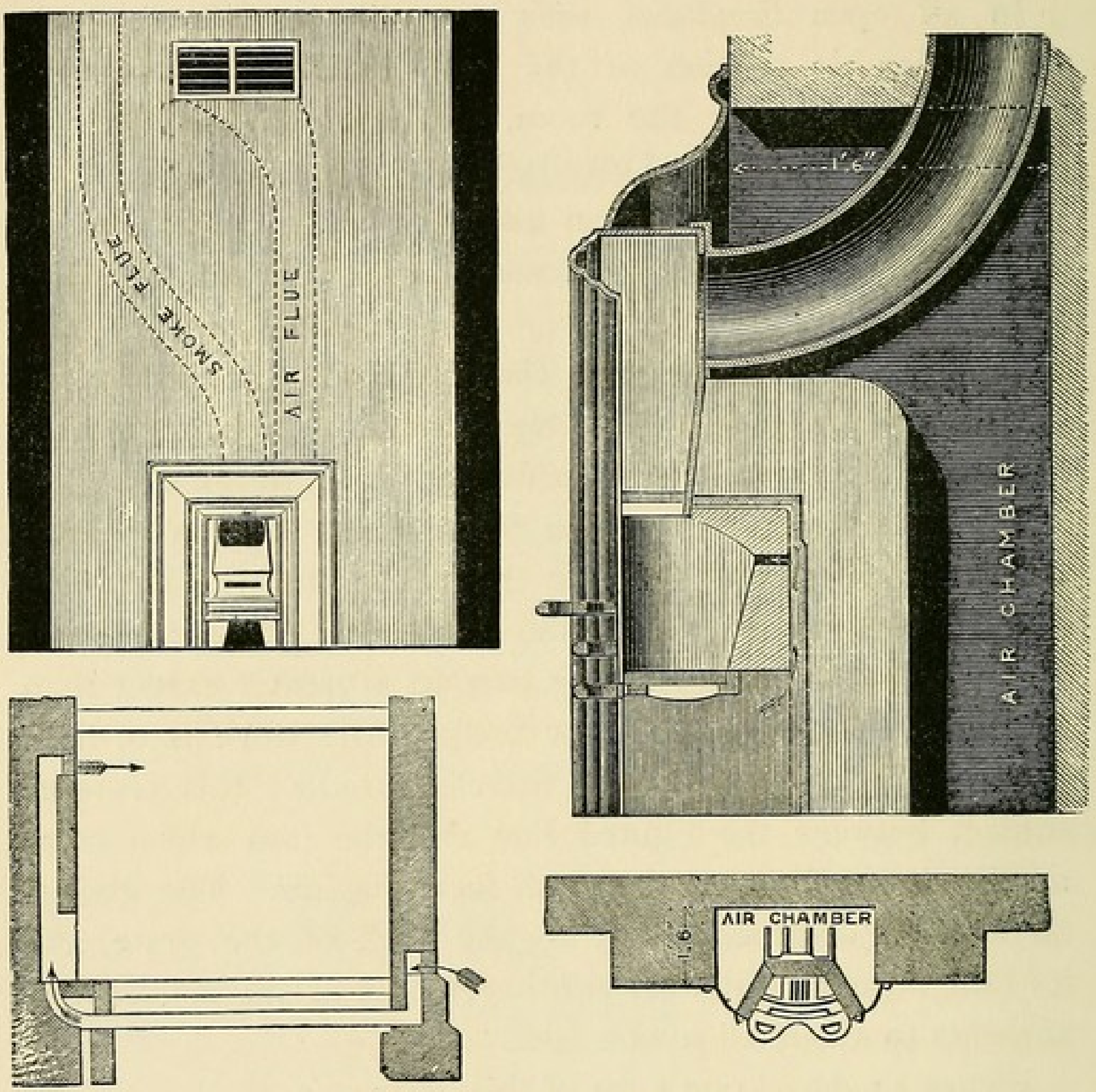


Fig. 14. Ventilating Fireplace.

by the heating surface in the air-flues in the fireplace, which furnish from 12 to 15 feet; Figures 15 and 15 *a*.

The fire stands in an iron cradle fitted to the fire-clay back and sides, and a current from the air of the room is brought through the fire-clay at the back of this cradle, *c*, where it becomes heated, on to the top of the fire to assist the combustion, and thus prevent smoke. The top of the stove is coved inside, to lead the smoke easily into the chimney, which passes down into the horizontal flue *b* under the floor. The main body of the stove is a mass of fire-clay, with flues *a* cast in it, up which the fresh air passes from the horizontal air-flue already mentioned, in which the chimney-flue is laid. Thus all the parts of the stove employed to warm the fresh air, with which the fire has direct contact, are of fire-clay.

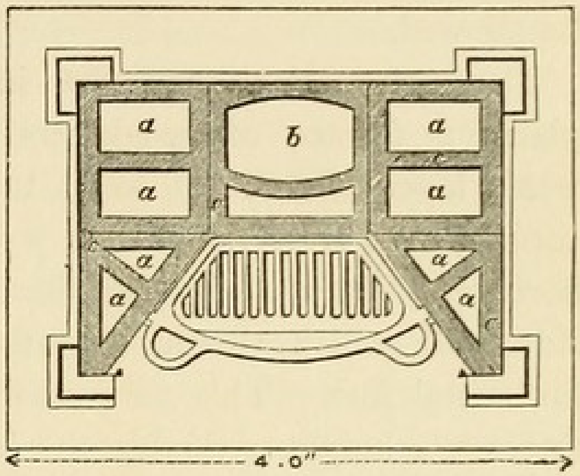


Fig. 15.

This is especially essential in hospitals, where every element of possible impurity of air should be avoided; and it has been shown by experiments at the Conservatoire des Arts et Métiers, that iron, and cast-iron especially, when heated to a high temperature, will allow of the passage through it of the carbonic oxide from imperfect combustion of the fuel in the grate: moreover, highly heated iron in contact with air may act on the organic matter, diminish the oxygen, and interfere with the freshness of the air.

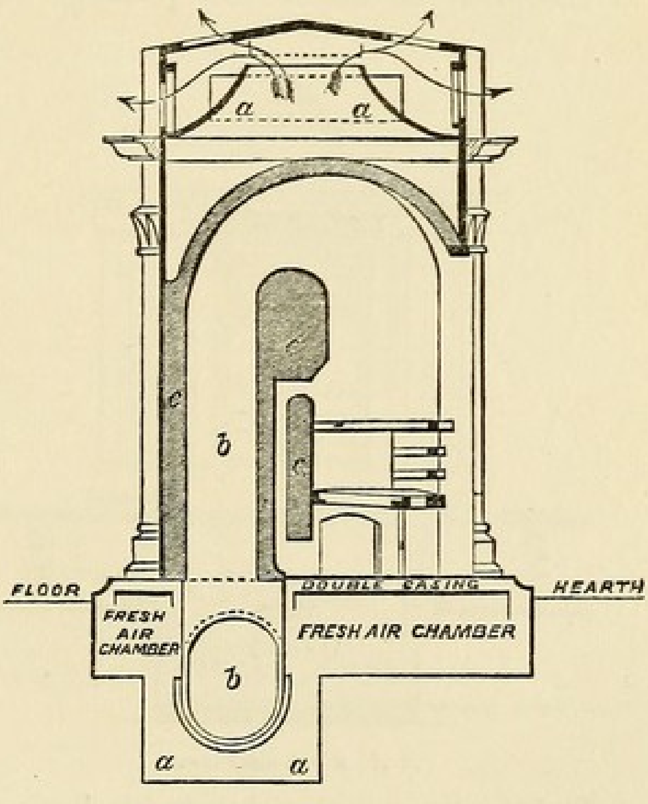
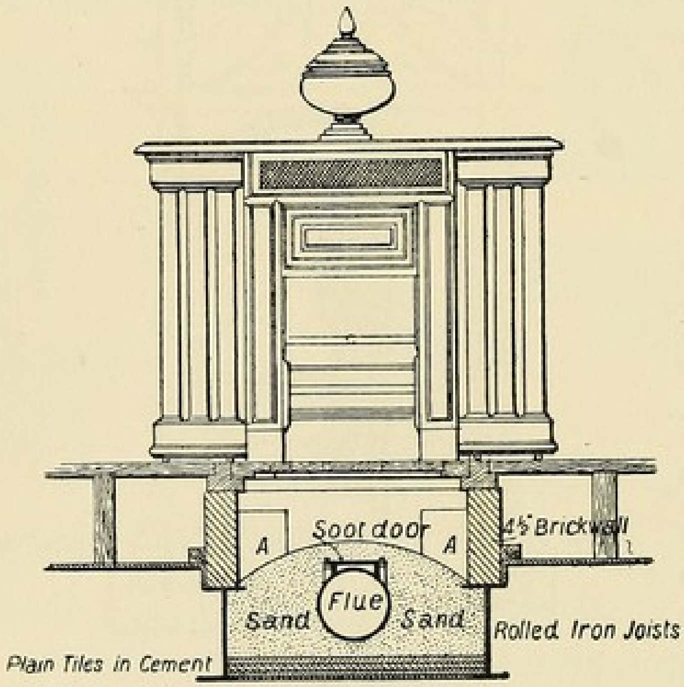


Fig. 15 *a*. Ventilating fireplace for Hospital.

The sectional area of the fresh-air flue with this arrangement of grate may be 1 square inch for every 100 feet of cubic contents of the spaces to be warmed, for favourable situations; but in cold or exposed localities a less area may be allowed.

The horizontal chimney-flue in the Herbert Hospital fireplaces is formed of two layers of sheet-iron, separated by a thin layer of fire-clay, so as to prevent overheating of the surface, and it is about 110 square inches in area. The horizontal chimney-flue terminates in a vertical flue in the side wall, which should be rather larger in area than the horizontal flue. This vertical flue is carried in the upper floors to a height of double the length of the horizontal flue, and is carried down to the basement, whence it can be swept. The points of connexion between the horizontal chimney with the descending flue from the fireplace, and with the ascending flue in the wall, are very carefully rounded, as this is essential to assist the passage of the smoke. The horizontal flue is swept from an opening, to which access is obtained by taking up a moveable board in the floor, and by pushing a brush along the flue, and thus forcing the soot into the vertical flue, whence it falls down and is removed at the opening in the basement.



A A Fresh-air Flues.

Fig. 16. Saxon Snell's Thermhydric Stoves.

There is placed a spare flue by the side of the vertical flue, terminating in a fire place in the basement, which enables the vertical flue to be warmed, so as either to make it draw when the fire is first lighted, or to enable a current to be maintained for ventilating purposes through the fireplace when the fire is not lighted. The portion of floor over the horizontal flue should be so constructed as to be taken up, in order to enable the air-flue to be easily and thoroughly cleaned periodically.

Another form of grate which increases the heating surface and provides fresh air is Mr. Snell's Thermhydric grate, Fig. 16.

In this fireplace a small boiler is placed behind the grate and communicates with a series of iron pipes alongside of it, in which the hot water circulates. These hot-water pipes are arranged to afford a large heating surface, over and through which air is admitted to the room. The grate occupies the centre of the room, and the products of combustion are carried off by a flue placed underneath the floor.

CHAPTER IX.

WARMING (*continued*).

II. *Warming by hot air conveyed along flues from a central source of heat.* Warmed by

(*a*) A furnace or iron cockle.

(*b*) Hot water or steam pipes.

There are some preliminary considerations which it will be desirable to notice.

(1) Preliminary tempering of the air. When a volume of air has to be heated at a central source, advantage may be taken of the earth's temperature in very cold weather for tempering the air.

At a very little depth below the surface of the earth, in all countries, the earth is of the average temperature of the climate, as may be ascertained by the temperature of springs. It will hence appear, that if the air which is requisite to supply a house in the winter of cold countries, were made to pass along a subterraneous cavity, it would become considerably warmed. It has been found by experiment, that a passage of two hundred feet in length in England has had the effect of warming the air of the atmosphere passing through it, to much above the arithmetical mean between the outer air and that of the earth.

In summer the hot air could be cooled by this means. In using such air-flues the air should be drawn from a height of at least eight to ten feet above ground level; and the impure air from the surrounding ground must be excluded. This could be adequately secured by a channel faced with glazed bricks laid in cement, or else by using iron pipes with properly made joints; small pipes would be more effectual for transferring the heat of the ground to the air than large ones, but with a large volume of air and small pipes, friction would be considerable. Such channels must be so arranged as to be always kept thoroughly clean, where possible, light, and free from damp or insects, &c. In hot malarious countries this arrangement if adopted would require especial precautions.

(2) Inconveniences of warming a room by means of heated air.

When hot air is conveyed into a room by flues from a stove or other central source of heat in the basement, it is necessarily warmer than the walls, consequently the walls and furniture of the room are warmed by means of the heat conveyed to them by the heated air, and are thus necessarily cooler than the air itself. The warmed air is less pleasant and invigorating to breathe than cold air. If you take two equal volumes of air, one heated and the other cold, the expanded heated air will contain less oxygen per volume than the colder air.

For instance, at a temperature of 32° a cubic foot of air weighs 567 grains, which would be distributed in the proportion of 448·8 grains of nitrogen to 118·2 grains of oxygen, whilst at a temperature of 80° the cubic foot of air weighs 516 grains, which would be distributed in the proportion of 408·4 of nitrogen to 107·6 of oxygen.

It is probably for that reason that the air of a frosty morning is so invigorating.

The method of warming the walls by means of the warmed air necessarily leaves the walls colder than the air of the room, and the heat of the body is radiated to the colder walls. Hence if the walls are to be warmed by the air admitted into the room, the temperature of the warmed air must be raised beyond what is either comfortable or healthy for breathing;

and thus if you obtain your heat by warmed air alone, admitted direct to the room, discomfort in one form or the other can with difficulty be avoided. It follows that if we desire to have comfortable rooms warmed with hot air, we ought either to have an open fire or steam, or hot-water pipes at a high temperature, to radiate heat to the walls, or else to make the warmed air pass under the floor, and through spaces reserved in the walls so as to warm them before it enters the rooms, and then we should not suffer from the discomfort of radiating away the heat of our bodies to cold walls; and the highly heated air which had parted with some of its heat to the walls would pass into the room at a comfortable temperature.

(3) Considerations affecting economy in using warmed air to heat a building.

In estimating the cost of warming air, and then through its means transferring heat to the place where it is required, as compared with that of placing the source of heat itself in the room to be warmed, an allowance above the actual volume of air to be warmed must be made (*a*) for creating movement to propel the air through the flues, (*b*) for the loss of heat from the distance traversed by the air between the source of heat and the space to be warmed, and (*c*) for the loss of heat from the position of the heating surface in chambers where it is warmed, especially when below ground.

As regards the latter cause of loss, when the subsoil is of clay, and the heating surface is placed in channels or chambers level with the foundations, great care should be taken to ensure that the drainage of the building is sufficiently deep to clear all water from these channels, or much loss of heating power will be caused, owing to the evaporation of the surface water which collects in different parts of the apparatus.

Of course the loss of heat from warmed air passing through flues depends upon the form of the building. In a compactly built house where all the heat generated in the central calorigen passes into internal walls, and the area of the outside walls is comparatively small in proportion to the cubic contents of the building, this heat would not necessarily be wasted; but in the case of a hospital, in which the principle of construction is, that the area of the outside walls should be large as compared with the cubic space, and in which the warmed air has to be conveyed to considerable distances through underground passages connecting the various buildings, and which afford large surfaces from which the heat can pass away unused, the question of loss of heat becomes material.

Moreover, the calculation of the heating surface to be fixed in a warming chamber, when the air to be heated is put in motion by mechanical means, either by an aspirating chimney or by propellers, is a more complicated one than when the heating surface is fixed in the space to be warmed.

(4) Necessity of enabling the occupants of each ward to control the temperature of air admitted.

In the supply of air to hospital wards, the temperature at which the inflowing air enters the ward is of great importance.

It is the province of the medical man to say what temperature should be maintained in the wards. Hence where the warming depends on the temperature of the air, there must be some subsidiary means of influencing the temperature of the air before it enters each ward, placed under the control of the ward attendants, beyond that afforded by the central calorigen.

In cases where the inflowing air is admitted as supplementary to an open fireplace, a temperature of 54° to 56° should generally suffice for the inflowing air. But where employed as the only source of warmth it should, in this country, probably enter the wards at a temperature of not less than from 58° to 64°. Indeed, some diseases, such as those of the respiratory organs, may require an even temperature to be always maintained, of probably not less than from 63° to 68° Fahrenheit.

On the other hand, in the United States, where the climate is very dry, it would seem that a temperature of 70° is not considered excessive, and that higher temperatures are sometimes demanded.

The duty of the designer of the hospital is to see, first, that the heating apparatus or central calorigen provides adequate means for maintaining the prescribed temperature; and secondly, that the sister in charge of the ward has it always in her power to modify the temperature of the air as it enters the ward.

The hot-air system must also be supplemented by some arrangement for moistening the air at will. In temperate weather, if fresh cold air is arranged to be mixed with warmed air this moistening might not be wanted.

When the outer air is cold and its capacity for moisture small, the moistening of the warmed air may, however, be found necessary.

A warm-air system for hospitals must depend either on propulsion or on extraction.

Air, like all other bodies, obeys the laws of gravitation, and is subject to those laws of inertia in virtue of which no body can change its state of repose or motion, except as a result of the forces by which it is influenced.

And hence the warmed air must be either drawn into the wards by extraction-flues or propelled into them by fans or blowers, i. e. it must be assisted or solicited by mechanical means in one form or other.

We will now consider the principal methods in use for warming air at a central source of heat.

(*a*) *Heating by Furnace or Cockle.*

The iron cockle for warming air was much in vogue before boilers and hot-water pipes had attained their present efficiency of construction, on account of its simplicity.

The ordinary cockle may be described as an iron box; its principle is to provide a large flanged surface to convey the heat from the fire which is placed inside to the outer air.

The surface of a cockle will attain a temperature of 280°, and with a large volume of air passing over it this will not affect the air injuriously.

But it has its disadvantages. It is necessarily very unequal in its effects. With a strong fire and a small volume of air it may overheat the air; if the fire gets low the temperature falls rapidly, and the uniform regulation of the temperature of the air is not so easy as with a boiler.

The Smead air-warmer is an improved form of cockle which, by affording a very large heating surface, tends to prevent over-heating the air; and it thus not only utilizes very fully the heat from the coal, but is calculated to warm a very large quantity of air.

The part of the fire-box which contains the ignited fuel is formed of corrugated plates by which the heating surface is increased. The actual fire-box is lined with an iron lining to prevent the fire from striking directly on the outside iron surfaces with which the fresh air to be warmed is in contact; and this lining is arranged with openings to admit of the air, which is heated by contact with it, passing to the incandescent fuel, so as to diminish the smoke.

There is an extension of the fire-box, also of corrugated plates. This is divided into two parts by vertical plates, and an interspace is thus formed, up which the outside air passes to be heated.

A further heating surface is afforded by two horizontal quasi-rectangular shaped boxes, along which the smoke travels back from the end of the extension of the fire-box to the front part of the apparatus; and it is thence conveyed to the chimney, which is at the back end of the fire-box, by a horizontal circular flue which lies between these rectangular boxes.

The whole is surrounded by brick-work, which is built so as to leave a space between it and the outside of the heater.

The fresh air impinges upon all the iron surfaces. This is an American invention, and certainly appears to be the most efficient form that has yet been arranged for heating air by the direct action of the fire.

The heat of the coal is utilized directly by means of a cockle, and if the heating surface is sufficient to remove the heat from the gases of combustion, so as to allow the latter to pass into the chimney at as low a temperature as the gases in the case of a low-pressure hot-water boiler, there ought to be economy, and there is certainly simplicity.

As already mentioned, impurities may pass through the highly heated iron of a stove or cockle into the warmed air, and, in any case, if a crack occurs in the joints, the fumes of combustion may pass into the warmed air and cause much inconvenience.

This source of evil may be removed, or at any rate mitigated, by warming the air by means of stoves of fire-clay or earthenware. This material is not, however, well adapted for warming large volumes of air, because of the slow rate of conduction of the material.

A hot-water boiler takes up and distributes the heat of combustion more uniformly and therefore more efficiently than a cockle, and as a general rule the heat of the smoke escaping from the boiler is less, on the average, with a carefully arranged boiler than that from the cockle. Therefore, even where the warming is by means of hot air, the air can generally be most conveniently warmed by hot-water or steam-pipes. But there is also the consideration that the temperature of each ward must vary with the orders of the physician or surgeon, and the furnace or cockle would not of itself afford means for supplementary heating.

CHAPTER X.

WARMING (*continued*).

(*b*) *Hot-water or steam-pipes.*

The considerations affecting hot-water and steam-pipes are equally applicable to pipes arranged to warm air at a central source of heat, or to pipes carried all round a building, and both these methods may therefore be conveniently discussed together.

Hot-water pipes for warming air are free from many of the objections arising from the direct application of heat to iron, because the heat can be regulated with exactness.

Water boils at 212° Fahrenheit under the atmospheric pressure of 14·7 lbs. per square inch, or 30 inches of mercury, i.e. at about the sea-level. Under one-half that pressure, viz. 7·3 lbs. per square inch, or 15 inches of mercury, it boils at 180°; and under a pressure above the ordinary atmospheric pressure, of 45 lbs. per square inch, it boils at 292°; and under a pressure above the atmosphere, of 175° lbs. per square inch, it boils at 377° Fahrenheit. Thus a high temperature may be obtained from water without generating steam by heating it under pressure.

Steam is generated under the mean atmospheric pressure of 30 inches of mercury when the boiling-point is attained, i.e. 212°; but before the water becomes vapour a further amount of heat equal to 966° is absorbed and becomes latent; this would have sufficed to raise the water to 1178°, if it did not turn into steam. The temperature of 1178°, which is thus required to produce steam, is necessarily constant, and consequently a greater or less amount of heat becomes latent according as the pressure is below or above the atmospheric pressure. This latent heat is given out on the reconversion of steam into water.

There are certain general conditions affecting hot-water and steam-pipes which it will be well to recapitulate here.

Hot-water pipes.

The question of using hot-water pipes at a low temperature, or hot-water pipes under pressure, as in Perkins' system, or steam-pipes for warming the air at a central source of heat, is almost entirely one of convenience of application and conditions of economy.

The considerations which apply are—1. Heat is emitted and absorbed in an accelerating ratio, in proportion as the difference of temperature increases between the body from which the heat is radiated and the body which receives the heat. And with the same difference of temperature between the recipient and the radiant, the effect of the radiant will be greater according to the increased temperature of the recipient; in other words, the ratio of the emission of heat increases with the temperature. That is to say, pipes heated by hot water under high pressure convey heat to the air with greater rapidity than pipes heated by hot water at low pressures; and steam-pipes are more effective than hot-water pipes; and steam at a high-pressure is more effective than low-pressure steam.

It would, therefore, seem that the most economical way of supplying heat to the large volume of air required for the supply of a hospital, would be either by high-pressure hot-water or steam-pipes.

2. But there is another consideration. Pipes at a low temperature give out their heat to warm the air, but they give out very little radiant heat to warm the walls; on the other hand, pipes at a high temperature like high-pressure hot-water pipes

and steam-pipes give out a considerable amount of radiant heat to warm the walls, as well as direct heat to warm the air in contact with them. Therefore, in an air-chamber in which fresh air is warmed, the high-temperature pipes radiate their heat to surrounding surfaces, and in that way afford an increased heating surface for warming the air.

3. The temperature of the pipes can be varied in the case of hot-water pipes, both at low and high pressure, by a modification of the fire in the furnace; with steam this is not so simple, but where a large heating surface is concerned, it would probably be found preferable to vary the temperature of the inflowing air by exposing more or less of the heating surface rather than by varying the heat of the fire. The whole body of fresh air would in this case be heated to a moderate normal temperature at the central source of heat, and then subsidiary pipes would be provided under each ward which could be applied or not to give extra warmth to the air of the ward at the will of the attendant. The amount of heating surface required to maintain the temperature of the main body of air might have to be varied according to the temperature of the outer air. This would be effected by some simple method of exposing more or less of this heating-surface to the inflowing air, according to the temperature of inflow required.

In the House of Commons, batteries, as they are called, consisting of numerous parallel flanges, are placed at intervals on the steam-heated pipes and thus create heating surface; and an attendant is constantly employed to cover with thick cloth or uncover one or more of these batteries, according to the extent of heating-surface desired to be exposed to the air. This arrangement renders it unnecessary to alter the heat in the pipes themselves or in the furnace. The plan already described by Mr. Key for the steam-pipes for warming the air in the Victoria Hospital in Glasgow fulfils the same object, and is well suited for controlling the heat of the general body of air in a hospital. The plan is to arrange the pipes in sections; one or more of which can be heated as desired. These sections are covered by a series of shutters of non-conducting material, of which one or more can be opened or closed at will; these prevent the fresh air from passing over the hot pipes or allow it to do so as desired, and the heating-surface which is exposed to the inflowing air can be thus varied accordingly. The volume of air passing in is not altered, because a corresponding bye-pass is opened at the same time that any shutter covering the hot pipes is closed, so as to allow cold air to pass in, instead of the air warmed by the pipes.

Each ward must be provided with a subsidiary set of hot-water or steam-pipes, so arranged that their heating-surface might be wholly or partly exposed to, or shut off from, the inflowing air for the regulation of the temperature of that entering the wards. The arrangement for this purpose in the Johns Hopkins Hospital is shown in Figure 25, page 161. The original plan of the building should include all the arrangements for warming and ventilating, and the hot-water engineer or the steam-fitter should commence his work in a new building at an early period of its construction.

Low-pressure hot-water pipes.

The efficiency of hot-water pipes depends upon the circulation of water in the pipes, in which the motive power is the difference in weight between the column of water ascending from the boiler through its top outlet, or flow-pipe, and that returning to the boiler through its bottom inlet, or return-pipe. As the water in the boiler is heated it expands, becomes lighter and ascends to the top of the boiler in the direction of the flow-pipe, and is replaced by colder and consequently heavier water from the bottom or return-pipe; this in turn gets heated, ascends, and is replaced by more cold water from the return-pipe, and this circulation continues so long as the fire is kept up; the hot water continually ascending, and the cold water descending. The efficient action of hot-water pipes depends upon the upward flow of the heated and expanded water, as it passes from the boiler, being made as direct as possible, and so protected as to lose little heat between the boiler and the place where the heat is to be utilized. The return-pipe, which brings back the water to the boiler after it has been cooled down by the abstraction of heat in warming the air, 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.

However, in all cases the fire should be as near to the bottom of the ascending column as possible; when quite at the bottom a short column will suffice to produce the necessary motion.

The quantity of heat which the water in the pipes can convey to the air will depend upon the velocity of flow in the pipes.

The velocity of flow in the pipes depends on the difference in weight of the two columns of water, which would be obtained from the specific gravity of the water at the temperature at which the water leaves the boiler and that at which it passes down the return-pipe back to the boiler, and the height to which the heated water has to rise.

The efficiency of a hot-water apparatus will be regulated by these conditions, by the sizes of the pipes, and by such other conditions as affect the flow of water in pipes.

It will be evident that to obtain an equal velocity of flow when the height of the vertical column is small, the temperature at which the water returns to the boiler must be lower than when the vertical column is long. Therefore, when the boiler or source of heat is very near the level of the pipes for heating the air, the average temperature which can be obtained in the pipes will be lower than when the vertical column is long. Hence, the heating-surface of the boiler, the area of the grate which regulates the flow of air to the fuel, and the surface of pipe which enables the heat from the boiler to be utilized, must be regulated with reference to this difference of level.

It may further be assumed that with small pipes, the temperature being constant, the velocity of flow in the pipe necessary to furnish a given amount of heat will vary as the ratio of the length of the pipe.

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.

Here 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 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.

For calculations as to the sizes of boilers, length and diameters of pipes, and similar practical details, the reader is referred to Hood, Box, and other authors [1].

[1] Mr. Hood gives the following rule, that one square foot of boiler surface exposed to the direct action of the fire, or 3 ft. of flue surface,

High-pressure hot-water pipes.

By Perkins' system the water is heated under considerable pressure, and a higher temperature is thus obtainable than with ordinary 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. 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; the water after having been cooled in its progress through the pipes, returns to the bottom of the coil to be re-heated. The heat attained in the pipes depends upon the length of tube exposed to the fire as compared with the length carried round the building.

Water when heated from 39° to 212° Fahr. expands about

would heat 40 ft. of 4-inch pipe. To find the length in feet of iron pipe required for heating the air in a building,—multiply the volume of air in cubic feet, to be warmed per minute, by the difference between the temperature in the room and the external temperature, and multiply by 1·12 for 2-inch pipes, by ·75 for 3-inch pipes, by ·56 for 4-inch pipes, and divide the product by the difference between the internal temperature and that of the pipes.

The same authority gives the general rule that the length of 4-inch pipe required to warm a room may be calculated by dividing the cubic contents of the room, in feet, by the divisor 150, in order to maintain a temperature of 60° Fahr., and that 3-inch pipes require to be one-third longer, and 2-inch pipes require to be double the length, of 4-inch pipes, to heat the same number of cubic feet, but this rule does not take into account the volume of air required in hospitals.

The following table from the same authority shows approximately the quantity of coal used per hour required to heat 100 feet in length of a 4-inch pipe and 2-inch pipe:—

Diameter of Pipe in inches.	Difference between the Temperature of Pipe and Room in Degrees Fahr.			
	150	125	100	80
4	4·7 lbs.	3·9 lbs.	3·1 lbs.	2·5 lbs.
2	2·3 lbs.	1·9 lbs.	1·5 lbs.	1·2 lbs.

5 per cent. of its original bulk. Therefore, in order to provide for the increased volume of the water when heated, a tube called an expansion-tube, proportioned in size to the quantity of tube to which it is attached, is placed above the highest level of the tube which conveys the heat to the distant parts of the building.

The filling-tube of the apparatus is placed on a level with the bottom of this expansion-tube, so as perfectly to fill all the small tube, and yet prevent the possibility of filling the expansion-tube itself. The expansion-tube being then left empty, allows the water as it becomes heated to expand without endangering the bursting of the smaller tube.

The apparatus is filled by pumping water into an opening connected with the lowest level of tubing, so that the water, as it rises, drives the air before it, and out through an opening in the expansion-tube. Great care must be taken to expel all air from the pipes by repeatedly forcing water through them. When the pipes are filled, both the opening in the filling-tube and the opening in the expansion-tube are closed by screw-plugs.

The form and size of the furnace varies according to the locality and the work the pipes have to do. A temperature of as much as 300° Fahr. is sometimes arranged to be obtained in the tubes.

Steam-pipes.—Steam in lieu of hot water is especially applicable, either where steam for other purposes is in use, as for instance where the exhaust steam from an engine is available, or where heating is required on a large scale.

So far as economy in heating is concerned, there is not much difference between the use of exhaust steam and that of steam taken direct from the boiler.

Steam-heating may be either on what is termed the high-pressure system or the low-pressure system.

The high-pressure system of steam-heating is generally considered to mean the system which allows the steam to escape after use or else to be passed into a feed water-tank, whence it has to be pumped back into the boiler.

The low-pressure system is considered to mean the system in which there is a flow-pipe from the top of the boiler for the steam, and a return-pipe into the bottom of the boiler for the water of condensation, so arranged as to require no pumping.

A low-pressure gravity system of steam-heating is probably the most economical and convenient form of steam-heating appliance: as it is equally applicable to heat a single room or a large building. Its principal merits, when well done, are: it is safe; noiseless; the temperature of the heating-surface is moderate and uniform; all the water of condensation is returned into the boiler, except a very small loss from the air valves; it is easy to keep the stuffing-boxes of the heater-valves tight; and it is no more trouble to manage than a hot-water apparatus.

With a high-pressure system the waste of heat is sometimes enormous with traps which discharge into an open tank, or into the atmosphere. The difference in favour of a gravity apparatus working properly, with direct return-traps, can always be estimated at 15 per cent., over apparatus which permits the water to escape, and thus either loses it, or utilizes it by pumping it back: and when traps are neglected (which is the rule), it may reach 30 per cent. of all the heat.

The general principle of the low-pressure form of steam service is that the steam should rise direct from the boiler into the main distributing pipe, and that this pipe should always have an incline downwards, so that all condensed water should run to the lower end, where it is passed by a relief-pipe into the return-main[1] (see Fig. 17). By this plan the steam and condensed water always flow in the same direction, and this is a great safeguard against noise.

The application of steam to a building requires to be done by an engineer thoroughly skilled in steam-heating.

[1] See Baldwin on Steam Heating.

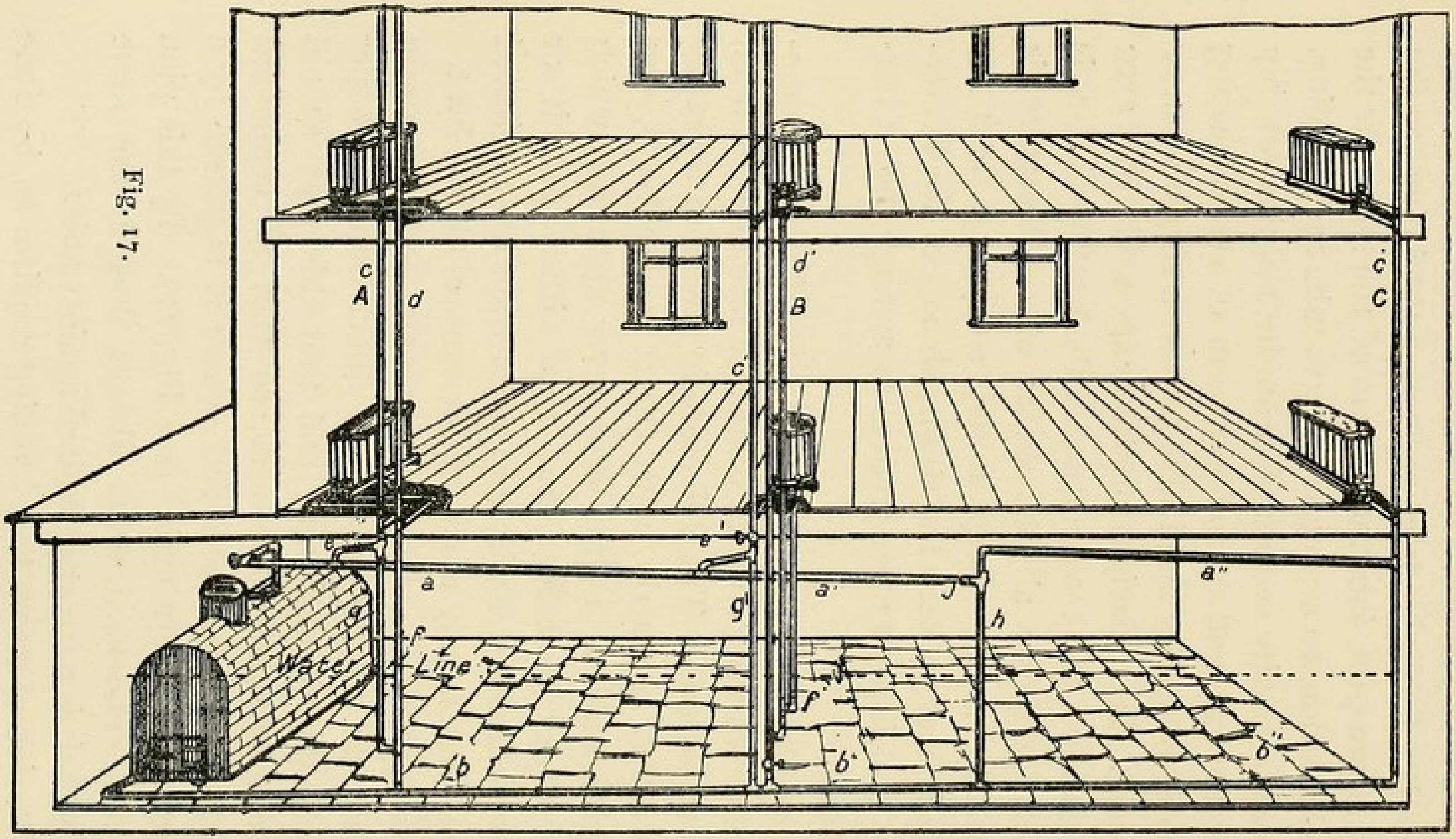


Fig. 17.

Low Pressure Steam Heating —Systems of Piping.—

a, a', a''. Main distributing pipe, showing incline.
b, b', b''. Main return-pipe, slightly inclined towards boiler.
c c', c''. Steam-risers, carrying steam from distributing pipe to radiators.
d'd'. Return-riser, carrying condensed water to main return.
e e. Steam-riser connexion, joining main distributing pipe and steam-riser.
f f. Return-riser connexion, connecting the return-riser with the main return-pipe *b, b', b''*—and which has one or more T's below water-line to receive the steam-riser relief.
gg'. Steam-riser relief, the pipe from the steam-riser into the main return-pipe to carry off any water that runs down the steam-riser.
h. Main relief-pipe, to carry water condensed in the main distributing pipe to the main return-pipe; acting also to equalize pressure in the system.
j. A relay, the rise in the main distributing pipe (with a main relief) to enable the main distributing pipe to be kept above water-level.

It may be useful to observe that the heat necessary to warm a pound of water at *mean temperature* (39° Fahr.) one degree, that is one heat unit, will warm $3\frac{1}{4}$ pounds of air one degree.

The heat necessary to convert one pound of water from the temperature of feed-water, or return-water, at 178°, to steam at one pound pressure (or to any pressure not noting the slight increase for high-pressures), is 1,000 heat units, and this will heat 48,000 cubic feet of dry air one degree; or 4,800 cubic feet of air 10 degrees; or 480 cubic feet of air 100 degrees, making no allowance for the expansion of the air, which will increase

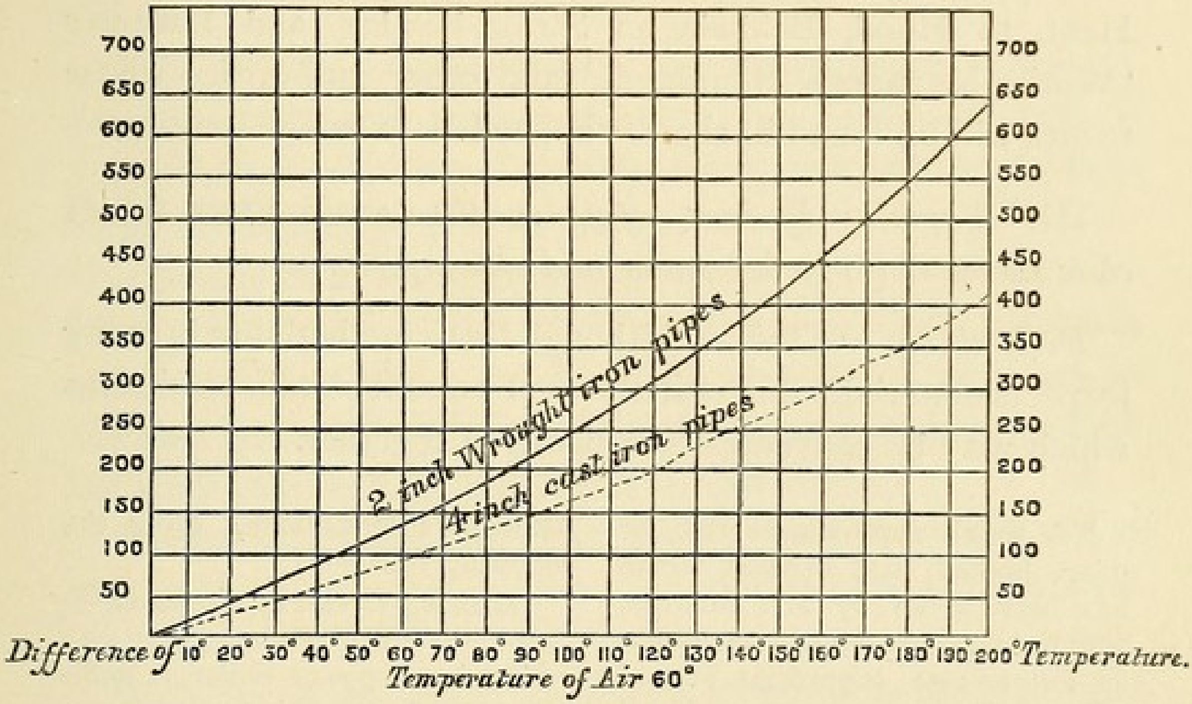


Fig. 18. Units of heat from cast-iron and wrought-iron pipes.

the bulk $\frac{3}{14}$ for a difference of 100 degrees; in other words, the 480 cubic feet will be increased to 583 when heated 100 degrees, and the 4,800 will be increased to 4,920 or $\frac{1}{40}$ of its bulk for a rise of temperature of 10°.

The annexed Figure 18, resulting from Mr. Anderson's experiments, is published in the Journal of the Institution of Civil Engineers for 1877, and shows the total units of heat given out by cast-iron and wrought-iron pipes, per square foot of surface, per hour, for various differences of temperature, applicable either to hot-water or steam-pipes.

Suppose, for example, it is required to know how much heat will be given out by 4-inch pipes at 190° in a room, the temperature of which is 60°, the difference of temperature being 130°: look along the line of abscissae for 130°, and the ordinate then gives 232 units for 4-inch pipes, and 356 units for 2-inch wrought-iron pipes per square foot per hour.

These data and those in the foot-note on p. 126 are merely mentioned to give a general idea of the effect of pipes. But for purposes of calculation the reader is referred to Box on Heat, to Hood, Baldwin on Steam-heating, and Hutton's 'Works Manager's Handbook,' and other authorities whose names will be found in the list appended to this volume[1].

III. *Warming by heat acting in the wards either* (*a*) *by close stoves or* (*b*) *by hot-water and steam-pipes.*

Preliminary remarks.—Although these methods are in many respects materially different, they yet present certain conditions which may be conveniently considered together.

[1] A rough approximate rule for pipes heated with exhaust steam has been given by Mr. Boulton, who has largely used exhaust steam as follows:—1 superficial foot of steam-pipe for each 6 superficial feet of glass in the windows; 1 superficial foot of steam-pipe for every 6 cubic feet of air removed for ventilating purposes per minute; 1 superficial foot of steam-pipe for every 120 superficial feet of wall, roof, or ceiling, allowing about 15 per cent. on the amount thus obtained for contingencies. He states that, roughly speaking, the exhaust steam due to one-horse power can be made to warm 30,000 cubic feet of space.

Mr. Hutton, in 'The Works Manager's Handbook,' gives the following rule:—

Heating Rooms by Steam at 212° Fahr.

A 1-horse-power boiler is sufficient for 48,000 cubic feet of space. To heat a room to 60° F. the length of steam-pipe may be found by the following rule—To find the length in feet of steam-pipe, multiply the volume of air in cubic feet, to be warmed per minute, by the difference of temperature in the room and the external temperature, and divide the product by 304 for 4-inch pipe, or by 228 for 3-inch pipe, by 152 for 2-inch pipes, and by 76 for 1-inch pipe.

In neither case is due allowance made for ventilation.

Stoves or pipes warm the air in contact with them, and give out a proportion of radiant heat, which passes to the walls and furniture of a room, dependent upon the degree of heat to which they are warmed.

Thus with ordinary low-pressure hot-water pipes, the temperature of which rarely exceeds from 120° to 130°, the larger proportion of the heat acts to warm the air of the room, and the air warms the walls and furniture.

But when stoves or pipes are heated to a high temperature, the heat is partly communicated to the adjacent air, and partly acts as radiant heat to warm the surface 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° Fahrenheit, 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 whole 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.

With flue-pipes heated to lower temperatures the air might receive much more than half the heat.

When, therefore, the object is to heat the walls of the room, rather than the air, the temperature of the pipes should be high.

For instance, with the Perkins' system of small pipes and closed circulation, the temperature of the pipes may vary from 150° to 250° or even 300°. With these latter more than half the heat would be radiated to the walls.

With low-pressure steam-pipes the heat will vary from about 230° to 180°, and with high-pressure steam-pipes as much as 300° to 400° may be obtained, and with both these much heat is radiated to the walls.

Thus the character of the heat which we desire to obtain must decide the form of heating, and the temperature to be maintained in stoves or pipes.

With warm walls and floors and furniture the air must be comparatively cool for comfort, or we should not be able to part with our heat at a sufficient rate; on the other hand, if the walls are cold we must have a hotter temperature in the air, to prevent the heat of our bodies being parted with too rapidly, but comfort is greater when warmth in the walls and floors is combined with cool air to breathe, as for instance, air at a temperature of 54° to 56°.

In considering the economy of these various methods of heating, it may be observed that with hot-water or steam-pipes a proportion of the heat generated by the fuel is applied to effect mechanical motion in the water or steam, and does not therefore appear as heat in the room; on the other hand, the non-conducting covering of the pipes should prevent the loss of any heat by the radiation from the pipes which might occur between the source of heat and the ward or place where it is utilized.

With a close stove in the room all the heat generated by the fuel, except a small proportion lost up the chimney, passes into the room.

(*a*) *Close stoves placed in the Wards.*

As a rule the close stove does not assist ventilation. If of iron, it may allow carbonic oxide to pass into the ward; if of tile, its temperature would be too low to afford radiant heat to the walls.

The most economical and probably the most perfect form in which stove-heating can be applied is the old German stove, or at any rate some modification of it. But it is limited in its application, and unless very large the fire-clay cannot give out sufficient heat to warm a large body of incoming air. Its economy depends upon its not being combined with the admission of fresh air through internal flues in the stove; when the heat is so extracted the expenditure in fuel is necessarily increased.

Moreover, a stove of fire-clay with a tile-surface is a more hygienic way of applying heat to air than an iron stove in which the fire is in contact with the iron, mainly because of the risk of gases from combustion passing through the iron.

A stove with a fire-clay lining which shields the iron covering from the direct action of the fire, but allows the iron to warm the air, affords a safe way of applying heat to air.

The simple iron-stove, if heated to a very high temperature, might supply a large proportion of heat to the walls of the ward, but such a high temperature might injure the air; on the other hand, low-temperature iron and other stoves only heat the air, which in its turn warms the walls.

All these methods of heating have the inconvenience of requiring the fuel to be brought into the ward, as is the case with the open fire; but they have not the advantage which the open fire has of supplying radiant heat, and of largely promoting the extraction of air from the ward.

A gas-stove is not a satisfactory form of heating for a hospital ward; the fumes are comparatively low in temperature, hence the draught they produce in the chimney is small, and they are therefore liable to pass back into the ward.

(*b*) *Hot-water or steam-pipes fixed in the locality to be heated.*

These may be used, as already mentioned, either in connexion with the open fire, or again, where warmed air is also supplied; or they may be applied as the only source of heat.

The selection of the method of heating the pipes will depend upon the local circumstances.

In the case of a large hospital, where steam-boilers are required for providing power for lifts, laundry work, &c., and where an engineer or artificer would be at hand, steam-pipes would probably be found the more convenient and economical method.

In the case of smaller local hospitals, it might be preferable to use hot-water under pressure or otherwise, which would not require skilled attention.

The low-pressure hot-water pipes, which do not convey heat to adjacent cold surfaces, have the tendency to cause the deposit of dust, therefore those pipes, such as high-pressure hot-water or steam-pipes, which are at a temperature which enables them to radiate heat to and warm the adjacent objects, would seem preferable, on the ground of cleanliness, to low-pressure hot-water pipes. But the low-pressure hot-water pipe which does not contribute much heat to warming the walls, might therefore be preferably used in connexion with the open fireplace, whose action is to warm the walls.

In a hospital ward it is preferable that the heat should be uniformly diffused along the walls; therefore it is better to lay the pipes along the walls without radiators, which collect the heat at certain points. It would also be advisable, as a means of equalizing the temperature of the walls, to carry a portion of the pipe-surface near the floor-level, and a portion round the upper part of the walls above the level of the windows, so as to distribute the heat more uniformly.

All heating-pipes in a ward should be laid above the floor level, exposed to view, with sufficient space between them and the floor or wall to enable dust or dirt to be easily removed.

A uniform distribution of heat over the whole floor of the ward, without the inconvenience of pipes exposed to view, has been effected by placing steam-pipes under a floor made of marmor terrazzo, and so warming the whole floor. Supplementary heating in this case might be applied by an open fire, or as has been provided in the instance under consideration by steam radiators, standing like stoves in the centre of the ward, through which fresh air is passed and warmed before it enters into the ward. In no case should a ward be warmed by pipes in the floor so laid as to admit of any communication between the ward and the channel in which the pipes are laid. For in that case the channel would only become a receptacle for dirt.

It is also an axiom that pipes for heating purposes should be entirely separate from pipes for the supply of hot water.

CHAPTER XI.

LIGHTING.

Day Light.—Light and particularly sunlight maintains the purity of the atmosphere and exerts an important influence on vitality. It is essential for the organic development of plants and animals: and on the other hand, sunlight, and especially the actinic rays of the spectrum, has been shown to kill some classes of spores and bacilli and to check the development of certain forms of micro-organisms in connexion with disease.

The absence of light seems to be one of the contributing causes of the low health and deformities often prevailing amongst the children of the poorer classes in towns, which is diminished if not removed by their exposure to light and fresh air in the country.

But independently of this, light is required in hospitals as an antagonist to dirt. Dark corners mean dirt, because dirt must be seen to be removed. The absolute cleanliness which is essential throughout a hospital can only be obtained where a flood of light is directed to every part of the building, as much under staircases, in closets, and in cupboards, as in the wards themselves.

So far as work or reading is concerned, it may be assumed, according to Dr. Förster[1], 'that the most perfect ease in reading, or in fine work, is felt in the open air on a summer

[1] See Willoughby's 'Hygiene and Public Health.'

day when the sky is overcast. Under these circumstances the light is ample, but it is perfectly diffused, there is neither glare nor shadow, and the light may be said to come from all sides, but from no one in particular.'

But it is an axiom that direct sunlight should penetrate into a room occupied by the sick. Hence the conditions required for light necessarily affect the shape of the hospital wards.

An East and West aspect for a hospital ward, which has windows on opposite sides, allows of this permeation of sunlight at some period of every day on which the sun shines.

Independently, however, of the question of direct sunshine the light should as far as possible come from the sky, and no part of a room can be deemed sufficiently lighted from which a certain amount of sky cannot be seen.

This affects both the question of the level of the upper part of windows as well as the proximity of buildings. Dr. Förster of Breslau laid down as a rule that the arc of sky visible from any part of a room should not be less than 5°. This seems somewhat small for a hospital ward, but if the height of the ward is made equal to half its width, if the windows are carried up to within about a foot from the ceiling, and if the adjacent buildings are placed at a distance equal to twice their height measured from the level of the ward floor, this proportion of sky illumination would be more than obtained, and, indeed, with windows of adequate size placed on both sides of a ward the light would be abundant.

Artificial light.—Every form of matter, when sufficiently heated, has the power of emitting rays of light, and thus becomes self-luminous.

This condition is termed incandescence.

All artificial sources of light depend upon the development of light during incandescence. In every ordinary flame we recognize two things, light and heat. But they are very different; the one depends upon the amount of incandescent matter diffused throughout the flame, the other upon the amount of matter oxidized or burnt in a given time.

A flame, that of a candle for example, structurally consists of two hollow cones, the inner of gases and matter going up to be burned, the outer of burning matter and of incandescent particles diffused through it.

For the purposes of lighting our streets and houses we have hitherto chiefly made use of a combustible gaseous combination of carbon and hydrogen which forms the chief constituent of ordinary coal gas. When this hydro-carbon burns, that is to say, when its elements unite with the oxygen of the air, it undergoes partial decomposition, the hydrogen unites with the oxygen, and forms water, and heat is evolved. The 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 presence of the particles of carbon may be easily shown by holding a non-combustible body in the flame, when the carbon, in fine powder, will be deposited upon it, forming a layer of soot, or what we generally term lamp-black. 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, when these substances unite and form carbonic acid; but if the supply of oxygen to them be insufficient in quantity, they partly go to form carbonic oxide, which is a highly deleterious gas. Moreover, a portion escapes into the air of the room as solid particles, the result of which is that the flame is said to smoke.

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

The Bunsen burner gives a smokeless and non-luminous flame. In the Bunsen burner ordinary gas is conducted into the tube of the burner, but at the same place air enters, and mixes itself with the gas in the interior of the tube; and thus oxygen is admitted, not only to the border of the flame, but throughout its whole mass, and the carbon is accordingly burnt into carbonic acid before it can separate in the solid form, so that the flame is composed of incandescent gases alone, and gives a very feeble light, and deposits no soot on bodies held in it.

If a solid body be introduced into this feebly luminous flame, such, for instance, as a piece of platinum wire, the incandescent metal glows with a brilliant light; and this fact has been utilized to produce the Welsbach and other similar forms of incandescent light.

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

The hot wick, which draws up by capillary attraction the fluid material about to be burnt, plays the part of a small gas factory, the produce of which is used on the spot, the only difference being that coal-gas is always purified before it is consumed, whereas the extemporaneous gas of a candle or lamp is consumed without being purified at all; on the other hand, the tallow, wax, and oil contain the carbon and hydrogen in a purer and more concentrated form than the coal from which ordinary coal-gas is made.

The flames of candles and of lamps all owe their luminosity to the incandescence of particles of carbon floating in them; and 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.

From this it is obvious that in order to obtain the highest illuminating power of a flame in which hydro-carbonaceous compounds are undergoing combustion the regulation of the supply of air is essential. This more perfect combustion is also essential to the maintenance of the purity of the air of the room.

In a hygienic aspect, it is also essential that the compounds used to produce light should be as pure as possible; and during the last twenty years vast improvements have taken place in the methods of purifying gas, so that now the London gas is almost entirely free from sulphur and its compounds.

The effect caused on the air of a room by combustion is (1st) to diminish the oxygen, and (2nd) to increase the carbonic acid and 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 used for illumination contains, besides the carbon and hydrogen which are necessary for purposes of illumination.

The standard which has been adopted for light is that of a No. 6 sperm candle burning 120 grains per hour.

Illumination consists of two factors, candle-power and distance.

The candle-foot, that is, the illumination produced by one standard candle at a distance of 1 foot, may be taken as the unit of illumination.

The candle-foot is a very convenient and 'comfortable' illumination. It is, for most people, the best illumination for reading, and is to be found on most well-lighted dining-tables. More than 2 candle-feet is seldom attained in artificial illumination. One candle at 1 foot is equivalent to 4 candles at 2 feet, and 9 candles at 3 feet. The illumination produced by a 16-candle lamp, at a distance of 8 feet, is only 0·25 candle-foot.

The following table affords a general comparison of the effects of the combustion of different materials employed for purposes of illumination upon the air of a room in producing one candle power; but the form of the wick and burner would modify the actual figures.

	Quantity Consumed.	Carbonic acid produced.	Water Vapour.	Units of Heat.
	Grains.	Cubic feet.	lb.	
Tallow . . .	154	·51	·023	97
Sperm . . .	120	·41	·020	79
Oil	91	·33	·018	72
Gas—Cubic feet	5·6	·40	·025	121

Oil gives out light with the least injurious effect on the air of a room. For the same amount of light, gas throws out the largest amount of impurity and also produces the largest amount of heat; the conditions are, however, altered by the use of regenerative burners.

Independently of this, the hygienic conditions in the burning of gas differ somewhat from those in the case of candles.

The gas comes from a street main, in which the pressure is constantly varying, partly in consequence of the continual variation which takes place in the number of lights in use.

With increased pressure much unconsumed gas may be forced through the burners, and this is of itself highly injurious to breathe, especially for the sick.

Indeed the leakage of unconsumed gas through burners when not in use is a reason not to place a gas-burner in a bedroom. Gas, in hospitals especially, is not safe without the use of some form of regulator. The efficiency of regulators is much affected by differences of pressure, hence it is preferable that each floor of a building should have a separate regulator.

The fumes from gas may under favourable conditions be utilized to assist ventilation, by being led into exhaust ventilating flues, but unless there is some motive power in the flue independent of the heat from the gas, the fumes are liable to return into the room. Gas contributes warmth to a room in addition to light, and for this reason is much appreciated by the less well-to-do classes of the community.

The electric incandescent light, formed by a thread of carbon, rendered incandescent by means of an electric current, and contained in a closed vessel out of any contact with the atmosphere, can in no way vitiate the air of a room, and is in fact the most hygienic form of light which can be imagined.

On the other hand, the arc electric light, which is not contained in a closed vessel, may be injurious to health in an occupied space because of the nitric acid developed. At the same time it must be borne in mind that the arc light, combined with artificial heat from hot-water pipes, will develop the growth of plants, produce flowers, and ripen fruit. May not, therefore, the same qualities in its light furnish curative influences on sick persons?

The electric light cannot be modified or turned low as a gas light can. With the incandescent electric light an 8-candle power light is probably the most convenient size to adopt in a ward. The lights should be distributed so as not to concentrate glare at any one point; the globes should be preferably frosted, and each light should be arranged to be shaded when desired. Every bed, or each pair of beds, should be furnished with an attachment into which the wires of a moveable light can be inserted, so that full illumination at any patient's bed may be afforded to the nurse or doctor when desired.

CHAPTER XII.

SOME OF THE METHODS IN WHICH THE BEFORE-MENTIONED PRINCIPLES HAVE BEEN APPLIED IN HOSPITALS.

HAVING thus explained the general principles which govern the movement and the warming of air, we now proceed to make a few remarks upon some of the methods by which these principles have been applied in practice.

It will be convenient to adopt the same classification as before, viz.

1. Simple natural ventilation by windows and fireplaces, or by stoves in the wards, assisted by additional inlets and outlets, the effect of which is dependent on natural movement of the air.

2. Mechanical extraction of the air from the ward, supplemented by the provision of fresh warmed air to take its place.

(*a*) By aspiration.

(*b*) By propulsion.

1. *Ventilation by windows and fireplaces, or by stoves in the wards, assisted by additional inlets and outlets.*

This is the general system in use in temperate climates, such as England, apparently because the climate is so variable. Whilst we may occasionally in winter have weather as cold as in Germany or the United States, it does not last, but a milder temperature generally prevails, which the warming must be continually varied to suit.

The convenience of this system lies in the fact that each ward is self-contained as to its ventilation. The simplest form of this plan is, when in small and old-fashioned hospitals the fireplaces depend for inlets on the windows only, by means of a broad bottom bar on the lower sash of the window, so that the window when raised affords a vertical inlet along the middle bar and avoids making an opening at the bottom of the window, which would cause a draught on the patients; or else one of the window-panes may be converted either into a Moore's ventilator or into a hopper ventilator.

Another arrangement is for the window to be divided into three parts, of which the upper part is made to fall in and form a hopper ventilator, whilst the two lower divisions are made either like an ordinary double-hung sash window, or like a French casement window, in which latter case almost the whole window opening can be utilized for admitting fresh air.

Inlets are also made independent of the windows. For instance, Sherringham ventilators are placed near the ceiling or midway between ceiling and floor, or vertical tubes with openings at 5 or 6 feet above the floor may be used, but these latter are objectionable, as affording convenient receptacles for the collection of dirt; openings just above the floor-level are sometimes adopted, which afford a useful means of occasionally sweeping out foul air from under beds, but these are unfit for continuous use because air thus admitted gives a sensation of cold to the feet both of nurses and patients.

The number of days in the year on which windows can be kept open in this climate is considerable.

With windows open on opposite sides of a room, and with a moderate movement of the atmosphere outside blowing across the building, air would enter the open window at one side, and would be extracted at the other side. The volume of air which would pass through the building by means of each pair of opposite windows, as well as that which passes through the walls, would amount to at least from 500,000 to 700,000 cubic feet per hour.

With a hospital ward which is arranged for one window to every four beds, this would afford some 120,000 to 180,000 cubic feet per hour per patient; and this would be a change of air difficult to arrange by any method of purely artificial ventilation.

On days on which the windows cannot be kept fully open, and when a fire is lighted, the chimney-flue forms a powerful extraction-shaft to assist the movement of air.

The fireplace is preferably placed in the centre of a ward, as it distributes thence its rays more equably.

If placed in a side wall, and if there are two fireplaces in the ward, it would be preferable for the movement of the air currents which the fireplaces generate, that both should be on the same side; but, on the other hand, for distributing the rays of heat to the walls they would be preferably on opposite sides.

In a circular ward three fireplaces placed round a central chimney would probably afford radiant heat to the whole wall-surface.

The change of air by means of open fireplaces depends upon the current in the chimney-flue; this is strong when there is a good fire.

In military hospitals an additional means of extraction is provided by vertical shafts carried from the room to above the roof. When these shafts are combined with fireplaces in winter ventilation they should invariably be carried from the floor-level to above the roof. But it is convenient to have them arranged with a valve, so that if desired in summer they may be used to remove the air from the ceiling-level, as shown in Figure 23 (page 157), because, in summer when the fire is not lighted and windows are much opened, extraction might advantageously take place at the upper part of the ward. All such shafts should preferably be straight and vertical, i.e. without bends, which create much friction. They should be of such a size that a moderate upward current may produce an adequate removal of air; and the movement of outside air will rarely afford a less movement in the shaft than 3 or 4 feet per second. If one were allotted to every two beds, a shaft 9 inches square at the low velocity of 3 feet per second (corresponding to a movement of the outside air of about 3 miles per hour), would remove a volume of air amounting to 2,000 cubic feet per hour. This, with the additional effect of the open fire in a ward of 20 beds, would be to cause the removal of at least 3,000 cubic feet per patient per hour. And with adequate inlets for air, accompanied by properly arranged shafts, a continuous and generally adequate ventilation would prevail, which might, however, require occasional supplementing by opening windows.

It may be here observed that the plan which is frequently adopted by architects of placing the fireplace in the centre of the ward and carrying up the flue directly through the ceiling, and thence utilizing it to warm a flue or chamber for assisting the extraction of air from the ward ceiling, is not recommended.

Firstly, it applies the extracting power of the heated flue much less efficiently than if the inlet for extraction were on the floor-level, because with equal temperatures in the flue the draught in a heated flue largely depends on the height of the warmed flue.

Secondly, a consideration of the method mentioned in a former chapter, by which a fire causes air currents to circulate in a room, shows that any part of the chimney-breast above the fire is the worst place from which to effect the removal of air from a room.

With the extraction of the air at the floor-level, the admission of air, exclusive of windows, should not be placed lower than at least halfway between floor and ceiling, and the inflowing air should be directed upwards.

But the inlets should be arranged to admit air also at the floor-level, for summer ventilation, or for occasionally sweeping air out of the ward.

With the large volume of air moved out, and of air admitted to replace it at the outside temperature, it is necessary to provide in hospital wards for some amount of warming besides the open fire.

In some hospitals this is effected by warming a portion of the incoming air, by means of a ventilating grate.

But in a large ward this will not suffice in cold weather. The use of low-pressure hot-water pipes is found to be a satisfactory adjunct to an open fire up to a certain point, because the radiant heat from the open fire warms walls and furniture.

But the fire does not shine on all parts of the ward, and consequently, to assist in warming the walls, a convenient arrangement is to have either high-pressure hot-water pipes or low-pressure steam-pipes carried round the outer walls of the ward.

Thus in Burnley Hospital, which is heated by steam, there are three rows of steam-pipes carried round the ward, each of a different size, so that the heating power can be varied either by using each pipe separately or any combination of the three pipes. By this means the temperature of the wards can be easily regulated at will from inside the ward, and although in this hospital fireplaces round a central flue entered into the original design of the hospital, they have not been used.

A better distribution of heat would be for two-thirds of the heating surface, i. e. two of the pipes, to be carried just above the floor-level, and one-third, or one of the steam-pipes, to be carried round the upper half of the ward, just above the windows or the upper inlets for air.

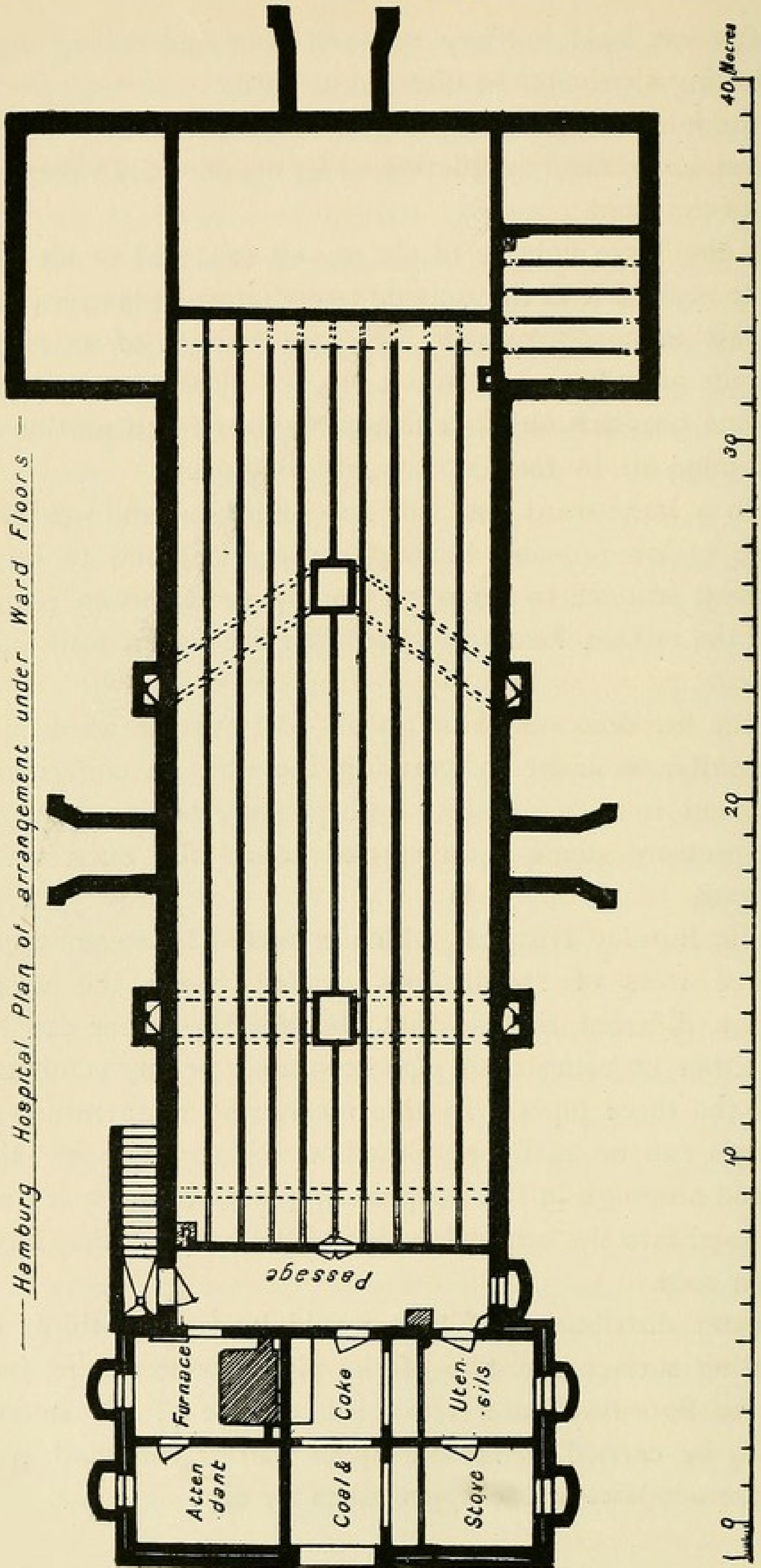

Hamburg Hospital. Plan of arrangement under Ward Floors
Passage
Furnace
Coke
Uten-sils
Atten dant
Coal &
Stove
0
10
20
30
40 Metres

Fig. 19.

The radiant heat from the high temperature of the pipes would thus distribute warmth over the walls and would prevent the feeling of draught from the incoming cold air. These pipes should be under the control of the ward sister, so that the regulation of the temperature of the ward would be self-contained.

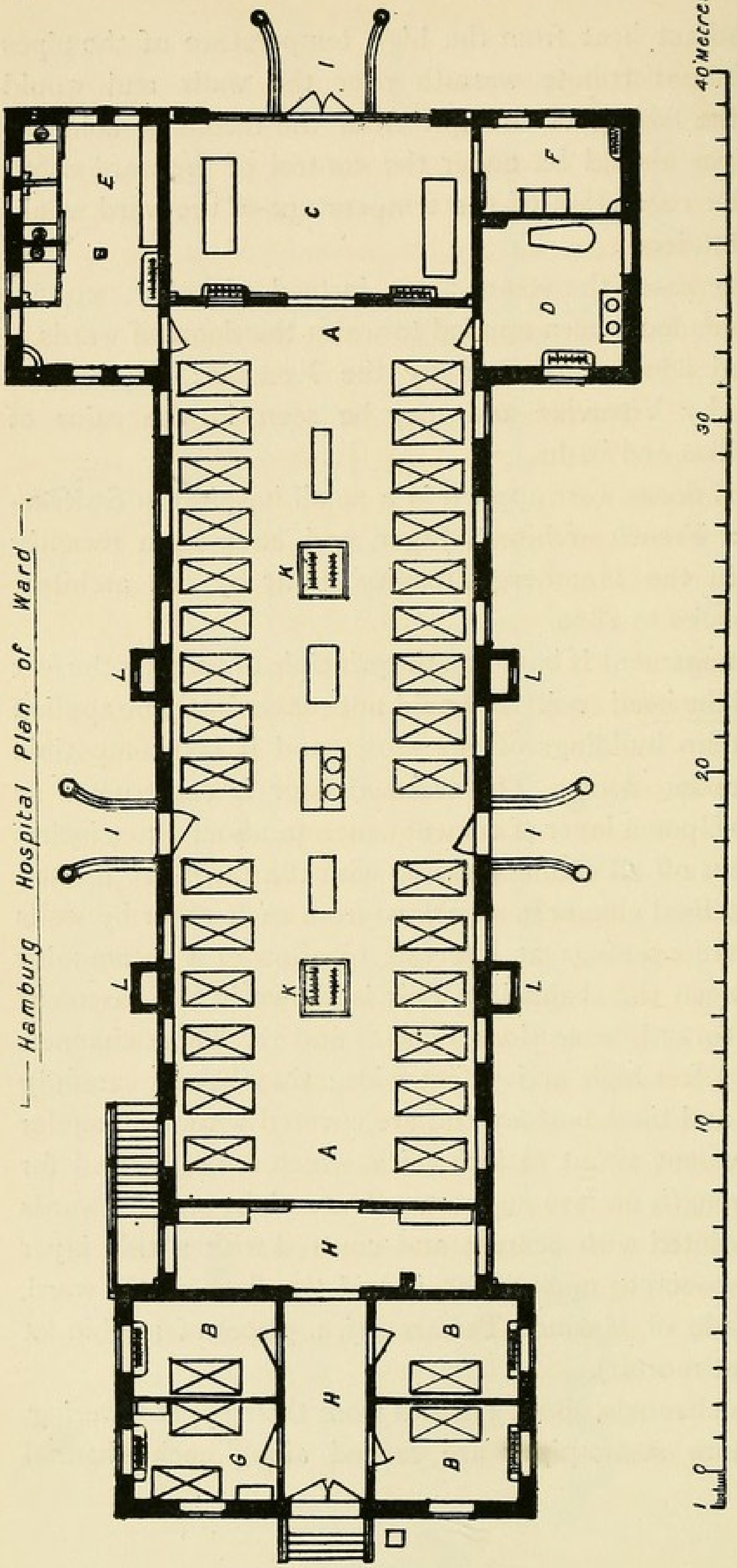
In other cases the steam-pipes instead of being exposed in the wards have been applied to warm the floors of wards.

Warmed floors were used by the Romans: the plan is described by Vitruvius and may be seen in the ruins of Roman villas and baths.

Warmed floors were applied in a small hospital in Switzerland by a French architect, Jäger, and have been recently adopted in the Hamburg Hospital, built by the architect W. F. Dencke in 1889.

The arrangement is based on the principle of keeping the feet warm and the head cool. It would not conveniently be applied to other than buildings of one story, and it is incompatible with a wooden floor. The warmed floor is constructed as follows:—Upon a layer of cement concrete, about 6 to 9 inches thick, to cut off all communication with the earth, are formed ten longitudinal channels, separated from each other by walls in which are openings at intervals to allow of a community of air between the channels. This is shown in the basement plan, Fig. 19, and the sections, Figs. 21 and 22. These channels are about 3 feet high and 3 feet wide; they have a carefully cemented and tiled bottom and are covered with rectangular slabs of cement about 1½ inch thick, which are supported for greater strength on iron supports. These slabs are afterwards carefully jointed with cement and covered with a thin layer of cement concrete upon which is laid the floor of the ward. This is made of Marmor Terrazzo (i. e. pieces of marble let into cement mortar).

In these channels, about 3 inches from their upper covering, one or more steam-pipes are carried along each channel



A. Ward for 30 beds.
B. Isolation wards.
C. Day room.
D. Lavatory and Bath.
E. W.C.'s., Urinal, and Slop Sink.
F. Ward Scullery.
G. Nurses' Room.
H. Corridors.
I. Ramps up to Ward floor level.
K. Steam Coils.
L. Fresh-air Channels.

Fig. 20.

supported on iron brackets let into the walls; the pipes are on the low-pressure system of steam-heating, and are so inclined as to allow of the water of condensation to pass through a return pipe back to the boiler. These channels have no connexion with the outer air or with the air of the wards; access is obtained to them through iron doors opened only when required for repairs.

The general plan of the ward itself with its appurtenances is shown in Fig. 20.

Instead of fireplaces or stoves there are two radiators in the ward heated by steam from the boiler; these radiators are unconnected with the underground channels or pipes. Fresh air is brought to them from the outside in ducts which pass under the heating channels but do not communicate with them.

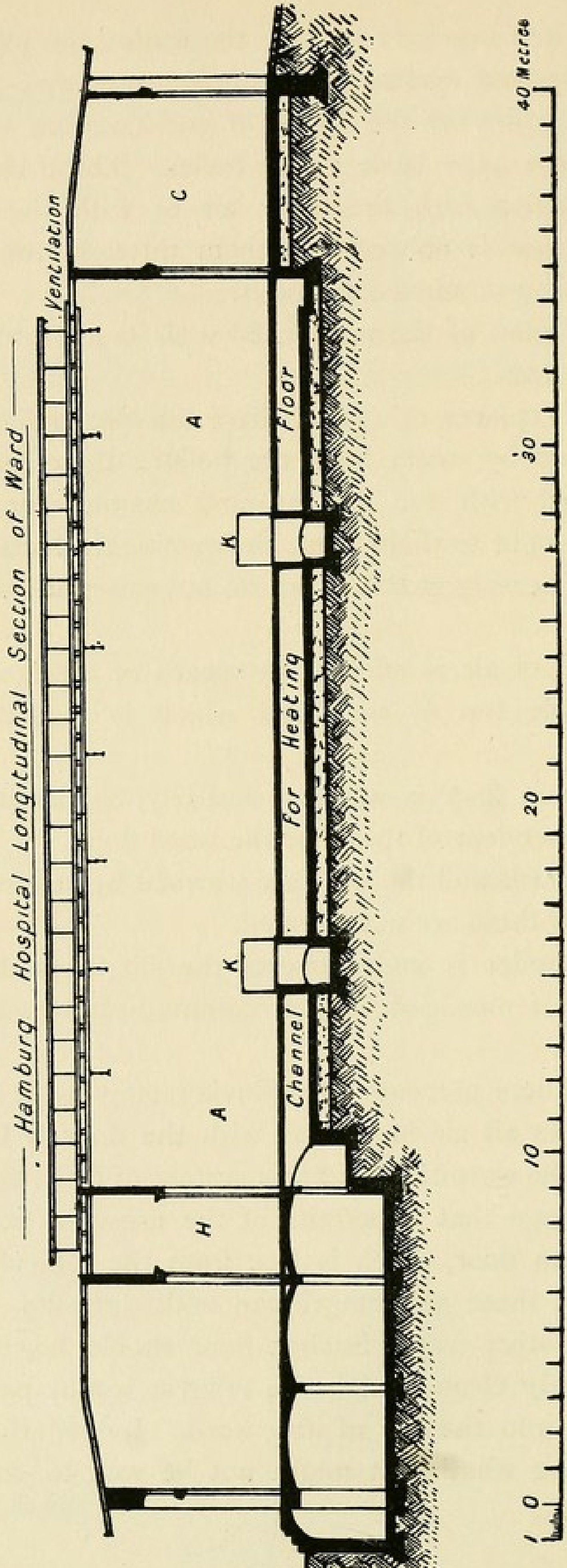
The removal of air is effected by means of a ridge outlet along the whole top of the ward which is regulated by valves.

The bath-room floor is warmed similarly, but its arrangements are independent of those for the ward floor.

The single wards and the w. c. are warmed by steam pipes, but the floors of these are not warmed.

The steam boiler is under one of the single wards in a basement, and is managed without communication with the ward floor.

The warmed floor prevents any effluvia remaining in corners or under beds, as all air in contact with the floor is kept in movement by the warmth. And this system of floor-warming has the advantage that it permits of the use of a perfectly impervious clean floor, which is free from the difficulties of wooden floors; these advantages can with difficulty be obtained in any other way. Such a floor should however be kept scrupulously clean; otherwise effluvia would pass upwards from it into the air of the ward. Indeed the consideration occurs whether it might not be well to combine



A. Ward for 30 beds.
C. Day room.
H. Corridors.
K. Steam radiators.

Fig. 21.

a warmed floor with removal of air from the floor-level between the patients' beds.

With the open fireplace warmed air from a central calorigen is sometimes used for the air supply of the wards.

As an instance of one of the earliest methods by which fresh warmed air was systematically applied in this country to hospital ventilation, the plan adopted by Mr. Sylvester for the original Derby Infirmary, built about 1810, may be mentioned.

The method adopted was to combine propulsion with extraction, both by natural means, upon the principle of the windsail of a ship's hold. The extraction was effected by flues carried up in the walls from the floor-level; the passage of air through these flues depended partly upon the difference between the inside and outside temperature, and partly upon the movement of the atmosphere; these flues from all the rooms were concentrated into a turncap above the roof, which was kept always turned away from the wind by means of vanes. The flues had openings for winter use at the floor-level, which were closed in summer, and openings for summer use at the level of the ceiling, which were closed in winter.

The propulsive force to assist the inflow of air was obtained by a turncap placed upon a tower at some distance from the building in an exposed situation, with the opening always kept turned by vanes towards the wind. The air was thus forced down the tower by the movement of the wind; and it passed through an underground passage, some 200 feet long, to a cockle in the basement of the hospital, where it was warmed and passed into the wards at a level between the height of the patient's head and the ceiling.

It may be mentioned that although the surface of this cockle was heated to 280° Fahrenheit, it was stated that it was not found to injure the air, apparently because of the large volume of fresh air which passed rapidly over its surface. The open fire was retained to assist extraction.

There were many ingenious and complicated arrangements in the old Derby Infirmary; but their control passed into the hands of a subsequent generation which did not under-

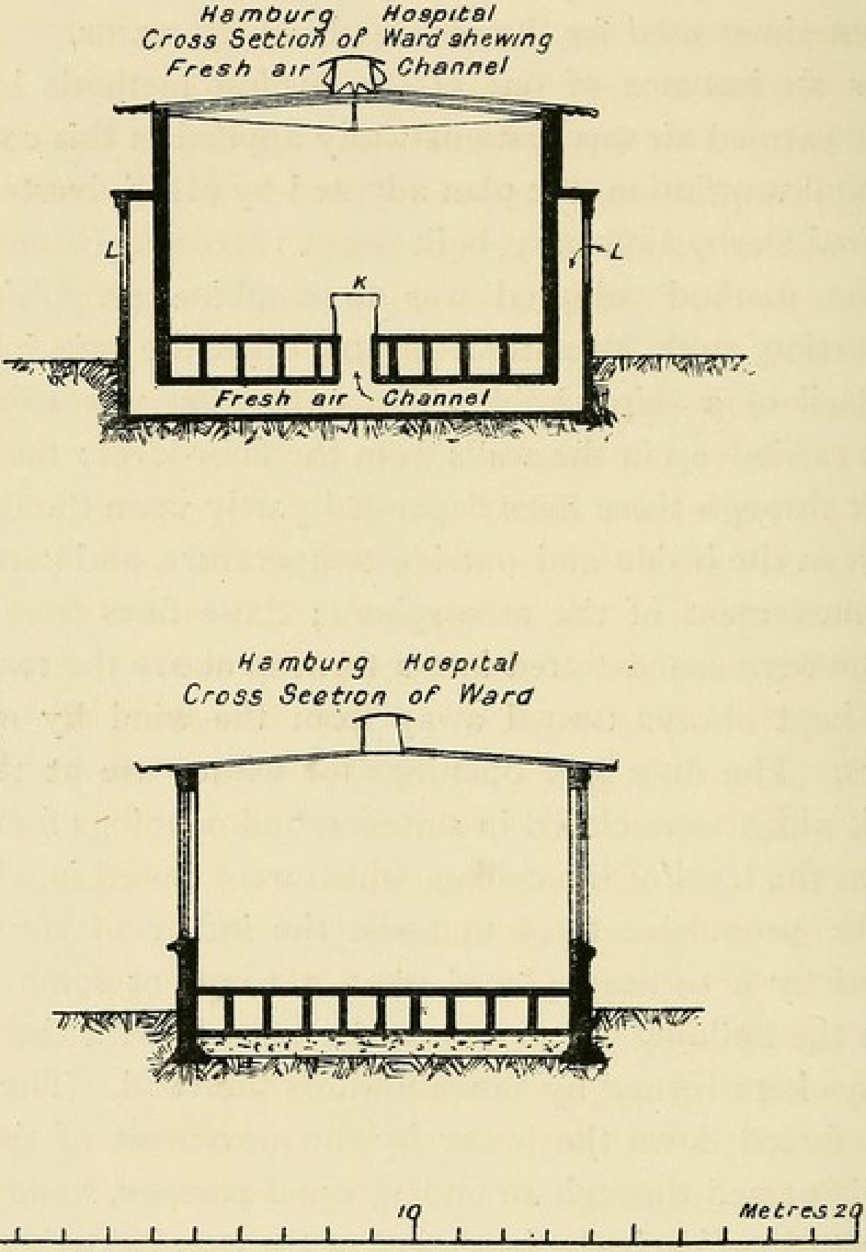


Fig. 22.

stand them and led to disaster. The moral to be drawn is that simplicity in the long run is the great element of safety in a hospital.

This system was identical in principle with that of General Morin, only it used the movement of the atmosphere for extraction instead of artificial heat. A plan similar to that of General Morin and Mr. Sylvester is in use in the United States, namely that of Mr. Smead, which uses artificial heat instead of the wind force as the motive power in the flue for extraction of air, and an improved form of cockle already described for warming the inflowing air.

The Smead system has also been applied in combination with a Blackman Fan, instead of heat, for obtaining motive power for the air.

The change of air in hospital wards by natural means was also made use of by Dr. Böhm (of Vienna). He combined ventilation with the German stove in the Rudolf Stift on the same principle of extraction as the flues in military hospitals.

He trusted for his ventilation to the windows and to the difference of the inside and outside temperature, as well as to the outside movement of the atmosphere. He provided for the admission of air by tubes which were carried from an opening into the open air at the floor-level to the upper part of the ward; there was an opening to the ward at the floor-level as well as one at the upper part of the ward; it being arranged that one should be closed when the other was open.

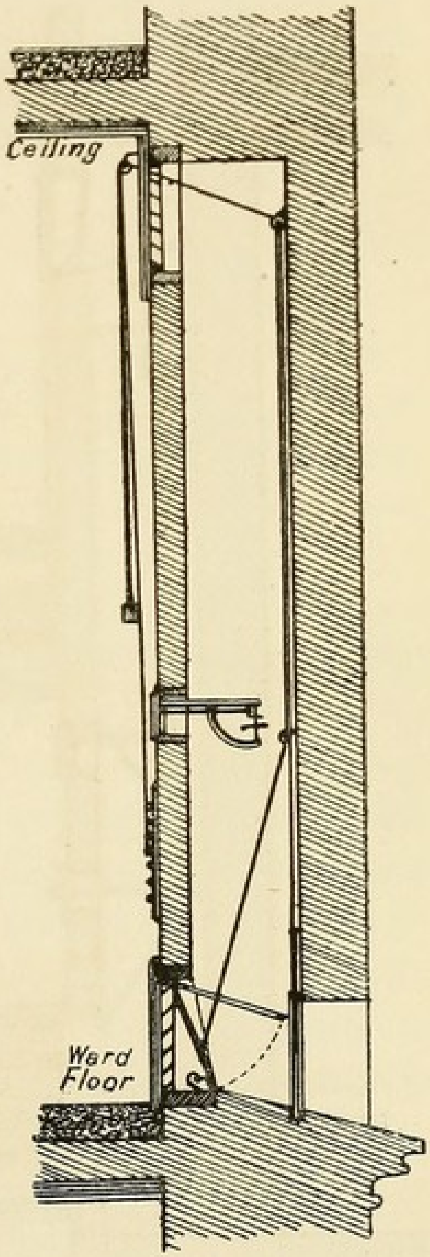


Fig. 23. Inlet flue for fresh air arranged to admit air either at floor-level or at ceiling-level as desired. Rudolf Stift (Dr. Böhm).

Fig. 23 shows Dr. Böhm's arrangement for inlet flues.

The air entered the flue from the outside at the level of the ward floor; and by means of valves, of which one was at the floor-level and the other just below the ceiling-level, the air was either allowed to pass directly into the ward near the floor, or it was directed upwards so as to pass in near the ceiling.

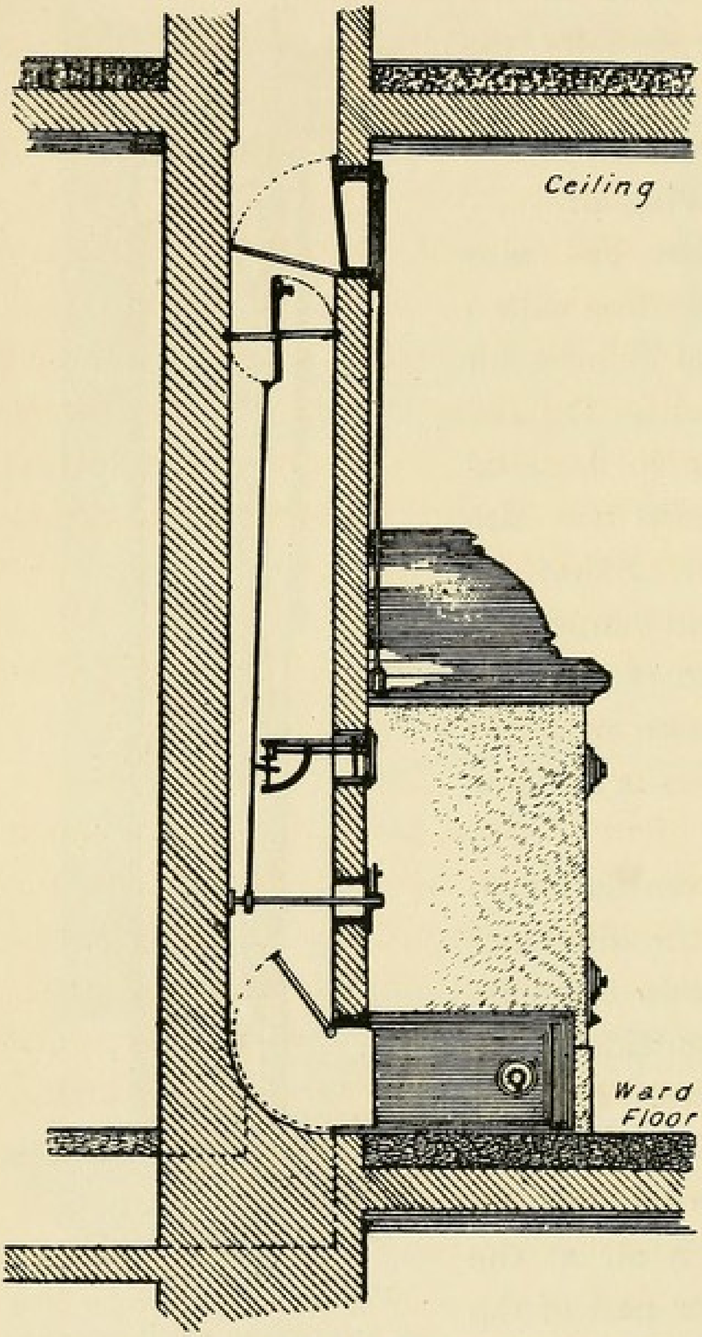


Fig. 24. Extraction-flue arranged to extract air either from floor-level or from ceiling-level as desired. Rudolf Stift (Dr. Böhm).

In summer, when the stove was not used, the lower opening for the admission of air at the floor-level was kept open. In winter, when the stove was in use, the lower opening was closed and the upper opening kept open.

For the extraction of air, Dr. Böhm carried a flue from the floor-level to above the roof; this flue had openings into the room at the floor-level as well as under the ceiling.

Fig. 24 shows the arrangement by which the lower valve at the floor-level could open and the upper valve near the ceiling close, and vice versa.

In summer, when there was no fire, he opened the upper opening and closed the lower one, so as to allow the heated air to escape at the top of the ward.

In winter, when the stove was lighted, he caused the upper opening to be closed and the opening at the floor-level to be opened, and the extraction was effected as it is in the open fireplace, from near the floor-level. The stove, a large porcelain one, fed from the corridor outside, maintained the temperature in the wards.

Similarly the Tollet system, with its ridge ventilation, depends on natural extraction.

The Hamburg Hospital, also with its warmed floor and ridge openings, is similarly largely dependent on natural means for change of air. It is the simplicity of the system which recommends it for use in this country, where atmospheric conditions are favourable.

2. *Mechanical extraction of air, supplemented by a supply of warmed fresh air.*

(*a*) By aspiration.

The simplest form of mechanical extraction is the open fire. But what is alluded to in the present case is the extraction of a definite regulated quantity of air, by means of flues led to a shaft in which a current is produced by the application of heat, and its replacement by a similar quantity of warmed air when necessary to keep the temperature within a defined range. This extraction of air should go on continuously day and night, winter and summer.

In the face of a regulated extraction of air, the windows ought not to be opened, because it will be apparent from the remarks already made that the effect of open windows might be to seriously check the outflow of air through the extraction-flues, as well as the inflow of warmed air; although open windows would effect a far greater change of air in the ward.

The fireplace would be abolished, because the more powerful extraction-shaft, acting on all the outlets, would tend to diminish the velocity in the smaller chimney-flue of the open fire, and might make it smoke, unless the chimney of the open fire was carried into the extraction-flue.

But the system is practically an extension of the system of the open fireplace, that is to say, the extraction-flues remove the air from the lower part of the ward, and the fresh warmed air is admitted above in the upper half of the ward.

The remarks on movement of air show clearly that whilst a fan may be advantageous for removing air in special cases and for occasional use, as in theatres or schools, yet that where a continuous large extraction is required day and night, as in a hospital, it will best be effected by the aspiration of a chimney-flue as proposed by General Morin, Sylvester, Sir Joshua Jebb, and others.

An adequate system of aspiration, with hot air introduced above and the foul air extracted near the floor-level, has been shown by General Morin and others to produce an equable temperature over the whole room.

Surgeon-General Billings of the United States Army mentioned an experiment in the Barnes Hospital, Washington, where fresh-air inlets for warmed air were placed near the ceiling and extraction outlets in the floor.

In this experiment it was found that when warm air was admitted near the ceiling there was a difference of 10° in the temperature between the floor and the ceiling, and that the patients complained of cold feet and discomfort. This case is mentioned because it is clearly an instance of the failure to keep the air in an adequate condition of circulation owing to the absence of sufficient aspiration.

Surgeon-General Billings also remarks that when the warm air is introduced near the ceiling it is impossible to vary the temperature at different beds, a thing which it is often desirable to accomplish in a hospital.

The necessity which may often arise for rapidly altering the temperature is indeed another consideration in connexion

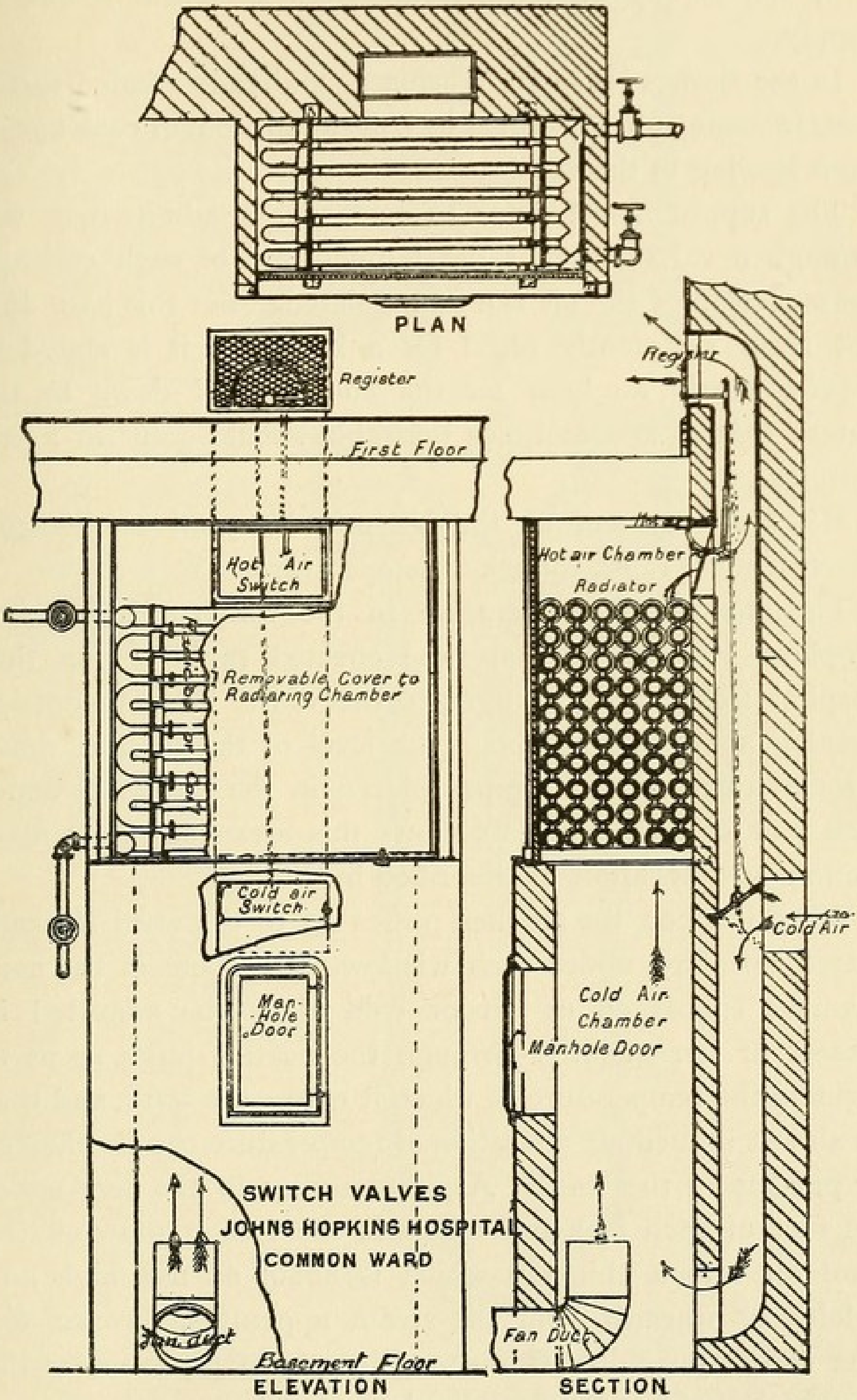

PLAN
Register
First Floor
Hot Air Switch
Removable Cover to Radiating Chamber
Cold air Switch
Man-Hole Door
SWITCH VALVES
JOHNS HOPKINS HOSPITAL
COMMON WARD
Fan duct
Basement Floor
ELEVATION
Hot air Chamber
Radiator
Cold Air Chamber
Manhole Door
Cold Air
Fan Duct
SECTION

Fig. 25.

with the supply of warmed air from a central source of supply.

In the Barnes Hospital, Washington, already alluded to, the fresh incoming air is warmed by coils at the foot of each upcast shaft leading to the ward.

The supply of hot water to each coil is admitted at will through a valve, so that the temperature of each coil and consequently of the air can be regulated. But this plan does not seem sufficiently rapid for a hospital; it is stated to require nearly an hour for the coil to cool down to the extent that it is sometimes desirable should occur in a few minutes.

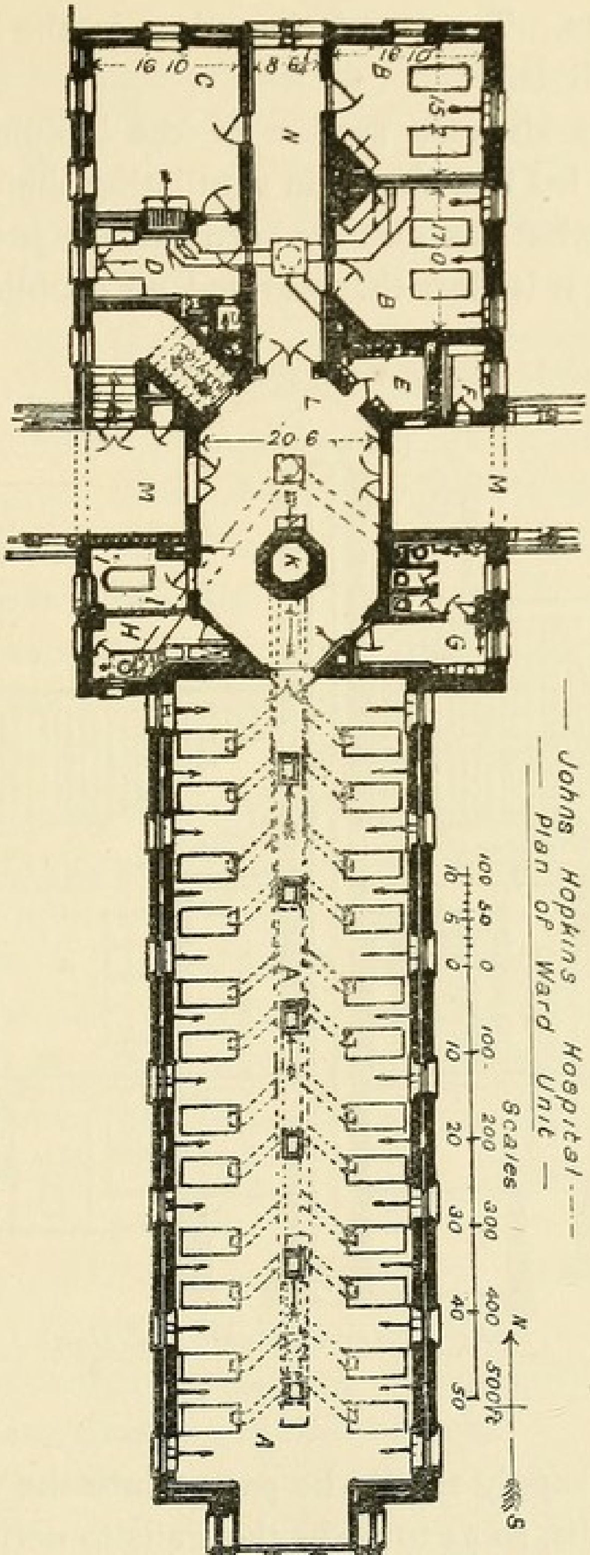
Mr. Key's system at the Victoria Hospital at Glasgow effects a more rapid change of temperature.

The change of temperature in the wards of the Johns Hopkins Hospital can also be effected rapidly. In that hospital fresh air is brought to the wards from an outside opening about 3 feet above the level of the ground, down through a coil of steam-pipes placed in the basement under each pair of beds. Fig. 25 shows this arrangement in plan, section, and elevation, as described by Billings.

When warmed the air then passes up to the ward through grated openings under each window. Dampers in the coil-chamber enable either hot or cold air to be admitted in greater or less quantity through the heating-pipes, so as to regulate the temperature at which it enters the ward, and thus an almost immediate alteration of temperature can be effected by persons in the ward. Aspiration-flues in the floor under the foot of each bed, and others in the ceiling, draw off the ward air into a chimney which is about 60 feet high, and obtains its warmth from the steam apparatus, furnace, &c. The end bay-window is warmed by steam pipes under the window just above the floor-level.

Figs. 25, 26 and 27 illustrate this arrangement.

Fig. 26 shows a plan of one of the ordinary ward units



A. Ward for 24 beds.
B. Separation Ward.
C. Day Room.
D. Tea Kitchen.
E. Patient's Clothing.
F. Linen Closet.
G. Lavatory, W.C., and Slop sink.
H. Nurses' Closet, Sink, and W.C.
I. Bath Room.
K. Heated Extraction flue 7 feet diameter.
L. Central Hall.
M. Corridor Roof.
N. Service Hall.
.... Ventilating Pipes under Floor.
- - - - Ventilating Pipes in Attic.

Fig. 26.

of the Johns Hopkins Hospital; each of which, except as regards cooking and general administration, may be said to form a complete hospital in itself.

The ventilating pipes under the floor are shown by the short dots. The ventilating pipes in the attic are shown by the long dots.

Fig. 27 shows a section of the building explaining how the air is led into the main ventilating shaft.

From what has already been said in previous chapters on warming, it is clear that warmed air supplied to a ward from

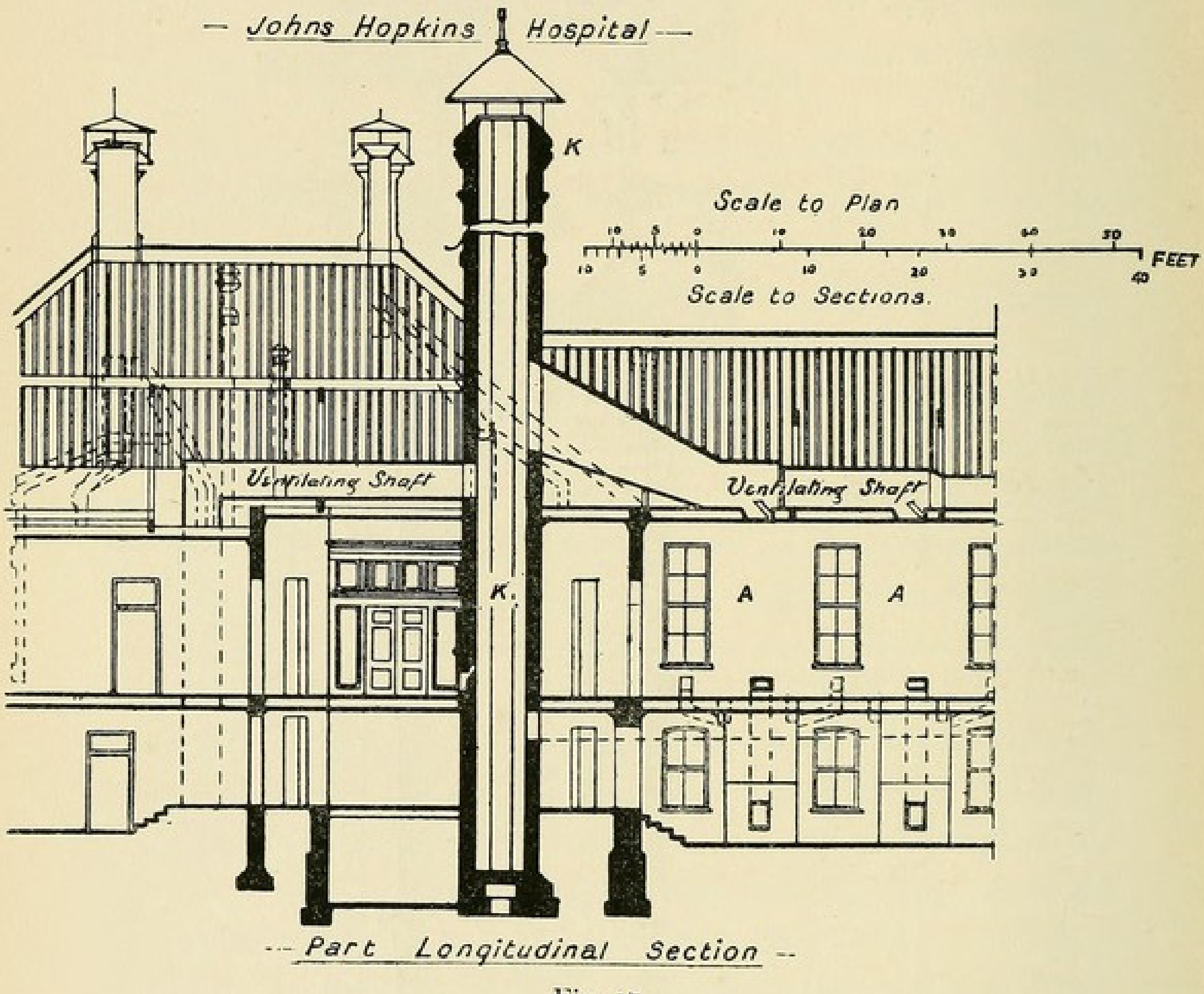


Fig. 27.

a central supply should be passed into the ward through flues in the walls, so as to allow the walls to derive some heat from the warmed air before it enters the ward.

When the flue is in the outside wall the side of the air-flue facing the outer side of the wall would allow heat to pass away unused into the outer air. This loss would be best diminished by making the flue semicircular and exposing the larger portion of the side of the flue to the ward, and protecting the side of the flue nearest to the outer face of the wall by a closed air-cavity which would enormously diminish the loss of heat.

The striking feature of recent hospital construction is the introduction of simplicity of form.

In the United States, in Germany, and also in France, the best examples of modern hospital construction have treated each large ward, with its subsidiary small wards and other appurtenances, as a separate hospital unit on one floor, and in most cases detached. This renders a combined system of ventilation and warming for the whole establishment more difficult and less economical ; but each ward unit is simple to construct and is self-contained.

The Johns Hopkins Hospital is an instance in point, but there, although the separation of ward units is a principal feature of the design, simplicity of arrangement in the ward unit itself seems to have been somewhat overlooked.

In some hospitals the extraction of air by shafts has been supplemented by propulsion in the introduction of fresh air.

Thus the Barnes Hospital at Washington is an instance of propulsion for fresh air, combined with extraction by heated upcast aspiration-shafts. This is applied in the winter only, the summer ventilation being by open windows.

Fresh air is supplied by a shaft 8 feet in diameter and 38 feet high, placed 74 feet west of the building.

This shaft is connected with a brick air-duct, which passes beneath the basement through its entire length.

At the point of junction of the vertical shaft with this fresh-air duct, is located the fan. This fan drives the air along the main duct into branch channels, leading to the coil-chamber, from whence the fresh-air flues are carried into the wards.

The removal of foul air by aspiration is effected by two chimneys in the administration building, which are warmed by iron flues from the boiler and other furnaces ; and to promote aspiration when the boiler is not at work a separate fire is arranged. The foul-air ducts from the wards are led into the chimney-shafts.

The aspiration system, although very simple and efficient, has not obtained any extensive adoption in hospitals in this country, partly from the fact that the arrangements for its due action are necessarily much interfered with by the opening of windows, which of themselves produce an inflow and outflow of air from ten to twenty times as great as any artificial extraction can pretend to give.

(*b*) By Propulsion.

Methods of propulsion of air for hospital wards are based on one common principle, namely, that the air is to be moved from a central position, from which it has to be conveyed in air-trunks, subdivided into branches, and finally admitted into the rooms at such points as may be determined on.

These methods generally provide for the egress of foul air from rooms so ventilated by means of foul-air shafts.

Two examples in use forty years ago, of the method of ventilation by propulsion, are those of Thomas and Laurent at the Hospital Lariboissière at Paris, and the plan of Dr. Van Heecke in the Hospitals Beaujon and Necker at Paris.

These plans may be briefly described as follows:—That of Thomas and Laurent consisted of two 15-horse power high-pressure engines, with fan-blowers attached, to be used alternately in case of accident to one. The air from the blower was conducted along the arched basement of the hospital, in which the machinery was placed, by means of a large plate-iron pipe, from which branches were given off to the different buildings, these branches being again sub-divided to convey air to the wards. As the air-flues passed under the floors, sufficient space was left between the floor and the ceiling of the room below for an air-trunk 14 inches deep. The fresh air was admitted to the wards through pedestals 4 and 5 feet high, in the middle of the floors, and the foul air escaped by openings close to the floor, one between every two beds, which openings communicated with flues in the walls, carried up to the roof of the building. The loss of force in driving air by means of a fan through a series of narrow and frequently bent tubes involves a serious outlay. Dr. Van Heecke's plan had the merit of greater economy. The form of his fan was better proportioned to its work, and by an ingenious provision the pitch of the screw used by Dr. Van Heecke was made to adapt itself to the velocity of the engine, an arrangement by which the air-current was maintained at one uniform strength; and at the Hospital Beaujon the air was propelled by a small steam-engine in the basement directly up through the centre of the wards, by a tube passing through the floors of each superimposed story, and left to find its way out.

In some other foreign hospitals propulsion is also resorted to.

In the Antwerp Hospital in summer the windows only are used, but the diameter of the ward, 61 feet 6 inches, is very large for ensuring thorough ventilation, and there is further a serious central obstruction to the movement of air. In winter fresh air is propelled into the wards by means of fans situated in the laundry building; this air is warmed by being passed over coils of hot-water pipes contained in a chamber situated in the basement under the central portion of each tier of wards, and the air so heated is propelled into the wards at the upper parts of the central columns.

In the Menilmontant Hospital the warming and ventilation is effected by propulsion. Fans drive the air through subways from a central point; these subways run beneath the various corridors of the buildings to the basements of the pavilions, in each of which there are placed coils of steam-pipes, enclosed in casings through which the air passes; it becomes heated by impinging against the steam-pipes, and is carried up vertically through flues in the walls, and discharged into the wards through ornamented pedestals which are placed on either side of the entrance doors. There are also additional inlets formed by the projecting jambs of the fireplaces. These are ordinary fireplaces with large open grates.

The removal of the foul air from the rooms is through outlet openings at both the level of the ceilings and the floors, which communicate with vertical shafts that ascend in the outer walls into channels running longitudinally along the centre of the roof to a chamber that is heated by hot air, for the purpose of further inducing an upward current; and it is discharged through the sides of the *flèche* surmounting the roof of the building.

In the New York Hospital propulsion is used both for supplying fresh and removing foul air. The hospital is built in the centre of the city. It is five stories high and contains 163 beds.

In the wards there is one window to each bed, each external pier of the building being a flue, which is lined with hollow bricks, to prevent, as far as possible, loss of heat by radiation. Through the centre of these flues run cast-iron pipes, intended to be fitted so as to be air-tight, through which fresh air is forced into the building by a fan.

The spaces outside these fresh-air iron pipes are the foul-air flues. These terminate above in pipes leading to an exhaust fan, placed at the top of the centre building. The heating is by steam, the coils being arranged at the bottom of the fresh-air pipes in such a way that the cool air from the propelling fan can be sent by a valve either through or around the heating coil. The fresh air is admitted to the wards through slits in the window-sills, forming a jet directed upward.

The openings for the exit of foul air from the wards are in part placed in the walls of the piers and in part beneath the beds.

The principle of placing fresh-air pipes inside of the foul-air ducts is objectionable, and on a par with placing water-pipes in sewers, for although the fresh air-pipes are of iron, and may have been tightly fitted, it is only a question of time when some communication will be established between the inner and outer surfaces of these pipes, either by rusting or by alternate expansions and contractions, and then the foul air may be carried back into the wards. The iron pipes are not moreover easily accessible, enclosed as they are in the brick walls, and there is no ready means of determining their condition.

There are peculiar difficulties to be overcome in attempting to secure a satisfactory distribution of air in a lofty hospital of many stories. While the resources of modern engineering are, no doubt, competent to secure satisfactory ventilation in a hospital of even ten stories high, if necessary, this can only be done at a comparatively great cost, and it is therefore now generally admitted that it is best to put hospitals where they can have plenty of room without being compelled to go upward in order to obtain fresh air.

A method of ventilation by propulsion is in use, as already mentioned, in the Victoria Hospital, Glasgow, where it is combined with purification or washing of the air.

It has been applied by Mr. Key and is the most recent application of the principle of propulsion to a hospital in this country.

It is unnecessary to repeat the arrangement adopted by Mr. Key for the purification and warming of the air; it will suffice to take up the description after the air has passed the air-tempering appliances. Two air propellers of the Blackman type collect the air and propel it forward through the main air-ducts leading to the administrative block and to the wards. The fans have been in use for 2½ years, for 23 to 24 hours daily, and are worked by two electric motors supplied by power from the laundry engine. These fans, which can be worked separately (or conjointly if desired), drive the air into the main ducts, which are about 5 feet high by 3 feet 6 inches wide. These ducts pass under the centre of the wards, and from them horizontal ones are carried to the outside wall. On each side, from these horizontal ducts, shafts of about 4 feet by 6 inches are carried by the side of, or in, the outside wall vertically up to the inlets provided in the wards.

Secondary heating-coils are placed at the base of the several shafts leading to the inlets in the wards, which can be used or not, as desired, by the persons in charge of the ward, and by this means the temperature of the air of each different ward can be varied at will to suit the orders of the medical man or the requirements of the ward sister.

The air forced into the wards is under a pressure of $\frac{1}{20}$ to $\frac{1}{10}$ of an inch of water column.

The size of the main ducts under the wards should be such as to allow a person to pass along them ; and the preferable arrangement would be that these main ducts should be carried close to the outer wall on either side, in order that each ward inlet might be supplied by a subsidiary duct leading vertically up from the main duct ; by this means the condition of cleanliness of every part would be capable of being examined at any time.

If therefore the inlets are in the outside wall, it would be advisable to have a duct on each side of the ward next the wall.

There is, however, no valid reason why the inlets should not be raised by means of half-columns placed along the centre line of the wards, with the outlets on the floor level in the walls.

The flues which lead to the inlets are either formed in the side walls or placed within the structure close against the side walls. The inlets are arranged to deliver the air vertically upwards at about 5 feet to 5 feet 6 inches from the floor. The air is warmed or cooled as may be desired. It passes away by ducts within the structure of the walls, opening into the ward just above the floor-level. These ducts are led up to the roof, where they are all collected into a square turret with louvred sides standing well above the roof; the louvres consist of hanging valves made of cloth, six inches deep.

These valves open outwards the full width of the frames, and are thus at all times available for the air to escape. Even in tempestuous weather, or during a gale, the outward flow is never interrupted, for while the valves are closed on the side of the cupola exposed to the influence and pressure of the wind, and prevent the wind from entering, those on the lee side are under no such pressure, the air passing out uninterruptedly.

The theory of propulsion when supplemented by shafts is based upon the assumption that the air will come in at defined inlets, and will similarly have its exit at defined apertures, and upon this assumption the opening of windows would entirely derange the condition of the supply.

Therefore Mr. Key urges that the use of windows for the admission of fresh air is incompatible with the system of ventilation by propulsion; and that in fact with this system windows must be kept closed and reserved only for light.

If there were an open fire the pressure of air in the ward would increase its draught. But its retention would not be logically consistent with this system of ventilation.

The system of propulsion for hospital ventilation has not found general favour with hospital architects or managers in this country. There is one very patent and valid reason, which is that in this climate windows can be kept open: and when windows are open the volume of fresh air which passes through a ward will be at least 20 times greater than either the theoretical 3,000 cubic feet per hour, or even the 5,000 or 6,000 cubic feet, which some of these systems profess to furnish, without entailing the large expenditure of fuel necessary for moving a large volume of air. For even at

3,000 cubic feet per bed a ward of 20 beds will require some 600 tons of air to be pumped into it in 24 hours.

Indeed experience would seem to justify the hesitation which has been felt with respect to artificial ventilation. The following quotation from the Report of the Barracks and Hospital Improvement Commission explains this partly:—

'In one hospital we examined, which was ventilated by one of the most perfect apparatus we have anywhere seen, and which professed to supply between 4,000 and 5,000 cubic feet of air per bed per hour, we found the atmosphere of the wards stagnant and foul to a degree we have hardly ever met with elsewhere. We at once pointed out this circumstance. An inquiry was immediately instituted, when it appeared that one of the valves of the supply pipe had been tampered with, for no other reason, that we could perceive, except to save fuel by diminishing the quantity of warm air supplied to the sick. The ventilation in this case was worse than a delusion.'

The writer has visited on several different occasions three of the important hospitals in Europe and the United States of America in which the ventilation depended on propulsion, and on every occasion the propulsion happened to be out of use for the time; in some cases evidently with the object of saving the expense of fuel.

Methods of artificial ventilation are more or less dependent upon careful training in the assistants, they may answer well when first put into operation, but the arrangements, in their simplest form, present some complications and require some special knowledge for their efficient working. Hence the changes in personel which necessarily take place in the course of time may introduce want of appreciation or of care in the management: moreover, the continuous cost of working presses upon the resources of voluntary hospitals. The more the question is examined, the more advisable does it appear to adhere to simplicity in all details of hospital construction.

As regards the opening of windows, it may be observed that the author visited a hospital recently in which the ventilation was by propulsion. The amount of fresh air which was entering the wards was stated to be at the time at a rate of over 5,000 cubic feet, per patient per hour, and yet there was a distinct feeling of relief and freshness on passing from the ward to the open air. This is not surprising if we consider how small is the volume of fresh air entering the ward compared with the volume of air which would enter by the window.

Moreover, the nurses in that hospital were said to prefer fireplaces and open windows in the Nurses' Home, to the system of ventilation and warming in the hospital. The reason of this seems abundantly supplied by the facts just mentioned.

Whilst, however, it would seem to be in the highest degree imprudent to trust in any hospital entirely to ventilation by propulsion, there are conditions connected with the air of large towns, in winter especially, which apparently can only be removed by a system of propulsion, combined with purification of the air from dust and fog by a system of air washing. These conditions are so eminently unfavourable to patients suffering from bronchial diseases, phthisis, or other respiratory trouble, that it would seem expedient, if not essential, to provide at least one or two wards with such a means of purifying the air in general hospitals and workhouse infirmaries in large towns.

CHAPTER XIII.

THE WARD UNIT.

The Wards. The distribution of buildings on a site depends on the form of the buildings. The ward with its necessary adjuncts is the central unit of hospital construction; the form of the ward will govern the features of a hospital.

The first principle upon which the pavilion system is based is to limit the number of patients placed under one roof.

The second is to afford to those patients abundance of fresh air by means of cross ventilation.

The third is to ensure that sunshine shall penetrate as large a portion of the building as possible—both inside and outside.

The number of patients under one roof.

The ward and its appurtenances under one roof practically constitute a small hospital of itself; and the multiplication of these, several small hospitals under one administration.

Dr. Rumsey said, '(1) That the disease in hospitals and other large institutions, especially the mortality following operations (and universally that after childbirth), are greatly increased by the mere aggregation of patients and, *ceteris paribus*, in proportion to the density of that aggregation, apart from all other circumstances which might affect success or endanger life; (2) that the death-rate calculated, as it should be, on the number of patients, and not on the number of beds, increases with the size of the establishment and the number of its inmates; and (3) that wherever this assemblage of the sick and hurt occurs in the centre of a crowded population, the rate of mortality attains its maximum.'

The accompanying table shows the number under one roof in some of the recently constructed hospitals.

Name of Hospital.	No. of Ward Floors.	No. of beds in Ward unit under one roof.				Total Patients, under one roof.	Observations.
		In Large Wards.		In Separation Wards.			
		No.	Patients.	No.	Patients.		
1. Tenon, Paris (Menilmontant)	3	8	156	10	17	173	In Medical Block Double Pavilion No air separation
2. S. Thomas	4	4	112	4	4	116	
3. Norfolk and Norwich . .	2	4	96	4	8	104	Double Pavilion No air separation
4. Royal Infirmary, Edinburgh	3	3	63	3	6	69	Medical Wards
5. Friederichs Hain, Berlin { 2 Floors	2	2	56	4	8	64	
{ 1 Floor	1	1	28	2	2	30	
6. Hamburg	1	1	30	3	3	33	
7. S. Eloi, Montpelier . . .	1	1	28	2	4	32	
8. Johns Hopkins	1	1	24	2	4	28	

Whilst this may be accepted as a general truth, no doubt the efficiency or otherwise of ventilation and aeration will govern the question to some extent.

The accepted doctrine of late years has been that the number of from 100 to 120 patients under one roof should not be exceeded. But this is certainly larger than is desirable in surgical and fever cases.

The one-story ward units do not contain more than 32 as a maximum. And if two floors of wards are superimposed the number would not exceed 64 under one roof, even in the case of a double pavilion, that is to say, if the staircase be so arranged that it will cut off the two pavilions from each other, so far as ventilation is concerned.

The form of ward has to be first considered, under the condition whether the ward is to be on one floor or to occupy two or more floors. Dr. Mouat says, 'The majority of cases, particularly of fevers, lung diseases, &c., demand a purity of atmosphere on their own account, which is difficult, if not impossible, to obtain in a multiplication of stories.'

It is very difficult to prevent the air from the lower wards from permeating corridors and staircases, and from passing up or down through windows so as to affect to some extent the air of the wards above or below.

In the United States, in Germany, and in M. Tollet's plans in France, single stories are preferred, for surgical wards especially; and unless under the exceptional condition of a town site, two stories are not exceeded for simple medical cases. In the Infectious Hospitals of the Metropolitan Asylums Board and in many country infectious hospitals the single-story pavilion is preferred for fever wards.

Wounded men when agglomerated in a building cause a larger amount of contamination to the air than probably any other cases, except possibly virulent small-pox, fevers, or lying-in women; for all such cases it is admitted that wards without buildings over them, that is to say one-story buildings, are best, and it may be almost assumed as an axiom that wards on one floor would be always preferable if circumstances permitted. This accentuates the conclusion that, having regard to the condition of town sites, all hospitals ought to be situated away from centres of population. But this is a practical impossibility for reasons already given.

On these grounds, in considering the construction of hospitals, the question must come in as to the nature of the sick to be treated.

Accidents, wounds, virulent infectious disease, lying-in women, should always be treated if possible in one-floor buildings, which should contain the smallest number of patients compatible with economy of nursing.

There are many cases, such as those suffering from degenerative diseases, that do not require either so large a floor space or cubic space as acute febrile cases or injuries, and it would seem reasonable that hospitals should be so divided as to afford a smaller floor and cubic space with superimposed wards for the milder and less urgent medical cases; whilst the larger floor and cubic space would be allotted to severe surgical and other serious cases.

The zone of aëration round any hospital should not be less than twice the height of the surrounding buildings, so as to allow sunshine to fall as fully as possible on the walls and surrounding grounds.

Where more than one superimposed ward has been considered unavoidable, in consequence of a confined site, the necessity of the arrangement should be discounted by special precautions.

Before considering the form of the ground-plan of a ward unit it will be convenient to discuss the section of the ward.

It is only in one-story buildings that any material difference in the shape of the section can prevail.

A ward which has no building over it possesses many facilities for aëration without resorting to artificial appliances.

But the full advantage of the one-story building for aëration will not be secured unless each ward with its ward appurtenances is detached; for that is the only way in which fresh air and sunshine can reach all sides of the building, and simplicity form the leading feature.

We have already shown that for large buildings the removal of warm and vitiated air can be advantageously made from near the floor level, but in a one-story building the facility for renewal of air by ridge ventilation materially alters the conditions.

The most usual section for a simple one-story ward is either a flat ceiling covered by a roof sloping to the ridge with a ventilating flue, carried from the ceiling to above the ridge, or the comparatively flat ceiling may itself form the roof, as is the case at the Hamburg Hospital, with ventilating flues passing through it. (See Figs. 21, 22, pages 154, 156.)

Or, again, the ceiling instead of being flat may slope parallel to the roof up to the ridge, where ventilation may be provided. This arrangement may be supplemented by dormers and windows in the sides and in the gables, if the latter are free.

If ridge ventilation is resorted to, it is clear that the more convenient form is that in which there are fewest angles and where the ceiling is made to slope upwards towards the ridge.

Ridge ventilation is very effective. In the Dresden Public Hospital the ventilation in wards of 30 beds was ascertained to amount to nearly 5,000 cubic feet per bed per hour, effected simply by a roof lantern which occupies rather more than two-thirds of the length of the ward, assisted by four aspiration-shafts, two in each of the end walls; the inflowing air being supplied by being drawn in over two caloriferes underneath the ward.

M. Tollet's plan for the section of the ward, which is adopted at Montpelier and at several other French military and civil hospitals, is based on the principle of ridge ventilation, and is therefore applicable only to one-story buildings.

M. Tollet adopts the ogival section for the sides of his wards (as in Fig. 28, in which the dimensions are given in metres), and he bases it on the following considerations:—

(1) If the air is to find its way to the ridge, the best form will be that which dispenses with any angles between the walls and the ceiling.

(2) Of all curved forms the ogival produces the smallest thrust in the side wall.

(3) It creates the smallest friction in the ascending air.

(4) It offers a smaller surface for absorption of impurities than the ordinary form, and is free from all cornices or ledges for the deposition of dust.

(5) This form, whilst being incombustible, at the same time dispenses with any complicated joinery for the roof. The construction is extremely simple. The inner wall of the ward is formed of ribs of double T-iron curved to the shape, which pass from the floor to the ridge, placed about 5 feet from centre to centre, where an opening to the air along the whole length is reserved and provided with valves for closing.

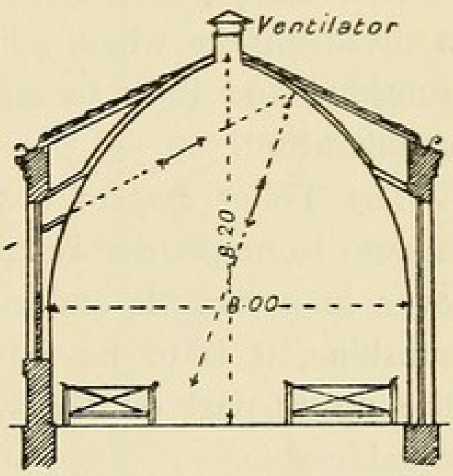


Fig. 28.

The space between these vertical beams is filled in with specially made bricks or tiles; concrete or any other convenient material might be used, reserving the openings for windows, doors, &c. The outer surface is covered with a coating of cement; the inner surface finished in plaster, which is painted in oil of a suitable colour, and can be scraped and renewed when required.

An outside wall with window spaces is carried up to meet a light roof covering. This latter affords an air space of about 3 feet at the wall cornice between the roof and the ogival vault, and protects this part from heat or cold; whilst at its upper end the roof rests on the ogival beams.

In warm weather and hot climates this construction at the ridge favours ventilation, as a maximum of sun heat acts to heat the ventilator at that part; in cold weather this effect would not prevail, but the movement of the atmosphere across the building would cause an extraction of air.

M. Tollet claims as an advantage of this form of construction, that air flowing in through the upper part of the window would strike the roof at such a point as to be reflected on to the floor space between the beds, whereas in the case of a flat ceiling, air similarly entering would be reflected down upon a patient's bed. But the fact that the top of the windows is necessarily some distance below the apex of the ward is a disadvantage when, as in our climate, the penetration of sunshine and light to all parts of the ward is an essential desideratum.

The Tollet system has many good points, but it would appear to be preferably applicable to warm climates. Moreover, in a variable and cold climate when there is not much sunshine, it is to be feared that the loss of heat through the upper part of the ward nearest to the ridge might be considerable.

A good example of a Tollet ward is afforded by the St. Denis Hospital unit, in which the rounding of all angles forms a main feature. See Figure 29.

The ward floor should never rest on a solid made-up bed. It should always have an air space between it and the ground, and this air space should have a dry floor, with circulation of air, admission of sunshine, and abundant light. No rubbish or dirt should be allowed to accumulate in it.

Hence the one-story hospital wards should always be well raised off the ground.

In the Montpelier Hospital they are raised to at least 10 feet above the ground, by means of a lower floor under the wards, which is used for various business purposes, or left open, which has itself an air space underneath. Figs. 30, 31.

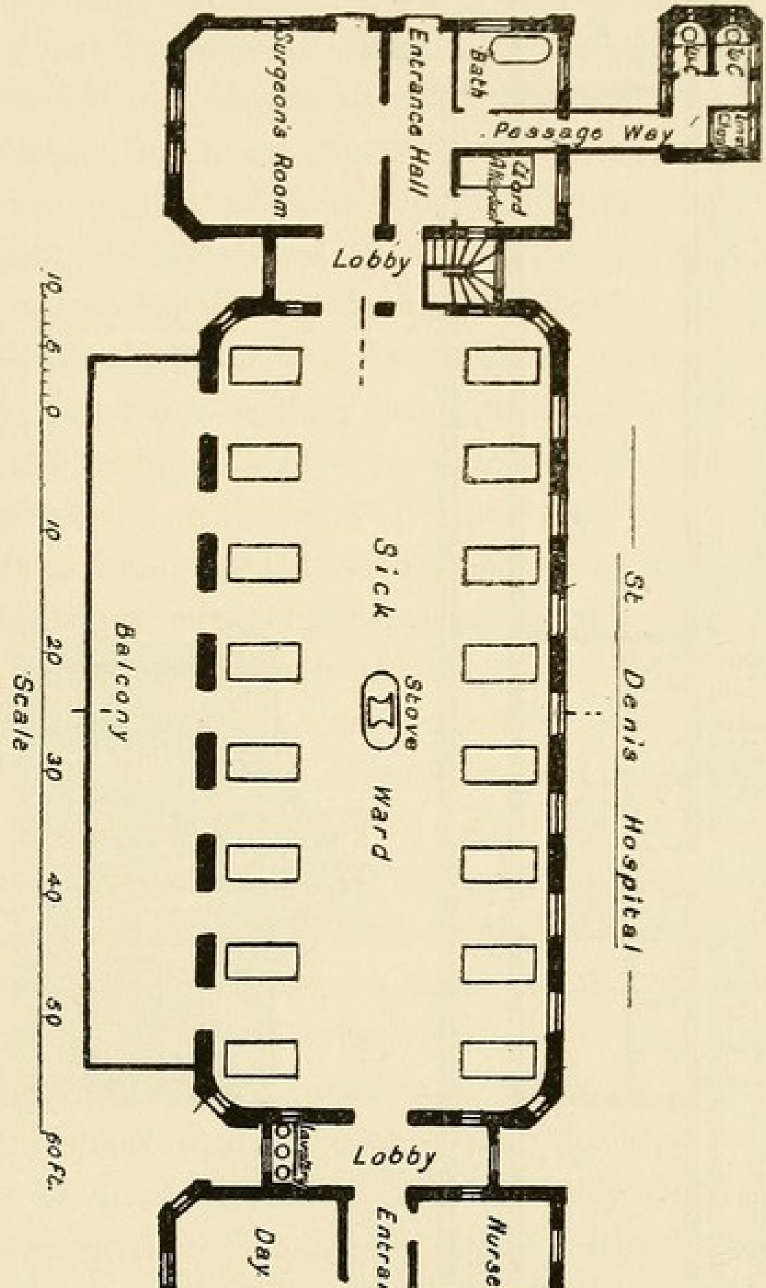
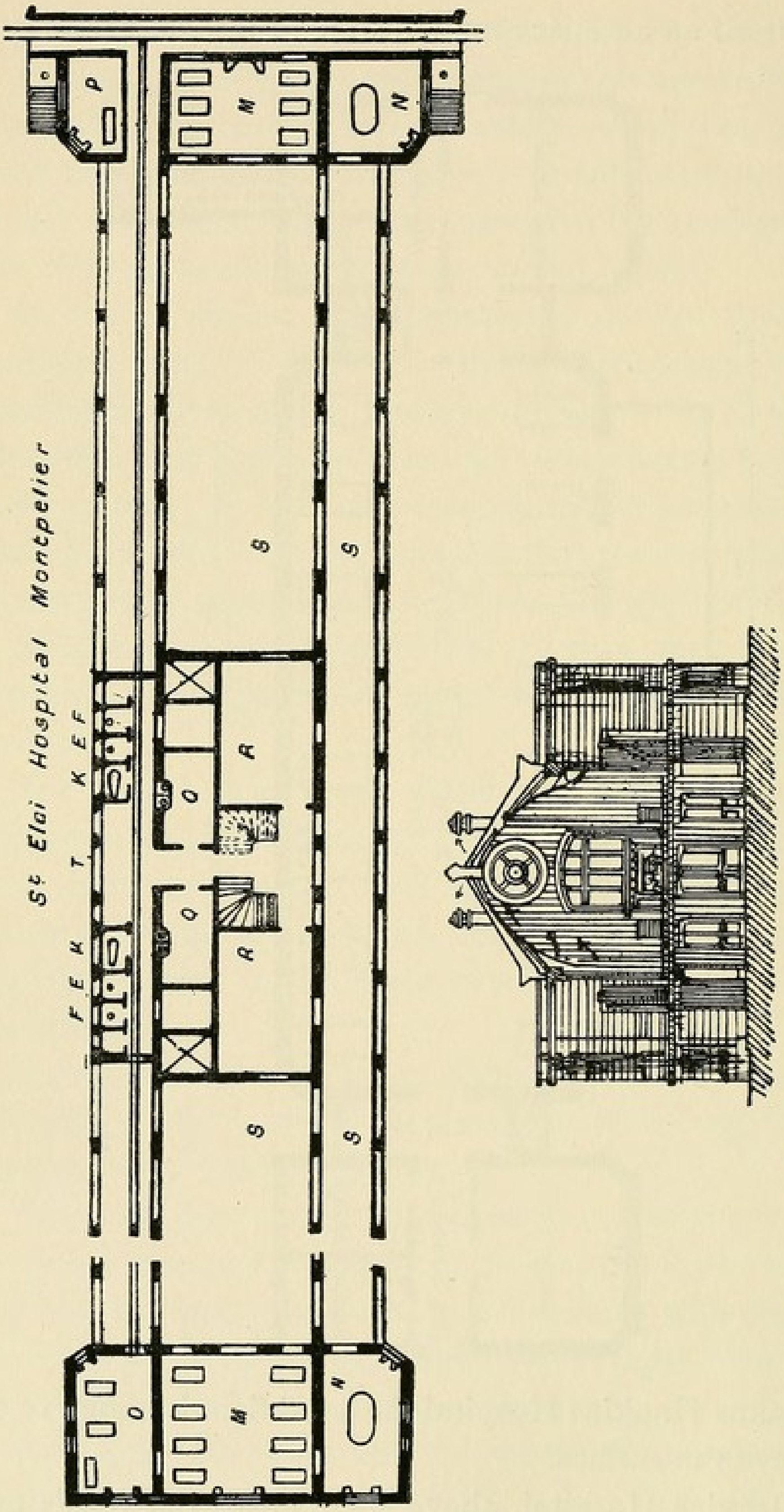


Fig. 29.

In the Johns Hopkins Hospital the ward floor is about 12 or 13 feet above the surface.

In the Dresden Hospital, above mentioned, the wards are raised about 7 feet above the ground. On the other hand, the Hamburg Hospital is only raised about 3 feet, but



E and *F.* W.C.'s and Urinals.
K. Bath.
M. Convalescents.
N. Day Room.
O. Attendants.
P. Stoves.
Q. Clothing Store.
R. Stove and Fuel.
S. Exercising ground (covered).
T. Ward Kitchen.

Fig. 30.

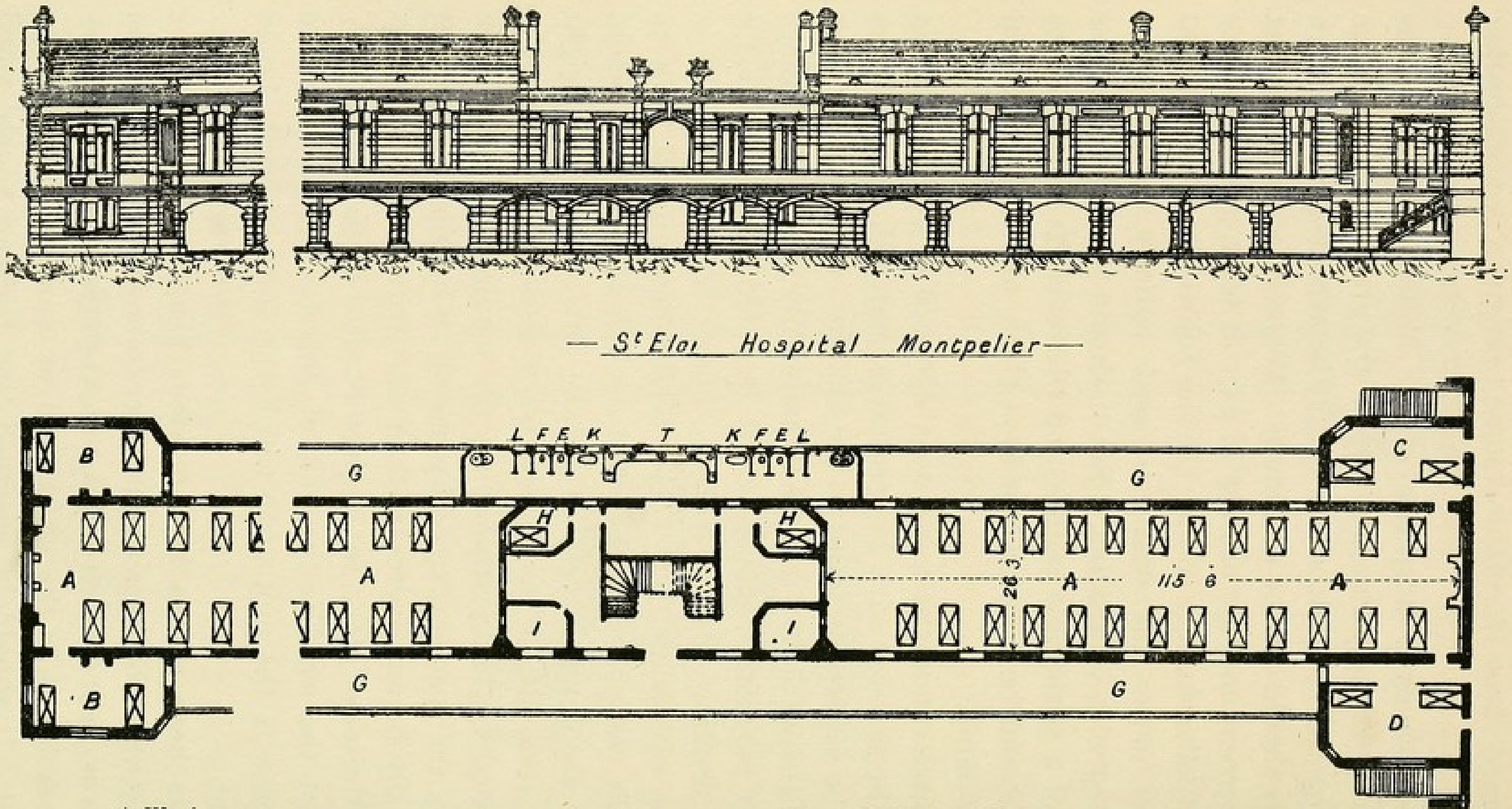
its warmed floor forms to some extent a compensating feature.

The single-story hospitals of the Metropolitan Asylums Board are generally raised 4 feet off the ground, but they are not suggested as models, and it may be accepted as an axiom that this should be the minimum. When raised 9 or 10 feet the basement may be utilized in part at least, as for instance at Montpelier, for day rooms. In the Johns Hopkins Hospital the part under the wards is used entirely for purposes connected with ventilation. But it should never be used for stores of a perishable nature, and whatever its height or its use it should be light and be kept clean, and its floor should exclude damp.

The area round the wards to a distance of at least 12 feet should be covered with impermeable material, and no water should be suffered to lodge in the vicinity of the wards. The level of the ward floor need not materially affect the distance between pavilions, because, whilst it would be preferable for the permeation of sunshine to place the buildings at a distance of double the whole height measured at least to the eaves, yet so far as the ward itself is concerned, it would only be absolutely necessary to take into account the height of the roof above the lowest ward floor, discounting the diminished space by asphalting the whole outer space. In this way the space occupied by one-story buildings would not necessarily be much greater than that required for buildings of two stories or more, for a given number of patients.

Whilst the ward is the unit of hospital construction, the floor space is the unit upon which the form of ward should be based.

It has been shown in a previous chapter that adequate space between the beds ought never to be less than from 4 feet 6 inches or 5 feet—which with a 3-foot bed gives 7 feet 6 inches—to 8 feet lineal as the width, and as much more as can be afforded. It should be assumed that the bed should stand



A. Ward.
B. Separation Ward, or Paying Patients.
C. Separation Ward, or in Surgical Pavilion, Operation Room.
D. Separation Ward for use after operation.
E. and *F.* W.C.'s and Urinals.
G. Verandah.
H. Nurse.
I. Medical Man.
K. Bath.
L. Ablution Room.
T. Ward Kitchen.

Fig. 31.

about 12 inches from the wall to allow of circulation of air behind; and there should be from 11 to 12 feet between the feet of opposite beds. This would give the minimum necessary for administration: and it would bring the length of each bed space to about 13 feet or 13 feet 6 inches. The ward suggested would thus be 26 to 27 feet wide, with a floor space of from 97 feet 6 inches to 108 feet. To this any necessary addition must be made in the wall space or the length of floor space for the extra aëration wanted in the case of wounds, lying-in women, infectious diseases and so forth, as well as for facilities for a medical school.

The following are the dimensions of the wards of some of the more recently constructed hospitals in Germany, France, the United States, and this country.

Name of Hospital.	Height of Ward.	Width of Ward.	Lineal Bed Space.	Floor Space per Bed.
Halle	15·9	29·6	9·2	135·6
Hotel Dieu	*18	29·3	8·4	125
Menilmontant . . .	*17	27·9	7	107
Johns Hopkins . . .	16	28·8	7·7	104
Leeds Infirmary . . .	16·6	27·6	7·5	107
Montpelier	†25	26·3	7·2	108
Herbert	13·6	26	7·4	97
S. George's Union Infirmary	13	24	6	72
Moabit, Berlin . . .	13·9	22·6	6·2	69
Hamburg	16·11	28·8	5·10	78

* First Floor Wards. † At centre.

These conditions being admitted, the form which the ward should logically take with the object of allotting to the patient the largest space between the beds (that is to say, the largest bed space which the proposed floor space will allow of), is the rectangular form, because that is the form which allows of a

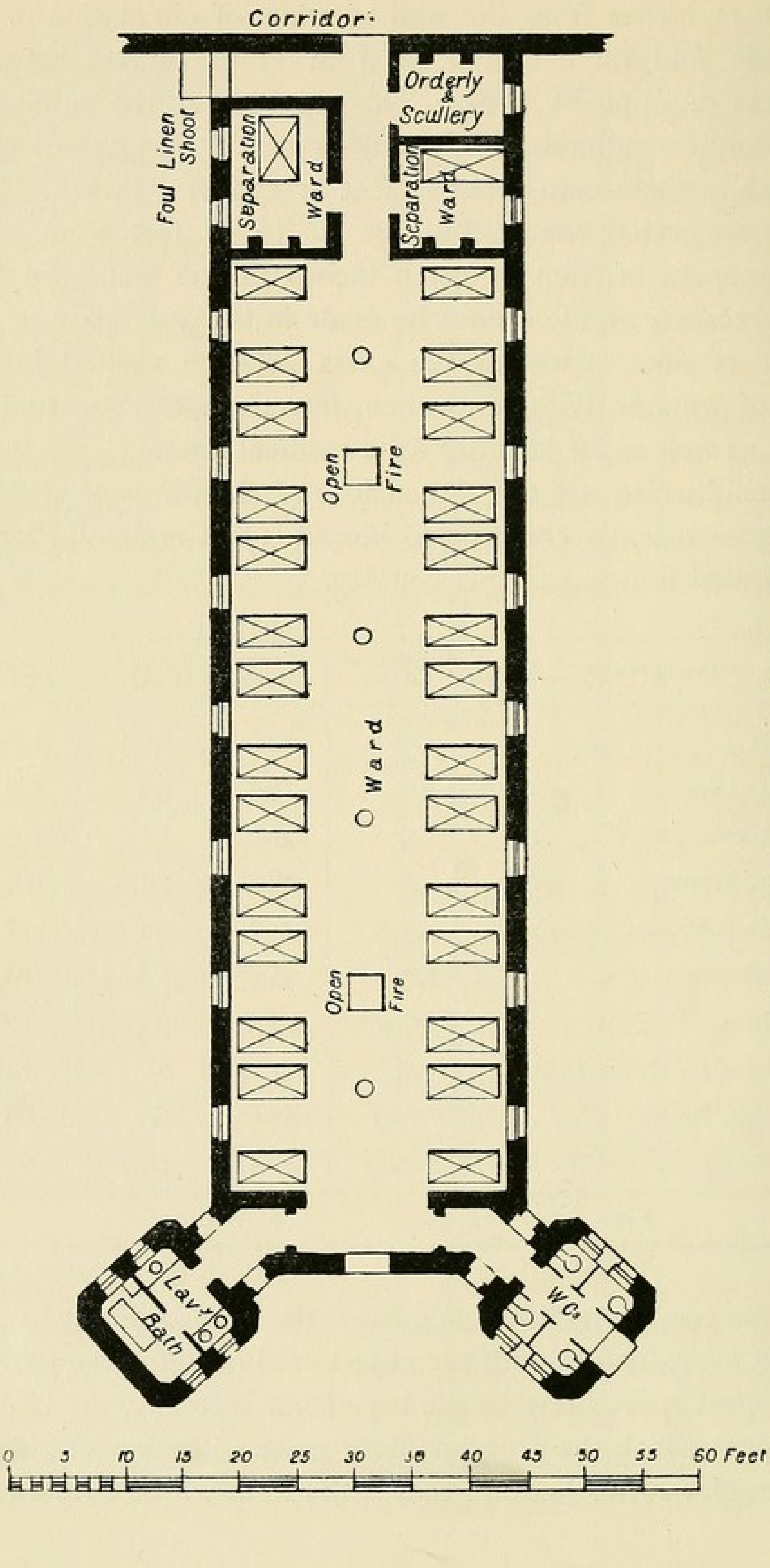


Fig. 32. Ward. Colchester Military Hospital.

maximum of wall space in proportion to the area. It is also the form which allows of the smallest distance between opposite windows, combined with adequate room for nursing, &c.; and the shorter the distance between opposite windows, the more effective will be the cross ventilation.

The annexed Fig. 32 shows one ward with its appurtenances in the new Military Hospital for Colchester.

The circular form of ward has recently found many advocates, and it is therefore necessary to weigh the relative advantages and disadvantages of the two forms. The circular form of ward is more expensive to construct, and it affords a minimum of wall space in proportion to the floor space. On the other hand, in a circular ward the walls are all available for wall space for the beds; but where the diameter of the circular ward exceeds what would be the width of a rectangular ward, a larger proportion of the floor space is away from the patients in the middle of the ward. For instance, in the Antwerp Hospital a ward of 20 beds has a diameter of 61·6 feet. The wall space per bed is about 9·6 feet, the floor space is 149 feet, the cubic space is 2,525 feet, and the distances between the feet of opposite beds would be 47 feet 6 inches; and, assuming the beds to be 3 feet wide, the actual space between the adjacent beds would be 6 feet 6 inches at the head, but only 4 feet 6 inches at the foot, and of the 149 feet of floor space and 2,525 cubic space, barely two-thirds would be within a distance of 14 feet from the vicinity of the head of the patient. This proportion of floor space at a distance from the patient is comparatively useless for its object; and the consequent additional cubic space furnishes a large volume of air, also at a distance from the patient and not of much use to him. A measure of this waste of cubic space is afforded by considering that in the circular ward, whilst the whole floor space per patient is 149 square feet, that within 14 feet of the wall would only be about 90 feet, and the cubic space only little over 1,500 feet out of the total 2,525 feet. Moreover, in large wards the distance between opposite windows in the circular ward is far greater than is desirable to ensure the aëration of a ward by means of windows. The sweeping out of all the impure air from the ward occasionally, so as to start afresh with pure air, is best effected by the direct action of currents of fresh air brought in by open windows placed on opposite sides of the wards. The distance between windows for this purpose must not be too great to prevent their efficient action in moving the air. Experience shows that a width of 24 feet affords very satisfactory results, and that opposite windows for such an object should in no case be more than from 30 to 35 feet apart. The space between the windows should not be obstructed by walls or partitions.

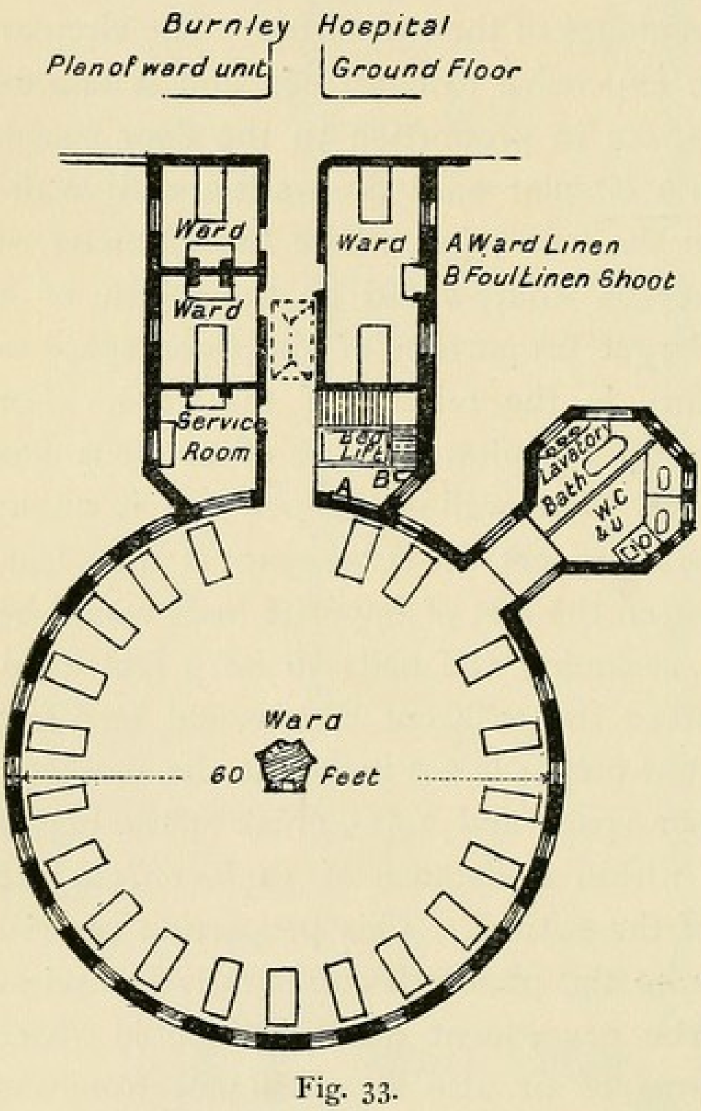


Fig. 33.

The same object renders it necessary to limit the number of patients—that is to say, the sources of impure emanations —placed between opposite windows to two.

In the Antwerp circular ward the central space is occupied by a concentric circular structure used for a nurses' room, built round the shaft for ventilation, which impedes the cross ventilation from windows; and in the Burnley Hospital in one ward the cross ventilation is impeded by a central staircase leading to a sun room on the roof.

In a rectangular ward of 28 feet wide, affording similar floor space to the Antwerp circular ward, the wall space per bed would be about 10 feet 8 inches, and the distance between opposite beds would be about 14 feet; assuming the beds to be 3 feet wide, the distance between the beds at both ends would be 7·8 feet, which is ample for nursing purposes; the whole floor and cubic space would be situated within 14 feet of the patient's head.

So far as the convenience of a medical school is concerned, it is said that the large proportion of floor space in the middle of the ward, in the case of a circular ward, and away from the beds is convenient, in that the bed of the patient under observation can be wheeled out into that space, and thus ample means be afforded for the students to see and hear all the remarks of the Clinical Professor.

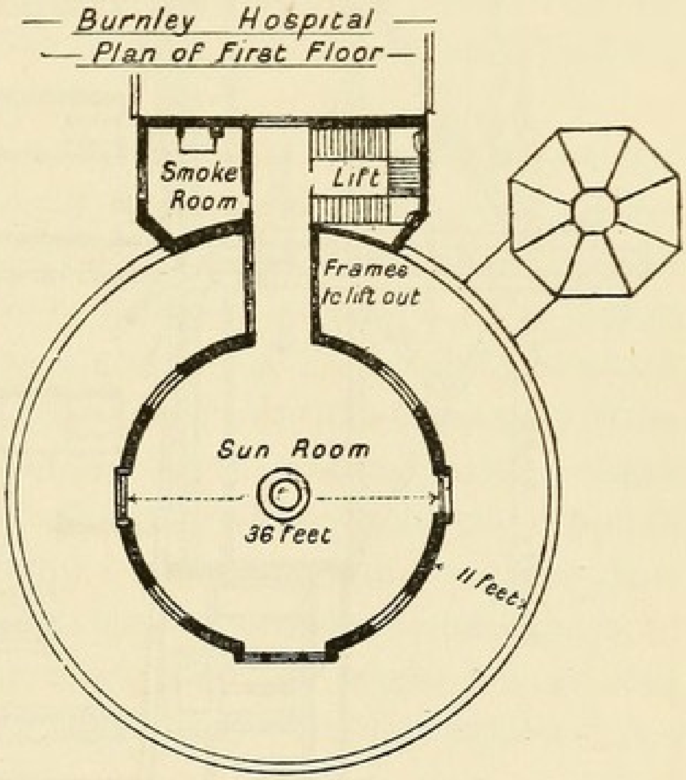
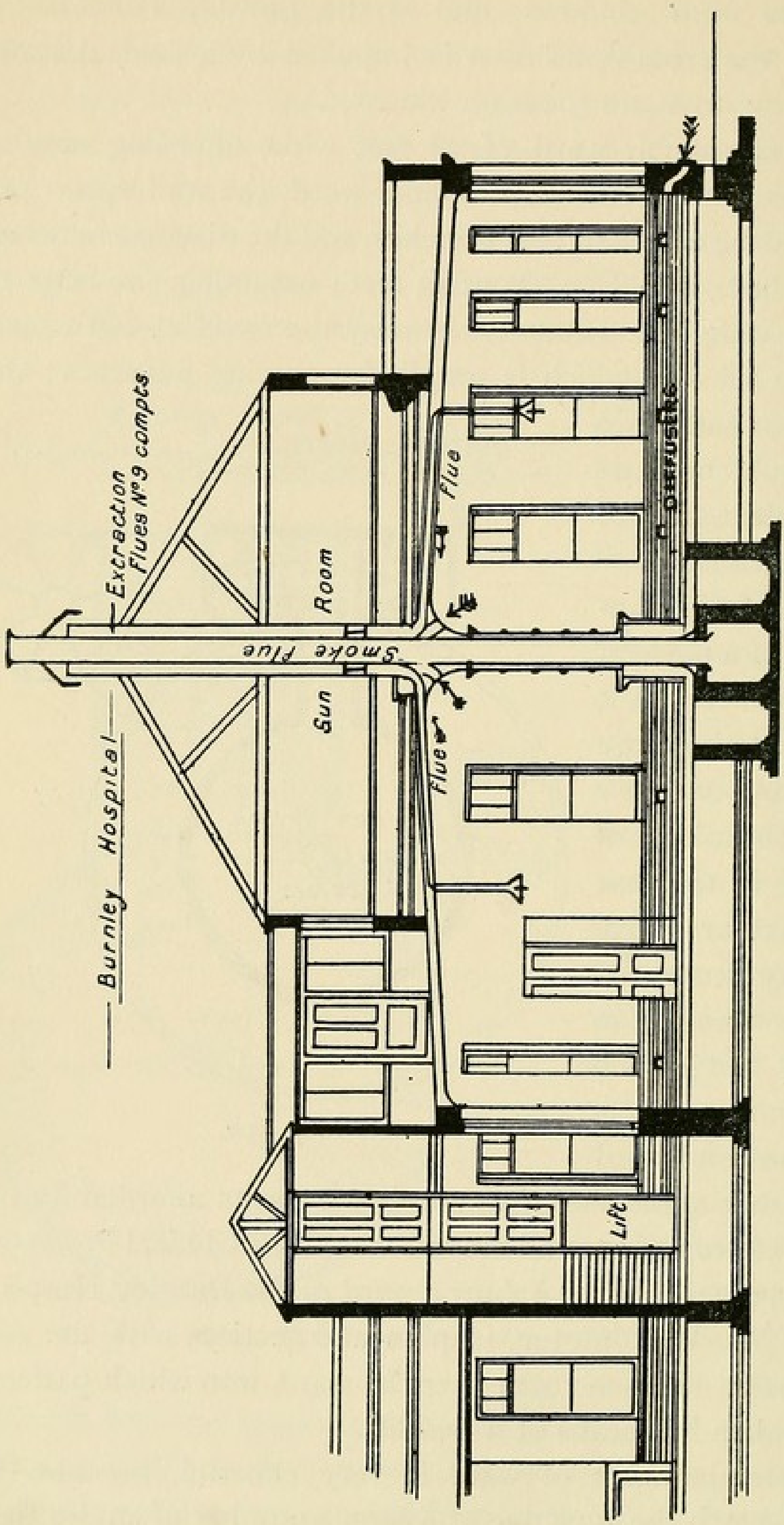


Fig. 33 *a*.

Figs. 33, 33 *a* and 33 *b* show a ward of the Burnley Hospital built by Mr. Waddington, in plan and section, with the day or as it is termed sun room over the ward, into which patients can be taken by means of a bed-lift.

The circular form of ward is very cheerful, because the windows catch the sunshine at a larger number of angles than is the case with the rectangular form.



Section through Ward and Sun Room.

Fig. 33 *b*.

The circular form is also convenient for artificial ventilation, in that the air can be extracted at a central flue and admitted equally all round the circumference. The larger area over which the admission of air is spread favours its coming in gradually, whilst a higher velocity may be given to the central outflow.

The advantage of the circular ward lies in the absence of angles. This advantage can be obtained to some extent in the rectangular ward by rounding all angles and avoiding all cornices, as shown in M. Tollet's St. Denis Ward, Fig. 29, and by placing a window at the corner of the ward, between the end beds and the wall.

The height of the ward for purposes of daylight must depend upon the width. Its height is also dependent to some extent upon its length, because the breadth, the height, and the length all influence the efficient circulation of air; it is of course assumed that the windows are carried up high both to admit daylight and prevent stagnation of air in the upper part of the ward. For a small single or double ward a height of 12 feet might suffice, but in wide wards due proportion for the circulation of air requires that this height be increased, and the table given in a former page shows that hospital architects have recognised this necessity. On the other hand, any height beyond that actually required means unnecessary cost in construction and more space to be warmed.

The floor space, the lineal wall space per bed, and the width of ward being decided on, the number of beds in the ward regulates the length, or in circular wards the diameter.

Whilst the medical man prescribes for the sick, he depends for the execution of his orders upon the nurse. The nurse applies the remedies, gives food, and regulates the atmosphere, as an hourly continuous duty.

The disciplinary and economical dispositions in a hospital require that each nurse should have the patients allotted to her placed in one ward, under her immediate eye; and the head-nurse should be supreme in the ward which she nurses. Moreover, as economy of labour in administering the hospital is a main object to be sought in hospital construction, the hospital should be so laid out as to enable the largest possible number of patients to be nursed by a given number of nurses.

The number of patients to be placed in a ward will therefore depend upon the number which can be efficiently nursed, and the form of the ward must be calculated to facilitate nursing as well as to ensure free circulation and change of air.

Miss Nightingale says that 'a head-nurse or sister can efficiently supervise, a night nurse can carefully watch, 32 beds in one ward; whereas with 32 beds in four wards this is impossible.' (Report on Cubic Space in Workhouses.)

Miss Nightingale further shows (in her 'Notes on Hospitals,' 1863) that if the annual cost of nursing be capitalized, and if a hospital for a given number of sick be divided into wards of nine patients each, the cost of nursing in perpetuity would be £428 per bed: whereas, if the hospital were divided into wards of 25 beds each, the cost would be £231 per bed, and with wards of 32 beds, the cost would be £220 per bed.

It has followed from these considerations, that from 20 to 32 beds have been taken as the unit for ward construction to include the number under one sister or head-nurse. In hospitals where cases of more than ordinary severity are likely to be received, it would be necessary to diminish the size of the wards on grounds of health, and thus to make some sacrifice of economy of nursing for the sake of the patients.

The apportionment of beds between Medical, Surgical, and other cases depends on local conditions. In the Metropolitan Asylums Board Hospitals, excluding small-pox, the percentage of diseases provided for is about 72 for scarlet fever, 10 for diphtheria, and 9 each for enteric and other diseases.

The following table shows the number of beds provided in large and in small wards in various hospitals:—

Name of Hospital.	Accommodation.	General Wards.		Small or Separation Wards.		Percentage of beds in Wards of one and two beds each to total accommodation.
		No. of Wards.	No. of Patients in each.	No. of Wards.	No. of Patients in each.	
Hamburg	1340[1]	30 11	30 14	11 11 119	4 2 1	10·5
S. Marylebone Infirmary.	744	24	28	36	2	9·6
Tenon (Menilmontant)	726	20 2 8	22 16 12	12 16 10 42	4 3 2 1	8·5
Herbert Hospital. .	650	15 5 1	32 28 20	8	1	1·2
S. Eloi (Montpelier)	600	12 6 6 4	28 10 9 8	37 44	2 1	19·6
S. Thomas'. . . .	573	15 3 7	28 20 8	17 3	2 1	6·4
Berlin Military Hospital.	504	14	16	27 24 23	6 3 2	9·1
Antwerp	380	16	20	60	1	15·7
Johns Hopkins . .	361[2]	10	24	1 27 64	3 2 1	32·6
Leeds Infirmary . .	328	4 6	32 28	2 5	6 4	
Norfolk and Norwich	218	6 2	24 17	1 17 3	3 2 1	16·9
S. Denis	166	7 4	16 8	6 10	2 1	13·2

[1] Includes accommodation for 72 paying patients and 29 delirious and violent patients.
[2] Includes about 28 paying patients, chiefly in one-bed wards.

The actual ward figure for each hospital must depend on the nature and to some extent on the size of the hospital.

But to every large ward there should be attached small wards. These form part of the ward unit under the charge of the ward sister.

Patients suffering from injuries to, or disturbances of, the nervous system suffer much from light, heat, noise, or presence of other patients in a ward. Other cases require isolation for treatment or for observation.

The number of these small wards, and the question as to whether they are to accommodate one or two or more patients, is necessarily a matter which the medical advisers on the local wants of the hospital must define in the original plan. It somewhat depends upon the provision made for paying patients.

But there seems to be a growing feeling that the number of small wards is insufficient in most modern hospitals. Thus the provision of one and two-bed wards in St. Thomas's Hospital amounted to 6·4 per cent. of the total; but in the Hamburg Hospital there has been provided 10·5 per cent. of one-bed and two-bed wards; in the Antwerp Hospital about 15·7 per cent.; in the Montpelier Hospital nearly 20 per cent.; and in the Johns Hopkins Hospital nearly 33 per cent.

From the conditions under which these smaller wards would be occupied the floor space and cubic space per bed should at least be full; and it would appear that the floor space allotted to separate wards rarely falls below 120 square feet, and occasionally amounts to 160 square feet per bed, with cubic space varying from 1,450 to 2,000 feet. A one or a two-bed ward may be warmed and ventilated by means of a ventilating open fireplace and the window, if the upper part of the window is arranged to fall in and make a hopper ventilator; but with more beds, a shaft to remove foul air and additional inlets for fresh air would probably be required, as well as additional heating arrangements. These should be adapted to such specialities of treatment as might be necessary, and their position with respect to the main ward, nurses' rooms and ward appurtenances, should be such as to facilitate convenience of nursing.

Day Rooms and Sun Rooms.

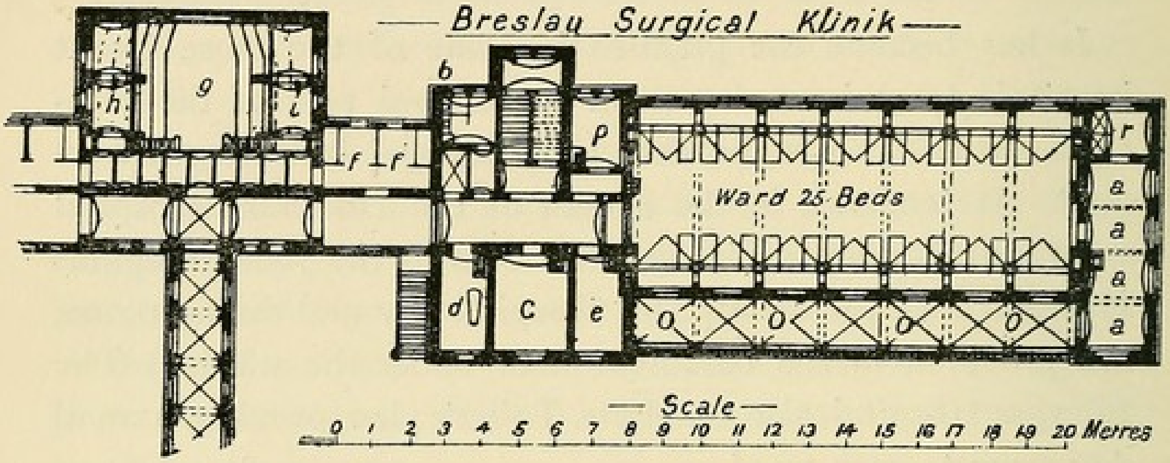
It has become the practice in some of the more recent hospitals to make a day room an integral part of the principal ward. This is the case in the Royal Infirmary, Liverpool. It is shown in the sketch of the Hamburg Hospital ward. It is adopted in another form in the Johns Hopkins Hospital. In the Montpelier Hospital day and dining rooms are provided in the basement floor under the wards. The Bourges Hospital, also on Mons. Tollet's plan, provides a small day room to each ward.

Some of the new circular hospitals in this country provide as one of their principal features a sun room, placed on the top of the circular ward, protected by glazed sides and warmed by steam-pipes, with a circular open promenade round it. The access to this is sometimes made through a staircase central to the ward. This obstructs ventilation, is necessarily dark, and furnishes dark corners, in which, sometimes patients' clothes and sometimes rubbish, is accumulated, and it does not allow of patients in their beds being brought into the sun rooms. A more recent arrangement is shown in Fig. 33, 33*a*, 33*b*. This leaves the circular ward free from impediment, except from a column in the centre which forms the chimneys and extraction flues, and access is afforded to the sun room by a staircase outside the ward, adjoining which is a lift for beds, so that a patient can be rolled out of his ward and conveyed up by the lift into the sun room.

The sun room when properly utilized forms a very useful and pleasant addition to a ward.

In some cases these rooms are divided into a reading room and a smoking room.

In the Breslau Surgical Clinical Hospital, in addition to a day room placed at the end of the ward, the object of a sun room is to some extent obtained by an open air verandah along the south side of the ward, into which patients' beds can be moved.



a. Day Room.
b. W.C., &c.
c. Isolation Ward.
d. Bath Room.
e. Linen Store.
f. Ward for recent operations.
g. Operating Theatre.
h. Undressing Room.
i. Instruments.
o. Open Verandah.
p. Attendant.
r. Laboratory.

Fig. 34.

It is not assumed that many of the patients would be able to leave their beds to occupy the day room.

The area of day rooms in the Berlin Friederichshain Hospital would appear to be nearly 23 feet per bed in the ward it accommodates.

The Johns Hopkins Hospital would afford nearly 12 superficial feet to each of the patients occupying the large ward. In the Hamburg Hospital it is a little over 15 superficial feet per bed in the wards. In the Bourges Hospital the day room only affords 5 superficial feet per bed. In the Tenon Hospital, Menilmontant, the floor-space for the day room is nearly 10 superficial feet per bed.

CHAPTER XIV.

THE WARD UNIT (*continued*).

Ventilating Inlets and Outlets, Windows, Doors, Walls, Floors.

Ventilating Inlets and Outlets for Air.—No inlet or outlet ought to be placed in the floor. Hot-water pipes ought never to be placed in channels in the floor with open gratings; such a position only affords receptacles for dirt; when placed in the middle of the ward, patients spit down them.

In the Johns Hopkins Hospital some of the extraction outlets are placed under the beds, but this does not entirely remove the objection to their becoming receptacles for dirt.

Any such opening should be above the floor-level, and therefore they are best in the side walls, with a sloping back, so that anything thrown into them falls back into the ward. Whilst outlets for extraction shafts may preferably be placed near the floor-level, inlets for the warmed fresh air should not throw cool air, or air whose rapidity of movement makes it feel cool, on to the feet. They are therefore best placed somewhere above 5 feet or 6 feet from the floor-level.

The velocity of inflowing air should never exceed 2 feet per second. Air should preferably flow in at a velocity of 1 foot or 1 foot 6 inches per second. The velocity of outflow in outlet flues as they leave the openings into the wards should, similarly, not exceed 2 feet per second on entering the mouth of the outlet, which should be large enough to limit the velocity to that speed; but it may travel along the outlet flues at a rate of from 3 to 4 feet per second or more.

Windows. — Second only to air, is light and sunshine essential for growth and health; and it is one of Nature's most powerful assistants in enabling the body to throw off those conditions which we call disease. Not only daylight, but sunlight; indeed, fresh air must be sun-warmed, sun-penetrated air. The sunshine of a December day has been recently shown to kill the spores of the anthrax bacillus.

In her article on 'Nursing' in Quain's Dictionary, Miss Nightingale observes that 'light should be meant to include colour, pleasant and pretty sights for the patient's eyes to rest on—variety of objects, flowers, pictures. People say the effect is on the mind. So it is; but the enlightened physician tells us it is on the body too. The sun is a sculptor as well as a painter. The Greeks were right as to their Apollo.'

The form of the windows must be considered first, in their aspect of affording light as a necessary means of promoting health; secondly, of affording ventilation; thirdly, of facilitating nursing and of enabling the patients to read in bed.

Light can always be modified for individual patients.

In order to give cheerfulness to the wards, and to renew the air easily, the windows should extend from within 2 feet or 2 feet 6 inches from the floor, so that the patients can see out, to within 1 foot, or if possible 6 inches, from the ceiling. Given a certain area of window, this would preferably be distributed in a tall and narrow window than in a wide and short window.

No room can be cheerful in which there is much space between the top of the windows and the ceiling, or between the bottom of the windows and the floor; or in which a portion of sky is not seen from every part of the room. The vertical arc of sky thus visible should not be less, in the aggregate, than 5° in any part of the room.

In special cases the lower part of the window could be shaded, but if a window is constructed too high from the ground, it causes a permanent want of cheerfulness.

In the pavilion plan of construction the windows are, as has been already explained, placed on each side of the ward, with not more than two beds between adjacent windows, so that plenty of light may be thrown on each bed, for facility of nursing.

Where the corridor system prevails and the windows are on one side only, the dimensions of the windows should be at least one-third more, in proportion to the contents of the ward, than in the pavilion system with opposite windows.

To promote cheerfulness, and for ensuring cleanliness in the angles of a rectangular ward, it is desirable to place a window at the angle next the wall. These windows need not be of the same width as those which regulate the bed spaces.

The distance between the windows must be regulated by the lineal bed space. Window openings themselves may generally be assumed at 4 feet 6 inches wide, with one window to two beds, or narrower with one window to each bed. The sides of the window openings may be splayed about 6 inches on each side into the ward.

In wards of military hospitals, affording about 1,250 cubic feet per bed, and with one window to two beds, the bed space between the end wall and the first window was made 4 feet 6 inches, and the spaces between the adjacent windows 9 feet. This afforded a lineal bed space of 6 feet 9 inches. But with a larger lineal bed space, the distance between the windows and the width of windows might be somewhat increased. An end window to a long ward is a great element of cheerfulness, and materially assists in the renewal of the air. It is essential to cleanliness that every part of the ward should be light. But the actual amount of window space must depend much on situation; in a town the amount sufficient for a free country aspect would be gloomy.

The window space will appear cheerful with light-coloured walls, whereas it may appear gloomy if the walls are dark-coloured.

The area of window space for light must therefore vary with climate, and also with position of a hospital, whether in a town or otherwise.

The architect Lorenz of Berlin appears to lay down 22 superficial feet of window space to each bed if the windows are on one side, as is the case with wards on the corridor system, and 16 superficial feet per bed with wards on the pavilion system. But this rule would omit considerations of cubic space.

In this country the area of window space with respect to floor space has been generally looked upon as the index to refer to; but the cheerfulness of a room will mainly depend upon the area in proportion to the cubic contents. One superficial foot of window space to from 50 to 70 cubic feet of space, according to position and climate, will afford a light and cheerful room. Where there is a verandah more window surface would be necessary in this climate.

The following table shows the proportion which has been adopted in different hospitals, calculated on this basis. It will be observed that there is no general concurrence in window space judged by this rule.

Glazed Surface.

In Towns.	One Square Foot of Window Space	
	to Square Feet of Floor Space.	to Cubic Feet of Cubic Space.
S. George's Union Infirmary	4·6	60
Leeds Hospital	4·9	80
Hotel Dieu *	6·7	175
Tenon (Menilmontant) * . .	6·	102
Halle	8·2	123
Herbert	5·1	69
Moabit	6·2	78
Johns Hopkins	4·8	78
Montpelier	4·7	112
Hamburg	5·3	84

* First Floor.

The loss of light through the windows varies with the quality of glass.

Polished British plate glass, ¼in. thick,	intercepts	13	per cent.	of the light.
36 oz. sheet glass	„	22	„	„
Cast plate glass, ¼in. thick . .	„	30	„	„
Rolled plate glass, 4 corrugations in an inch	„	53	„	„

Clear glass is thus of great importance, and the thicker it is, consistent with clearness, the better, because thin glass allows of a more rapid loss of heat, and it is essential, especially in this climate, to economize heat in wards, with so much outer wall as the provision of windows on both sides requires.

The loss of heat through windows amounts to that lost by radiation added to the loss of heat by contact with air.

It may be assumed with thin glass that the temperature of the outer surface of the glass is a mean between the temperature inside the room and that of the outer air.

With thick glass the conducting power of the material may be taken into account, as in the case of a wall.

From these considerations it is desirable to make the windows of thick plate glass. Double windows of ordinary glass would very largely reduce the loss of heat and facilitate ventilation ; but they would greatly diminish the light passing through.

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, with an intermediate space between the windows of ·8 of an inch, the loss of heat of the single window to that of the double window was in the proportion of 1 : ·47; with a distance apart of 2 inches, the proportion was as 1 : ·55; with a distance apart of 2·8 inches, which is nearly what exists in practice, with double windows the proportion would probably be as 1 : ·6.

On these grounds the windows of all hospitals should be double. This may be effected either by double sashes or by a French sash inside and a double-hung sash outside; but according to Péclet a better result for saving heat may be effected by double glazing the lower sashes. In this case the window bars must be prepared on their inner side to receive the inner plate of glass; this should be laid on a narrow flannel band and secured by means of a wood fillet screwed into the side of the window bar.

The flannel will be the most effectual way of keeping the inner surfaces clean. Dirt penetrates to the space between the two sheets of glass, by means of the constant inflow and outflow of air going on as the result of changes of temperature, and the flannel acts as a filter to retain the dirt which the outer air would otherwise carry into and deposit in the interspace.

The method of fixing the fillet should be one that will afford easy means of removal for cleansing. The double glazing has however the disadvantage of always obstructing light, whereas, in the case of the window with a double sash, one sash can be left open at times, or altogether removed in summer.

The best form of sash for ventilation in this climate is the ordinary sash, opening at top and bottom; but windows made in three or four sections, each of which falls inwards from an axis at the bottom of the section, have been extensively used in hospitals, and possess many advantages; although it is certain that the air of the wards cannot be so thoroughly changed by means of these windows as by means of the ordinary sash.

It would therefore appear desirable to make hospital windows in either two or three divisions, the lower divisions occupying between $\frac{2}{3}$ or $\frac{3}{4}$ of the height of the window, the upper portion between $\frac{1}{3}$ or $\frac{1}{4}$; the upper portion being hung on hinges at its lower part, so as to fall inwards. Glazed triangular sides project into the room into which it falls, so as to create a sort of hopper when open, which admits fresh air upwards and prevents side draughts on the patient. The lower half of the window may be preferably a double-hung sash, which with the aid of a deep bottom bar enables an opening to be maintained at the centre bar, without any opening at the bottom bar which might create draught upon the patient.

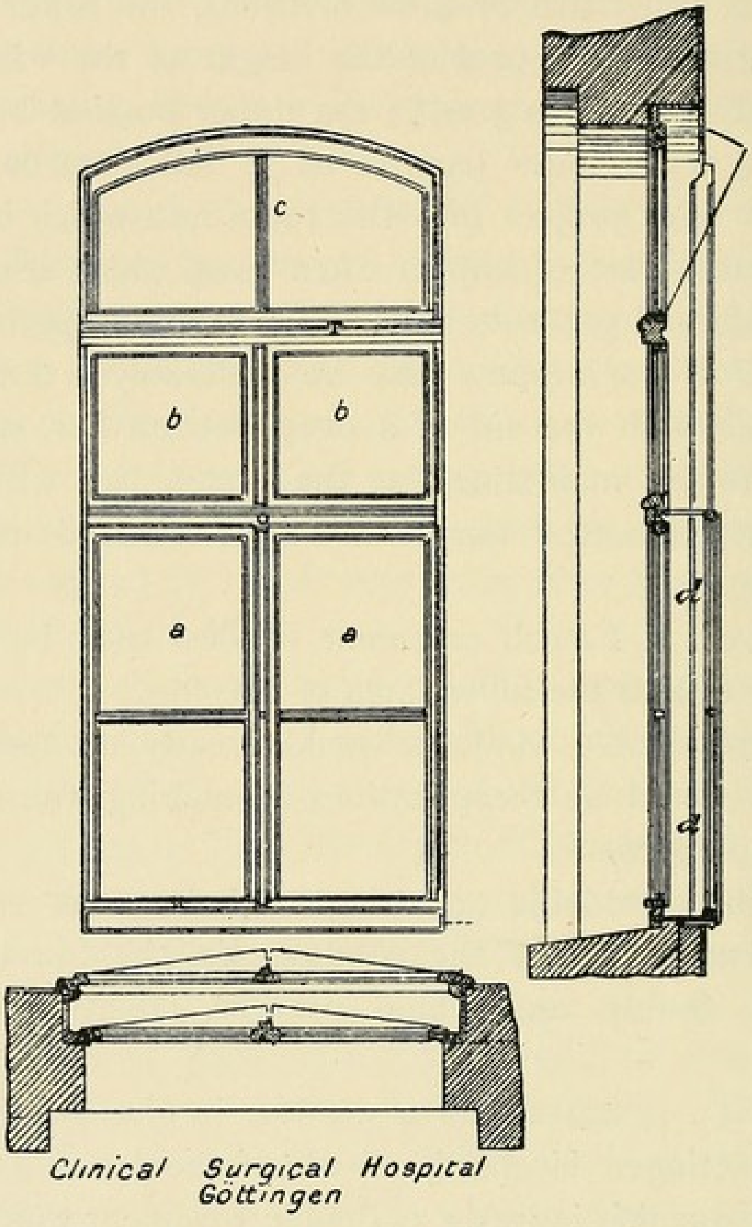
If desired, a French casement window may be adopted; this latter affords the fullest area of opening.

Although double windows would greatly economize heat, yet there would be complications in making the upper in-falling flap double.

A combined double and single window will enable the most essential part of the window, viz. the lower part, to be made double, and would prevent radiation from the patients.

Figure 35, p. 204 shows a window in the Surgical Ward of the Göttingen Hospital, of which the lower half (*a*, *a*) is double, opening inwards as double casement windows; the middle part (*b*, *b*) is a casement opened by cords, above and independent of the former; and the upper part (*c*) falls in to create a hopper ventilator. In the Surgical Hospital, Bonn, the upper single portion of the window is made to open by falling inwards, and the lower casement, occupying two-thirds of the height of the window, is made double.

The woodwork of windows, as well as all woodwork in a ward, should be of hard wood painted and varnished, so as to admit of easy washing and cleansing. The cleanest and most durable material is varnished light-coloured wainscot oak or teak.



a. Double Window casement. *b.* Single Window casement. *c.* Single Window falling in on bottom hinge. *d.* Interspace between Windows.

Fig. 35.

Doors.—Ward doors should be arranged in number and position so as to facilitate nursing and prevent panic in case of fire. They must be large enough to allow of the passage through of sick on moveable stretchers.

Double doors are not very convenient, because the opening of the whole door is somewhat troublesome, unless they are made on Mr. Appold's plan, in which the leaves are connected by a lever at the top and the two leaves open simultaneously in opposite directions.

In large wards, operation-rooms, &c., double doors are often necessary, and should afford an opening of about 5 feet.

Single doors should afford an opening of from 3 feet 8 inches to 4 feet; which would allow of the passage of stretchers, trays on wheels, &c. It is generally convenient that the principal ward-doors should open both ways, and be self-closing.

To prevent panic in case of fire, a second door opening outwards should be placed at the end of the ward opposite the principal entrance.

Doors into bath-rooms should be large enough to allow of the passage of a moveable bath; probably 3 feet 9 inches would suffice. The doors for lavatories should be of the same width, but doors for w.c.'s might well not exceed 2 feet 4 inches.

The material for ward-doors is preferably hard wood, such as oak, varnished, which can be easily washed.

The construction of all doors in and near wards should be such as to present as few projections, interstices, or other places for the accumulation of dust as possible. The upper part of the entrance doors to wards and all swing doors might advantageously be glazed.

Walls.—All walls should be protected from damp rising in them by a dampcourse of slate, asphalte, an efficient form of glazed brick, or some impervious composition. The top of the wall should similarly be protected so that rain shall not sink in at the top; and eaves or cornices should project sufficiently and be so formed as to prevent a drip from the roof on the face of the wall. The walls should be such as will allow of a smooth surface. A wooden hospital has the advantage of being erected rapidly; but the numerous joints and chinks, which are favourable to the permeation of air, become after long use adverse to cleanliness. A wall of brick or of some material which can be used without presenting chinks on the surface, is therefore preferable in hospitals of any degree of permanence

With a view to economize heat in winter, and to keep the rooms cool in summer, the walls should be hollow, care being taken that the hollow air-space is closed in top and bottom to prevent circulation of the enclosed air.

All hospital wards should be ceiled, and the roof constructed of a good non-conducting material. If of slates or tiles, they should invariably be laid on boards and felt.

Our gradually extending knowledge into the causes of disease shows that in houses and hospitals where diseases have appeared to linger, or to break out afresh after long periods of being shut up, there has generally been ample opportunity for dirt to lodge in the cracks of the floor or the interstices of the walls, or for nitrogenous organic matter to be absorbed into plaster, where warmth and moisture may favour its decomposition. And there has been no more striking exemplification of the value of cleanliness than that afforded by Sir Joseph Lister's system of treating wounds; a system based on the most absolute cleanliness.

It has followed that this absolute cleanliness is a necessary feature of a well-managed hospital. Now this means that the walls shall afford no lodgement for dust, that there shall be no cracks in woodwork, or between the woodwork of windows and doors and the walls, and that walls and floors shall not be absorbent nor afford corners where dirt can lodge or interstices into which dirt can penetrate. As regards corners, it is possible to scrape with a penknife from the floor in the corner of an ordinary room an amount of dirt which is surprising. In a hospital this dust may consist of epithelium, threads of lint, and other objectionable matter. This may be avoided by replacing the angles made by the walls with each other and with the ceilings and floors with curves or quadrants, the concave surfaces of which face the wards; in fact, by carrying out to their fullest extent the principles advocated by M. Tollet.

As regards interstices or cracks, the best lining for a hospital ward would be an impervious polished surface, which, on being washed with soap and water and dried, would be made quite clean. Plaster, wood, paint, and varnish all absorb the organic impurities given off by the body, and any plastered or papered room, after long occupation, acquires a peculiar smell. Ammonia is always found on surfaces of occupied rooms. In a discussion in the French Academy of Medicine, a case was mentioned in which an analysis had been made of the plaster of a hospital wall, and 46 per cent. of organic matter was found in the plaster. No doubt the expensive process which is sometimes termed enamelling the walls, which consists of painting and varnishing with repeated coats, somewhat in the manner adopted for painting the panels of carriages, would probably prove impervious for some time, but it would be expensive, and very liable to be scratched and damaged.

Parian cement polished has been much used for wall surfaces, but it is costly, and it is difficult to get it of an even colour, it becomes discoloured apparently from internal change, and is therefore disappointing; it can only be applied on brick or stone walls, and not on woodwork or partitions, because, being very inelastic, it is liable to crack. The want of elasticity in Parian cement is unfavourable to its use in ceilings. Cracks in a hospital ward are inadmissible, as they get filled with impurities and harbour insects. For this reason it is advisable that all division walls in hospitals in connexion with the sick be built of brick.

Glazed bricks have however been largely adopted as a lining for wards of late years; but from their numerous joints these can only be safely used provided the joints are most carefully made in cement and painted. A very good specimen of glazed brick is to be found in the Burnley Hospital, where the bricks were specially ordered to be made as true and straight in the edge as possible: they were laid in very fine mortar: the joints were scraped out and pointed with Keene's cement, and this was painted with two coats of white enamel—albarine, or Aspinall's enamel—a mixture of zinc white and varnish. As these joints after five years show no sign of imperfection, it may be assumed that with care the glazed brick will afford a safe wall-surface for wards.

In default of a satisfactory impervious wall covering, cement well trowelled to a flat surface and oil-painted makes a good wall, which can be washed with soap and water, and scraped and repainted from time to time. A safe arrangement is plaster lime-whited or painted, provided it be periodically scraped so as to remove the tainted surface, and be then again lime-whited or painted.

When plaster is used, it is essential, for the reasons before mentioned, that at the expiration of a very few years the whole outer coat of plaster should be removed from the walls and ceilings, and new plaster substituted. Of course these arrangements require the wards to be periodically vacated, which is of itself a great recommendation to the use of plaster.

The material used for colouring walls connected with the sick should be one capable of being washed. It should present a cheerful light colour, but of a tint restful to the eyes.

The walls and ceilings should be quite plain, and free from all projections, angles, cornices or ornaments which could catch or accumulate dust. As already mentioned, angles at the junction of walls and ceilings and elsewhere should be rounded, or rather coved.

Floors.—It is essential that wards for the sick should be raised above the ground level, with a free air-space under.

This view is endorsed in the most recent hygienically built hospitals, as for instance the Johns Hopkins, the Montpelier Hospital, and the Hamburg Hospital.

Broadly speaking, the higher the floor is above the ground-level the better. In the first place, aqueous vapour is always rising more or less from the ground. A layer of cement or of concrete will not entirely prevent the ground air from rising from the part under the building: an interposed layer of asphalte may do so; but it is liable to cracks, in which case it would not prevent the ground air from rising. Moreover, the ground air will in any case rise from the space round the building; and for that reason it is essential to cover the spaces between pavilions with asphalte or tar pavement.

In this country this argument has not been fully recognized, although it is even more important in consequence of the dampness of the climate and soil. Indeed, some of the medical men in the hospitals of the Metropolitan Asylums Board have stated that those wards which have tar-paved surfaces between the pavilions are more favourable to the recovery of patients than those where the surface is garden or grass.

When the ward is raised above the ground-level, the spaces thus left under the wards should be light, accessible, and kept clean and free from any substance which could create unhealthy emanations; for instance, they should not be used as coal-stores, or stores for perishable things.

As regards the material for the floor of a ward, if any one will examine the floor of any hospital when there are only small spaces at the joints between the floor boards, he will find these joints filled with filthy matter. If the floors are washed, this is carried down into the cinders and other substances used for deadening sound. If the boards are taken up, it will be found that this dirt has penetrated and lodged beneath the floor, and that it affords a birthplace for putrefaction, and possibly for germs of diseases. As bearing on

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this, Dr. Emmerich of Leipzic investigated the effect on the air of the room of the material used for deadening sound between floors. He found the substances under the floors of dwelling-rooms highly contaminated with nitrogenous organic matters, and their decomposed products.

Professor Carnelly and Miss Johnston in 1889 made corroborating experiments on the material of floors at Dundee, and concluded that the deafening material for floors is a source of contamination of the air of dwellings, in that it furnishes a good and suitable medium for the growth of micro-organisms and gives off fetid gases from putrefaction, provided the necessary factors—moisture, warmth, and nitrogenous organic matter—are present.

On these grounds there should be no sawdust, cinders, or other organic matter subject to decay under the floor. When one ward is placed over another it is essential that the floor should be non-conducting of sound. But the above-mentioned experiments show the great care that must be taken to watch the character of the material used for this purpose. The floors should also be so formed as to prevent emanations from patients in the lower ward from passing into the upper wards.

Similarly, where there are skirting-boards round the ward, some interstices will be found to exist, affording a receptacle for dirt.

It is partly because this foul matter may be carried down under the floor by water, and also because of the damp introduced into the ward, that medical men generally forbid the practice of washing the floors.

Many matters are spilt on a hospital floor which should not be allowed to sink in, therefore the surface of the floor should be as non-absorbent as possible. Floors of stone, cement, or asphalte, although favourable for cleaning, are too cold for sick persons, and would be equally bad for nurses who have to occupy the wards by day and by night; hence for the sake of warmth to the feet, floors must in this country be either of some material like marble terrazzo warmed underneath as in the case of the Hamburg Hospital, or else of wood.

All wooden floor-boards must be of well-seasoned wood carefully planed, grooved, and tongued. If of deal or pine they require especial care. With the best workmanship and materials, interstices between the boards will appear, and their width will vary with changing meteorological conditions; débris of all sorts will be gradually sifted through and accumulate putrefying organic filth between the floor and ceiling.

One plan for delaying this result is to caulk the interstices between the floor-boards, like a ship's deck, to about half their depth, then to fill up the other half to floor-level with marine glue; thus connecting the boards by means of an elastic waterproof surface. This floor should be saturated with drying linseed oil, well rubbed in, stained not too dark so as not to hide dirt, beeswaxed with turpentine, and polished. If the floor-boards are alternately wetted and dried in the process of washing, their consequent expansion and contraction may form openings between them and the marine glue. In an old hospital, cracks can be filled in with clean sand, and the upper part of the joint made good by putty and then painted.

Oak, teak, or any other close hard wood, with close joints, with iron tongues, oiled and beeswaxed, rubbed to a polish, makes a very good floor, and absorbs very little moisture. A floor of teak or oak with joints as close as the best parqueterie, affording no inlet for the lodgement of dirt, and the floor saturated and the interstices filled with paraffin or even beeswax, makes a very good floor.

An economical floor can be obtained by first laying rough deal boards and covering them across with thin, narrow, closely-laid oak boards beeswaxed and polished. The double boards assist in preventing the penetration of dirt.

A very good hospital floor is one in use in Germany, which is of pine wood, oiled, lacquered, and polished, so as to resemble French polish. It is damp-rubbed and dry-rubbed every morning, which removes the dust. The only objection to it is want of durability.

The processes above mentioned render the floor non-absorbent, and do away with the necessity of scouring. A French floor, oiled, beeswaxed, and polished, stands the most wear and tear, but it must be cleaned by a *frotteur*, which is more laborious than scrubbing, and does not remove the dust. The proper process for cleaning such floors is to wipe them every morning with a damp cloth and polish them with a floor-brush, or else to clean them by a broom with a cloth tied over the head, the beeswax or paraffin being renewed from time to time as necessary. This wet and dry rubbing process of cleaning is far less laborious than either *frottage* or scrubbing, and completely removes the dust and freshens the ward in the morning. Practically, with care, a well-laid oak floor, with a good beeswaxed surface, can always be kept clean by wiping over with a damp cloth and rubbing. An old-fashioned, simple method of sweeping a ward floor is to use tea-leaves sprinkled with carbolic acid ; these collect and retain the dust very efficiently.

All ward floors should be scraped and repolished periodically.

CHAPTER XV.

THE WARD UNIT (*continued*).

Ward Offices.

THE ward offices are of two kinds:—

(*a*) Those which are necessary for attendance on the sick and for facilitating the nursing and administration of the wards, as the room for the medical man, the nurses' room, and ward scullery.

(*b*) Those which are required for the direct use of the sick, so as to prevent any unnecessary processes of the patients taking place in the ward; as, for instance, the ablution-room, the bath-room, the water-closets, urinals, and sinks for emptying foul slops. There should, in addition to the bath-room here mentioned, be a general bathing-establishment attached to every hospital, with hot, cold, vapour, sulphur, medicated, electric, shower, and douche baths, which are gradually assuming a prominent position in curative treatment.

Hot and cold water should be laid on to all ward offices in which the use of either is constantly required, to effect economy of labour in the current working of the hospital.

For convenience and economy of administration, when the wards are on two or more floors, lifts should be provided to carry up coals, trays, bedding, and patients. Miss Nightingale ('Notes on Hospitals') estimates that a convenient arrangement of lifts and the laying on of hot and cold water economizes in attendance as much as one attendant to thirty sick.

(*a*) *Ward Offices connected with Nursing and Administration.*

Surgeon's Room.—Wherever there is a medical school in hospitals it is advisable to have a surgeon's or physician's room, forming a part of the ward offices attached to the ward unit. This is the more necessary with detached pavilions; but, on the other hand, one for every ward unit would add materially to the cost. The object is to have a place for necessary examination and in surgical cases for minor operations. It should be light, airy, and if for the last-mentioned purpose, afford a floor space of not less than from 150 to 180 superficial feet.

Nurse's Room.—In some hospitals the nurse lives close to her ward; in that case she should have a bed-room and a sitting-room. This plan is not desirable, as it is of importance for health that the nurse should always sleep and take her meals quite away from the ward air; and at night the night-nurse would take her place.

The nurse's sitting-room should be sufficiently large to contain a bed. It should be light, airy, and well ventilated, as a cheerful room is a material assistance to a nurse. It is necessary to discipline that it should be close to the ward door, and that it should have a window looking into the ward, so as to command it completely. If the nurse has two wards to supervise, her room should be placed between the two, with a window opening into each; in any case it must be so placed as to afford supervision over the small wards forming part of the ward unit.

Ward Scullery.—There should be a scullery attached to each ward, adjacent to or opposite the nurse's room, so as to be under her eye.

The scullery should be supplied with complete, efficient, simple apparatus, for its various purposes; there should be a small range for ward cooking, so that the nurse can warm the drinks and prepare fomentations, and a sink for washing up but not for slops, &c. The sink for washing up and for cleaning utensils should be of a light colour to show when it is not clean, and of a non-absorbent material capable of being easily cleaned. It should have hot and cold water laid on, with taps affording a full supply, and a waste-pipe large enough to discharge rapidly, and trapped close under the sink.

Care should be taken that the waste-pipes deliver into the open air over a trapped gully, so that there should be no direct communication between the waste-pipe and the drain, otherwise foul air is certain to find its way into the hospital. Shelves or racks should be provided for ward crockery, but it is undesirable to have many cupboards or closed recesses, as they become in time receptacles for dirt and rubbish. There should be no dark corners under the sink or anywhere in the scullery, and it should have ample window-space. The scullery should be large enough for the assistant nurses to sit in, and to have their meals comfortably, if required.

There should be provided in connexion with the scullery, a separate place for keeping the necessary provisions such as milk, fitted with a refrigerator, but cut off from the ward air; a miniature dairy receptacle outside a window, and with perforated sides, is a convenient arrangement for this purpose. Also a hot closet for airing clean towels and sheets. For foul linen it is undesirable to have any receptacle near the wards, or indeed in the hospital building. It should all be placed in galvanized iron receptacles, or trucks on wheels, and conveyed as soon as possible to the laundry. Ward-sweepings and refuse should similarly be placed in moveable receptacles, and taken out of the building with as little delay as possible; structural provision is not advocated for the retention of these in or near the hospital.

Brooms, brushes, pails, &c.—There must be a closet for these cleaning appliances, but it must be very light and airy to prevent its becoming a receptacle for rubbish.

Store for patients' clothes.—Patients' clothes are removed on their entering the hospital; the linen, cotton, or woollen clothes are washed, and the cloth clothes disinfected by heat or otherwise. When they have been so treated it is generally convenient, as a matter of administration, to restore them to the care of the ward nurse.

In this case it is necessary to attach a store to each ward unit. This store should be very well lighted, kept scrupulously clean, and supplied with racks, and numbered divisions, to allow of each patient's clothes being kept separately.

A store for patients' clothes without direct window light is objectionable.

The clothes should be taken out, unfolded, re-folded, and put away again at least once a fortnight to prevent moths.

In an infectious hospital this arrangement will not suffice. The patient will wear hospital clothing while in hospital. His own clothes, after washing and disinfection, will go to a general store, adjacent to the discharge rooms. These rooms consist of waiting room and undressing rooms, opening in to bath rooms; these latter open into dressing rooms connected with the discharge room on the other side. The patient leaves his hospital clothes in the undressing room, goes into the bath, and then passes on to the dressing room, where he puts on his own clothes, and is then discharged.

(*b*) *Ward Offices required for the direct use of the Sick.*

The custom has been to place this, the second class of ward offices, at the opposite end of the ward to that occupied by the nurses' rooms, scullery, &c. This entails additional expense in the pipes for the supply of hot and cold water, and sometimes in that of the drains for the removal of refuse water. There is, however, no reason why they should be so placed with the present improved arrangements for the removal of foul water, and the construction of drains outside the buildings.

Moreover, expense would be diminished if these appurtenances were placed nearer to those of the first class.

Ablution Room, Water-Closets, &c.—These ward offices of the second class ought to be as near as possible to the ward, but cut off from it by a lobby, with windows on each side, and with separate ventilation and warming, so as to prevent the possibility of foul air passing from the ward offices into the wards. When placed at the end of the ward, furthest from the entrance and nurses' room, they are best distributed at each side, so as to enable the ward to have an end window.

In the Breslau Surgical Hospital and some other German hospitals, as well as in the Johns Hopkins Hospital, these ward offices are placed at the same end of the ward as the scullery, nurses' room, &c.; but the arrangements in these hospitals leave something to be desired. M. Tollet's plan at Montpelier also places them centrally, and seems to cut them off more effectually than in the cases just mentioned.

The principle which M. Tollet would appear to advocate most strongly is in the St. Denis Hospital; there he allows no air connexion between the w.c.'s and slop-sink, &c. and the ward and other ward offices; he effectually cuts off the w.c.'s &c. by placing them in a detached turret-building on two or more floors, access to which is obtained on each floor by means of a light covered bridge arranged to impede ventilation as little as possible. In the Women's Hospital, Euston Road, and in the new Derby Infirmary, the w.c.'s, lavatories, and bath-rooms are placed in detached turrets, separated by an air space from the ward blocks; access being afforded by means of covered bridges.

The diagrams (Figs. 26 to 34) show these and other arrangements for the ward offices.

Adjacent to the ablution-room there should be a bathroom with one fixed bath supplied with hot and cold water. Terra-cotta when once warmed has the advantage of retaining the heat longer than almost any other material and of being always cleanly, but it absorbs a great deal of heat at first. Hence when the bath is frequently used it is the best material; but if the bath is seldom used, then copper is better, or polished French metal, which latter should be kept scrupulously clean or it acquires an offensive appearance. There should be no inclosed space round the bath, so that no dirt may accumulate; a broad wooden bar round it affords all necessary support to the bather.

A lavatory table of impervious material, such as slate or, what looks cleaner, common white marble, with a row of sunk white porcelain basins with outlet tubes and plugs, each basin supplied with hot and cold water, should be placed in the same compartment as the bath, but separated from it by a partition and door. It is a common mistake to place these lavatory basins too near each other, so that they cannot be used conveniently by patients standing abreast. Two feet six inches from centre to centre is a minimum distance.

There should be a full delivery of water from hot and cold water taps; and the waste-pipe should be large, to admit of rapid emptying. There should be a trap on the waste close under each basin, and each waste should deliver in the open air over a trapped gully. It is undesirable to have closed spaces under the basins, as they only accumulate dirt; all parts under the ablution table, and elsewhere, should have ample light; nothing should be kept in these offices but what is required for constant use, and everything should be open to inspection and arranged for easy cleaning. All fittings should be light-coloured, as they then show any want of cleanliness.

The waste-pipes, soil-pipes, and supply-pipes, both for hot and cold water, may usefully be painted in different colours so as to distinguish them at sight. There should be room for a portable bath for each ward, which should be provided with noiseless wheels, and hot and cold-water taps at a convenient height for filling; and there should be a sink on the floor-level for running off the water out of the bottom of the bath after it has been used.

Water-closets should not be less than two feet ten inches wide by four feet long. They should never be placed against an inner wall, but always against the outer wall of the compartment. A pan of a hemispherical shape, never of a conical shape, with a syphon, abundantly supplied with water to flush it out with a large forcible stream, is the best contrivance for the water-closet of a hospital. On the male side the urinal is always a structural difficulty, and it is only by great attention that it can be kept inoffensive. Probably moveable utensils standing on a light-coloured non-porous slab would be best.

The sink for slops, bed-pans, expectoration-cups, &c., which should have a compartment of its own, adjoining the water-closets, should be a high, large, deep, round pierced basin of earthenware, with a cock extending far enough over the sink for the stream of water to fall directly into the vessel to be cleaned, and of a large size with an ample supply of water; this sink should have a separate service arranged to flush it out like a water-closet pan. The space round it should be sloped into it either by means of a leaded or what looks cleaner a pottery surface, and there should be as few angles as possible to allow of accumulation of dirt. The space underneath should not be closed in; if it is, the enclosed part will be made a receptacle for rubbish.

The place for the retention of utensils, for the inspection of the medical man, is best arranged in a cupboard, with a door shutting it off from the lobby in which the w. c. and slop-sink are placed, but with a large grated opening to the outer air, and preferably a glazed flue may be led from it direct to above the roof: sometimes a perforated zinc receptacle for this purpose is fixed outside a window.

Walls of ablution-rooms and water-closets should be covered with white glazed tile, slate enamelled or plain, or Parian cement; plaster is not a good covering for them on account of their liability to be splashed, and of the necessity for the walls to be frequently washed down.

The nurses should have separate private water-closets. They should not use those of the patients.

There should also be water-closets for the patients who are well enough to leave their wards.

Water-closets and the ablution-room should each have ample windows opening to the outer air, certainly not less in proportion than the wards. They should have shafts carried up to above the roof, to carry off the foul air, and ventilating openings to admit fresh air independently of the windows. Warmth should be supplied to them independently both of the wards and of the lobbies, which should cut them off entirely from the wards. The lobbies should also be carefully ventilated by flues for extraction of air and by inlets for fresh air, and they should be well warmed.

Care in these details is essential to prevent any of the air from these conveniences passing into the wards and thus becoming a source of danger to the patients, especially in cold weather. All woodwork, such as seats to water-closets, should be of non-absorbent wood. The floors, unless warmed, must be of non-absorbent wood, and the greatest care should be taken in the jointing.

Drainage.—The following are the general principles to be observed with respect to the drainage of a hospital.

(1) Drains should be made either of glazed stoneware pipes with cement joints, or preferably of strong cast-iron pipes jointed with carefully made lead joints, or with turned joints and bored sockets. In no case should a soil-pipe be built inside a wall. It should be so placed as to be always accessible. Junctions between pipes of different materials should take place outside the buildings.

(2) The pipes should be generally 4 inches diameter. In rare instances need a drain-pipe for a hospital exceed 6 inches in diameter.

(3) Every drain 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, flush-tanks at the head and at intervals in its length should be provided. The drains should be laid in straight lines from point to point. At every change of level or of direction there should be reserved a means of access to the drain. Between these points the drains should be proved to be water-tight by plugging up the lower end of the drain-pipe, and filling it with water, provided always the extreme pressure in the pipes should not exceed 2 feet of head of water.

(4) No drain should be constructed so as to pass under any part of a hospital building, except in particular cases where it is unavoidable. In such cases the pipe should be of strong cast-iron, laid in a straight line between inspection chambers outside the building on each side, and the length of drain laid under the building should be freely ventilated at each end, with a flush-tank placed at the upper end.

(5) Every drain should be arranged so as to be flushed and kept at all times free from deposit.

(6) Every drain should be ventilated by at least two suitable openings, one at each end, so as to afford a current of air through the drain, and no pipe or opening should be used for ventilation unless 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 building from them.

(8) The soil-pipes from all water-closets, and waste-pipes from slop-sinks for urine, should be continued above the eaves of the house for ventilation, and there terminate, with the ends open to the air; and if such ends be at or near any

window of the house, it would be necessary to continue such pipes up to the ridge of the roof. Every such continuation should be of the full size of such soil or waste-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.

(9) 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 building, and discharging with an end open to the air.

(10) Waste-pipes from cisterns, sinks, baths, lavatory basins, &c. should be trapped close to the cistern, sink or bath or basin; otherwise the deposit which takes place even from clean water would in time create an offensive smell.

(11) All pipes for the removal of foul or the provision of fresh water should be carefully protected from frost.

There should be an intercepting chamber between the drains from each building and the main drain of the hospital. The drains from operation room, post-mortem room, and mortuary, should especially be carefully intercepted. The main drain should be ventilated and arranged to be flushed independently.

Proportion of Ward Offices to Wards.—These various offices will vary but little with the size of the ward; that is to say, a ward of twenty beds will require nearly as large ward offices as one of thirty-two beds. The number of water-closets and lavatory basins depends to some extent on the severity of cases treated; twelve per cent. of the number of beds may be assumed as a rough approximation in each case. But whilst three water-closets per ward will suffice for a ward of thirty-two beds, two at least will be required for wards containing eight to ten beds. The superficial area to be added to the hospital in the case of wards of thirty-two beds for these appliances would be about 30 square feet per bed, whereas in wards of twenty beds each it might come to above 60 square feet per bed.

The following table shows approximately for a few hospitals the superficial area of the space occupied by ward offices, passages, &c., exclusive of day or dining rooms, per bed in the ward unit.

Hospital	No. of Beds.	Superficial Feet per bed.
1. Eloi	62	30
2. Tenon	56	22 { exclusive of staircase
3. S. George's Union	32	20
4. Bichat	30	18
5. Johns Hopkins	28	64
6. S. Denis	16	67

This shows roughly how much cheaper large wards are than smaller ones in first construction.

CHAPTER XVI.

AGGREGATION OF WARD UNITS.

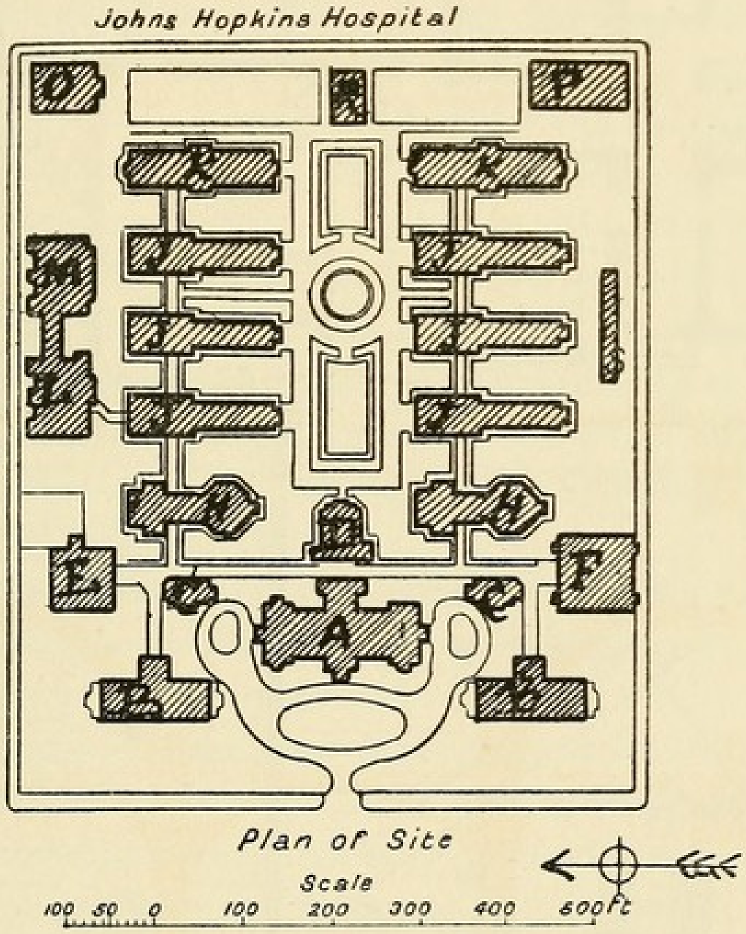
THE ward, with its ward offices as before described, is the unit or basis of hospital construction. It is a small hospital which would only require certain administrative additions to make it complete. It forms a basis for any hospital. It could be developed into a Cottage Hospital, an Isolation Hospital, a Children's Hospital, or indeed, under varied conditions of internal arrangement, into almost any other form of small hospital; the principal ward being made larger or smaller according to the requirements of each case.

And in addition to this, a large hospital of any required size might be formed by the addition of similar units.

There are, however, two important considerations in reference to the number of wards which should be kept prominently in view, in designing a hospital.

In the first place, the necessity of arranging the number of wards in proportion to the number of patients, so that in each year every ward shall be closed once for aeration, cleaning, and repairs. Such closing should preferably occupy one month, so that there should in large hospitals be one extra ward in every twelve. And in smaller hospitals there should be always one spare ward. This is a matter which is very much overlooked in the original design of a hospital. A main object of this resting is to flush the ward with air as we flush a drain with water; hence the object of having openings on floor levels which, if not used during the occupation of the ward by patients, would be of great utility for the aeration of the ward.

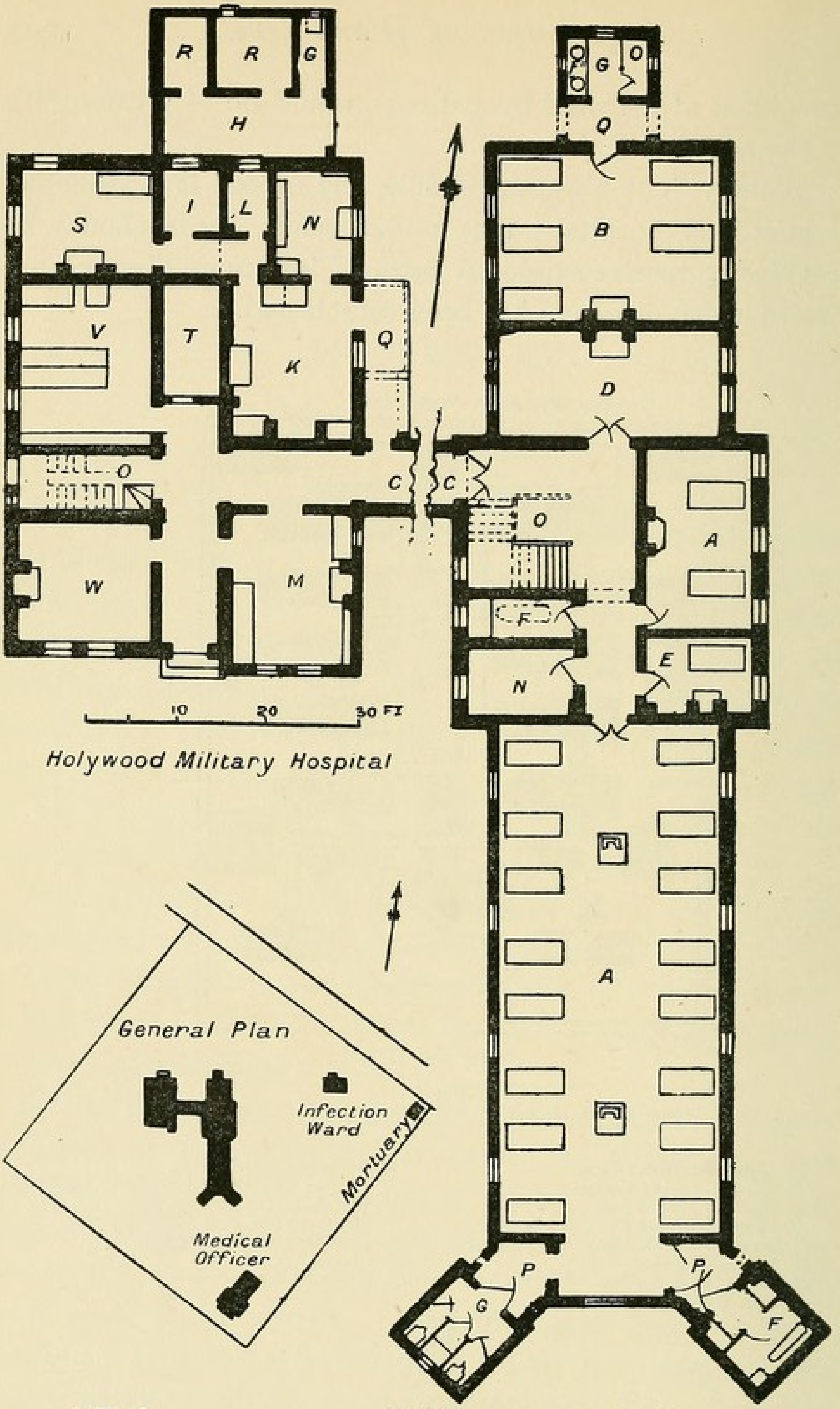
Secondly, it is always desirable, and indeed it is essential, in infectious hospitals, that probationary wards should be provided to receive supposed cases of infectious disease until a satisfactory diagnosis has been established.



A. Administrative Offices.
B. Private Paying Patients.
C. Bathing Establishment.
D. Dispensary and Drug Stores.
E. Kitchen and Domestic Apartments.
F. Nurses' Home.
H. Sick Wards.
J. Sick Wards.
K. Isolation Wards.
L. Lecture Theatre and Students' Building.
M. Out-patients Department.
O. Mortuary and Post Mortem Room.
P. Laundry and Wash-house.
R. Chapel.
S. Green House.

Fig. 36.

Many of the more recent forms of hospital units and their aggregation into hospitals are given in the admirable work of Dr. Mouat and Mr. Saxon Snell on hospital con-



A. Wards.
B. Orderlies Barrack Room.
C. Corridor.
D. Day Room.
E. Orderly.
F. Bath Room.
G. Lavatories and W.C's.
H. Yard.
I. Med. Comfts.
K. Kitchen.
L. Larder.
M. Surgery.
N. Scullery.
O. Staircase.
P. Lobby.
Q. Open Porch.
R. Wood and Coals.
S. Cook's Room.
T. Wine and Beer.
V. Pack Store.
W. Waiting Room.

Fig. 36 *a*.

struction, and in Mr. Burdett's 'Hospitals and Asylums of the World.'

The plan of the Johns Hopkins Hospital (Fig. 36) affords a good illustration of the arrangements of buildings on a site.

Whilst the Johns Hopkins Hospital shows a carefully devised plan for a large hospital, the accompanying plan of the new Military Hospital at Holywood, Belfast, shows a convenient grouping of the several buildings required for a small hospital.

This hospital is arranged to afford the necessary height of 13 feet for the wards and their appurtenances; whilst the subsidiary accommodation, including the Day Room and Orderlies' Barrack Room in the main or ward building, is limited for economy to 10 feet high.

The upper floor contains two wards similar to those on the ground floor and, in addition, a ten-bed ward over the Day Room and Orderlies' Barrack Room, opening from the staircase on a lower level.

The upper floor of the administrative building contains the Hospital Sergeant's quarters, Linen Rooms, and other such stores.

Aggregation of ward units in the construction of a hospital.—The principles upon which these units of ward construction, or, as they are generally termed, pavilions, should be arranged when aggregated are as follow:—

(1) There should be free circulation of air around and between the pavilions.

(2) The space between the pavilions should be exposed to sunshine, and the sunshine should fall on the windows and walls. The arrangement by which sunshine will always fall to the largest extent on the space between pavilions and also be distributed most evenly over the wall surface, is obtained in this country by placing the pavilions on a north and south line or axis, because the slanting rays of the sun fall in the morning on the eastern, and in the evening on

the western side. With an east and west axis one side of each pavilion and part of the area between the pavilions is sunless for most of the year: this might possibly have advantages for a hospital in a southern climate, but in a hot climate, just as much as in a cold climate, direct sunshine is necessary to promote healthy conditions. A place from which sunshine is always excluded is never healthy.

(3) The distance between adjacent pavilions should not be less than twice the height of the pavilion reckoned from the floors of the ground-floor ward to the eaves, if with a very sloping roof, or to half the height of the roof, with a steep roof. This is the smallest width between pavilions which will prevent the wards from being gloomy in this climate. Where there is not a free movement of air round the buildings, the distance should be increased. In the new wards of the Western Fever Hospital at Fulham, whilst the two-story fever blocks are placed 70 feet apart, the diphtheria blocks are placed 112 feet from the fever blocks.

As regards the question of wards on one floor or wards superimposed in two or even more floors, it may be accepted that, so far as the sick are concerned, they would, as a rule, be better placed on one floor in a ward unit well raised off the ground without anything over them. These units could be entirely separate, or they could open out of a common open verandah or glazed corridor; and if land is cheap, and the site fairly level, it is probable that such an arrangement might be more economical than building two-story buildings. The pavilions might be nearer together than in the case of wards on two floors, and consequently the distance to be traversed by the medical men on visiting the wards would be from 30 to 35 feet horizontally between the pavilions in the case of the one-story hospital, as compared with ascending from 14 to 16 feet by a staircase in the case of a two-story building. On the other hand, the cost of drainage may be somewhat greater, and facilities for supplying hot and cold water to the ward offices will be less, in the one-story hospital.

On town sites it is sometimes absolutely essential to build hospitals as compactly as possible; in these cases, whilst the first cost may be greater, the current expenses would probably be less in a building with wards on two floors provided with lifts and other labour-saving appliances. A new town hospital should not be commenced unless the funds admit of an area adequate to healthy construction. But where a town hospital has to be remodelled on an existing site, it may be necessary to accept special arrangements in order to mitigate some departure from entirely satisfactory hygienic conditions. The necessity for superimposed wards, which in some town hospitals cannot be limited to two floors only, would render a special construction of staircases advisable to prevent communication of air between wards. The proximity of a noisy street would require special arrangements in the foundation of the buildings containing wards, to prevent the patients from feeling the vibration of heavy drays, and might even compel a corridor system of ward construction next the street instead of the pavilion system in order to ensure quiet for the patients. But where space admits, the location of each single ward unit, or possibly a double ward unit as a small separate hospital, is preferable to the aggregation of patients in large buildings. Unless connected together by means of covered corridors this would entail, no doubt, more exposure to nurses, attendants and doctors than their aggregation in palatial buildings; but where nurses and attendants have been provided with proper protection against the weather, in going to and from the wards to the administrative buildings, such exposure has not been found injurious to health.

Whilst separation of the ward unit has been the principal feature of modern hospital construction in Germany and more recently in the United States, the complete separation of ward units in this country has only been adopted in some of the

Metropolitan Asylums Board and other Infectious Hospitals. In the aggregation and connexion of ward units, except under special circumstances, there should not be more than two floors of wards in a pavilion. If there are three floors or more, in addition to the increase of patients under one roof, the distances between the pavilions become very considerable if the rule, which ought to be absolutely observed, is adhered to, of placing the pavilions at a distance apart equal to at least twice the height of the pavilion, measured from the floor level of the ward nearest to the ground. Moreover, heated impure air from the windows of the lower wards has occasionally a tendency to pass into the windows of the wards above. Besides, when two wards open upon a common staircase, there is to some extent, danger of a community of ventilation. On these grounds it is not desirable that a hospital should have more than two floors of wards one over the other; and the basement or lower story under sick wards should not be utilized for purposes such as cooking, &c., from which smells might penetrate into the wards.

When possible, it is best not to continue the staircase into the basement.

When there are as many as four wards, one over the other, the staircase becomes a powerful shaft for drawing up the impure air of the lower wards, and the upper part of the staircase therefore requires special care in ventilation to prevent impure air from penetrating into the upper wards.

In the case of Fever Hospitals for the Metropolitan Asylums Board recently erected by Messrs. Harston, for two floors of wards, the objection to the staircase forming a shaft for impure air between the lower and upper ward has been met by cutting off the staircase entirely from the entrance to the lower wards. The pavilions are connected by means of a covered way consisting of a roof on columns. From this covered way there is a direct separate entrance marked A to the lower ward, whilst the staircase leading to the upper ward has a separate entrance marked B so arranged as to give access from the covered way only to the upper wards. An outside staircase is also provided at the further end of the ward for escape in case of fire.

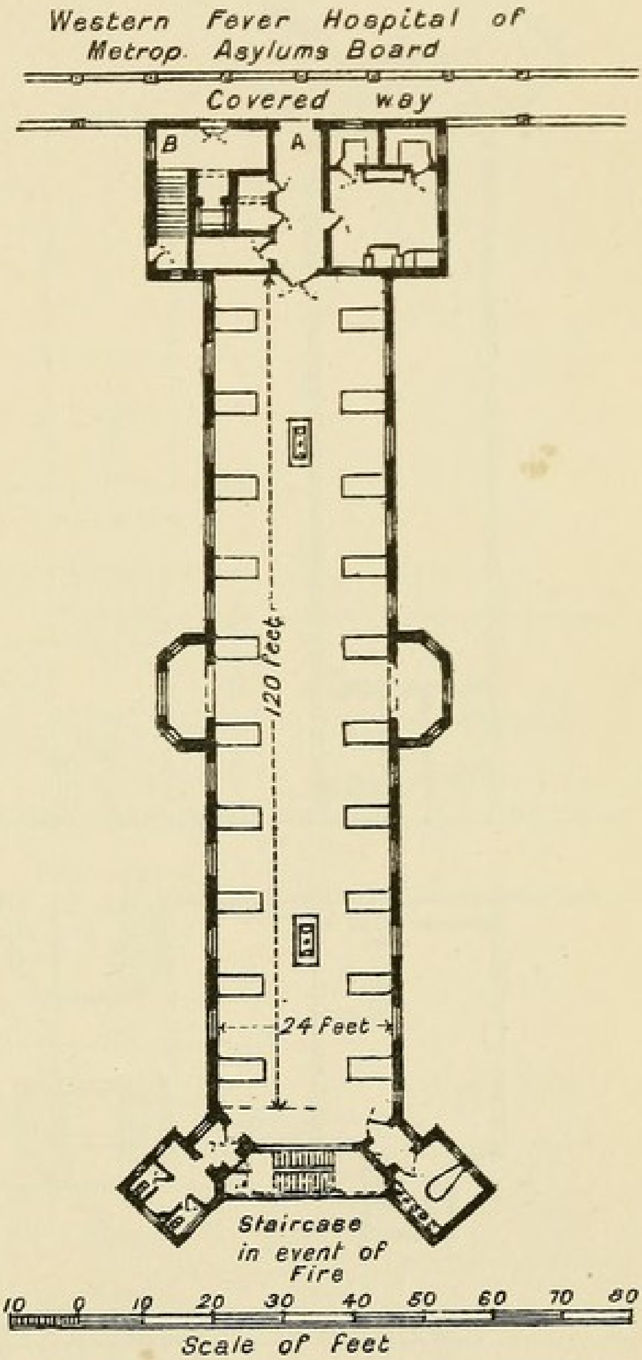


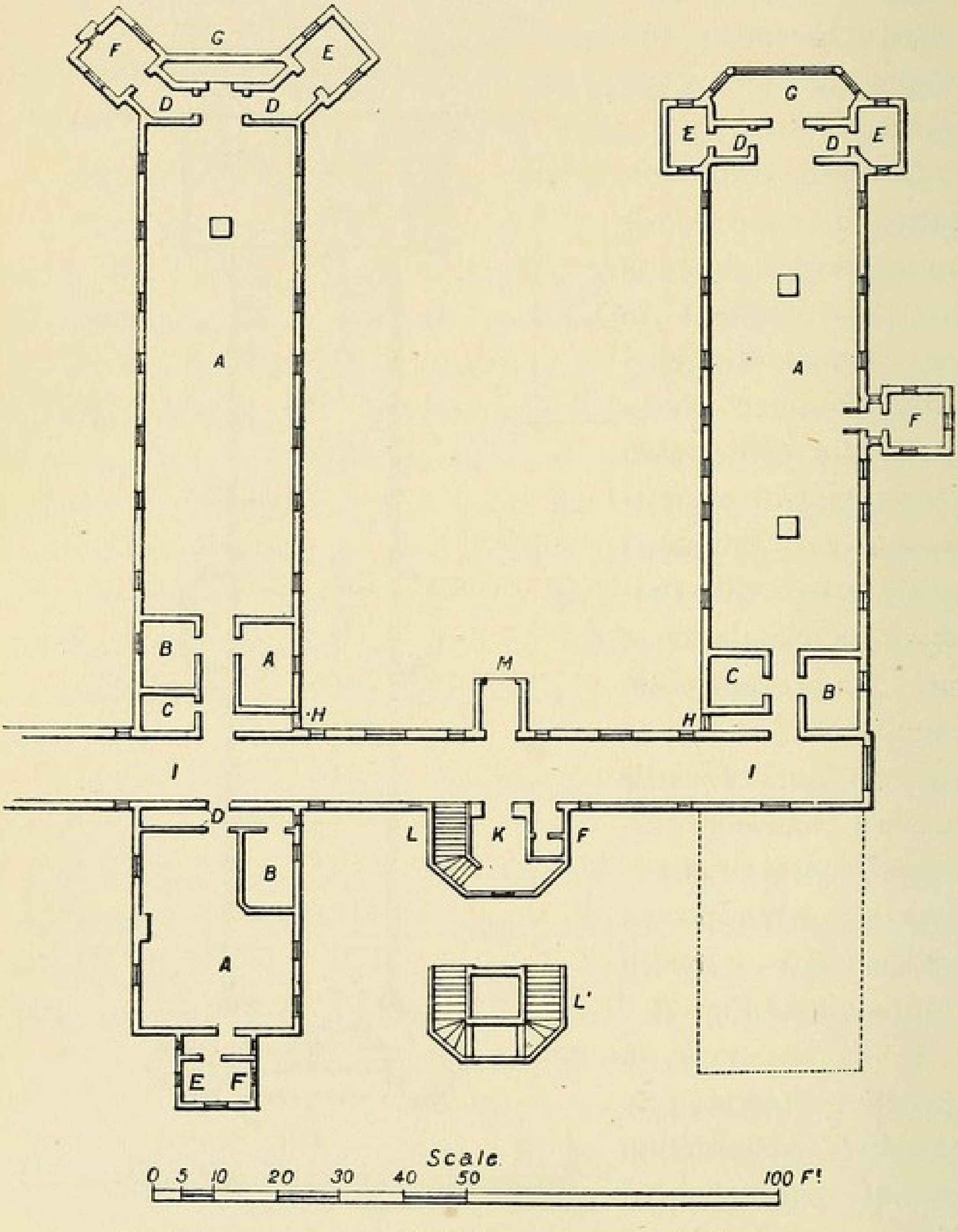
Fig. 37.

Covered communication between wards on the several floors of parallel pavilions in large hospitals is generally obtained by a block of superimposed corridors, with a staircase at each pavilion; this interferes with sunshine and circulation of air. To prevent community of air between the two floors of wards in the Colchester Military Hospital the staircase has been placed intermediate between the pavilions Fig. 38.

It is, however, a defective feature in hospital construction to unite parallel ward units, which consist of two or three or more superimposed floors of wards, by solid corridors on each floor so as to form closed courts.

Hence the communication between parallel pavilions should be arranged with as little interference as possible with the light and flow of air between the pavilions.

COLCHESTER MILITARY HOSPITAL.



A. Ward.
B. Orderly.
C. Scullery.
D. Lobby.
E. Bath, Lavatory.
F. W.C.
G. Balcony.
H. Foul Linen.
I. Corridor.
K. Store.
L. Stairs.
L[1]. Upper ditto.
M. Porch.

Fig. 38.

The staircase leading to the two ward units in a double pavilion should break the air connexion between them. To effect this neither ward unit should in any way trench upon the staircase, which should be amply lighted, warmed

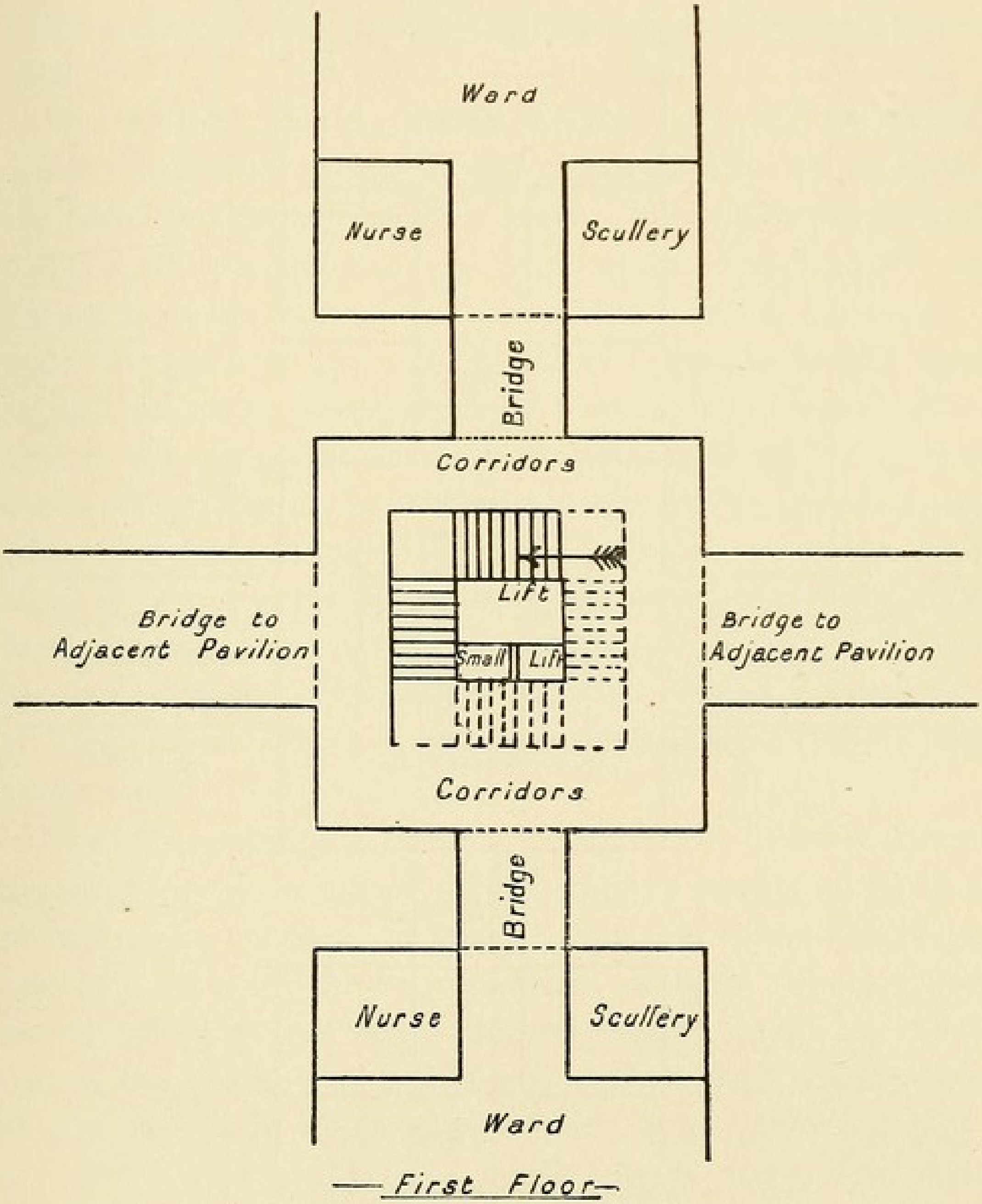


Fig. 39.

and ventilated independently of either ward. An arrangement of this sort has been adopted by Mr. Keith Young in the new Derby Infirmary.

To secure the object above mentioned, the staircase should be entirely detached, as shown in Figs. 39, 39*a*, and connected with all adjacent wards by means of light bridges; an open bridge would be best, but it would probably be desired to have a roof and glazed sides, in which case it should not

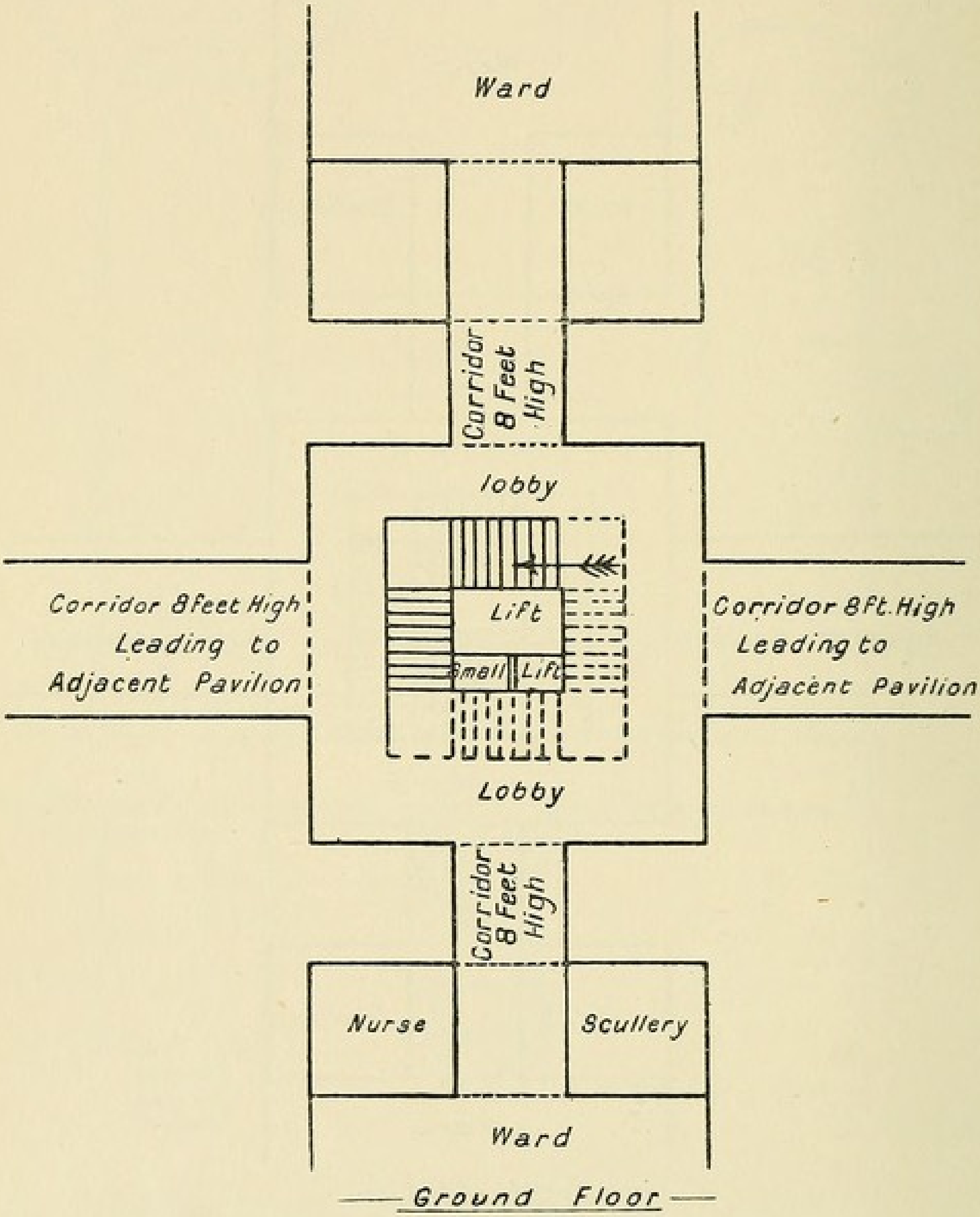


Fig. 39 *a*.

exceed 7 feet 6 inches or 8 feet in height, and be provided with ample cross-ventilation.

The centre of the staircase would afford a space for two lifts, one for patients and attendants, the other, a small one for food, coal, &c., both carried down to the subway in the basement.

This detached staircase would largely discount one of the objections to superimposed wards and would probably be the safest arrangement for a town site when several floors of wards exist

If a covered corridor unites the ends of pavilions on the ground floor only, its roof should not at most be carried above the floor level of the first-floor ward. For, whilst the floor of the first-floor ward would be from 14 to 16 feet above the ground-floor ward, it would be unnecessary for purposes of communication to give the corridor a greater height than 7 feet 6 inches or 8 feet; there is however this consideration, that if the top of the corridor is made level with the ward floors of upstairs wards, it affords a convenient terrace on to which the beds of patients can be wheeled, so as to allow them to lie out in the open air. But a more convenient place, because more sheltered from wind, would be afforded by a broad verandah in front of the end-ward window, or, as shown in Figs. 31 and 34, by a broad verandah running along the side of the ward.

The communication on the upper-ward floors between adjacent pavilions would be effected by means of bridges, which might be open, or covered and with glazed sides, as desired; these would be supported on light columns, and would afford places on to which patients could be rolled out of the wards into sunshine if desired, and would allow of the free flow of air underneath. The girder supporting the bridge could have ample depth above the floor of the bridge, so as to leave as much space as possible between the top of the lower corridor and the floor of the bridge for the free passage of air. At Antwerp, and at Mons, bridges connect the upper wards with the adjacent buildings.

In the Women's Hospital in the Euston Road, of which

Mr. Brydon was architect, in order to obtain the maximum of aeration on the restricted site on which the hospital is built, the connexions between the administrative buildings and the wards on the upper floors are all made by means of bridges, which admit of circulation of air underneath.

The treads of a hospital staircase intended for patients should preferably be 1 foot wide by $4\frac{1}{2}$-inch rise, and in no case should they exceed from $5\frac{1}{2}$ to 6-inch rise. There should be a handrail on each side. There should be a landing after every eight steps, for the easy ascent and descent of patients. There should be nothing combustible in or near the staircase. To prevent panic in cases of fire a subsidiary staircase at the opposite end of the ward may be advisable. This can be conveniently carried down from an open balcony in front of the end window of the ward.

But if the wards are free from combustible material, and if superimposed wards are separated by fire-proof floors, the risk from fire ought to be small. It is, however, essential that every hospital should be provided with simple and easily-applied means for checking the spread of fire. Adjacent to every ward and on every floor hydrants with hose should be placed. There should also be a hand engine available, and fire buckets always kept filled; extincteurs would also be useful. Glass grenades are questionable, as the pieces of glass from a grenade thrown on to a fire to extinguish a chimney on fire have flown back into the ward among the patients. It may be assumed that, whatever the apparatus, the members of the hospital staff should be accustomed to its use by periodical exercises.

The service of a hospital with more than one floor of wards can conveniently be carried on by subways under the lower corridor connecting the ward units. The connection of the subway with the ward floors must be by lifts. It would probably be found more economical to have lifts of two sorts, one for carrying patients or attendants about 7 feet × 4 feet wide, the other for coals, food, &c., about 2 feet 6 inches × 2 feet 6 inches. High-pressure hydraulic power is at present the safest and most convenient force for working lifts, but electricity may eventually take its place.

The larger lift would bring up patients and take down the dead to the subways, whence the body would be conveyed to the mortuary.

It has already been explained that there is a limit to the numbers which should be congregated under one roof. But the limit may be safely made to depend to some extent on the nature of the cases.

With military hospitals, into which in time of peace many slight cases are received, it was decided that as many as 136 cases might be placed in one double pavilion, divided into two equal halves in such a way that the communication between the halves was cut off by through ventilation. Of course in time of war, with wounded men, other conditions would prevail. In town hospitals, where the cases are of a more severe character, a similar double pavilion would probably not contain above 80 to 100 beds.

An increased size in any given hospital ought not to be determined by increasing the number of beds in any one building, but by increasing the number of units, each containing from 80 to 100 beds; and the extent to which these units should be multiplied would, if the units have been properly constructed and arranged, be determined not so much by the number of patients as by considerations of economy in administering the hospital.

At the same time it is not advisable to have very large hospitals. It would be more convenient to the inhabitants of a town to have two hospitals of 500 beds each, serving a particular district of the town, rather than one large hospital of 1,000 beds, which would after all only be convenient for one of the districts; and in selecting sites and making arrangements for new hospitals it should be remembered that the actual area per bed required for a hospital should be increased in proportion to the increase in the number of beds; thus if 80 beds per acre are assumed as the admissible number for a hospital of 250 to 400 beds, a smaller number of beds per acre should be adopted in the case of a hospital with 1000 beds.

CHAPTER XVII.

ADMINISTRATIVE BUILDINGS.

THE accommodation for the wards must be supplemented by the arrangements for what is called the administration. But it is beyond the scope of these notes to enter very fully into this part of hospital construction.

The position and general construction of the administrative buildings should be made quite subservient to the accommodation for the sick, and to the broad general principle that these buildings should not interfere with the circulation of the air around or the light of the wards.

The first point is to consider what is the smallest amount of this subsidiary accommodation which will suffice, and to provide that amount, and no more. Many rooms mean many servants, much cleaning, and consequent additional expense.

As already mentioned, the necessary subsidiary accommodation falls under, firstly, that connected with the admission, treatment, and discharge of the patients: secondly, that connected with boarding the patients: and thirdly, that connected with general supervision.

(1) *Rooms connected with admission, treatment, and discharge of patients.*

Reception, examination, and discharge rooms.—These are required, however small the hospital may be. They are placed near the entrance. There is a waiting room, examination room, and patients' bath room. The doors of these should all be wide enough to admit of the passage of a stretcher on wheels.

In hospitals where the patient's clothes are taken from him on entering, and where he is supplied with complete hospital clothing, the linen clothes would be sent to be washed and the woollen clothes to be passed through the disinfection chambers, after which they would then be returned to the store, conveniently near the discharge room, labelled for delivery to the patient when he leaves the hospital. Whilst in the store they ought to be unfolded, examined, and refolded at least once a fortnight as a preservative against moths.

In the case of Infectious Hospitals the discharge room consists of an undressing room where the hospital clothing is taken off and left, a bath room where the patient bathes, beyond which is a dressing room where the patient resumes his own clothes and departs.

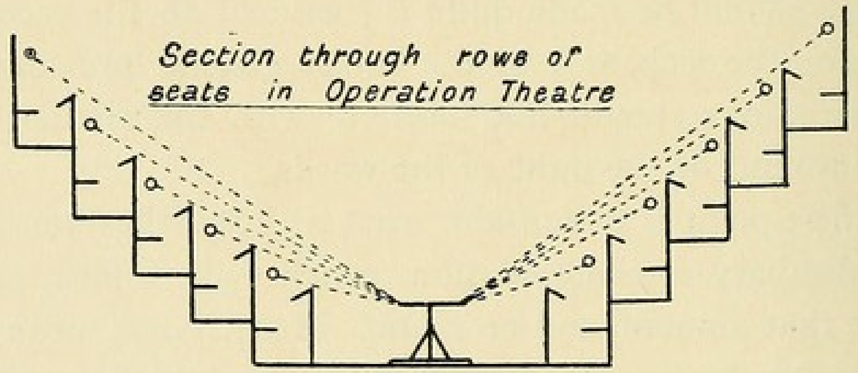


Fig. 40.

Dispensary and drug store.—The former should be in a fairly central position. Where there is an out-patient department it may be convenient that it should supply the latter as well as the hospital. It requires a still room fitted with necessary appliances next to it.

The Splint Room should be conveniently placed with respect to the surgical wards and to the operation room. It should be light, and should have a small workshop attached, with the necessary tools for the work connected with splints, bandages, &c.

Operating Room.—The doors should be double, of varnished oak or hard wood, about 5 feet wide, to allow ample room for beds on wheels to be wheeled in and out. The floors should preferably be of marble terrazzo or of some substance which would not absorb the fluids that necessarily fall upon it. The lower half of the walls should be of some glazed or polished material, durable, easily washed or cleaned, and of a

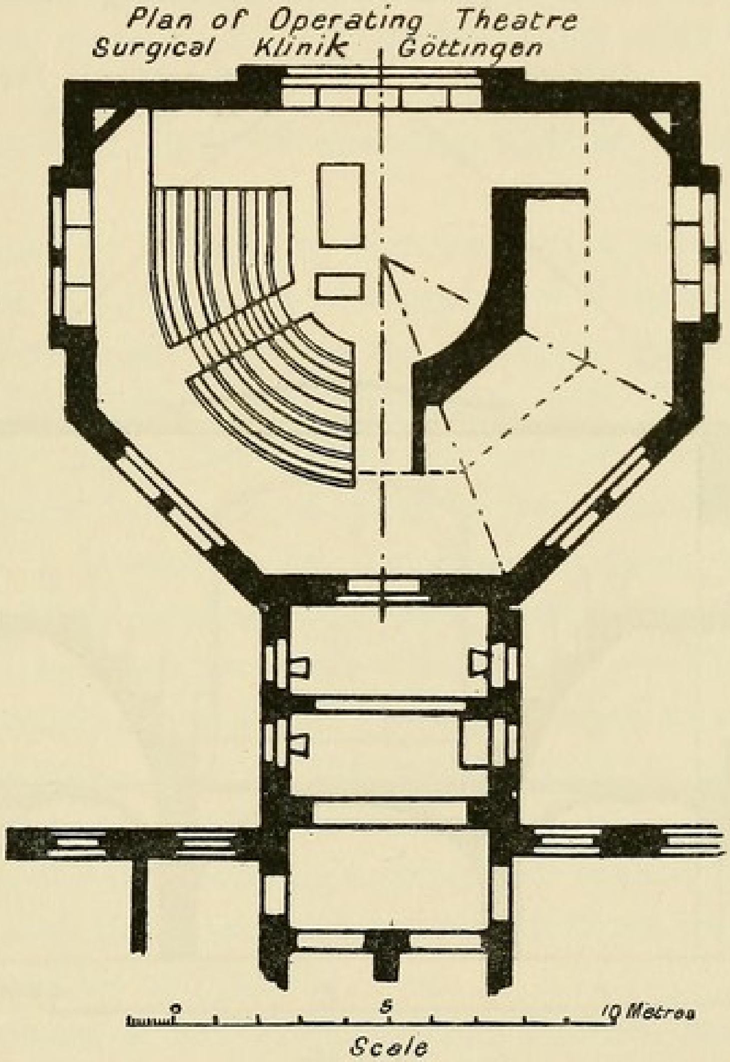


Fig. 41.

restful colour, which would not absorb light. The upper part may be of plaster, similarly coloured or painted. Operation theatres in small hospitals have sometimes had their walls entirely covered with sheets of glass.

In the operating theatre of medical and surgical schools seats must be carefully arranged to enable the students to see over each other's heads when seated.

There should be ample light, and no dark corners where dirt or dust might accumulate, either under the seats or otherwise. There should be windows in the sides, and a large window, if possible, to the north as well as top lights, but the windows should be so distributed as to avoid glare.

Figure 41 shows a plan of the operating theatre of the

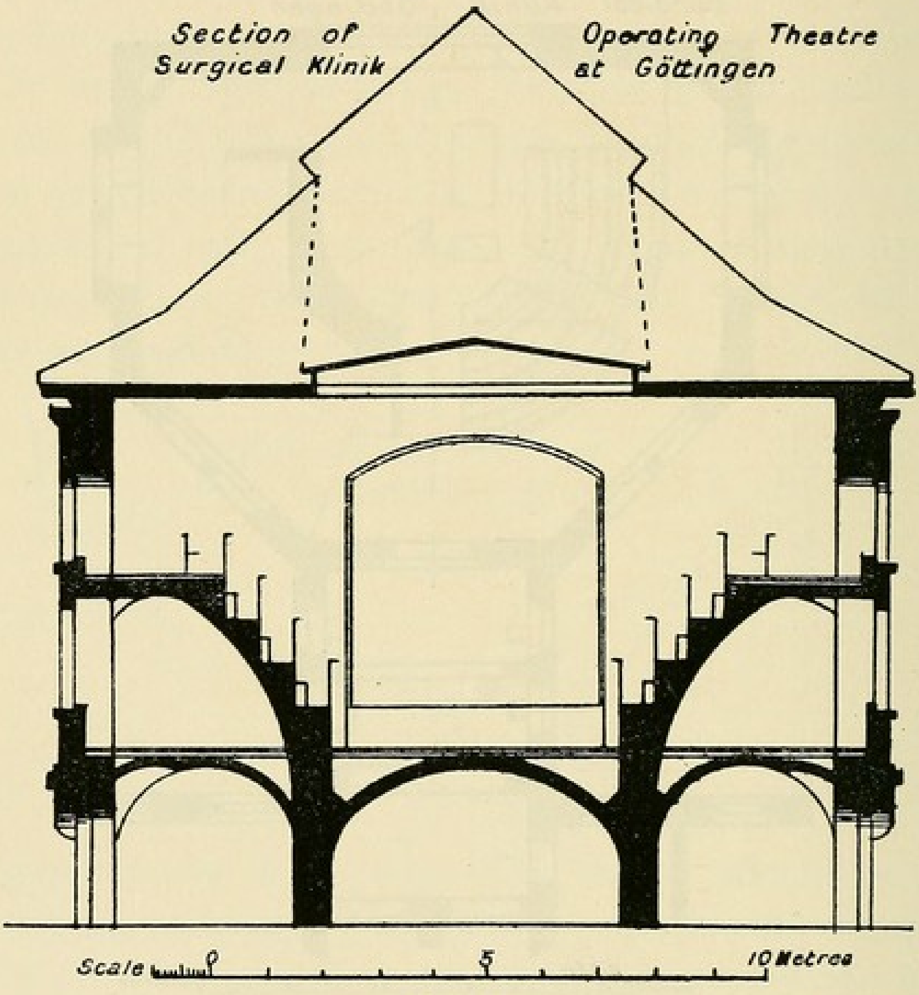


Fig. 42.

Chirurgische Klinik at Göttingen, which was completed at the end of 1889: the section of the theatre is shown in Fig. 42.

This theatre is of a half-elliptical form, and large enough to hold two operating tables at the same time. The section shows how light penetrates to every part.

The students come in on the upper gallery, and the patients are brought in through the centre on the ground floor from the waiting room without encountering the students, and pass out to the room for patients operated upon, whence they are taken to their wards.

There are vertical windows on the side. The principal window is to the north, and is 14 feet 6 inches wide and 16 feet high: it is furnished with shutters, which can cover it nearly up to the ceiling, and thus if desired the whole light can be made to fall on the operating table from the ceiling.

A semicircular form of operating theatre is sometimes preferred.

It must not be omitted to mention that a room close at hand for the administration of anæsthetics is necessary; and that it is convenient to place the room, for applications of plaster of Paris bandages, in connexion with the operation room. The tables and shelves for instruments, &c. may advantageously be made of glass or very hard wood, for cleanliness; it is needless to say that the most scrupulous cleanliness should be observed in every part of the room.

Adjacent separate wards are occasionally provided, either as resting wards or as wards for certain cases to remain in after operations. But in the more recent hospitals this practice does not appear to prevail largely.

Special baths are becoming a recognized branch of hospital treatment, and these should be provided in addition to the baths required for each ward.

These consist of medicated, vapour, Turkish, and electric baths, as well as permanent water-baths.

They might with advantage be placed where they could be made available for out-patients as well as patients in the hospital.

A dead-house and post-mortem room should be provided, quite outside and detached from the hospital: it should have a surgeon's room and dressing room, as well as a room in which the coffin would be placed previous to removal of the body.

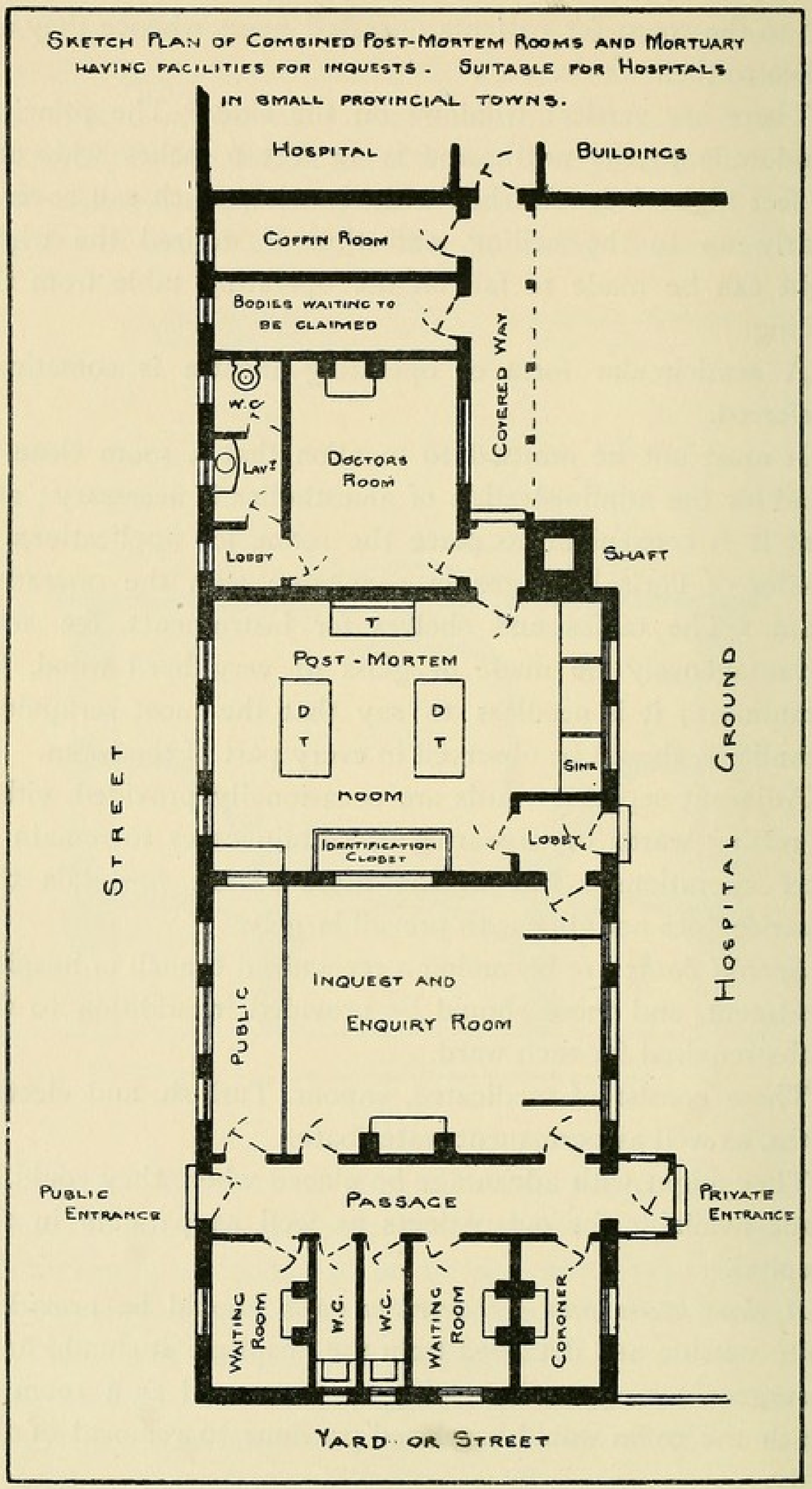

SKETCH PLAN OF COMBINED POST-MORTEM ROOMS AND MORTUARY
HAVING FACILITIES FOR INQUESTS. SUITABLE FOR HOSPITALS
IN SMALL PROVINCIAL TOWNS.
HOSPITAL
BUILDINGS
COFFIN ROOM
BODIES WAITING TO BE CLAIMED
COVERED WAY
W.C.
LAVY
DOCTORS ROOM
LOBBY
SHAFT
T
POST-MORTEM
D T
D T
SINK
ROOM
IDENTIFICATION CLOSET
LOBBY
STREET
HOSPITAL GROUND
PUBLIC
INQUEST AND
ENQUIRY ROOM
PUBLIC ENTRANCE
PASSAGE
PRIVATE ENTRANCE
WAITING ROOM
W.C.
W.C.
WAITING ROOM
CORONER
YARD OR STREET

Fig. 43.

There should also be a waiting room for the patients' friends; and the doors should be so arranged that the hearse can come in and go out unseen from the hospital.

If the hospital has a medical school attached to it, it would be convenient that a post-mortem room, with dissecting tables, microscope room, a chemical, bacteriological, and physiological laboratory, a pathological museum and lecture-room, should be arranged in connexion with the mortuary.

There should also be lavatories, room for hats and coats, dressing room, and general waiting room required for the students. These should be abundantly light and kept scrupulously clean.

All the rooms in this section should be quite plain, and without projections or ornaments, which only form a resting-place for dust.

In smaller hospitals, and especially in hospitals in country places, it occasionally happens that the holding of an urgent inquest occasions considerable trouble. This involves the viewing of the body, and unless facilities are afforded for the inquest near the hospital inconvenience results to the jury and others officially connected with it.

This would be obviated by the plan shown in Fig. 43, from the design of Mr. Peach, architect.

Out-patients' Department.—Those hospitals which afford out-door relief require a dispensary for out-door sick as well as casualty rooms for surgical cases, but the latter would be used also for cases which would go direct into hospital.

The out-patients' department is in reality a separate establishment, and should always have an entrance separate from the hospital; indeed, it might preferably be altogether detached, except for the convenience of the medical men and the school, and in order to have one drug store and one place for making up medicines.

This department, and especially the waiting-room which is always a fertile source of impure air, should never be placed under the wards, nor in interspaces between wards, nor near the windows of wards. In fact, the whole department would be preferably detached and near the entrance gate; but it should be well ventilated and warmed and very light. In a General Hospital it would be convenient to place it near the Dispensary.

There must be waiting rooms for males apart from females, each with separate entrances and exits, and W.C.'s attached. A refreshment stall is desirable; and in some hospitals a dining-room is appended for children and sickly patients.

The number of examination rooms must be proportioned to the number of medical men who attend. They would probably include male and female surgical casualty rooms; consulting and operating rooms for ear and throat; a gynæcological consulting room; ophthalmic examination room; medical consulting rooms; a room for massage and electric treatment; and rooms for isolation, and for the temporary reception of insane or noisy patients, with beds.

Each examination room should be well lighted and large enough for simple operations, and provided with necessary sinks, and hot and cold water laid on. Each should have a small dressing room with a double entrance, so that, when the patient has had to undress, the physician or surgeon may at once be left free for the next case. In some of the surgical departments operating and recovery rooms are necessary.

There should be a microscopic room, and arrangements for darkening parts of the examination rooms or otherwise for ophthalmoscopy, &c. A small chemical and a physical laboratory should also be attached; but these might be conveniently placed in connexion with the dispensary, and be common to the other departments of the hospital. To this department lavatories for the physicians and surgeons would be attached.

The walls, floors, fittings, &c., should be of some non-porous material; there should be no projections for dust, and all the rooms should be light and be kept scrupulously clean.

As already mentioned, the baths for treatment should be arranged so as to be available for out-patients.

(2) *Rooms connected with Boarding the Patients.*

The kitchen and the provision and other stores, between which and the wards there is constant movement, should be as central as possible, so as to save labour; but the kitchen should be cut off from any corridor connecting together the pavilions.

In connexion with this department would be a receiving and weighing room for receiving the provisions, convenient larders, and other stores.

The kitchen should be fitted up with adequate means of cooking rapidly and economically; the cooking apparatus should be adapted to cook a variety of food, and to secure the greatest digestibility and economy in the nutritive value of food; these are matters essential to the patients' comfort and recovery, and to economical administration.

The kitchen should communicate with a large scullery attached for washing up; the serving-room would give access to both. The food would be delivered from the kitchen into small wagons of non-conducting materials arranged to prevent any loss of heat; and the dirty dishes and plates would be handed back through the serving-room to the scullery.

In hospitals in towns, where the kitchen must be in connexion with the main structure, it has sometimes been placed on the top floor. This is the case with the new Liverpool Hospital and the Hospital for Women in the Euston Road. The kitchen had been previously so placed in the Barnes Hospital at Washington, and in the New York Hospital designed in 1875. Surgeon-General Billings observes upon the former: 'The placing of the kitchen in the third story of the hospital, which was the best feature in an otherwise poor hospital, was a decided success in more ways than one. The odours from cooking are almost entirely excluded from the building, although sometimes the lift which passes through the kitchen down to the dining room acts as a sort of air pump, and draws or forces some of the air from the kitchen down to the second floor.'

A kitchen on the upper floor may have advantages in some respects on a restricted town site. With a system of lifts, the provisions received in an office below would be conveniently sent up, nor would there be any difficulty in lowering all the food to the basement in small wagons designed to retain heat, and moving it in the subways to the pavilion for which it is destined.

Refuse.—It is an axiom of hospital administration that no refuse of any sort should remain on the hospital premises. The refuse consists of—

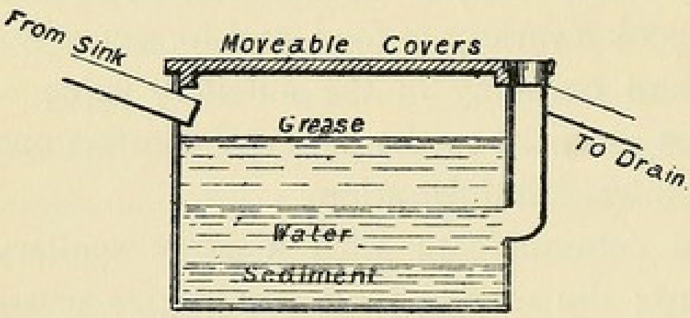


Fig. 44.

(*a*) Liquid refuse, including water from washing, slop water, &c. This would be removed by drainage. In connexion with this, provision must be made for catching the grease from the kitchen waste water, as shown in Fig. 44. A moveable pan placed under the sink, constructed on the same principle, would answer probably better.

(*b*) Excreta should also be generally removed by drainage in any permanent hospitals; and where it could not be conducted into an existing system, it should be applied to land—either by irrigation or intermittent downward filtration according to circumstances. In small country hospitals earth-closets might be made use of; but they require great care to avoid nuisance, and the simpler they are in construction the better[1].

(*c*) Ashes. These would be removed by a contractor.

(*d*) Vegetable and animal refuse. Some of this refuse might be sold or given away; but much of it would be best destroyed on the premises.

(*e*) Refuse connected with treatment of the patients, not disposable in the drains. This latter class of refuse should be destroyed on the premises, and for this purpose there should be a destructor attached to every hospital in which refuse matter either connected with the wards or the kitchen department could be destroyed.

In the Metropolitan Asylums Board Infectious Hospitals, all the kitchen refuse is destroyed instead of being sold, but this would not be necessary in an ordinary hospital.

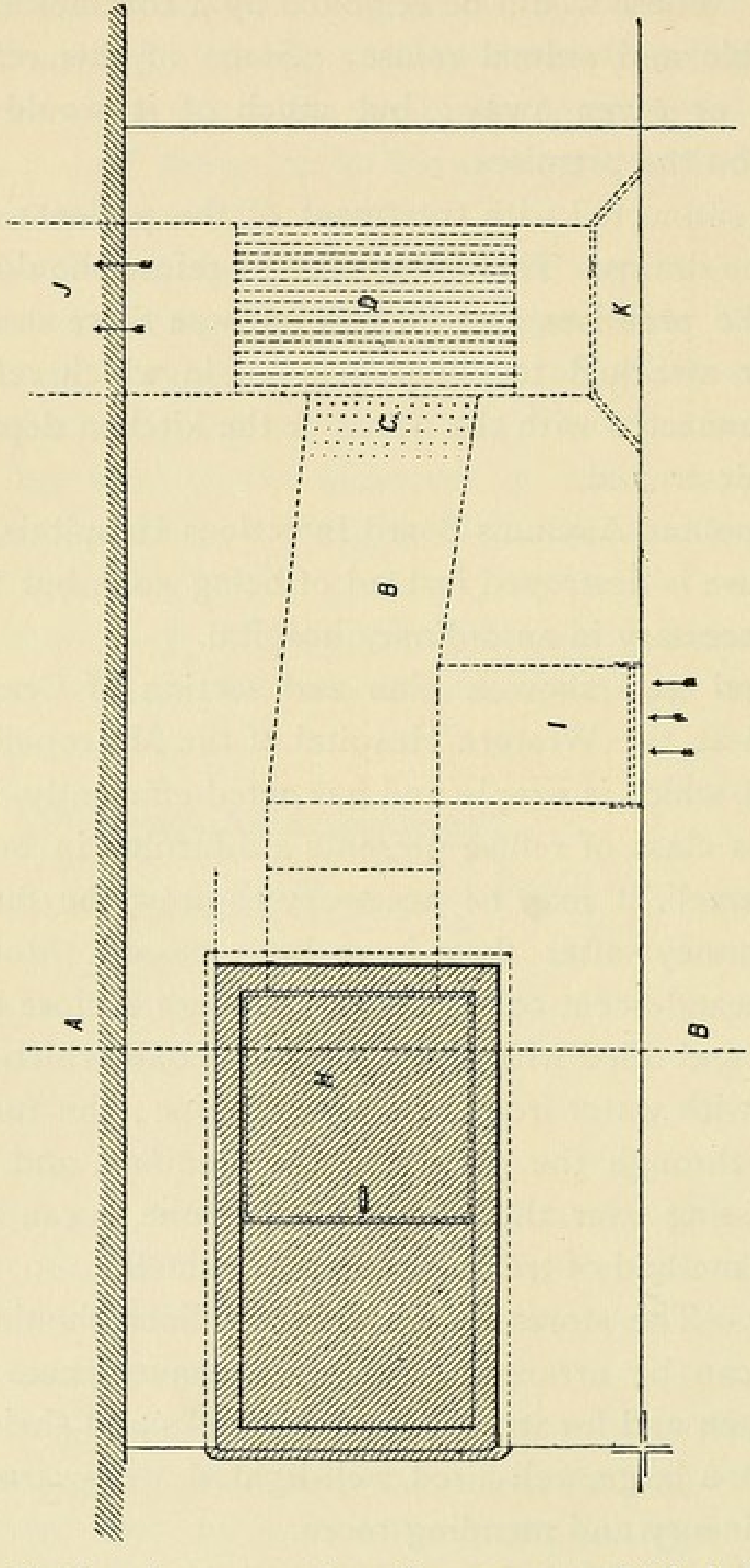
Figs. 44 *a* and 44 *b* show a plan and section of Crane's destructor used at the Western Hospital of the Metropolitan Asylums Board, which is simple and has acted efficiently. In cases where this class of refuse presents a difficulty in being burnt without smell, it may be necessary to draw the fumes into a tall chimney, after they have been passed through a thoroughly incandescent coke fire, and through a close box lined with lead and filled with small pieces of coke, which are kept sprinkled with water from a perforated pipe; the fumes are drawn up through the coke into the chimney, and the water, after passing over the surface of the coke, is run into the drain; this method of treatment removes smell.

Linen Stores.—The stores for bedding and linen should be as central as can be arranged, and have conveniences for receiving the linen and for storing it on dry racks and shelves. There should be a large, well-aired, well-lighted, well-warmed, well-arranged linenry and mending-room.

Laundry.—The hospital laundry should be entirely de-

[1] Surgeon-General Marston, C.B., made a very good earth-closet for a field-hospital out of Kerosene tins.

tached from the hospital. Special care should be taken to make the buildings very airy and light, with ample means of



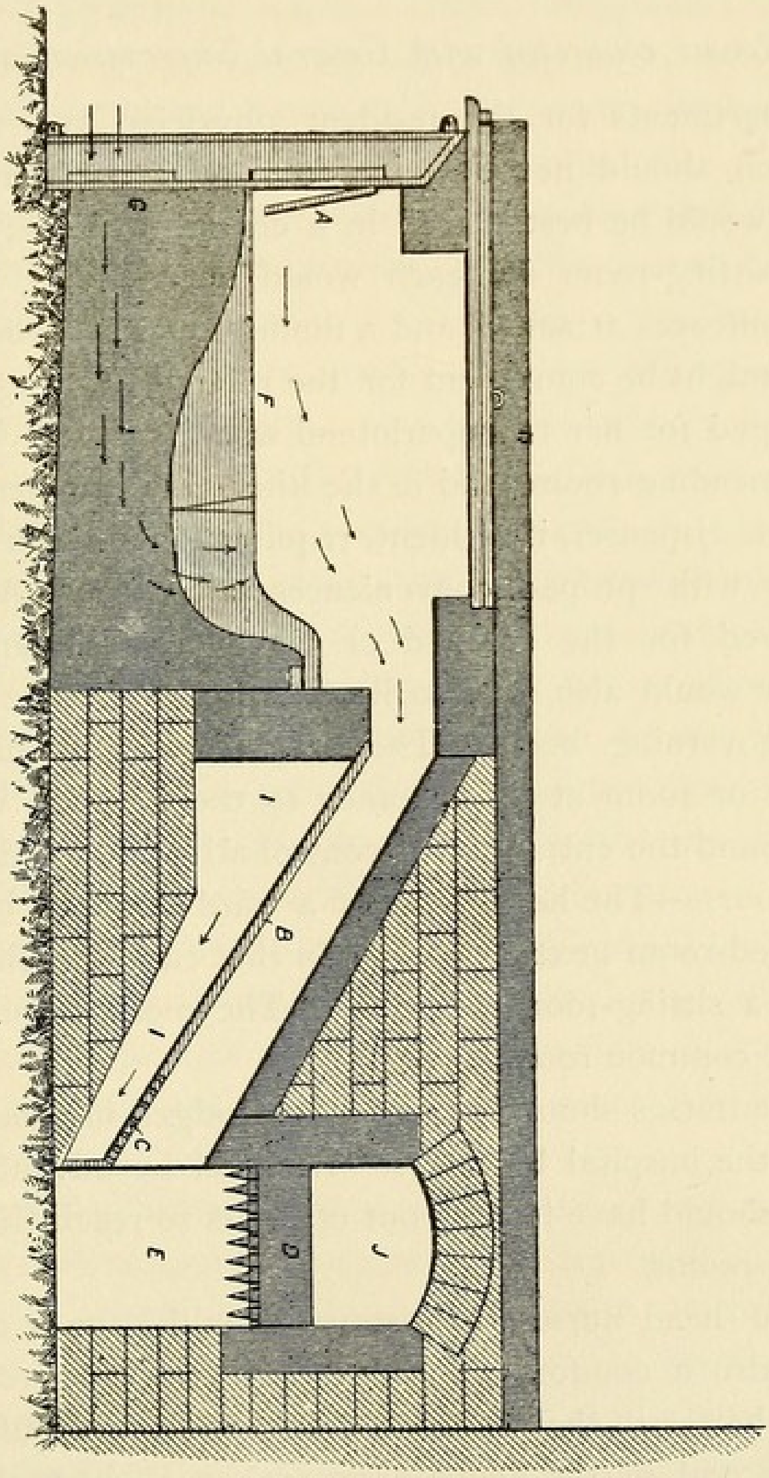
A. Serrated Pad with Back Lever for regulating.
B. Cast-iron division Plate.
C. Cast-iron division Plate perforated.
D. Coke Furnace.
E. Ashes Pit.
F. Refuse Fire.
G. Door of ashpit under refuse fire, always open.
H. Sliding Door for feeding with refuse.
I. Fresh-air Chamber.
J. To Shaft of Chimney.
K. Furnace and Ashpit doors both closed when apparatus is in operation.

Fig. 44 *a.* Plan of Crane's Destructor.

ventilation for removing the steam, which is heavily charged with organic impurity, and with ample space for the washers.

There should be a separate room for the linen which requires disinfection, attached to which should be the appurtenances for the disinfection of dry or woollen clothes.

There should be separate drying and ironing rooms.



Scale ½ inch to 1 Foot.

Fig. 44 *b*. Section of Crane's Destructor.

Servants.—The servants' bed-rooms should be airy and light. They would preferably be placed in a convenient central situation in the administration building. The male servants should of course be separate from the female servants. They could dine together in a common servants'-hall, but a sitting-room would be required for the women servants.

(3) *Rooms connected with General Supervision and Nursing.*

Apartments for the resident physician and surgeon and matron should not be under the same roof with the sick; they would be best placed in a central position; a bed-room and sitting-room for each would be required, with proper conveniences attached, and a dining-room for joint use.

It might be convenient for the matron's sitting-room to be arranged for her to superintend what went on in the linen- and mending-rooms and in the kitchen department.

The dispenser, if resident, requires a bed-room and sitting-room with proper conveniences attached. An office is required for the steward or purveyor, or financial officer. There would also necessarily be a room for the meetings of the governing body. The porter would require either a lodge or room at the entrance to the hospital, which would command the entrance and control all ingress and egress.

Nurses.—The head nurse of a ward in some hospitals has her bed-room next the ward; in that case she should always have a sitting-room adjoining. The meals should be taken in the common room.

The nurses should preferably be lodged in a building apart from the hospital buildings. It would be advantageous that they should have to pass out of doors to reach their bed- and living-rooms.

The head nurses or 'sisters' should have a dining-room, and also a comfortable, well-furnished sitting-room. They work better in their wards if they are made comfortable: for sisters and nurses now-a-days are, or ought to be, educated women. It is undesirable that they should have to seek necessary amusement out of doors. Nurses should dine in the sisters' dining-room, but at a different hour; and in a large hospital there would probably be required an additional dining-room for ward assistants.

In hospitals with an establishment for training nurses, which every large hospital ought to have, the probationers or pupil nurses (in a proportion not exceeding one to every ten or twelve patients) would live in a 'home' under the hospital roof, and under the direction of the hospital matron.

The 'home' should consist of:—(1) Class-room and nurses' library—large, airy, and convenient. (2) One or two dining-rooms, in which sisters and nurses might also dine, and pantry adjoining. (3) Two rooms and an office for the 'home sister' (class mistress). (4) One separate bed-room for each probationer—sufficient to contain press, table, chair, bookshelf, washstand, bedstead, and arm-chair.

Each floor should have a bath-room and other conveniences, and baths in the proportion of one to eight persons; the W. C.'s should be in the proportion of one to ten persons in addition to the W. C.'s for nurses adjacent to the wards. Baths and W. C.'s should be in separate compartments; so arranged that when one was in occupation the use of the other would not be interfered with.

Bed-rooms for probationers on night duty should be cut off from the noise of the 'home.' There should also be provided —one sick room, one visitors' room, and servants' offices and bed-rooms for cook and other necessary servants with adequate conveniences.

In all these buildings the same observations occur as in the wards and the appurtenances, viz. that the materials used in construction should be such as to be easily cleaned, that there should be no cornices or projections to catch dust, and that there should be abundance of light with absolutely no dark corners in the building, even under staircases, and no closets without good-sized windows.

CHAPTER XVIII.

Observations on some points connected with Hospitals for Incurables, Children's Hospitals, Convalescent Homes, and Infectious Hospitals.

It is beyond the scope of this work to describe special hospitals, but there are some points connected with the institutions mentioned at the head of this chapter to which it is desirable that the attention of a hospital architect should be called:

(1) Hospitals for Incurables.
(2) Children's Hospitals.
(3) Convalescent Homes.
(4) Infectious Hospitals.

Hospitals for Incurables.—The cases treated by incurable hospitals are principally cases of chronic rheumatism, gout, paralysis, and various affections which cripple the limbs, &c. They do not require the same cubic and floor space that hospitals for acute cases may need. But they should afford warmth, and consequently covered places for exercise, baths, and the opportunity for patients lying in the sunshine.

These hospitals, while treating cases within their walls, are no doubt productive of benefit to the community: but the system of granting pensions from the hospital funds to out-patients appears to have a questionable side, as there does not seem to be any guarantee or proof from the friends of the patients that the money given is spent for the purpose for which it is intended.

Children's Hospitals.—The question of children's hospitals is somewhat complicated. There are many diseases which occur in children of a lymphatic nature or scrofulous tendency, or which arise from latent tuberculosis, either inherited or otherwise, especially among the poorer classes, which being of slow and gradual development tend to fill our hospitals. These diseases might be overcome at an early stage by continuous treatment in healthy surroundings.

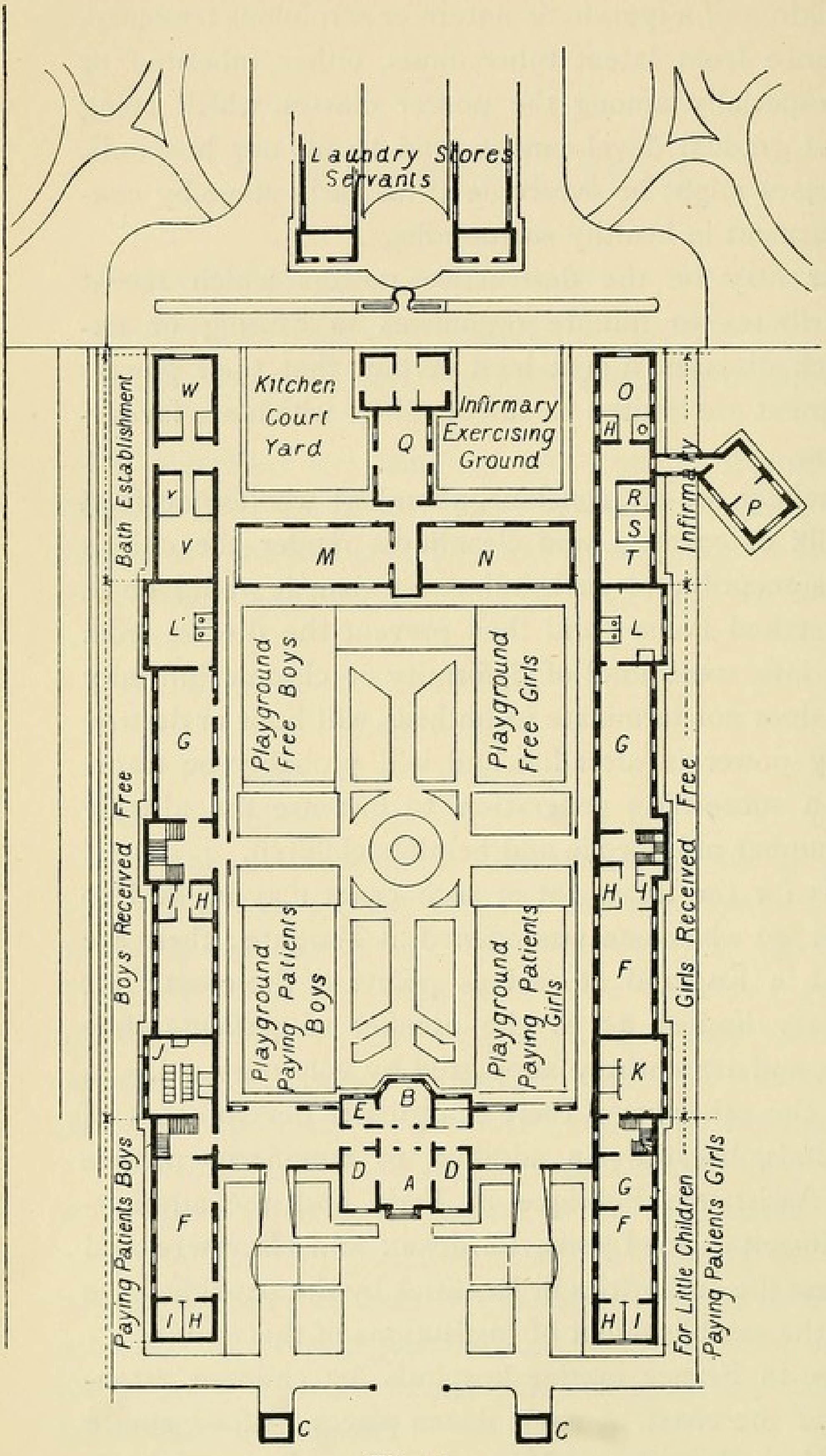
Whatever may be the destructive powers which recent science attributes to minute organisms in causing or extending such diseases, it is at least certain that their powers of development are limited to surroundings which are favourable to them.

Air, especially sea-air, sunshine, abundant wholesome food such as milk or oatmeal, and cleanliness render the child's body less susceptible to such influences than it would be in its own wretched home; and thus prevent the disease from developing into some kind of deformity or chronic infirmity which, if it does not terminate in phthisis, will limit or destroy the working power in after-life, and will probably be transmitted to a succeeding generation, to increase the already too large number of imbecile and helpless children.

Hospitals for the treatment of such cases may be said to date from 1796 when one was opened at Margate: there are now several in England at various points of the coast; but they are very limited as to the number of patients they can receive, and are entirely supported by voluntary aid. In France, on the other hand, there is a greater development of these hospitals, because—in addition to munificent private gifts—the Assistance Publique at Paris and the administrators of hospitals in Lyons, Bordeaux and elsewhere, and in other cases the authorities in localities by the sea-side, have assisted in the establishment of institutions of this nature.

There are in France marine hospitals for children established round the coast, at some dozen places, as for instance Berck-sur-Mer, Banyuls-sur-Mer, Avraches, Renne-Sabran,

SKETCH-PLAN OF CHILDREN'S HOSPITAL, BANYULS-SUR-MER.



A. Entrance Hall.
B. Director.
C. Porter's Lodge.
D. Rooms for examination and treatment.
E. Pay Department and accounting.
F. Dormitory 670 cub. ft. per bed.
G. Day Room.
H. Attendant.
I. Lavatory and W.C.
J. School room for paying patients, Boys on one side Girls on the other.
K. Infant's school or for very little children.
L. School room for Girls received free.
L[1]. School room for Boys received free.
M. Refectory for Boys.
N. Refectory for Girls.
O. Ward for sick children.
o. Small single ward after operation.
P. Operating theatre.
Q. Kitchen and its appurtenances.
R. Duty room in Infirmary.
S. Dispensary and Drugs.
T. Store room.
V. Baths.
v. Heating appurtenances for ditto.
W. Medicated, Vapour, Douche and other baths for treatment.
X. Covered Playground for paying Patients, Boys.
Y. Covered Playground for paying Patients, Girls.

Note.—There are two stories. Dormitories and attendants' rooms occupy the upper floor. This diagram is on a scale of $\frac{1}{400}$.

Fig. 45.

St. Pol-sur-Mer, Ver-sur-Mer, Cette, Cannes, &c., which contain in all probably from 1,800 to 2,000 beds.

The statistics of these hospitals are stated to show that with a stay averaging 423 days, from 75 to 80 per cent. of the cases are entirely cured of scrofulous and tubercular diseases.

The proportion of cures increases and the period for remaining in hospital decreases when the children are sent at the commencement of the manifestation of the disease.

The diagram annexed shows the arrangement at Banyuls-sur-Mer, which accommodates above 200 patients. It is situated on the sea-shore, where the children spend most of their time. They are accommodated in dormitories (in which the cubic space amounts to between 600 and 700 cubic feet), day-rooms, school-rooms, and refectory, and there is moreover an establishment for baths and hydrotherapeutic treatment. Dr. Leroux has recently published an interesting account of all these establishments, entitled 'Hôpitaux Marins.'

A hospital for children in a town is not advisable. It can only be looked upon as an adjunct to an out-patient department.

Children, as a rule, are better cared for in their own homes than in a hospital, but in cases of accidents and acute diseases they may require special care and treatment which their homes would not afford; such are appropriate cases for a town hospital. There is the additional consideration that the hospital provides means of affording clinical instruction to medical men.

With regard to the question of providing hospitals in towns solely for children, it is of universal hospital experience that the intermingling of ages is desirable.

Sick children can never be left alone for a moment. It might almost be said a nurse is required for every child.

This is why in a general hospital it is much better for the children to be mixed as far as possible with the adults, and if judiciously distributed it does the woman in the next bed as much good as it does the child, or the man as it does the little boy.

If there must be a children's ward in a general hospital, let it be for the infants.

If there is a separate children's hospital the age of admission on the female side would preferably include 15 years.

A child's ward-nurse ought to feel for each child as if her happiness were bound up in its recovery.

The general arrangements as to fresh air, &c., would follow those already described; small special baths would be required.

Children's water-closets must be self-acting, with no possibility for a child to fasten itself in or to communicate with another child when inside; they should be well lighted night and day.

A children's hospital should be provided with establishments for bathing, playing indoors and out, large garden grounds, gymnastic grounds and halls, both in and out of doors; gymnastics should be under a professor, and out-patients should be always admitted to the exercises; there should be school-rooms: and a 'sister' should be appointed to superintend these places. It is desirable that singing in chorus be taught, and that a chapel should be provided for secular as well as religious teaching by a chaplain; here only should the boys and girls meet.

Before closing these observations on children's hospitals, it is desirable to add a few remarks upon school infirmaries or sanatoria.

A boarding school of any size requires special provision for the reception and treatment of the sick members of its community.

Broadly speaking, each school should possess—

(1) Adequate accommodation for the reception and treatment of such of its inmates as may be suffering

(*a*) from ordinary non-infectious illness, or

(*b*) from the effects of accident and injury.

(2) Separate accommodation for—

(*a*) temporary and separate isolation for those who have been exposed to any of the several forms of infectious disease, but in whom the disease has not yet manifested itself;

(*b*) the treatment of those actually suffering from infectious disease. In this case there should be provision for isolating and treating separately from each other two or more different infectious diseases, should they occur simultaneously.

The amount of accommodation for sick or injured in a school depends to some extent upon the average age of the scholars.

Amongst young children the incidence of infectious diseases is more frequent, whilst accidents and injuries will prevail more amongst older boys.

It has been laid down by the medical officers of the Schools Association, that where the average age of a school does not exceed 12 years, the infirmary accommodation should be at the rate of 5 per cent. of the boarders; and that with an average age of 15 years the allowance should be from 6 to 7 per cent.

Cases of infectious and non-infectious disease are best treated in separate buildings, and in order to provide adequate isolation for these, some addition to the above percentages would be necessary.

For ordinary diseases and accidents the floor space should not be less than 100 square feet with about 1,200 to 1,400 cubic feet, according to the height of the wards; the infectious wards should not afford less than 2,000 cubic feet of space, and 140 to 160 square feet of floor space.

The wards should vary in size from 2-bed wards upwards; it would probably be more convenient in any school to limit the size of wards to 8 or 12 beds as a maximum.

With a small separate hospital the accommodation, as to wards and ward offices with all necessary conveniences, would follow, on a smaller scale, that which has been laid down for hospitals; and such a building would require accommodation for a trained nurse as matron and other nurses and servants in proportion to its size.

A surgery, with hot and cold water, cupboards and shelves for instruments and drugs; and an examination room would be required, in which any boys requiring to see the doctor would be examined. A waiting-room, a day and dining-room, and an exercising ground or garden for convalescents would be desirable, if the school hospital were at all large.

In small schools where an establishment of this sort is impracticable, separate rooms with water-closet, slop-sink, and bath-room with hot and cold water laid on must be allotted (1) to ordinary cases, (2) to infectious cases, with additional rooms and a small ward kitchen for the special nurse who would be appointed to take charge.

No refuse or foul linen should be retained on the premises.

The several rooms should not communicate with each other: they should be continuously isolated if possible, by being approached by means of a separate staircase.

The school drainage should be intercepted from the hospital drainage.

Convalescent Homes.—It may be useful to make a few remarks upon these as adjuncts to a hospital.

Every hospital should possess a convalescent home in a healthy open position and in a suitable climate. If possible it should be placed by the sea.

It is an axiom that no patient (especially a child) should remain in hospital longer than necessary. Hence a convalescent institution should be as like a home and as unlike a hospital as possible.

But whilst there should be as little as possible in a convalescent home to remind the patients of a hospital, yet, as relapses are occasionally unavoidable, it is necessary that some provision should be made for sick rooms and nursing.

During relapses continual supervision is essential, consequently there must be two small wards, one for males and one for females, with the sister's room between them, looking into both, placed in a central position.

In a convalescent home absolute separation of males and females is essential, especially as a safeguard against immorality.

To see the men and women patients going out walking together is to see that there is no discipline.

Hence the best form of convalescent home is probably that of separate cottages holding each not more than 8 patients; the males in one, and the females in another.

The men and women should never meet except in the dining-room.

All the cottages would be connected with the dining and day-rooms by means of a covered way or corridor. If the corridor is glazed and warmed, it would afford a place for exercise in cold or wet weather.

The sleeping rooms of a convalescent home should have as efficient a system of ventilation as hospital wards; but as they are occupied by night only, the cubic and floor space might be more restricted.

The convalescents' beds may be separated by curtains about 6 or 7 feet high on a rod to be pulled quite back in the daytime.

Patients on the female side should never be obliged to go to lavatories, a washhand-stand would therefore be provided for them within their compartments.

Three or four beds is a good number for each convalescent room. Children are best placed to sleep in the rooms with women, if they can be so placed judiciously, otherwise they would require the supervision of a nurse at night.

In the case of a child occupying the next bed to a woman, the curtain may always be drawn far back.

There must be baths; one bath-room to 8 patients is the smallest calculation. There should also be smaller baths for children; close supervision whilst bathing is most important for children. A nurse or bathing-woman must always be present.

An ablution-room would be provided for the males.

The number of water-closets would be in the proportion of 1 to 8 patients.

There should be a water-closet or two adapted for children, so that they should never be able to lock themselves in. These would also require the closest supervision.

For occupation, men would be preferably employed in the garden under a gardener than at indoor trades in the day-room.

When indoors the women should be occupied in household work as much as possible, at least on their own side, but never without permission from the medical officer, and under the surveillance of the sister. They may even do cooking, if with a hot plate in the kitchen; but some who are able to walk, may not be able to use their arms. Of course such indoor work must never interfere with outdoor exercise. Some convalescents will want entire rest; all must be prevented from damping their feet. Indeed, frequently the treatment will be entire rest with good food and fresh air.

In the daytime feeble children should be with the women, but noisy ones must have a good airy play-room. A garden, not too pretty to play about in and make 'houses' in, is a great desideratum for children; and they must not be mixed up with the men.

The convalescent home would require supervision by a matron or sister, for whom a bed-room and sitting-room in a central position must be provided. Under her there would be the necessary nurses; these would best be distributed among the cottages. The servants would be lodged near the kitchen and stores. A porter or gardener would live on the male side, or in a lodge near the gate.

A kitchen with scullery, larder, &c., would be provided; also a linen and mending-room, well lighted and warmed, and a small store-room.

All refuse should be removed daily to a distance.

A surgery would be necessary for the medical man who would periodically visit the institute.

Infectious Hospitals.—Although the general features of construction in infectious hospitals are the same as those of other hospitals, there are a few points connected with their general working in their bearing on the public, which it will be convenient to note.

In the first place, Dr. Sykes, in his valuable treatise on Public Health Problems, says: 'Probationary wards should never fail to be provided in all infectious hospitals. It is sometimes extremely difficult to diagnose an infectious case correctly at the onset. In the meantime, the rest of the family or of the household in crowded dwellings may run great risk. The medical attendant is justified in advising isolation, and with proper dwelling accommodation this may be carried out; he is not the less justified in advising removal to hospital where the accommodation is inadequate. It therefore remains for the hospital authorities to provide such means of isolation as may avoid both the retention of such cases in crowded dwellings and the infection of the patient, if after removal to hospital it should ultimately transpire that a non-infectious or less dangerous malady develops itself.'

In the next place, the safety of the public requires that there shall be strict precautions observed as to the communication between the hospital employés and the outside world.

It will be useful to show what those precautions are.

It must be borne in mind that, while the public must continue to be jealously guarded not only against actual risk, but even against apprehension, vexatious and unnecessarily irksome restrictions ought not to be lightly imposed.

The precautions which are adopted in the hospitals of the Metropolitan Asylums Board to secure these objects are classed under the following heads, viz.: (1) *Visitors to Patients;* (2) *Staff;* (3) *Patients' Letters;* (4) *Disinfecting Machines;* (5) *Destruction of Refuse*, &c.

(1) Visitors to Patients. The following regulation is in force at the present time, viz.:—

Visitors will be required to wear a wrapper (to be provided by the Board) covering their dress and head, when in the wards, and to wash their hands and faces with carbolic soap and water before leaving the hospital, or to use such other mode of disinfection as may be directed by the medical superintendent.

(2) The Staff.—No member of the staff, except when employed on ambulance duty, and messengers specially named for outdoor duty, is permitted to leave the hospital premises without having first changed his or her uniform, clothing, and stockings. No member of the staff going out with the intention of sleeping away from the hospital is permitted to leave the hospital without having first changed all his or her wearing apparel, and, except in case of exemption by the medical superintendent or matron, taken a bath.

Subordinate officers, upon leaving the service of the Board, must satisfy either the steward or the matron that their clothing has been cleansed and disinfected, and that they have taken a bath.

(3) Letters.—Patients' letters are baked before being posted.

(4) Disinfecting Machines.—All the hospitals are provided with a super-heated steam disinfecting machine of modern type.

(5) All refuse is destroyed.

CHAPTER XIX.

LYING-IN INSTITUTIONS.

HOWEVER great is the necessity for ventilation, freedom from contamination of air, and absolute cleanliness in the medical and surgical wards of a general hospital, it may be safely asserted that these necessities are tenfold greater in the wards of a lying-in institution.

The great susceptibility of lying-in women to poisonous emanations, and the excessively poisonous emanations from lying-in women, constitute a hospital influence on lying-in cases brought together in institutions, second to no influence we know of exercised by the most 'infectious' or 'contagious' disease; and yet the *raison d'être* of lying-in wards is that they shall be continuously occupied by a succession of cases.

The conditions of hospital construction which have led to the greatly diminished mortality in recent years in these institutions appear to have been due to the greater isolation and separation of the cases.

Inspector-General Massy, C.B., in a report to the Army Medical Department in 1869, mentions a small lying-in hut hospital at the Colchester Camp, used exclusively for lying-in women. It was an ordinary wooden hut; had a nurse's room at either end; and the centre was divided into four small wards for one patient, each 10 feet, by 9 feet 10 inches, by 10 feet. Ablution was performed in the wards; there was no water-closet in the ward, and the excreta were at once removed by hand. In five years 252 women were confined in this hospital without a single death.

At Waterford the lying-in hospital consisted of a small house, in which one ward was used for the delivery of patients and two rooms received four beds each. (There were two such wards.) The mortality was 1 in 1328 in a period of 23 years.

These hospitals seem to have owed their immunity from disaster to the limited number of cases accommodated at one time in the hospital, and to extreme care in management.

The Hospital Tenon has provided a small establishment containing a separate ward for each lying-in patient.

The wards occupy two floors; each ward is entered through a small lobby from an open gallery, so that there is no air communication between the wards. The floor space in each is about 150 superficial feet, and the ward is nearly 10 feet high; the floors are of cement or of marble terrazzo. Each ward has an ordinary casement window in the side opposite the door, and an open fireplace. Opening out of the entrance lobby is a small scullery with sink, &c. Hot and cold water is laid on to a fixed wash-hand-basin in the ward.

The matron has a duty-room at the end of the gallery on each floor, with which each patient can communicate by means of an electric bell.

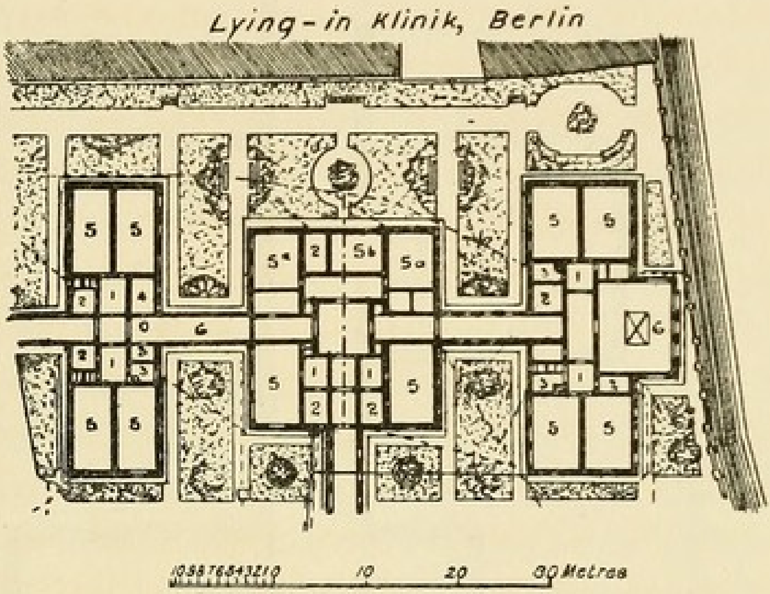
After each occupation the walls of the room are scraped and whitewashed.

In the system adopted at the Lying-in Clinical Institution in Berlin, a special room is provided into which the patient is taken for the delivery, and then is taken back to her ward. The annexed Figure 46 shows a small portion of this establishment, which will suffice to explain the general arrangements of the lying-in wards.

The wards are in separate pavilions, and contain 4, 3, and 2 beds each.

But whatever be the structural arrangement, success depends on cleanliness in the nursing; all the architect can do is to facilitate cleanliness. In the Tenon Hospital, as well as in the Berlin Hospital, the most scrupulous cleanliness is observed, and the delivery-room and the walls and ceilings of the wards are frequently scraped and whitewashed.

The following summary of the principles which should be



1. Ante-Room.
2. Nurses' Room.
3. Bath Closet.
4. Students' Room.
5. Ward, 4 beds.
5ª. Ward, 3 beds.
5ᵇ. Room for Midwives.
6. Delivery Room.

Fig. 46.

observed in constructing these institutions is reproduced from Miss Nightingale's notes on lying-in hospitals :—

Lying-in institutions must be in the immediate neighbourhood of great towns or centres of population.

There should never be more than four beds in a ward, or single-bed wards might be arranged in groups of four. Also, it must always be borne in mind that four beds mean eight patients. Including the infant, there are two patients to each bed to use up the air, which is besides used up by a necessarily far larger number of attendants than in any general hospital.

The general arrangement suggested is shown in Fig. 47.

There should be two floors, or eight beds at most in a pavilion, but it would be preferable to have wards on one

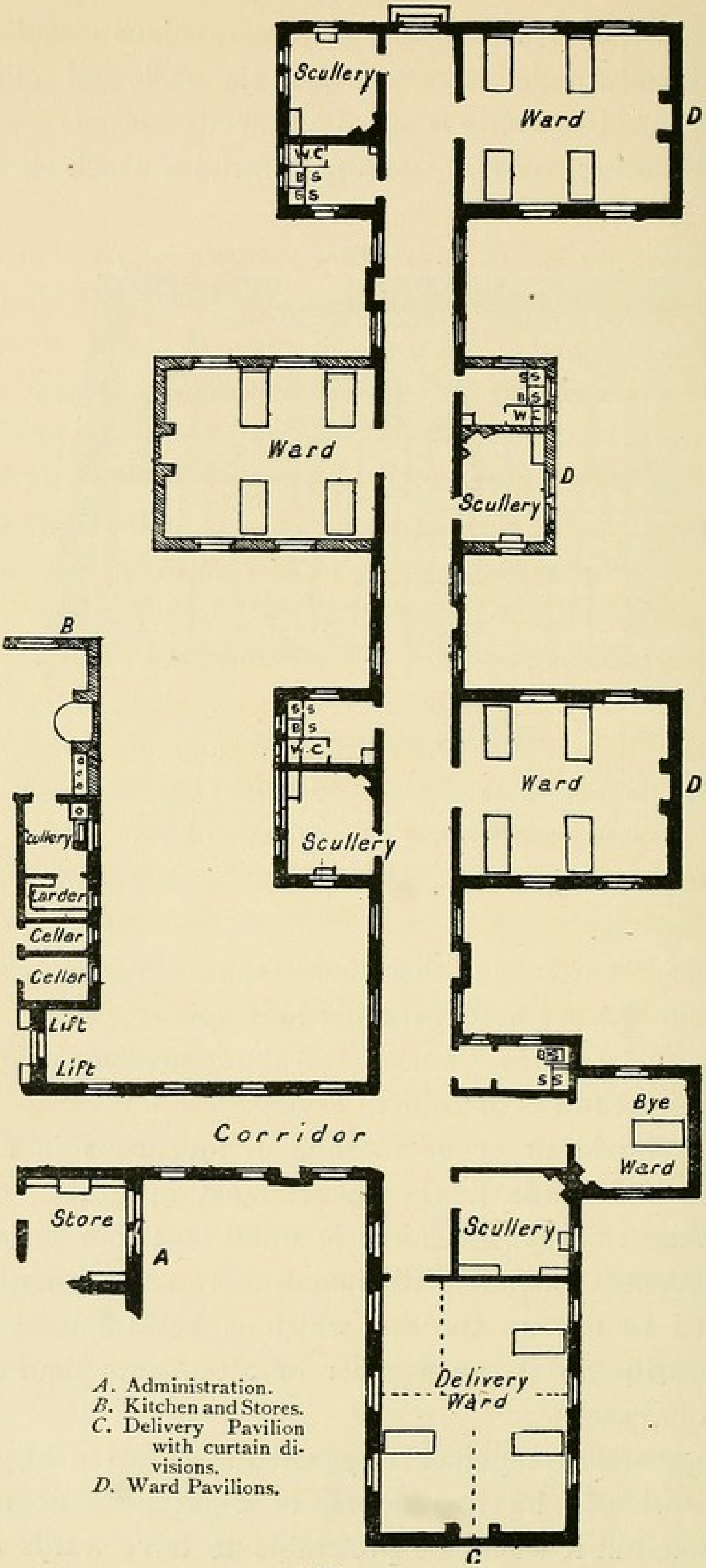

Scullery
W.C
B S
S S
Ward
D
Ward
S S
B S
W.C
D
Scullery
B
Scullery
Larder
Cellar
Cellar
Lift
Lift
S S
B S
W.C
Scullery
Ward
D
B S
S S
Bye
Ward
Corridor
Store
A
Scullery
Delivery
Ward
C
A. Administration.
B. Kitchen and Stores.
C. Delivery Pavilion with curtain divisions.
D. Ward Pavilions.

Fig. 47.

floor only. If on two floors, it is desirable that every alternate pavilion should consist of a ward on one floor only, unless the pavilions be so far apart as to cover an extent of ground which would make administration difficult.

The minimum of ward cubic space for a lying-in woman, even where the delivery ward is, as it ought always to be, separate, is 2,300 cubic feet in a single-bed ward, and 1,900 cubic feet, per bed, in a four-bed ward. In wooden huts, where the air comes in at every seam, this cubic space may be less.

As it is a principle that superficial area signifies more than cubic space, the surface of floor for each bed should not be less than 150 square feet per bed in a four-bed ward, and in a single-bed ward not less than 190 square feet, because this is the total available space for all purposes in a single-bed ward. This space has to be occupied, not only by the lying-in woman and her infant, and perhaps a pupil midwife washing and dressing it at the fire, but often by the midwife, an assistant, possibly the medical officer and pupil midwives. In a four-bed ward there is space common to all the beds. There should be two beds and two windows on each side of the four-bed ward.

In a single-bed ward the bed should not be placed directly between window and door; and it must never be in an angle[1]. There must be room for attendants on both sides of the bed.

There should be two delivery wards for each floor of a lying-in institution, so arranged and connected *under cover* that the lying-in women may be removed after delivery to their own ward. And for this purpose the corridors must admit of being warmed during winter, especially at night, so as to be of a tolerably equable temperature.

[1] It may be mentioned here that in one Lying-in Institution the medical record of the beds occupying the angles of wards was relatively much worse than that of the other beds differently placed.

Unlimited hot and cold water should be laid on day and night; a water-closet sink, bath sink, clean linen, must be close at hand.

The delivery ward ought to be separate in every lying-in institution; it *must* be separate in an institution of more than four or five beds, though in separate compartments.

The delivery ward should be so lighted and arranged that it can be divided, by curtains only, into three if not four compartments, with one window to each bed.

The curtains, of washing material, are only just high enough to exclude sight, not high enough to exclude light or air, and are made so as to pull entirely back when not wanted. Each area enclosed by the curtains should of course be sufficiently ample for pupils, attendants, and patient; also for a low truck on broad wheels covered with india-rubber, to be brought in, on which the bedstead with the clean warm bedclothes is placed, and the newly-delivered woman conveyed to her ward.

Every delivery bed should stand in a superficial area of not less than 200 square feet, and a cubic space of not less than 2,400 cubic feet.

Each delivery bed should have window light on either side, and also ample passage room all round and on both sides the bed. Care should be taken that no delivery bed should stand exactly between door and window, on account of draughts.

The reason why there must be two delivery wards for each floor of a lying-in institution, to be used alternately, one 'off' and one 'on,' is, that one delivery ward on each floor must be always vacant for thorough cleansing, lime-washing, and rest for a given period, say month and month about.

Newly-delivered women cannot be removed from one floor to another.

The position of the delivery wards should be as nearly as possible equidistant from the lying-in wards, and should be such that the women in labour, on their way to the delivery ward, need not pass the doors of other wards.

A separate scullery to each delivery ward is indispensable, such scullery to be on at least an equal scale to that of ward sculleries. Hot and cold water to be constantly at hand, night and day. A sink-bath is desirable for immediately immersing soiled linen from the beds and the like in water.

The scullery of the delivery ward should contain a linen-press, small range with oven, hot closet at side of the fireplace, sink with hot and cold water, &c. A small compartment should contain a slop-sink for emptying and cleansing bed-pans, and a sink in the floor, which is intended for filling and emptying a portable bath.

Beyond the scullery, so as to be as far removed as may be from the traffic of the main corridor and the noises of the delivery ward, should be the bye-ward, with not less than 2,100 cubic feet of contents. One of such single-bed bye-wards should be attached to each delivery ward, for an exhausted case after delivery, till she is able to be moved to her own ward.

All that has been said as to the necessity of impervious polished floors and walls for hospitals applies tenfold to lying-in institutions, where the decomposition of dead organic matter, and the recomposition of new organic matter, must be constantly going on.

It is this, in fact, which makes lying-in institutions so dangerous to the inmates.

And it may be said that the danger increases in a geometrical ratio with the number of in-cases.

With respect to the sculleries, lavatories, and water-closets of the other wards it must be borne in mind that the necessary consumption of hot and cold water is at least double or triple that of any general hospital. Sinks and water-closet sinks must be everywhere conveniently situated.

There should be a scullery to each four beds; and the scullery needs to be much larger and more convenient than in a general hospital. All the ward appurtenances, scullery, lavatory, &c., should stand empty for thorough cleansing, when the ward to which they belong stands empty in rotation for this purpose, and should not be used for any other ward.

Therefore, for each four-bed ward, or group of four one-bed wards, or for each floor of each pavilion, there must be one scullery, with a plentiful and unfailing supply of hot and cold water, with sinks and every convenience. The reason of this is twofold :—

(1) To allow each scullery, with the other ward offices, to be thoroughly cleansed and whitewashed with its own group of four beds.

(2) The work in a scullery and in all the other ward appurtenances day and night, night and day, is many-fold that which it is in a general hospital scullery.

In a lying-in hospital the infants, most exacting of all patients, must frequently be in the scullery.

Even under the very best circumstances there are many lying-in cases among weakly women where the mother's state is such as to render it necessary for a 'crying' infant to be washed and dressed elsewhere than in its mother's ward. These infants are best washed, in that case, in the scullery, which should be so arranged that infants can be washed and dressed without being exposed to a thorough draught, and that nurses and babies may not be hustling one another.

There must be a good press in each scullery; in which a supply of clean linen and other necessaries will have to be kept.

Besides this, general hospital patients ought never to be allowed to enter the scullery.

Fixed baths are not necessary. But there must be the means for filling with hot water moveable infants' baths at all hours at a moment's notice.

There should also be a moveable bath for each ward for the lying-in women, with the means of supplying it with hot and cold water and for emptying it. Lying-in patients are not able to use either fixed baths or lavatory.

Glazed earthenware sinks should alone be used, as being by far the safest and cleanest.

No dispensary, or dispenser, is needed in a lying-in institution.

A medical officer's room is necessary. The medical officer is not resident.

A waiting-room is necessary. There must be a room where the head midwife can examine a woman.

A segregation ward is necessary, completely isolated, where a sick case, brought in with small-pox, erysipelas or the like, could be delivered and entirely separated from the others; and a ward to which a case of puerperal fever or peritonitis could be transferred.

The segregation ward must have a nurse's room, and other necessary ward adjuncts, such as sink, slop-sink, &c.

The question may, however, arise whether an infectious case originating in a ward should be removed from the ward, or whether all other occupants should be removed: and, indeed, it would always be advisable in Lying-in Hospitals of any size to provide for one ward to be always at rest; such an arrangement would meet emergencies of this kind. It is also frequently desired by medical men, in order to meet symptoms suggestive of possible blood-poisoning, to surround the patient with fresh air, or, as it were, to flush her with fresh air. To this end a verandah would be a convenient adjunct to a ward; indeed, a balcony on to which a patient could be moved into the open air may sometimes offer less risk in such circumstances than the enclosing walls of a ward with its floor and furniture.

It has, no doubt, been found that domiciliary confinements have generally afforded better results than those in hospitals;

but experience shows, on the other hand, that with adequate attention to structural arrangements, especially if combined with absolute cleanliness, the Lying-in Hospital ought to produce results scarcely less favourable than the home; and the hospital is certainly of manifest advantage for difficult cases.

CHAPTER XX.

REMARKS ON TEMPORARY STRUCTURES, AND CONCLUSION.

BEFORE closing these observations upon the construction of hospitals, it may be desirable to say a few words upon moveable hospitals.

The argument has been often advanced that it would be preferable for all hospitals to be of a temporary character, so that the materials of which they are composed could be periodically burnt and new hospitals constructed.

This argument has great force in the case of buildings constructed like many of those which exist in our principal towns. That is to say buildings, which in many places will be found suitable for the collection of organic matter under conditions favourable for decomposition, and where a nidus is afforded for the development of organisms whose presence is assumed to be a concomitant of diseases. There are few hospitals in this country the interstices of whose floors, skirting boards, walls, and ceilings are not filled with organic matter in such a condition. No doubt walls can as a rule be scraped and plastered. But it would not be safe to restore such buildings without removing floors and ceilings, and without scraping and replastering the walls in such a manner as would be nearly tantamount to a rebuilding of the structure; and there would still remain the chances of pollution from the long occupation of the ground.

On the other hand, in the case of hospitals constructed on the principles laid down in this treatise—with that destroyer of organisms, sunlight, penetrating to every part—with impervious floors, walls, and interspaces between buildings, in which there are no dark places for the lodging of impurities, the same conditions would not prevail, and a long occupation with periodical emptying, cleansing, and aeration of all parts, both in the occupation of the patients and otherwise, would keep the building in a hygienic state.

On these grounds with a hospital which is intended to have any degree of permanence, or which is certain to be used at recurring intervals, as is the case with infectious hospitals, a brick building is preferable to one of wood or to a moveable hospital.

In regard to temporary hospitals in towns there is the further consideration that sites for temporary occupation would be difficult to obtain at short notice ; wooden structures would be liable to fire ; iron structures would be hot in summer and cold in winter. Hence the most practicable plan is to have permanent structures for town hospitals adequate to meet the needs of the urban population, who would thus be secure of being treated with the best available professional skill ; and to supplement these hospitals by sanatoria in the country, to which convalescing patients could be moved.

The moveable hospital is of course a necessity in war, but when it has been applied in this country by local authorities to meet outbreaks of infectious disease, with the idea that it might be taken to, and erected near, the locality of such an outbreak, it has been found, first,—that time is required to obtain and prepare a site with necessary adjuncts of water and provision for refuse: and, secondly, that even if the materials were stored ready, some further time is necessary to erect and prepare the hospital for occupation, all of which operations postpone very considerably the date at which the hospital would be available for the reception of sick, and this necessary delay causes more inconvenience than would be experienced by carrying the patients a reasonable distance in a properly appointed ambulance to a permanent hospital in some fixed position.

The subject of moveable hospitals for purposes of war assumed prominence during the wars of the last thirty to thirty-five years largely through the efforts of the managers of the Red Cross Society. The principle was laid down, and has practically been accepted by governments, that if the soldier has the right to receive the best equipment to enable him to fight when he enters the field of battle, he has equally the right to expect the best care which surgery and medicine can afford, if he has the misfortune to be wounded on the field of battle.

The late Empress Augusta of Germany, who took so strong a personal interest in the solution of the question, offered prizes at the Antwerp Exhibition of 1885, and again in 1889 at Berlin, when not only buildings but appliances of all sorts for fitting them up were exhibited.

The exhibition was based upon the assumption that the arrangements for aid to sick and wounded in war cannot be satisfactory unless they are made quite independent of the chance resources which may be found in the neighbourhood of a field of battle.

The basis laid down was that the unit of accommodation should provide for 60 patients in moveable hospital huts, with accommodation for the necessary staff, viz. 2 medical men, 2 subordinates, 1 cook, and 6 attendants for service on the sick.

The programme assumed that three huts about 50 feet long and 16 feet wide would each accommodate 20 sick, and that two additional huts would accommodate the personnel and the necessary administrative requirements.

These were fitted up in every detail with moveable articles required, whether for the patients or for providing for their wants.

It is beyond the province of this treatise to discuss the details of this question, which, moreover, would require much space.

The hospitals which may be required in the rear of an army or at the base of operations would usually be reached by the aid of railway transport, and would possess a character of greater permanence.

A few remarks upon the materials used in such quasi-permanent buildings will not be out of place.

These materials are generally corrugated iron, wood, Willesden paper or oiled canvas on wood frames.

As regards iron, it has the great defect for hospital purposes of being hotter and colder than other material, it must therefore be lined with wood, and the interspace packed with some non-conducting material. Sawdust is not desirable, as it may decompose; slag cotton is preferable, because it contains no organic matter. But iron has the further defect of being impervious to air. One of the chief advantages of a temporary hospital of wood is that its walls are permeable to air at all points; but the walls must be made double, and if in a cold country the interspace should be filled in by a porous material. It was the permeability to air and the porosity of the walls which proved the chief element in the comparative healthiness of the hospital huts erected in the American War of Secession and the Franco-German War of 1870–1871.

The paper or oiled canvas types of temporary moveable hospitals, which have attained to some degree of use by various local authorities in England, are the Daeker or Ducker. They consist of a waterproof material stretched upon wooden frames which are of definite shapes and numbered so as to be put up rapidly and form a weather-proof hut ready for patients. But others and at least equally convenient forms were shown at the exhibitions of portable huts for military purposes already mentioned.

Although it is beyond the province of this work to enter into the details of this class of hospital, it may be observed that British troops have generally had to provide for a hot climate rather than for that of the continent of Europe.

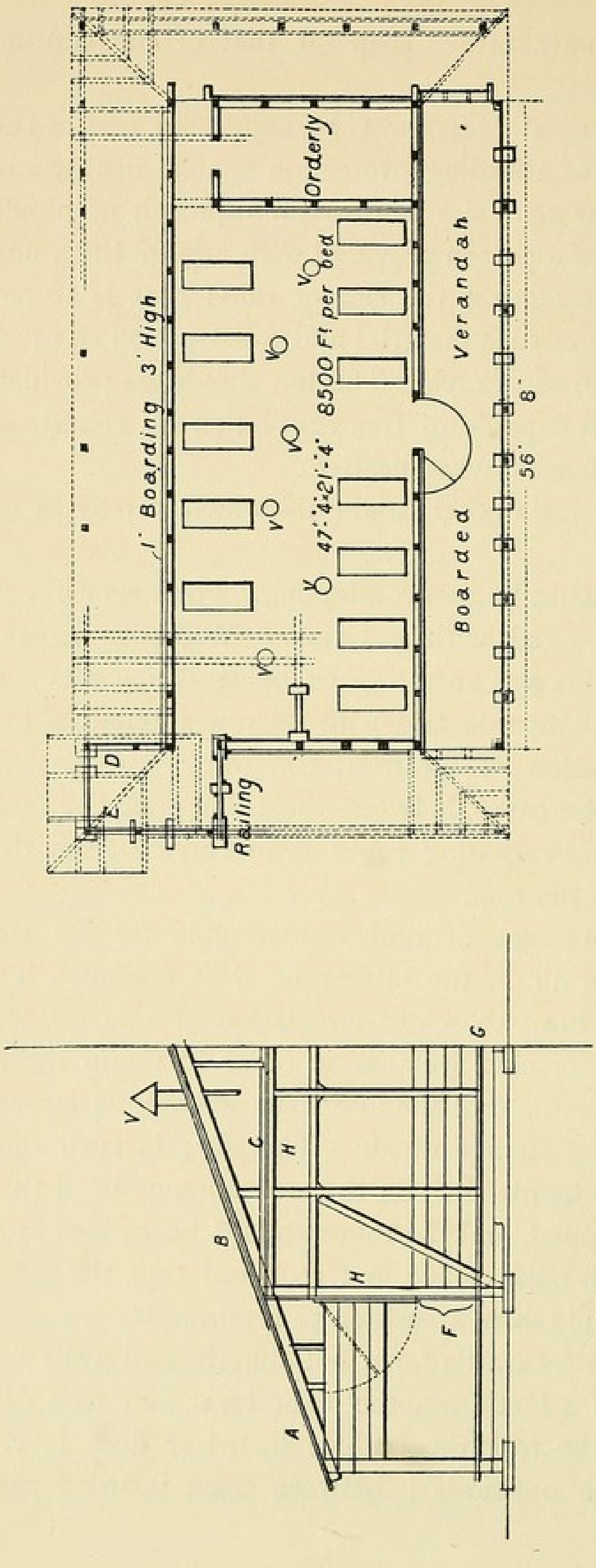
Surgeon-General Marston, C.B., suggested one of the best forms of hut for affording protection against heat in summer. The object was to make as near an approach as possible to the condition of a person provided with a large thick umbrella as a protection against the sun or rain; that is to say, the roof should be of such material and construction as to exclude the heat of the sun's rays. The hut should be provided with verandahs, and capable of free ventilation all round; as well as shelter from wind when desired.

There are certain other conditions which it may be well to summarize.

The roof should be non-conducting. For a very hot climate cork slabs covered with waterproof Willesden paper were used; under this was an air space, below which was a ceiling formed of inch boards laid with narrow interstices to allow of the circulation of air from the ward, and also air was admitted at the eaves, between the ceiling and the roof, near to the ridge; ventilating tubes were carried from this air-space through the roof.

This arrangement of roof was suitable for hot weather, because if the air in the interspace were confined, it would become very hot; therefore circulation of this air was desirable. But for cold weather in order to retain the heat it would be advisable that the interspace should be closed so as to allow of no change of air. Therefore in such cases the ceiling should be fitted close, the admission of air at the eaves should be stopped, and the tubes should be carried from the wards through both ceiling and roof, and thus the air in the interspace would form a cushion to retain heat.

The temporary wards for a hot climate had walls boarded to a height of 4 feet from the floor level, and to a depth of 2 feet from the top (the bottom board at floor level being hung to open outwards); between these boarded parts the



D. Lavatory.
E. Earth Closet.
F. Boarding, 3 feet high from floor.

G. Bottom Board hinged.
H. Hinged Shutters.
V. Ventilators through roof.

A. Willesden Paper on Boards.
B. Willesden Paper on Cork and Boards.
C. Ceiling joists, twenty-one inch Boards.

Fig. 48.

wall was formed of matting which could be rolled up when desired.

The roof was continued over the walls to form a verandah 7 feet 6 inches wide all round, on to which patients' beds could be wheeled. At one corner of the verandah the earth closets and ablution rooms were placed, and being railed off from the verandah by an open railing, there was no air connexion between them and the ward.

The ward floor and verandah were on the same level and raised from 18 inches to 2 feet off the ground, with free circulation of air underneath.

The plan and elevation of this hut is shown in Fig. 48, and fuller particulars will be found in the Report of the Army Medical Department for 1884. The main arrangements shown would—with the necessary modifications for protection from cold—be applicable in temperate climates for hospital purposes, where temporary accommodation for a limited period was wanted.

The object of this book, however, is not to give actual designs for hospitals, but to suggest the principles which should govern their design. These principles, if rightly appreciated, would apply as much to the creation of a permanent as to that of a temporary hospital.

CONCLUSION.

A considerable development has been taking place in the construction of hospitals in late years, especially in England, France, Germany, and America, and it seems probable that this activity will continue in this country under the influence of the County Councils and other bodies to whom the management of local affairs are being by degrees entrusted. The time therefore appeared to be opportune for bringing to a focus those principles which educated experience has shown to be essential, if we are to deprive of their powers of mischief those agencies which always seem to arise from the congregation of many persons under one roof; and, at the same time, to place the subject in a form which might be helpful to the medical man and the architect, as well as to those who are charged with obtaining the funds necessary for the erection of hospitals.

It has been a matter of regret that whilst so much sickness and misery prevails which can be alleviated by the extension of hospitals, the cost of their construction has risen to almost prohibitory sums. This has not resulted entirely from the increased appreciation of the importance of providing light, air, and warmth, which are the first essentials of hospital construction, but it has been partly due to the desire to erect palatial structures, which shall impress the eye and become a standing advertisement of the originator or of the architect of the hospital.

The principles enumerated in this book are not new; they are well known, but they lie somewhat scattered through various publications, and the object of this treatise has been to bring them together, and by showing what points are essential to health in hospital construction, to enable those upon whom the regulation of the construction devolves to concentrate expenditure upon these matters alone.

It is hoped that by bringing together this information, the erection of large, palatial hospitals in towns or other localities which are not suited to them will be discountenanced, and that the hospital architect, instead of seeking to erect a monument of his skill and taste in architectural design, will be content to provide simple structures abundantly supplied with light and air, in which the interests of the patients and their recovery will be not alone the first, but the only consideration.

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