SOME LESSONS LEARNT FROM RECENT OBSERVATIONS OF AIR IN RELATION TO HEALTH AND COMFORT.*

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IN attempting to assign a relative value to the various external factors governing that maximum condition of vitality which we, as medical men, strive for on behalf of those who seek our advice —whether these be individuals or communities—we cannot fail to be impressed by the supreme importance of the quality of the air environment. For while the quality of water or of food supply is confessedly of immense moment, the action of these factors is to some extent intermittent; the operation of the air environment, on the other hand, is continuous.

It is becoming realized that health is something more than mere absence of disease. Perfect health implies a balance on the credit side—a capacity for resisting fatigue and disease that may be termed aggressive. It will probably be undisputed that this condition of "fitness"—a condition that largely determines the quality of work that the human machine can produce, especially mental work—is, under ordinary conditions, very intimately dependent upon the quality of the air environment. The term "bracing" or "relaxing," applied by the public to describe the positive or negative effect of the atmosphere of various places upon their vigour, is witness to this, and the speed with which fatigue is engendered by the air of a closed room is familiar to us all.

The intimate relation between quality of the air environment and bodily condition and health is no modern discovery. It may be of interest, however, to recall that Francis Bacon, in his fable "The New Atlantis,"† prophesied amongst other discoveries to result from systematic investigation of Nature, the following:—

"We have also certain chambers which we call Chambers of Health, where we qualifie the Air as we think good and proper for the cure of divers Diseases and Preservation of Health."

Although I do not propose to deal with climate in the present paper, I would venture to call the attention of those interested in this matter to a valuable address on Climate and Health, delivered at the Congress

* A paper read before the Midland Branch of the Incorporated Society of Medical Officers of Health, April 11th, 1907.

† *Sylva Sylvarum*. London, 1664.

of the Royal Sanitary Institute at Bristol, last year, by Dr. W. N. Shaw, F.R.S., Director of the Meteorological Office. After describing the meteorological records available for study of the relation between climate and health in this country, Dr. Shaw selects three particular localities, viz., London, Oxford, and Cambridge, and compares the physical quality of their atmospheres, with a view to elucidating a subjective difference he has observed between their effects. This difference he describes by saying that it is easier to go on working in London than at Oxford and Cambridge, and he believes that the variation is not due solely to altered social circumstances and habit. On comparing the three atmospheres with regard to temperature, sunshine, rainfall, and humidity, however, he was unable to extract from the figures much information of a kind to directly elucidate the difference in their physiological action. The most conspicuous feature was the relative smallness of the London sunshine—which was hardly to the advantage of London. Leaving that out of account, he found a persistent elevation of minimum temperature in London, and he suggested that this might be connected with a corresponding increase in the effective dryness of the atmosphere. "But," he goes on to say, "if that be the whole explanation, the human organism must be regarded as a much more sensitive instrument than the thermometer, and great hygienic effects must be attributed to small meteorological causes."

As my present object is to describe the outcome of some recent observations of air in enclosed spaces, I shall not concern myself with the qualities of open air, interesting and of first-rate importance though I believe that matter to be in relation to human comfort, vigour, and health. In the present paper I propose to deal mainly with the impairment in quality that air in occupied rooms is liable to undergo from the presence of human beings; and more especially I propose to lay before you some considerations that arose in course of a recent investigation of the ventilation of the Debating Chamber of the House of Commons. That investigation, which was of a very detailed character, and took over two years to complete, was planned and carried out on behalf of H.M. Office of Works for the purpose of defining the conditions of the Debating Chamber system—a necessary antecedent to obtaining the best results out of that system, and thus improving the quality of the air in the Debating Chamber when in use. Full details of this investigation have been published*, and also some recommendations based on its results; but as the points that

* House of Commons (Ventilation) Reports and Recommendations, 1905, 1906—Wyman.

arose in course of it apply to the artificial supply of air to persons in enclosed air spaces generally, I shall refer to them in some detail.

While the air in which we live has a continual influence upon us, and we are provided with a special and highly delicate sensation whereby we are warned of fluctuations in its quality, sensitiveness to the condition of the air environment, like all other subjective phenomena, is not a constant value, but varies considerably in different individuals, and even in the same individual at different times. This variation constitutes one of the chief difficulties which are encountered in practice when attempting to supply a room full of human beings with the quantity and quality of air best suited to their temperament and health. As an extreme instance, the case may be cited in which the same quality of air has been found to cause one man to complain of its heat, and another of its coldness. On the whole, however, such extreme divergences of subjective response are, I believe, exceptional, and, other conditions being equal, the majority of normal people would seem to react fairly equally to the same quality of air.

I. Standard of Purity desirable for the Air of an Occupied Room.

The first point to be determined with regard to ventilation may be put in form of a question: What standard of purity should the air of a room be made to conform to in order that it may satisfy requirements as to health and comfort of the occupants?

Now, in this matter, whatever standard be desirable theoretically, there is only one to be aimed at in practice: the air of the room must be free of objectionable smell or property. In other words, it must be free of impurity when judged by the subjective senses.

In estimating the purity of an atmosphere by the subjective test, the sense of smell is, of course, one of the chief guides; and the standard which is generally accepted as desirable is that when the room is entered from the fresh outer air its atmosphere should not be found to smell differently from the fresh air. It is very necessary to realize in this connection the enormous delicacy of the human sense of smell. This sense has been computed by Berthelot to be a million times more delicate as a test for the presence of musk than the spectroscope is for the presence of sodium. As the latter test exceeds in delicacy the ordinary chemical test for carbonic acid by about the same degree, it is clear that the atmosphere of an occupied room may be irreproachable as regards exhaled carbonic acid, and yet abominable to the olfactory sense. The sense of smell, moreover, is a constant test which, unlike standards of carbonic acid, systems of ventilation needs must satisfy. Its extreme delicacy—providing as it does an enormous margin over the chemical test for pollution—compensates to some extent for the two chief drawbacks attached to its use, viz.: (1) the rapidity with which it becomes fatigued; and (2) possibly the result of (1), the variation which this subjective faculty exhibits in different persons, and in the same person at different times. For this reason it is essential that when applying the sense of smell to estimate the purity of the atmosphere in an enclosed and inhabited air-space, the sensation observed directly on entering the room should alone be recorded.

Personally I believe that when properly used, the sense of smell is the most valuable of all our guides to the purity of air, and I look forward to the time when this most vital question of the purity of the air supply shall have received the attention it deserves from our legislature, and even to a time pictured by Mr. Hudson,* when air inspectors (with standardized sense of smell) shall enforce the doctrine of the open window.

Another subjective sense of great moment in regard to ventilation is the thermal sense. As a means of detecting deficient ventilation, the sensation of heat, stuffiness, or closeness, is of no less importance than the sense of smell.

A third subjective effect produced by the atmosphere of a room in which ventilation is at fault is seen in cases in which the deficiency is only of moderate degree. It was this quality of the air that was complained of in case of the atmosphere of the Debating Chamber of the House of Commons. The Committee of Members that was appointed to look into the ventilation in 1903 did not complain in their report that the air of the Debating Chamber smelt badly, nor did they say that it was too hot: what they said was this:—

"It is the common experience of many Members that the air of the Chamber lacks freshness, that there are some qualities possessed by it which lead to a stay for a length of time in the Chamber causing in Members a lassitude and feeling of heaviness which tends to interfere with the due performance of their duties."

In answer to the question previously stated, therefore, we may lay down the following standard of purity. In a properly ventilated room the air must possess no objectionable odour; it must not be hot or oppressive; it must not engender fatigue or "lack freshness"; and unless the atmosphere of an occupied room passes these three subjective tests, the ventilation is imperfect. To this I hope the further condition may some day be added that the air shall not convey infection, even though an infectious person be present.

* Transaction of the Surveyors' Institute, Vol. xxxix, Part 6.

II. *Factors of Pollution.*

1. *The Causation of Stuffiness.*—The arduous and classical work of De Chaumont, whereby he correlated the amount of respiratory impurity expressed as carbonic acid with the corresponding degree of stuffiness, is well known, and likewise the four qualities of air which he distinguished by this means. His observations led him to infer that in order to keep the respiratory impurity below two parts of carbonic acid per 10,000 of air, the amount of fresh air required per head was 3,000 cubic feet per hour, or 50 cubic feet per minute. De Chaumont's observations were mostly made in barrack-room dormitories during the night, and in hospital wards. In the latter case—either because the wards were in continuous occupation, or because of the more offensive quality of air vitiated by the sick—he found that 4,000 cubic feet were required per head per hour, or about 66 per minute, to keep the air fresh and pure to the subjective senses.

The observations of De Chaumont went to show that in his own words, " the sense of smell carefully employed gives a very fair idea of the amount of respiratory impurity in an inhabited air space." The chief criticism of his results lies in the fact that his observations were limited to barrack-room dormitories and hospital wards. The atmospheres which he examined do not appear to have been overcrowded, and they were relatively cool. His object was to correlate the amount of respiratory impurity expressed as carbonic acid with the degree of pollution observed by the sense of smell, and to define the quantity of air necessary to keep the atmosphere of a room free of objectionable odour arising from the exhalations of its inmates; and in these points he succeeded admirably.

On the other hand, the more recent and elaborate observations of Flügge, Heyman, Paul, and Erklentz were made with the object of defining the causation of the injurious effect that air acquires in places such as schools, theatres, and churches, when crowded, and these experiments go far to prove that the bad effect in question is due entirely to physical vitiation of the air. Their experiments included a number of tests made in a specially constructed glass chamber in which the physical and chemical qualities of the air could be rigorously controlled. They found that with a respiratory impurity of carbonic acid exceeding any recorded up to that time as having been found in the air of a crowded room (e.g., from 10 to 15 or even 17 per mille), absolutely no injurious property of the air could be demonstrated so long as the temperature and humidity were kept low; and that under these circumstances the absence of any disturbance was so complete that the power of co-ordination remained intact, as was proved by the ease and normal manner in which certain arithmetical calculations given by way of test were carried out. Parallel results were obtained in case of a schoolroom crowded with children, but in which the temperature was kept low.

On the other hand, as soon as the temperature and humidity were increased to beyond a certain point, there appeared, both in normal and in diseased persons who were submitted to experiment, the usual symptoms that occur when people are crowded together in one room, i.e., feeling of inconvenience, oppression, lassitude, giddiness, nausea, etc. These symptoms, however, could be relieved at once by reducing the temperature and humidity of the air to normal.

The temperature of the air at onset of unpleasant feeling in these experiments appears to have varied from 70–86° F., and the humidity from 45–86 per cent; the unpleasant effect becoming manifest at a lower relative humidity at the higher temperature.

Following on these observations, Dr. J. S. Haldane, F.R.S., has carried out a series of experiments to determine the actual point at which a rise in the temperature and humidity of the air environment produces a definite rise in the body temperature. He found the all-important factor in this matter to be the wet bulb temperature of the air. In still air the "critical" temperature was 88° F., wet bulb, though, in case of moving air, a wet-bulb temperature up to 93° F. could be borne without abnormal rise of body temperature, provided the body was at rest. If muscular work was being performed the critical temperature of air was 78° F.

2. *Air in Relation to Infection.*—Before proceeding further, I must say a few words about recent observations of air in relation to infection. Morbific virus may conceivably be given off from an infected person in the expectoration, in the excreta, in discharge from a mucous cavity, or in particles shed from the surface of the skin; and of such particulate products, those which have hitherto been found to be especially liable to convey infection to others are the materials derived from mouth and intestine respectively.

It is hardly necessary to observe that from the point of view of Preventive Medicine, the importance of being able to identify the presence of particulate material derived from mouth or intestine is great. For where environment is such that particulate pollution derived from the human mouth or intestine has continual access to the alimentary or respiratory system of others, it is only a matter of time and opportunity for infection to be successfully transmitted by the same route. Tests, therefore, by which particulate material derived from mouth or intestine can be identified, and the frequency and extent of such pollution measured, are tests by which the danger of the access of morbific virus may be discerned, and the efficiency of measures adopted with view to preventing such access gauged and controlled.

1. *Particulate Matter derived from the Mouth and Upper Respiratory Passages.*

In the case of influenza, diphtheria, scarlet fever, small-pox, and a number of other infections, including epidemic cerebro-spinal meningitis, the bulk of evidence tends to show that their virus is mainly transmitted through air: in other words, that air is the medium through which particulate matter containing the disease germ passes from one person to another. The large proportion of cases of such air-borne diseases to the total number of cases of infectious disease of all kinds in this country would seem to point to air as the most active of operating vehicles of infection at the present day.

The work of Flügge and his pupils has thrown considerable light upon the mechanism of the process whereby infective material present in the upper respiratory passages is transmitted through air. By artificially infecting the mouth with *B. prodigiosus*, and then performing certain acts such as coughing, sneezing, and loud speaking, in a room in which agar plates had been exposed at various levels and distances from the person performing the acts referred to, Flügge and his pupils have shown that minute particles or droplets of mucus are expelled from the upper respiratory passages into the air in these acts, and that they are wafted by air currents such as exist in ordinary rooms to all levels, and to distances as far as 40ft. away. In some cases patients suffering from phthisis were experimented with, and *B. tuberculosis* expelled by them in the act of coughing was actually demonstrated to penetrate through the air to a distance of one metre or so from the mouth of the patient. Another observer showed that the leprosy bacillus was emitted to much the same distance by lepers under similar conditions.

Having repeated some of the experiments of Flügge with *B. prodigiosus*, and confirmed them, I proceeded to enquire whether there was not constantly present in the normal human mouth some micro-organism which might be utilized as a bacterial test or index for detecting particulate matter derived from the mouth in the same fashion that *B. coli* is used for identifying material derived from the intestine. As a result of quantitative bacteriological examination of a number of samples of normal human saliva, I found that strepto-cocci were present in every case, and far exceeded other bacteria in abundance. In each sample of normal saliva examined streptococci exceeded 10,000,000 per cc., so that they serve as a test whereby 0·000,000,1 cc. of saliva can be detected. On examining the character of these streptococci, I found that though several varieties are present in saliva, one streptococcus in particular, *Streptococcus salivarius*, is present with far greater constancy and abundance than the others. This streptococcus, therefore, promised to provide the index for which I was seeking.

Streptococci develop in broth far more readily than on solid media. It was by inoculating the highest dilution of saliva directly into broth that I succeeded in proving the enormous abundance of streptococci in normal saliva. Hence, in testing for the presence of salivary streptococci in air I used broth, and exposed this medium in suitable receptacles to the air. Moreover, salivary streptococci grow as well anærobically as ærobically, whereas many of the commonest bacteria in air, such as *B. subtilis*, *mesentericus*, etc., are inhibited by anærobic conditions. After exposing the broth to the air, therefore, I incubated it anærobically at 37° C.

I need not enter into further details of these experiments, as they have already been fully described elsewhere.* Suffice it to say that by this streptococcus test I succeeded in proving the spread of particulate matter from the mouth through the air of the room to the same extent and distance as in previous experiments carried out with *B. prodigiosus*. The advantage of using a microbe normally present in the secretion of the mouth, however, for this purpose, is obvious: for by this means one obtains a test whereby the degree of particulate contamination which the air of a given room undergoes in actual practice can be determined, and, further, the influence of various systems of ventilation on the spread of particulate matter sprayed into the air in the acts referred to can be tested under actual working conditions.

Before proceeding to develop this streptococcus test for particulate material emanating from the upper respiratory passages, it became necessary to see if it were possible to distinguish between streptococci of saliva and streptococci of other origin. By examination of a number of streptococci in a variety of media, I succeeded in showing that this differentiation could be readily effected by observing, in addition to their ordinary morphological and cultural characters, their bio-chemical behaviour in the presence of certain sugars, alcohols, and glucosides, in regard to their action on which these streptococci differed *inter se*. It is now as necessary in case of a given streptococcus

* Reports Medical Officer Local Government Board, 1902-3; 1b, 1903-4.

to examine its characters by a series of tests of a proved differential value before drawing inferences as to its significance as it is in the case of coli-like micro-organisms.

2. *Particulate Matter derived from the Intestine.*

Identification of the presence of minute traces of excremental contamination by means of *B. coli* and the spores of *B. enteriditis sporogenes* is too well known to need description here.

The use of streptococci as an index of the presence of fæcal matter is due to Dr. Houston. Dr. Houston has classified streptococci of fæcal origin on similar lines to those used by me in reference to salivary streptococci ; and his results show that although the variety of these microbes in fæcal matter is as great as in the case of saliva, the frequency of some kinds is greater than that of others, and one streptococcus in particular, which, amongst other things, changes mannite with acid reaction, would seem to be particularly characteristic of fæcal matter.

In course of the experiments described above, a streptococcus that differed morphologically, and also in cultural respects, from salivary streptococci, was frequently obtained from the air of rooms, and also from the open air. Later on, when tested against various sugars, etc., this streptococcus was also found to differ markedly from streptococci of saliva in bio-chemical action. At first I called this micro-organism "the air streptococcus," because I came across it so frequently in air. On ten occasions fifty litres of the air of London, E.C., were sampled, and the air streptococcus was recovered in this quantity of City air eight times. On the other hand, the air of Blackheath only yielded this streptococcus in three out of eleven parallel tests, although, in the aggregate, double the quantity of air was examined in these Blackheath tests. The air streptococcus, therefore, was much more abundant in the air of the City of London than in air on Blackheath.

When I subsequently examined the air of the House of Commons, I came across this air streptococcus frequently, and found that it was the most frequent streptococcus in air directly contaminated by material brought in from the streets by Members upon their boots. Dr. Houston found it to be frequent in fæces, and Dr. Andrewes has found it in great abundance in horse manure, and has called it *Streptococcus equinus*.

This micro-organism, therefore, would appear to serve as an index of the presence of particles of horse manure in air. I may add that I recovered it from air at the level of the lantern on the Clock Tower at Westminster.

3. *Particulate Matter derived from the Skin.*

Working on similar lines to those adopted when developing the bacterial test for particles of saliva, I have shown that a certain staphylococcus, possessed of constant and definite characters whereby it can be identified, is uniformly and abundantly present in particles detached from the human skin or scalp, and that this micro-organism serves as an index whereby the presence of such material can be identified. The skin staphylococcus in question grows well anærobically, and is best detected in air by exposing broth and then incubating it anærobically at 37° C. This micro-organism, which is identical with *Staphylococcus epidermidis albus* of Welch, differs from *Staphylococcus pyogenes albus* in a number of points, notably by reason of the fact that it fails to decompose mannite with an acid reaction, whereas *Staphylococcus pyogenes albus* rapidly decomposes that alcohol with a strongly acid reaction.

I have recovered this skin staphylococcus from the air of rooms in which people were moving about, though I failed to obtain it from the air of such rooms when empty. No doubt its demonstration would be possible in the air of a theatre after much clapping of hands. I have found it in abundance in bath water.

4. *Special Factors of Pollution.*

Although identification in air of particulate material derived directly from a human being is limited at present to the tests described above, it is well, before proceeding further, to touch upon a few other factors of pollution to which air in occupied rooms is liable. The first of these calling for attention is sewer air.

(*a*) *Sewer Air.*—When a few litres of sewer air are aspirated through a plug of sterile wool, it has been found that the bacteria thus obtained (Gel. 22° C.) are fewer than in case of a similar sample of air drawn at the same time from the air of the street above the sewer. This result cannot be gainsaid, as the experiments of independent observers have placed it beyond dispute. But in spite of its freedom from bacteria when judged by this method, sewer air would appear to have a bad effect on health when it makes its way into a house ; and the explanation of this pernicious attribute has for long puzzled us.

A recent investigation by Drs. Andrewes and Hurtley of air in the sewers at Hampstead* has considerably added to our knowledge of the properties of sewer air, and suggests a possible clue.

Dr. Andrewes, by exposing plates to the air of the sewer, obtained evidence of their infection by micro-organisms present in the sewage.

* Report to the Hampstead Sanitary Authority, 1905.

On one occasion he obtained *B. coli*, and on several occasions streptococci were obtained, the characters of which were found to differ from those of streptococci recovered from air in the street above, and were similar to those exhibited by streptococci isolated from the sewage itself. The question of occasional particulate contamination of the air of the sewer by the sewage itself is as yet, therefore, by no means settled in the negative.*

Dr. Hurtley's results are hardly less interesting. He noticed that the air of the sewers was always either saturated, or very nearly so, with water vapour, hence, even if only a small diminution of temperature occurs, condensation takes place, and moisture settles on any particulate matter floating in the air, and this becomes deposited. At night, such condensation occurs regularly, and the air of the sewer is thus automatically cleansed of any suspended matter.

Furthermore, carbonic acid is only slightly soluble in water, and hence this humidity of the sewer's atmosphere does not materially affect the prevalence of that gas. But ammonia is 200 times as soluble as carbonic acid, and hydrogen sulphide is four times as soluble as carbonic acid ; hence these two gases of decomposition tend to be diminished very considerably by the humidity of the sewer's atmosphere.

(*b*) *Fumes and Dust.*—About other special conditions of pollution of air, such as arise in manufacturing processes from the presence of fumes or dust, I do not propose to speak more than to say that it is obvious that special impurities require special measures for their removal. It is of importance that the efficiency of such removal should be proved by the actual test of experiment. Nothing less than this should be accepted ; the arrow diagram and routine formula threaten to become actual impediments to progress in practical improvement of the art of ventilation, because they tend to detract attention from the all-importance of proving, by actual experiment upon the spot, the efficiency or otherwise of systems of ventilation.

III. The Limit of Ventilation.

As the best test of the purity of the atmosphere of an inhabited room is the subjective test, so also the maximum quantity of air that can be supplied is limited by the subjective sensation of discomfort or draught.

The relation between movement of air and sensation of draught

* The remarkable experiments of Major Horrocks, published in a recent issue of PUBLIC HEALTH, have confirmed and considerably amplified these observations with reference to particulate contamination of sewer air.

has been experimentally defined, and it has been found that the velocity of air at a temperature of 55° to 65° F.—

(1) At 1½ft. per second is felt by none.

(2) At 2 to 2½ft. per second is felt by only a few very sensitive persons.

(3) At 3ft. per second is felt by most.

Since a velocity of 1½ft. per second is felt by none, the quantity of air that can be supplied per head per minute without provoking draught is limited chiefly by the sectional area of available inlet. With an inlet area of 1 sq. foot per head, 90 cubic feet of air can be supplied per head per minute without draught, and 120 to 180 cubic feet without movement of the air being perceptible to more than a few very sensitive persons. The sensation of draught is dependent to a considerable extent on the temperament of the occupants, their habits, and the time of day. In the early hours of the morning, during an all-night sitting, the velocity of the air at the House of Commons has to be considerably reduced. The influence of relative humidity of the air has still to be defined in relation to draught.

IV. Observations made during a recent Investigation of the Ventilation of the Debating Chamber of the House of Commons.

Complaints of Members about the quality of the atmosphere of the Debating Chamber led to the appointment of a Select Committee of Members, whose report and recommendations, published in 1903, have been already referred to. One of the chief causes of the appointment of this Committee was an outbreak of influenza, which disease had attacked Members with particular frequency.

The Committee examined a lot of witnesses, and caused a chemical and bacteriological examination to be made of the air of the Debating Chamber. The result of the chemical examination, which was made by Mr. Butterfield, was satisfactory—the respiratory impurity, in the form of carbonic acid, being found to vary from 1·0 to 1·86 per 10,000 of air in one test, and from 0·19 to 2·15 in another. The bacteriological examination of the air made by Dr. Graham Smith at the same time with Frankland's method, showed a mean of 5·8 micro-organisms per litre of air in the Debating Chamber. The Committee remarked that though less exact and less satisfactory than the chemical results, the bacteriological results could not be regarded as other than satisfactory.

In contrast to the results of these objective tests, the Committee pointed out the unsatisfactory nature of the air from the subjective standpoint, and instanced its lack of freshness and its tendency to produce lassitude and fatigue. After suggesting many improvements, including better cleansing of the Debating Chamber, the substitution of a suitable extract fan for the old coke-fire exhaust, and the replacement of the in-put fan by one of more powerful type, the Committee made a final recommendation that enquiry should be instituted into problems of ventilation still unsolved, with the view of introducing further improvements into the present system.

The recommendations of the Committee were acted upon, and I received instructions from H.M. Office of Works to make an investigation. The matter which was determined in the first place was the degree to which the air of the Debating Chamber was liable to pollution from particulate matter derived from various sources, and subsequently it became necessary to go into other aspects of the ventilation of no less importance. The inquiry which has been made owes a great deal to the late Sir Michael Foster, who throughout its course spared no trouble to make the investigation as far-reaching and thorough as possible. As a physiologist, and as Chairman of the Committee of Members who had reported on the ventilation, his interest had been keenly aroused in the problem of improving the atmosphere of the Debating Chamber, and throughout its course he continually imparted encouragement, and even enthusiasm, to the enquiry.

After my preliminary examination of the system, the First Commissioner of Works appointed a committee consisting of Sir Michael Foster, Chairman, Dr. J. S. Haldane, F.R.S., Dr. W. N. Shaw, F.R.S., together with Mr. Patey, of the Engineering Department of H.M. Office of Works, and myself, to continue and complete the investigation. Important help was also rendered by Dr. W. H. Hurtley, who made a further chemical investigation of the air, and by Mr. R. G. K. Lempfert, of the Meteorological Office, who carried out an investigation of the physical quality of the air in regard to temperature and humidity. Dr. John Aitken, F.R.S., also rendered valuable advice and assistance in course of the enquiry.

The investigation which was made of the ventilation comprised enquiry under the following three heads :—

1. The quality of the air at the inlet, and before and after passing through the Debating Chamber respectively.

2. The quantity of air supplied and withdrawn.

3. The distribution of fresh air within the Debating Chamber.

(*a*) *Quality of the Air.*—Subjectively the air on the Terrace of the Houses of Parliament is remarkably pure and fresh, and when in 1904 I began to investigate the system as it was under the old conditions (the improvements recommended by the Select Committee not having then been carried out), I was forcibly struck by the subjective difference between the air of the Terrace and that of the Debating Chamber on the same occasions. Furthermore I, by painful experience, confirmed the tiring effect of the air delivered at the Debating Chamber at that time. The bacteriological and chemical results failed to furnish any explanation of this difference, but a striking objective difference was nevertheless detected by the dry and wet bulb hygrometer, for it was found that the temperature of the incoming air was being raised at the expense of its relative humidity. The observations were made during the months of May, June, and July, 1904, and a number of tests of the air at the inlet, and as delivered at the Debating Chamber respectively, showed that the air entering the system had a mean humidity of 71 per cent, whereas by the time this air reached the Debating Chamber its humidity was reduced to 63 per cent. In other words, the air, on arrival at the Debating Chamber, possessed a capacity of absorbing moisture 50 per cent over that exercised by fresh air on the Terrace at the same time. Now, although expired air is saturated with moisture, it is clear that dry air will primarily tend to saturate itself at the expense of moisture present in the upper respiratory passages, and this " thirstiness "of the air—which would, of course, be far greater in the winter months, when the temperature of the fresh air would require to be still more raised—is a factor that deserves more attention than it has yet received in reference to " want of freshness " and liability of air to encourage catarrhal conditions.

At a subsequent stage of the enquiry Mr. Lempfert, of the Meterological Office, carried out a number of observations of the temperature and humidity of the air for the Committee, and his report is well worth the perusal of those who may be called upon to keep these most important qualities of air under observation. A number of the thermographs and hygrographs used by Mr. Lempfert have since remained in constant use at the Debating Chamber, and provide a continuous record of these qualities of the air. Such instruments should be in use in all systems of ventilation of any importance.

Dr. John Aitken also rendered valuable assistance to the investigation, and by means of the ingenious and accurate instrument which he has invented for counting the number of minute dust-particles in air of various sorts, succeeded in measuring the value of two filtering processes for removing these particles from the air. In these experiments I had the honour to assist him, and on both occasions when we tested it we found that the air on the Terrace contained about 40,000 of these minute particles per cc.—a number by no means large for London air, and suggestive of the comparative freedom of the Terrace air from smoke. On testing the air before and after its passage through the water screen at the inlet we found no diminution to be effected in the number of these particles, though observations of the bacteria contained by the air before and after passage through that screen showed that they were reduced by 60 per cent. But while the water screen failed to remove these minute particles of dust, we found that the cotton-wool screen (which is used only in time of fog) reduced them by about 80 per cent.

The chemical investigations made by Dr. Hurtley proved a valuable supplement to the carbonic acid observations of Mr. Butterfield, previously mentioned. Dr. Hurtley examined the air at the inlet quantitatively for oxygen, ozone, nitrous acid, nitric acid, and sulphuretted hydrogen. His results are fully described in the Appendix to the Committee's report. He made some particularly valuable observations in connection with the water spray then in use at the inlet for moistening the air when the break between dry and wet bulb was over 5° F. Dr. Hurtley tested the value of this spray for removing free and albuminoid ammonia from the incoming air. His observations showed that a very material decrease in these two constituents was effected by the spray in question, and he determined the quantity of water necessary to obtain the best results. These observations of Dr. Hurtley cannot fail to be of interest to all concerned in the problem of purifying air.

Dr. Hurtley also applied lithium for the purpose of ascertaining the extent to which air in the Debating Chamber is liable to contamination by dirt brought in by Members on their boots. In these experiments I applied *B. prodigiosus* for the same object. By the spectroscope Dr. Hurtley showed the presence of lithium in dust falling down through the floor of the Debating Chamber at the same time that I obtained *B. prodigiosus.*

The air at the inlet showed no evidence of contamination by particulate material derived from the mouth or intestine, except in the case of a side inlet which was under a grating on which people walked, and at that point the air was found to be liable to contain excremental bacteria on such occasions from minute particles of street dust detached from the boots of persons passing over the grating in question. This inlet has now been abolished. Although I tested the air at the inlet on several occasions for a number of hours at low tide, I failed to find any of the bacteria which I had ascertained to be most abundant in the mud of the river by the Terrace.

The air enters the Debating Chamber throughout the whole, or almost the whole, of its floor, which is one vast metal register. I found that there were two areas where the up-going air was especially liable to contamination from material brought in from the streets by Members on their boots—these spots being the places where traffic is most active during debates, i.e., between the Bar and the door under the clock, and at the opposite end of the Debating Chamber behind the Speaker's chair.

The air in the Debating Chamber itself could not be examined during debates by the methods I was using, but on one occasion I tested it as soon as possible after the House had adjourned. Only three salivary streptococci were recovered; but it is significant that one of these was recovered from air over the Treasury Bench, and another from air over a bench where one of the Members, who had taken an active part in the debate, had been speaking. As some ten minutes elapsed before I could spread the broth plates, etc., about for this test, no doubt many of the particles contained by the air had time to gravitate to the floor before the plates were exposed.

A large number of bacteriological observations were made of air leaving the Debating Chamber during debates, and the chief particulate contamination contained by it under these conditions was found to be material derived from the upper respiratory passages. When the House was empty, on the other hand, no such contamination was found present. *Streptococcus salivarius* and other salivary streptococci were present in the air leaving the Debating Chamber during debates, and occasionally *Staphylococcus aureus* was obtained. I regret that at this time I had not yet developed my test for the presence of particulate material shed from the skin, as it would have been interesting to have seen the degree to which *Staphylococcus epidermidis albus* was present in the air leaving the Debating Chamber during use.

B. mycoides was occasionally found in air leaving the Debating Chamber during debates, and as this micro-organism was also recovered from air under parts of the floor where contamination from particles brought in on the boots of Members was most active, the presence of *B. mycoides* in air leaving the Debating Chamber was regarded as indicating the presence therein of particulate contamination derived from Members' boots. Further evidence to the same end was provided by certain streptococci of unusual type recovered in the same tests from air below the Bar, and from air leaving the Debating Chamber. *B. coli* was never found in air leaving the Debating Chamber; though I got it on rare occasions from air under the Bar. In the experiments previously referred to, in which earth infected with *B. prodigiosus* was laid down at a point outside the Debating Chamber, that organism was recovered from air in the

Equalising Chamber below the floor of the Debating Chamber, but was not found in air passing out of the Debating Chamber. Though that air was tested continuously over a period of many hours in these experiments, *B. prodigiosus* was only found once in the air passing out; and this single observation may have been accidental.

During these observations of air passing out of the Debating Chamber, the opportunity was taken of determining the distance to which particulate matter given off from the respiratory passages could be traced though air by means of the streptococcus test. The farthest distance to which it was traced was to a point 150 ft. from the person who spoke.

Quantitative Observations of the Air-flow.

Coming now to the second division of the enquiry, namely, the all-important question of the quantity of air supplied and withdrawn, I may say that this and the subsequent stage of the investigation were carried out conjointly with Mr. Patey, at that time resident Engineer at the Houses of Parliament. The instrument used throughout this part of the enquiry was the anemometer. We made, in the first place, a number of comparative trials with various anemometers, and decided upon Casella's instrument.

This we then had tested at Kew, and its error determined for velocities of air between 50 and 1000 ft. per minute. We next determined by experiment the distance at which this instrument should be held from the body in taking observations in the airway, and various other points were examined with a view to obtaining comparative results of reasonable accuracy. These points have been described at length in the report previously mentioned. Two of them merit attention, as they are bound to occur in similar enquiries. The first difficulty which we had to solve was the question as to whether the velocity reading given by an anemometer when passed about an inch above the face of a thickly barred grating should be multiplied by the sectional area of the whole grating, or only by the sectional area of that part of it which was actually patent. Mr. Patey had a "cuff" fixed round one of the gratings in the floor of the Equalising Chamber, and by measuring the air at the face of this grating, in the ordinary way, and by then repeating the observation near the top of the cuff (about 2½ ft. above the grating), where the currents had all merged, we proved that the velocity reading given by the anemometer held at about one inch above the face of the grating should only be multiplied by the sectional area of the part of the grating which was actually patent.

A second difficulty met us when measuring quantitatively the air issuing at the bench inlets on the floor of the Debating Chamber. One of the inlets through which air issues into the Debating Chamber is furnished by a space 1¼ in. in height, and extending between the extremity of the valance which hangs down between the seat and the floor. The extremity of the valance is fringed, and this added to the difficulty. The diameter of the wheel of the anemometer was 3 ins., and the problem was to determine the extra correction necessary when only exposing part of its surface to the air current at the spot mentioned. Mr. Patey, by an ingenious experiment which is fully described in the report, proved that it was necessary to add about 37 per cent to the reading given by the instrument at this point, besides adding the correction needed for velocity.

By means of the anemometer we measured the quantity of air passing through the system as a whole, and through each part separately, under various conditions, and we determined the actual quantity of air issuing at each bench per Member per minute. Some of the major points discovered were that the extract fan was exhausting the Debating Chamber in excess of the supply at that time, and that the ventilation of the Division Lobbies was very deficient. By joining the extract fan to the Division Lobbies these two difficulties were met by the same remedy.

The experience acquired in this part of the investigation has convinced me of the enormous practical value of the anemometer; and, indeed, to me its accuracy was as surprising as welcome. By putting the fans at the same speed as on a previous occasion—even though the previous test was made perhaps three months before—we obtained the same air flows. On taking a reading at the inlet airway at a point where the sectional area was 45 sq. feet, and then repeating it at a point 200 ft. farther along, where the air was more diffused, the sectional area being now 270 sq. feet—we again and again obtained results that showed us the accuracy of the method. On one occasion we missed a few thousand cubic feet of air at this second site, and on investigation found that a shaft from the airway, which was supposed to be closed, had remained open. A further point which we ascertained was the wonderful extent to which the Equalising Chamber under the floor of the Debating Chamber fulfils the intention of its designer, Dr. Reid, and equalises the air currents. So delicate is the balance of the air at that part of the system that the uplifting of the valances in the Debating Chamber was sufficient to divert a considerable quantity of air from the Division Lobbies into the Debating Chamber. The following tests show the accuracy of the anemometer method in this connection. In an experiment made on August 14th, 1904, the valances which had been lifted up were lowered in the Debating Chamber, and as a result 2,640 cubic feet more air were found to pass into the Division Lobbies. On making the reverse test three months later, and raising these valances, 2,502 cubic feet less air were found to flow into the Division Lobbies.

An interesting result arising out of the anemometer investigation was that we were able to measure the percentage of Terrace air in the atmosphere of the Debating Chamber under various circumstances, by deducting the air flow at the floor from the quantity of air found issuing at the outlet over the ceiling near the extract fan.

Distribution.

The distribution of fresh air within the Debating Chamber was determined by making a series of anemometer observations all over the floor, and also over the ceiling at the points where the air issues between the panels, which are all raised from their supports. We also used smoke for this purpose. The smoke tests were particularly valuable for confirming our anemometer results, and for demonstrating the extent to which the galleries were supplied with Terrace air.

These, then, are the chief results that I wished to bring to your notice. Objective tests of air do not compare with the subjective senses in delicacy, and preferably purity of air should be judged by the latter standard. As air at a temperature of 55–65° F. moving at a velocity of 1½ ft. per second can be borne by all without sensation of draught, the question of air supply is limited largely by the sectional area of the available inlet and its distribution. Humidity of air is as important to observe as temperature, and both should be rigidly controlled in all public systems of ventilation. In inspecting systems of ventilation, the subjective test and a suitable form of dry and wet bulb hygrometer, which rapidly picks up the temperature of the air, are of more value than the carbonic acid test; though the latter has its uses, particularly where insufficiency of ventilation is gross.

Our knowledge of air-borne infection is only in its infancy; but as the spread of infection through air is mechanical, it is possible that in time this may be controlled by mechanical means.

Although I have dealt with the relation between air and infection solely from the point of view of the transit of virus, there is another aspect of this universal problem that merits equal attention, namely, the question of individual susceptibility. At present we know exceedingly little of this matter, but from what we do know, there can be little doubt that resistance to disease is very intimately related to purity of the air environment.