Correspondence.

Mr. A. S. E. Ackermann noticed that the Author gave a formula for calculating the quantity of air required per minute to ventilate a tunnel, but he thought he should have explained how it had been deduced. If the following method had been adopted, it would be seen that no account had been taken of the air required for the actual combustion of the coal. This amounted to nearly 1·0 per cent. of the whole, and in any case should have been mentioned. In the formation of CO₂ the equations C+O₂ = CO₂ (12+2×16=44) (where the second equation referred to the atomic weights of the elements) showed that 12 lbs. of carbon combined with 32 lbs. of oxygen to form 44 lbs. CO₂, or 1 lb. of carbon gave $\frac{11\times3}{3}$ lbs. of CO₂. At atmospheric pressure and a temperature of say 60° F., about 8·6 feet of CO₂ weighed 1 lb., hence 1 lb. of carbon gave $\frac{11\times8.6}{3}$ = 31·5 cubic feet of CO₂. The coal was not all carbon; hence 31·5 cubic feet of CO₂ was not obtained per lb. of coal; but, taking a high percentage of carbon, 29 cubic feet CO₂ was given per lb. of coal. The permissible amount of CO₂ in the tunnel air was taken at 200, hence for every cubic foot of CO₂ 500 cubic feet of air must be supplied; hence 29×500 cubic feet of air per lb. of coal were required; 32 lbs. of coal were burnt per mile, therefore 29×500×32 cubic feet of air were required per train-mile.

Lastly, if there be a train every 2½ minutes, $\frac{29\times500\times32}{2\frac{1}{2}}$ cubic feet of air per minute was necessary per mile of tunnel, excluding the air required for the combustion of the coal. From the equation C+O₂ = CO₂ it was seen that CO₂ required for its formation its own volume of oxygen; hence 29 cubic feet of oxygen were registered per lb. of coal for combustion. Now 21 per cent. by volume of air was oxygen; hence $\frac{29\times100}{21}$ = 140 cubic feet of air were required per lb. of coal for its combustion, or $\frac{32\times140}{2\frac{1}{2}}$=1,794 cubic feet of air per minute were required in addition to the 185,600 cubic feet per minute given by the above
Mr. Acker- mann. That is nearly 1 per cent. more. The general formula, to include the air necessary for combustion, was:

\[ \frac{C \times 31.5P \times l \times n \times 10,000}{t \times p} + \frac{31.5P \times 100 \times C \times I \times n}{21 \times t} \]

\[ = \frac{C \cdot P \cdot l \cdot n}{t} \left( \frac{315,000}{p} + 150 \right) \text{cubic feet of air per minute,} \]

where \( C \) was the coal burnt per train per mile in lbs.;

\( P \) " the carbon in 1 lb. of coal;

\( l \) " the length of the tunnel in miles;

\( n \) " the number of trains that pass through the tunnel in \( t \) minutes;

and \( p \) " the number of parts of \( \text{CO}_2 \) per 10,000 permitted.

Exhaled air was referred to by the Author as "air-sewage"; but it was not so much the \( \text{CO}_2 \) in the air-sewage that was obnoxious as the organic matter. Professor Huxley had stated that the poisonous effect of \( \text{CO}_2 \) had been very much exaggerated, for as much as 15 per cent. to 20 per cent. (i.e. 2,000 parts in 10,000) of \( \text{CO}_2 \) might be contained in air without producing insensitivity, if the quantity of oxygen be simultaneously increased. He also stated that there were 33 cubic inches of \( \text{CO}_2 \) per 100 cubic inches of blood, and even in the brightest arterial blood there was more \( \text{CO}_2 \) than oxygen. The amount of \( \text{CO}_2 \) in exhaled air was about 4.5 per cent. by volume. On the other hand, if a cold glass bottle be taken into a hot close room, containing many people, moisture containing the organic matter will condense on it, and if one drop of this moisture be injected into a rabbit it was killed. The number of micro-organisms per litre of air in sewers was given in the Paper as 8.9. This was extremely low, and was partly accounted for by the fact that in sewers the micro-organisms were undisturbed by wind, and when once they settled they did not rise again, owing to the moisture on the internal surface of the sewer. The theatre of the Institution was referred to, and it formed a very convenient example for such reference in order to make various figures, which were constantly mentioned in connection with ventilation, more real. For example, allowing 8 parts of \( \text{CO}_2 \) per 10,000 as the limit of vitiation (though often stated at 6), there was 1 part per 2,500 in addition to the 1 per 2,500, which was normally present. Each person gave off 0.6 cubic foot of \( \text{CO}_2 \) per hour; therefore 0.6 \( \times \) 2,500 = 1,500 cubic feet of air per hour per person must be supplied. Taking the seating
capacity of the theatre at $350 \times 350 \times 1,500 = 525,000$ cubic feet per hour should be supplied, as compared with the $420,000$ cubic feet that could be. On special occasions, such as the opening meeting, 600 members had been present. Still $\frac{420,000}{1,500} = 280$ persons, and this no doubt covered most of the meetings. The dimensions were $60 \times 40 \times 27$ feet roughly, $= 64,800$ cubic feet, which only allowed for 65 persons at the 1,000 cubic feet per person rate (the lowest for hospitals), or 260 at the very low rate of 250 cubic feet per head (the minimum for workshops and factories). Supposing the necessary air were admitted by the whole of one side of the theatre (1,080 square feet), then

$$\frac{525,000}{1,080 \times 60 \times 60} = 0.132 \text{ foot per second would be the necessary velocity of the air.}$$

Now air at 60° F. was barely perceptible when it had a velocity of 2 feet per second, and was only a draught when the velocity was greater than 3 feet per second. At 70° the velocity could be greater. Hence allowing a velocity of 2.1 feet per second, the opening to supply the above quantity of air would have to be $8.2 \times 2$ feet square, i.e., 1/4 the area of one side of the theatre. If, however, the positions of the inlets were suitably arranged, the velocity of entry could be 5 feet per second. The Royal General Hospital, Birmingham, was mentioned in the Paper. When visiting this hospital some three months ago he had looked down the warm fresh-air inlets (of the children’s surgical ward), which discharged upwards just in front of the windows, and there saw a collection of rubbish. In the children’s medical ward there was no such collection, the children being too ill to throw the toys over in their gambols, as was the case in the surgical ward. The air, though no doubt suitably warmed and cleaned, certainly lacked freshness. In the Appendix, p. 15, it would add to the usefulness of the Table if, in the case of the natural draught, the temperatures inside and outside the chimney were stated.

Mr. J. R. Bell failed to see why the tests used were based on Mr. Bell’s carbonic-acid rather than on gases which are apparently more freely miscible in the air and were undoubtedly more noxious. The trains under the Mersey were calculated to aid the admirably designed artificial ventilation very materially. The grading was ideal and constituted just such a “momentum dip” as the Central London authorities had deliberately adopted. In the first train length out of either station a sharp decline took up the work of haulage on the switchback principle, and it was only after passing
Mr. Bell. the central outdraught, if then, that the engine began to "rush the bank" and emit any gases. Although the engines were heavy and the fuel indifferent, there was no occasion for surprise at the moderate consumption of coal and the still more moderate emission of noxious gas under such conditions. As to the effect of these upon the ventilation it would perhaps be agreed that the amount of induced air-current, like that of air-resistance, bore a geometrical rather than a simple arithmetical ratio to the speed. In this case the trains accelerated the pre-arranged draught when at their highest speed with the gas-emission at its minimum, and counteracted the ventilation when at their least speed and greatest gas-emission. The ventilation under the Mersey was in popular belief much better than that of the landward section from James Street to Central Station—a matter which the Author could doubtless set at rest by explaining the system there adopted and the results of analysis. That train-induced currents helped the fans to a very appreciable extent at all times seemed not unreasonable, and consorted with the belief that artificial ventilation in mines and tunnels seldom performed all the work, but acted largely as a make-weight to determine which of two outlets the air-currents would adopt. The Author's very neat and simple formula for determining the requisite fan-power omitted to mention the length of tunnel, which presumably was 1 mile. That would seem to show that between 2,000 and 2,500 cubic feet of air had to be changed for each pound of coal burnt in the tunnel, whatever its length. In tunnels with steep continuous gradients like the Mont Cenis, not to mention rack-rail gradients, the consumption of fuel was enormous, but a good deal could hardly be said to be burnt, being merely pulled out of the fire-box by the blast. In reference to the excessive wear and wastage of rails in tunnels, he had not hitherto recognized the importance attached in the Paper to ventilation. Tunnels with fairly level gradients were often ill-drained, and in those with steep gradients the free use of sand under driving wheels was often a serious factor. He believed that, before water was substituted, the sand taken yearly out of the Giovi Tunnel amounted to many wagon-loads. Where instead of sand being removed new ballast was wanted in tunnels it appeared to indicate that the original ballast became yearly more compacted and clogged into a hard inelastic pan. The sole of a tunnel below the ballast acted even more like an anvil than the bed of an open-rock cutting. The rail-joints in tunnels were seldom so well packed as outside, and it was not unusually the case that the rails were either ground up with sand in steep tunnels or hampered to pieces in flat ones.
There was, he thought, little difference in wastage between the ill-ventilated Cenis and the well-ventilated Box Tunnel. Assuming that the Cenis rails were changed as soon as they had lost 10 per cent. of their original weight, the renewal of 300 tons a year denoted a wastage of 30 tons in some 8 \(\frac{1}{4}\) miles, say 3.61 tons per mile, or 2.3 lbs. per yard. If the view taken above were corroborated by home experience, it would be found that in, e.g., the Box Tunnel, on a gradient of 1 in 100 there would be more wear on the descending than on the rising road, and this it was understood was the fact. It was not easy to see how ventilation alone could materially affect one road in the same tunnel more than the other. If, as suggested above, compacted ballast affected the matter, the rail-wear would increase with the age of the line. It was perhaps hardly fair to take the Author’s suggestion to the effect that the annual cost of renewing 150 tons of rails would go far to equal that of fan-ventilation for Mont Cenis, too seriously. After allowing scrap values it seemed unlikely that the renewals would exceed £1,000 a year, while the ventilation plant suggested would apparently have to deliver quite 1\(\frac{1}{2}\) million cubic feet a minute through an 8-mile duct. On the Indian frontier steep tunnels descending through the rims of elevated plateaux tended to act not unlike the natural passes which were but notches in those rims, hot air ascending in the heat of the day and cold pouring outwards in a stream at night. Forcing cooled air down hill was seemingly not only the desideratum but the easier operation. There was apparently no great difficulty in bell-mouthing a tunnel portal with the Saccardo system instead of contracting the gangway, but the air used in that method should be cooled and moistened at the intake. The Indian Government had had occasion to study such questions in the interests of the frontier railways. Its most notable work of this class, the Khojak Tunnel, was some 3 miles long, and was originally divided by two shafts into three lengths. From near mid length one end falls \(\frac{1}{4}\) and the other \(\frac{1}{3}\), so that between the two shafts there lay, as it were, a pocket of dead air. There the ventilation had been much improved by closing both shafts, and it was not thought necessary to do anything in the direction of artificial ventilation. Another tunnel, which, but for the danger of falling boulders, might be opened out, was drained by side adits some 100 yards apart, but these failed to keep the air on the footplate breathable and oblique blow-holes had to be made. This tunnel was half-way up a \(\frac{1}{10}\) bank of some miles in length. It was only worked in daylight, and with a full load the uphill
Mr. Bell, speed was but a walking pace with a consumption of fuel reaching hundredweights per mile. The local coal was exceedingly sulphureous and the line was only worked in daylight, i.e., when the air-flow ran usually uphill. The only troublesome cases in India were tunnels at elevations of 3,000 to 5,000 feet above sea-level. So far the advice tendered to the Government of India as to tunnel ventilation was mainly of a negative character and might be summarized as follows:—"Fan-installations were not yet necessary. Having adopted the vacuum brake, supplying the engine-crews with air compressed outside was infeasible. Breathing-masks fed by pipes with air from the front buffer beam were of little use when the wind was with the train. On new lines tunnels should be flatter than the ruling gradient outside. The roomy engine-and-tender cabs should be closely curtained at sides and back with wetted canvas in tunnel sections. Welsh coal alone should be used on certain sections with troop-traffic." Those, till quite lately, were the leading recommendations. If artificial tunnel-ventilation had no field in India, domestic ventilation was very extensive. In Kurrachee the roof of every native hut had a rough but effective fixed cowl for catching the sea-breeze. Up country in the hot season the punkha was universally used. The primary object of punkhas, as of hand-fans, was to move the air rather than to change it, and the cooling effect was due to moving air evaporating imperceptible perspiration from the hands and faces of those fanned. Buildings occupied by Europeans in the Plains were closed tight against hot winds during 8 hours or 10 hours a day for months together, so that a forced draught, cooled by wetted screens, was useful in every case and absolutely necessary in all public buildings. Experience showed that plenum fans delivering at a little above floor-level were better than exhausters near the ceiling. The latter were very similar to the small electric fans now in common use at home, while the plenum fans, known as Thermantidotes, resembled the fans of the Mersey Railway and varied in diameter between say 4 feet for a private house and perhaps 25 feet for a large suite of railway offices. In the abstract the exhauster was the better appliance, but it failed in practice because it drew in hot air from incidental crevices instead of through the watered "tattie" screens. The plenum fan used more power, but it only supplied what was wanted, which would in England appear to be air properly filtered and either cooled, damped, heated or dried, according to the season. Rarefied air was not in itself found objectionable in India provided
it were fairly dry. Some of the healthiest hill-stations had Mr. Bell, a mean barometrical pressure of but 24 inches of mercury. It should be added that in the plains during the hot season no attainable amount of forced draught was regarded as a substitute for the evaporative effect of the punkha. Indeed without the punkha a dry and hot draught produced far less discomfort than if damp and therefore ostensibly cool.

Mr. Morgan W. Davies hardly thought it could be satisfactorily proved that 1 cubic foot of carbon dioxide would vitiate 500 cubic feet of air to such an extent as to render it inconvenient; but a mixture of carbon dioxide with other deleterious gases, and especially carbon monoxide, if present in the atmosphere to that extent, would probably have that result. Scheurer Kestner, the eminent Alsatian chemist, in a series of experiments he conducted in 1870, on the gases given off from an ordinary boiler, discovered that where the proportion of carbon dioxide averaged 14 per cent., the proportion of carbon monoxide averaged 0.9 per cent. Schwackhoefer, again, discovered, by burning coal in a calorimeter, that after combustion there resulted from 0.2 to 0.8 per cent. of carbon monoxide. Again, some coals were very sulphurous and emitted fumes of a deleterious nature, especially SO₂. It might therefore be assumed that in the atmosphere of a tunnel, when it had been vitiated by the fumes of an ordinary locomotive engine, there were gases present other than CO₂ in larger or smaller volumes, otherwise the proportion of air to render it innocuous need not be so great as 500 to 1. Applying the Author's deductions to the ventilation of the Simplon Tunnel, and assuming the consumption of coal to be 30 lbs. to 40 lbs., say a mean of 35 lbs. per train-mile, and the time occupied in going through the tunnel 40 minutes, the volume of air required per minute would be

\[
\frac{35 \text{ lbs.} \times 29 \text{ cubic feet} \times 500 \times 12.25 \text{ miles}}{40 \text{ minutes}} = 155,420 \text{ cubic feet}, \text{ say 156,000 cubic feet.}
\]

Calculating the sectional area of the tunnel at 250 square feet, the velocity of the current per minute would be 624 feet, or about 7 miles per hour.

If \( P \) = ventilating pressure in lbs. per square foot.

\[ R = \text{surface exposed to friction} = \text{length} \times \text{perimeter} = \text{length} \times 60 \text{ feet.} \]

\[ V = \text{velocity of current in feet per minute.} \]

\[ K = \text{coefficient of friction for velocity of 1 foot in a minute, which for railway tunnels may be taken at 0.0000000228.} \]
Mr. Davies. Then

\[ P \times \text{area} = K R V^2 \quad \text{and} \quad P = \frac{K R V^2}{\text{area}}, \]

\[ P = \frac{0.0000000228 \times 60 \times 64,680 \times 624^2}{250} = 13.75 \text{ lbs.}, \]

or dividing by 5.2 lbs. the weight of a superficial foot of water 1 inch deep = 2.6 inches of water-gauge. These conditions, both in regard to volume of air in circulation and the water-gauge pressure, were frequently found in the ventilation of an ordinary colliery, so that there would be no difficulty in passing through the tunnel an adequate supply of fresh air on the basis of the Author's deductions, which would certainly be sufficient for all purposes. Having regard to the best system adaptable for the ventilation of long tunnels where a shaft at, or near mid length was impracticable, the Saccardo system undoubtedly offered many advantages over any other system that had so far been applied, inasmuch as the bell-mouth arrangement of the fan drift through which the propelled air entered the tunnel admitted of a more uniform distribution of the inflow air, and with less shock than would be obtainable by any other system of in-blowing ventilator; whereas, on the other hand, any arrangement of exhausting ventilator would necessitate the provision of a door at the outflow end of the tunnel. Such door might, it was true, be made without difficulty to work automatically, but it would involve the introduction of mechanical appliances for opening and shutting it, which, if possible, it would be well to avoid.

Mr. Dolby. Mr. E. R. Dolby observed that carbonic-acid gas was not the only source of impurity to be considered, and although 1,200 cubic feet of air per person might be sufficient in the case of hospitals, 3,000 cubic feet of fresh air per bed per hour should be aimed at. Ventilation could not be considered alone, but must be dealt with at the same time as the heating, and the standard to be aimed at had been well expressed as that of the condition of the air "upon a hill-side on a bright spring morning." So long as the temperature of the external air was at or about 60°F., no heating would be needed and ventilation could be effected by open windows; but if the temperature were lower outside, then heating would be required. Air colder than the desired temperature of the room should not be permitted to enter, and, if possible, such air should be clean; if the external air were not sufficiently clean, then it was desirable to use mechanical means to render it clean, and in that case mechanical ventilation, by means of a fan, became essential, as the resistance offered to the current by the cleaning apparatus
could not be overcome by natural draught. In Great Britain it Mr. Dolby was usual to use either hot water or steam for heating purposes. He considered that each radiator used in a hospital ward should be fixed in a case provided with adjustable openings, so designed that on first heating the ward the air should be caused to circulate through the case and no external air be admitted, and that after the temperature had risen to 60° F., the external air should be admitted as required. If the inlet for the external air were at floor-level, then if the outlets were at ceiling-level there was always a danger in the still air of the wards for a current to be formed direct from inlet to outlet, leaving a large part of the air of the ward stagnant; he considered two outlets were desirable, one at ceiling-level to the upcast flue, and one at floor-level to the same flue, and special valves should be used so that both outlets could never be open at the same time. If open fireplaces were used as an auxiliary means of heating, then these would act as outlets at floor-level and the top outlets might be closed. In public schools in the United States external air was drawn by flue suction into a tiled basement chamber containing a heating apparatus and thence passed up special flues to the rooms. Each room had a special flue direct from the basement chamber. The air, heated to 90° or 100° F., entered the room through a large grid or grids at about 3 feet above floor-level, and the opening of the flue was regulated by a valve. The heated air rose to the ceiling and passed out by a number of openings at floor-level, thence below the boards—thus heating the floor—and through a special down-cast flue to a foul-air chamber in the basement, thence through the ranges of latrines and up the large main ventilating shaft. All excreta were perfectly dried (no water-closets were used) and it was only necessary to pour about half a gallon of petroleum on to the dried mass, after which it could be lighted and burnt away. In England Drs. Drysdale and Hayward had given the subject of heating and ventilation of private houses very careful attention, and each had built a house for himself ventilated upon the system alluded to below. The success was so great that one of the members of the family, who for years had been obliged to winter in the south of France, was able to remain in England. The system consisted in using the ordinary kitchen flue as the means of heating a main ventilating-shaft, which caused a suction upon the air in the building. External air was drawn into a basement chamber and, heated by steam or hot-water radiators, it then passed up flues to the rooms. In each room the air was delivered at 65° F. through the cornice and fell through the atmosphere, which was warmer.
Mr. Dolby. than this owing to respiration of the occupants. The heated air passed out through outlets in the cornice at the opposite side to the inlets, thence to a foul-air chamber at the top of the house, down a main flue to the basement-level, and up the main ventilating-shaft. He had found it very difficult to satisfactorily study the course of the slow and feeble currents set up in most buildings by ventilation; it was possible to do so in certain cases by the use of gardeners' smoke-cones, but he believed the method of experiment with models so strongly recommended by Sir Benjamin Baker was decidedly the best.

Mr. Druitt Halpin. Mr. Druitt Halpin considered Mr. Saccardo's arrangement for ventilating tunnels mechanically a very useful one, but he thought a much better efficiency could be produced by a modification of the apparatus, making it more suitable for the large volumes and low pressures of air with which it had to deal. Instead of admitting the air from the fan through one opening only, the efficiency might be very greatly increased by making a petticoat arrangement similar to the one occasionally used in locomotives as shown in Fig. 4, care should be taken to have the main entrance well bell-mouthed and formed by easy curves. With regard to the purification of air for use inside buildings, there were four main conditions to be attended to particularly if the air was to be used by persons suffering from consumption: (1) the air should be perfectly free from all mechanical impurities, which experience had already shown could be effected by filtration through cotton wool; (2) the question of temperature, which obviously could be easily dealt with; (3) the hygrometric condition of the atmosphere, and this could probably best be dealt with by the beautiful process described by Mr. Nelson, in which, by a suitable reduction of temperature, all the water contained in the air was frozen out of it, the water being deposited, and any required degree of humidity could then be produced by spraying distilled water into the air; this system of moistening would be absolutely under control and was

similar to the course pursued in producing Bessemer metal, where
the whole of the carbon was completely removed from the iron and
a certain definite amount is subsequently added. The fourth process
was the removal of all micro-organisms from the air, and this could
be done at the same time as the first part of the third process,
while the refrigeration was being carried out, as it was now
ascertained that very severe dry cold was absolutely inimical to
such forms of life. An apparatus similar to an economizer behind
a stationary boiler might be used, having vertical pipes from
which the snow could be removed by scrapers acting continuously.

Mr. Mervyn O'Gorman remarked that two palliatives for the
evils of bad ventilation, among which a risk of consumption un-
doubtedly figured, were: (1) the filtration and moistening of the
air; (2) its proper admission. If moistening were omitted, the air
movement incidental to good ventilation produced an evaporation
from the body which resulted in a feeling of chill and a parching
of the mucous membrane of the nose and throat well known in
cold weather, when the body provided both warmth and moisture
to the expired air. If filtration were neglected there was admitted
with the large quantity of air now deemed necessary an amount
of dust which could only be realized by examination of an efficient
filter after a week's run. Ventilation-shafts were useless unless
they be made large and accessible for cleansing, and unless they
were supplied with air properly filtered, warmed and moistened.
The dust, cold and discomfort introduced by some ventilation
shafts, as well as their eventual evil odour, easily explain the
religious fervour with which such openings were often sealed by
those who had to breathe the air supplied, and it was their opinion
that was alone worth having. The only way all the entering air
could be warmed, filtered and moistened, was on a plenum system.
In railway carriages as in rooms, the more thorough the extraction
of air the greater the inward leakage through dusty chinks and
the worse the draughts. On long runs, instead of 3,000 cubic feet
per hour, a passenger had 30 cubic feet, which he preferred to the
only alternative of a draught and dirt from the locomotive. Many engineers spent as large a fraction of their lives in trains as
others did in Committee Rooms of the House of Commons, and it
would before long become important for the railway companies to
improve on the present state of their carriages. A simple im-
pulsion fan cheaply served this object. The admitted air could be
steam-heated from the exhaust with no greater expense than the
heating at present entailed, but the air should not rise from the
floor where, unfortunately, people still expectorated. From ex-
Mr. O'Gorman. experiments he had recently made it seemed that the air-supply to a railway carriage could be warmed with a compact electrical apparatus measuring $\frac{1}{3}$ square foot by $\frac{1}{3}$ inch thick. Fifty-six feet of platinoid wire zigzagged across a frame 1 foot square had a resistance of 4 ohms, and at 100 volts carried 25 amperes. With a 12-inch fan behind this, delivering about 1,000 cubic feet of air a minute into a room containing 1,500 cubic feet, he found that in 15 minutes the temperature in the room was raised from $8^\circ$ C. to $12^\circ$ C., at a cost for current 2½d., and in the course of that $\frac{1}{3}$ hour 15,000 cubic feet of air had been delivered into the room. If a train were one long Pullman and this supply were kept up, the traveller would be in comfort; not a speck of dust would enter even when doors and windows were opened. The cost to the company for current would be 9d. per hour; exhaust steam might be substituted, the cost of the heat properly administered was very small. Micro-organisms were numerous almost in direct proportion as the air was dusty. The monetary significance of dust in daily life was measured by the labour expended in London households, say £2,000,000 per annum, allowing one-tenth of a housemaid's time for dusting to each ten of the population, and even without smoke prevention, this expenditure might be halved by the use of filters and fans. Comfortable breathing required a hygrometric state measured by $3^\circ$ to $9^\circ$ difference between the wet and dry bulbs; this might be obtained by a pulverized spray, a wet screen, or a water-trough placed after the heater in the air-way. These also intercepted fog particles, which were vehicles of dirt; indeed it was held by some that fog was more easily removed than other impurities in air owing to this attraction for water. Where the air-velocity was low, a water-spray itself would efficiently wash the air without the spray being carried over mechanically, but this method was expensive because of the large ducts required for the low velocity (say 4 feet by 4 feet 6 inches for this room). It had the advantage, however, of affording little resistance to the passage of air and little expense for filter renewals. If air were drawn through the pores of a fabric or cotton wool, or made to brush past a hairy surface edgewise, trouble arose from the increase of resistance with an increased efficiency of filter. To avoid this a large filter-area was required—thus with a 5-foot fan this room required 400 square feet of filter. If so large an area was not available it became necessary also to introduce exhaust fans (which might be noisy) on the roof, or to increase the speed of the main-supply fan to give the required air-pressure, thus entailing a disproportionate energy consumption.
owing to air-churning. A method which obtained the advantages of vertical jute strings kept constantly moist and periodically flushed. To diminish the resistance a large area should be employed, say twenty times the fan area. This filter required cleaning. With a cotton-wool filter, such as was used at the House of Commons, after a short period of use the incoming air came into close contact with the deposited dirt on the outer layers of the filter. This dirt being dry was dangerous. He alluded more particularly to the risk of consumption from dust infected by the dry sputum of consumptives. He thought Professor Huxley was one of the first to point out this risk of dry, as distinct from wet particles, and deduce from it and other evidence that the belief in hereditary consumption was erroneous. This risk had come to be admitted by many medical men who might not agree with his deduction. A system which combined the advantages (if any) of cotton wool with those of the water spray, and added to them the efficiency of charcoal as a deodorizing and filtering agent, was the Blackman screen. In a modification specified by his partner, the charcoal or coke screen was constituted of rectangular baskets of portable size, and so arranged that the screen, which was 10 inches deep, was made up of two layers. This allowed the baskets on the intake side to be removed one by one and their foul contents burned under the boiler or radiator. The coke must be kept damp with trickling water to cool, or damp the air, or washed in time of fog. The chief drawbacks to a coke filter were its weight and size (say twenty times the fan area); the absorption of ammonia and other odours was an advantage not to be overlooked. Washing the screen with a hose and leaving the coke permanently undisturbed through a year or two was tolerated by the inventors, though he could not help doubting the wisdom of this course. During a record fog, without a word of warning, he had visited a Bermondsey laundry to examine the linen which was drying in air filtered by this means. There was no water allowable on this filter, but he was bound to admit that the linen was admirably white and speckless. There was a prejudice in favour of withdrawing vitiated air from the top of a room, but when the problem of admission was considered, this view must in many cases be modified. To admit at the floor-level, as in the House of Commons and other places where ventilation had received much attention, was to foul once more the air which had been purified. There were similar objections to admitting air at any level lower than people’s heads, for there were inevitable emanations from all living beings,
Mr. O'Gorman. and dust was easily stirred by the feet into the fresh-air current. Air admitted at the level of people's heads must be directed not horizontally nor downwards, but towards the ceiling. This plan appeared good and was sometimes adopted. There would be leakage if the outlet be in the ceiling, for air unutilized would pass away. This was avoided at Huddersfield Infirmary by outlets at the floor-level; there was no leakage, and the draught, if any, was entirely under the beds. Another method of admission which had been tried, and which on examination showed the utmost promise, consisted of admitting air at the top of the room, through a sheet of uniform texture having the full area of the roof of the chamber. Such a sheet must be capable of being washed (or cleaned by dry process) at long intervals, and was adaptable to large or small rooms. It would have the same effect as deflector-plates in the air-admission holes in the roof of shattering the column of air, which would otherwise descend unbroken on the heads of inmates. The filtered air would pass through the sheet with a low velocity owing to the large area, and for the same cause with little friction. The good air would meet the bad in its ascent, dilute it and drive it out, not only through the apertures provided 1 foot above the floor, but through all natural chinks or open windows to the exclusion of fog and dust. Since the function of the sheet was not to filter, but merely to spread the down draught uniformly, the fabric might be fairly coarse, so that increase of friction need not be considered. It was probable that a prejudice would arise against this arrangement, yet it might, without unsightliness, be adopted in all meeting places (unless indeed the Colisseum were unsightly or the ancient amphitheatres). Silks and tapestries, or prints of any shade of colouring or design, might for this purpose be introduced.

Mr. Rutter. Mr. Henry Thornton Rutter agreed that mechanical ventilation properly applied to the Metropolitan Railway would overcome in a large measure the present cause of complaints. If shafts were taken between the stations, and fans of large diameter running at a low speed were provided, using the stations as the intake of fresh air, the result required would be obtained; at present, owing to varying temperatures of the air inside the tunnel and that of the outside atmosphere, the blow-holes now provided sometimes acted as intakes of fresh air, thereby flooding the station with fumes and vice versa, irrespective of the movement of the air caused by the passing of the trains. As regarded the ventilation of buildings, even now many architects thought they had only to cut a hole through to the outside air to
obtain ventilation; and it was the simple principle of the necessity of not only supplying means for the escape of the vitiated air, but also providing inlets for fresh air without causing draughts that seemed so difficult for them to learn. These requirements led to the conclusion that the plenum system was the most reliable, as, properly applied, by these means the temperature of the air in the various spaces to be ventilated could be adjusted without interfering with the volume of air supplied, whereas in most buildings, where "natural ventilation" was in vogue, the volume of the air supplied was usually capable of being altered. As regarded the quantity of fresh warmed air necessary to be provided, 800 to 2,000 cubic feet per hour per child for schools, according to the class of children attending, 2,500 to 3,500 cubic feet per hour per patient for hospitals and asylums, and 500 to 1,000 cubic feet per hour per person for assembly halls, &c., had given excellent results in his own observations; and, provided the air was introduced sufficiently warmed into the rooms, it could be sent with a velocity as high as 7 feet per second without a draught, though 5 feet per second was the usual velocity adopted. As to the position of inlets and outlets, the fresh warmed air in winter and well-washed and cooled in summer should be introduced about 8 feet 6 inches above floor, and outlets provided at the floor-level for winter, and at ceiling-level for summer use, and so arranged that it was impossible to alter the volume of air either in the fresh-air trunks or vitiated-air outlets, and also that all air-trunks of whatever description could be easily cleaned, as when Tobin or similar tubes were used they were usually so full of dust and debris that they vitiated the air before entering the room.

Mr. A. Schrafl, of Lucerne, stated that in the autumn the St. Gothard Tunnel was traversed daily by ten fast through trains, eight omnibus trains, sixteen regular and twenty-seven optional goods trains, in all sixty-one. The first passed through in 15 minutes, the omnibus trains in 22 minutes, and the goods trains in 28 minutes. The use of briquettes was confined to the locomotives of fast through trains, all the others burnt coal. At the centre of the tunnel the minimum temperature of the year varied between $58^\circ$ and $62^\circ$, and the maximum temperature between $72\cdot5^\circ$ and $74^\circ$. It was not so much the combustion of the briquettes as the rapid succession of trains, combined with the momentary equilibrium of barometric pressure between the ends of the tunnel, which caused the accumulation of thick smoke, and the shutting in of the noxious gases in intolerable quantity. The passengers
Mr. Schrafl and the personnel of the engines and trains were, however, not so much affected as those engaged upon the repair of the tunnel and the surface men. It would be impossible to construct airshafts. During the course of 1898 the installation had been undertaken at the north end of plant upon the Saccardo system. The works consisted essentially of two ventilators, 4.9 metres in exterior diameter, with an annular air-chamber in the interior of the tunnel, all the passages for the junction being in masonry. The apparatus would at first be driven by a steam-engine of 450 HP. With such arrangements it was proposed to drive into the tunnel 126 cubic metres of fresh air per second, and to produce in it a current of 3 metres per second in the direction of north to south, when the natural current in that direction, or vice versa, did not move at that or a greater speed. When this result was once obtained, not only could the survey and the repair of the permanent way and the masonry of the tunnel be carried out in pure air, but a considerable diminution of the wear of the metallic parts of the structure was expected; it was now six times as great as on the open sections of the line. It was presumed also that the ventilation would reduce the time during which the products of combustion would remain in contact with the line, that it would absorb the vapour of water, and that it would prevent in a considerable measure the deposit of soot upon the walls of the tunnel; all advantages which would diminish the formation of rust and so permit of considerable economy upon the cost of maintenance being effected. A trial of the apparatus had been made on the 16th March, 1899, with good results. The atmosphere of the tunnel was formerly in almost complete equilibrium, or there prevailed a feeble current of air in the direction of south to north. The artificial ventilation had produced, in the direction of north to south, a current with a speed of between 3 metres and 2.8 metres per second; so that the repair of the permanent way between 12th and 13th kilometres from the north entrance could be carried out under excellent conditions, while formerly it was necessary to entirely suspend the work. At this point of the tunnel, a momentary stoppage and re-starting of the fans could be perfectly felt. Enquiry was to be proceeded with as to the exact speed of the fans and the driving-power necessary under varying atmospheric conditions, as well as the speed of the current of air at different points in the tunnel.

Mr. W. Schönhayder thought that in most cases the best manner of warming and ventilating buildings where warm air only was employed for the dual purpose, was that in which the fresh
warmed air was admitted near the ceiling and the waste air was withdrawn at the floor-level. The air which was admitted to warm an apartment must necessarily be at a higher temperature than that which it already contained, and it must therefore at once rise to the ceiling, where it ranged itself nearly horizontally on the top of the existing cooler air. The new air was again displaced downwards by a further fresh supply of warmed air and so on continuously, whereby the whole of the air in the room was caused to descend in approximately horizontal layers, the new air thus searching and refreshing every corner of the room, and was ultimately withdrawn through apertures in the floor, or by suitable outlets in the walls close to the floor; the circulation of the air being caused either by warm upcast shafts, or by the plenum system. Where very large quantities of gas were burnt the ventilation must be considerably augmented compared to what would ordinarily be required, as stated in the Paper, or separate outlets near the ceiling must be provided. Further, for excessively large areas, or for unusually large window surfaces, specially contrived arrangements were needed. Generally, however, and for moderate-sized rooms, he considered the down-flow mode to be the best, as it gave uniformity of temperature with absence of draughts. Having warmed and ventilated several private houses, rooms and offices with entire success he had experience of the system, the ordinary chimney serving as an upcast shaft, sometimes assisted (especially in mild weather) by a small fire. In a range of offices recently fitted, where chimneys had not been provided, he made an upcast-shaft in each room by inserting a rectangular galvanized tube, reaching through the roof and provided with a windguard as well as a wire screen for birds, &c., and terminating about 3 inches from the floor-level. A small gas-jet was provided inside, and near the base of each tube, to assist the ventilation in comparatively mild weather. In one of these rooms 22 feet by 12 feet 6 inches by 10 feet high, he found one day when the inside temperature was 62° and the outside temperature 52°, or only 10° difference, that the air-discharge was 1,280 cubic feet per hour; but with the assistance of the gas-jet, burning some 3 to 4 feet of gas per hour, the ventilation was 3,170 cubic feet per hour; showing the great help to ventilation by a small quantity of gas properly applied. Difference of temperatures at floor and ceiling from 2° to 3° F.; four people generally occupied the room. To facilitate the work of the stoker he had a thermometer fixed to the "flow" pipe of the hot-water apparatus, and for several weeks he took careful readings of the external temperature, the temperature...
of the flow, and the temperature of the principal room, from which he constructed a Table showing what temperature should be kept in the flow pipe under a given external temperature in order to ensure the desired inside temperature. It worked so well that the inside temperature seldom varied more than 1° or 2°, excepting only through the occasional neglect of the night-watchman. In very cold countries the system of warming by hot air only was not satisfactory, as it necessitated a very high internal temperature of the air (70° was very general in American rooms) in order to counteract the chilling effect of the walls; in other words, the strong radiation of heat from the body to the cold walls. Some system of double walls, say brick external and thin internal of iron, wood or cardboard, with a system of heating pipes between, would probably be found efficacious for all walls communicating with the external air, proper ventilation being provided for.

Prof. Smith.  Prof. R. H. Smith observed that an approach to theoretically perfect ventilation would render possible considerable economies in building construction. The commonly adopted basis of calculation of so many cubic feet of space in each room per person meant that the object aimed at was the slowing down to a standard time-rate of the vitiation of a stationary quantity of air. From this idea was derived that of supplying per hour between 30 and 200 times as much fresh air as was actually inhaled by the living inmates of the room. The true idea of perfect ventilation was evidently to inject and extract only a moderate excess, say 5 to 10 times as much, over that actually inhaled, and to do so in such manner, that (1) the exhalations did not mix with the fresh supply, and (2) the inflow was properly diffused and did not pass direct to the outlets in merely local currents or "draughts." To do so under these conditions was admittedly a mechanical problem of the greatest difficulty, but one which ought not to be considered insoluble. With such ventilation small bed-rooms and living-rooms with low ceilings would be more sanitary and more comfortable than large ones with lofty ceilings without such ventilation. Except for architectural effect, high ceilings mean simply the provision in the upper part of each room of aerial cesspools—a plan which was both insanitary and disgusting. He had examined several cases of large complex ventilation installations on the plenum system, and found it unsatisfactory unless under careful, skilled and continuous supervision. Air being so light a substance, the small differences of pressure in the outside atmosphere arising at one place every few seconds, and simultaneously on different faces of even a small building, were sufficient to cause back draught in one
outlet duct finding its escape by increased forward draught in another. This difficulty was common to the plenum and extraction systems if the motive power of the forced draught of a complex system be concentrated at one place. The rational cure seemed to be the decentralization and proper distribution of this motive power in a degree proportioned to the ramification of the whole installation served. This might be accomplished either by electrically-driven small fans or by gas-jets properly protected from being blown out by back draught. Another help was the insertion of light check-valves placed near the extremity of each outlet duct. Mica-plate flaps could easily be made noiseless by providing them with wash-leather seats to fall upon. They should hang slightly open when no current passed. As the exhalations from the lungs did actually rise, the "down-current" or "ceiling-to-floor" system was incapable of producing the theoretically perfect ventilation alluded to above. Its advantage was the easier uniform distribution of the fresh-air current over the horizontal area of the room. Again, inflow at the floor invariably had chilling effects, and also swept the fresh air over a surface that could not be kept scrupulously clean. The perfect inlet would seem to be a perforated pipe running all round each room at a height of 3 or 4 feet from the ground; and the perfect outlet 2, 4 or more vents at the ceiling on opposite sides of the room. With perfect ventilation the quantity of inflow needed per hour was so small that the mechanical driving power required would be vastly decreased; the velocity of the air-current was so low that "draughts" would be much more easily avoided, and the heat that must be expended to warm the air to a comfortable degree was also correspondingly diminished. It might fairly be doubted whether any air-warming at all would be needed for perfect comfort even in the coldest weather. Living bodies were not warmed but cooled by contact with air, and the only utility of air-warming lay in the diminution of the chilling effects of draughts. Living bodies were warmed chiefly by internal combustion, and the only available external sources of heat were "radiator." Even in a hot bath at 105° F., the supply of heat by conduction from the hot water to the body must be very small, the main warming effect resulting from the complete or partial stoppage of loss of heat from the body. The suggested "perfect" ventilation was evidently incompatible with warming by open fires placed near the floor. With these the main extraction was always at the fire-place.

Mr. G. W. Walker agreed that where fans were employed, Mr. Walker. and in short tunnels, their best position was about the middle of the tunnels, extracting the foul air from that point and causing
Mr. Walker, the fresh air to rush in at either end. The Author stated that objection had been taken to this system of placing fans midway in the tunnel, as a strong wind blowing in at either end would effect the suction of the fan, i.e., unbalance the sucking power of the fan, which might tend to pull more from the windward and might even neutralize the natural air-current on the lee side; he did not anticipate much difficulty on that score, natural currents being, as a rule, feeble. Atmospheric conditions caused natural currents of air in a tunnel. Sometimes they flowed in one direction and sometimes in the other, but the natural currents were quite inadequate for efficiently ventilating a tunnel, say, like the Severn or Mersey or even the Metropolitan. There were also other currents caused by the motion of the trains. If an anemometer were held from the window of a moving train, a strong current would be noticed in an opposite direction to that of the motion. But these currents did not ventilate the tunnel, they only stirred the stagnant mass of air. There was, however, a feeble current carried along with the train due to skin friction. This current would act as a ventilating one if the trains were always travelling in the same direction, so that a current of air, even if feeble, would be caused to flow in a definite direction. But this moving current was liable to be opposed and reversed by trains coming in the opposite direction. It was perfectly clear that trains did not act as pistons, nor could they efficiently ventilate a tunnel. He did not think the ventilation for tunnels was quite similar to that of mines. The air-resistance in mines was considerable, owing to the tortuous flues and passages, and a fan working at a high-water gauge was necessary. But the resistance in a tunnel due to its large sectional area was practically nil. In dealing with large volumes of air, great caution was necessary, or a considerable waste of power was liable to occur. In a tunnel $\frac{1}{2}$ mile long and 400 square feet sectional area, the energy spent in moving 240,000 cubic feet per minute amounted to only 0.8 HP.; but if the volume of air had to be discharged through a duct 4 feet in diameter and 100 feet long, the velocity of air would have to be increased sixty-four times and the HP. varied as the square of the velocity, which would bring the HP. due to the increase in velocity up to 1,640, friction would absorb an additional 600 HP., and the HP. would thus be raised to 2,224 HP. There was no limit to the waste of power which might result in trying to force large volumes of air through a contracted opening. In the majority of cases of tunnel ventilation, 90 per cent. of the power was spent in trying to get the air through contracted outlets or through the fan itself. The latter
might have a high efficiency measured by the work done, but 90 per cent. of this work might be spent in giving the air an unnecessarily high velocity. The ventilation of buildings might be divided into two main systems—the vacuum or extraction and the plenum or propulsion system. In the former the foul air was extracted, say, with an air-propeller, causing a partial vacuum in the room or hall, which caused the fresh air to rush in at various places. The pure air entered through openings in the outer walls, protected by grating, and passed over heating coils placed in the various recesses. The foul air might be extracted from the top or bottom of the room. In the plenum or pressure system the pure air was drawn from one central source, filtered and warmed, and forced into the room, the foul air being therefore forced out. The great advantage of the plenum system was that it gave complete control of the air, so that it was easily filtered and warmed. With the vacuum system it was difficult to say where the air came from; the air in the room being extracted, fresh air rushed in on all sides; and if a drain, sewer, or soil-pipe happened to be near, polluted air might be drawn in. It was also found that the chances of draught were greater in the vacuum system, the entering air might have a tendency to take a short cut to the fan, leaving the bulk of the air in a stagnant condition. The inlet should be, say, 10 feet from the floor; and from experiments in a Board School at actual work, it had been found that the best results were obtained when the foul air was taken off near the floor-level, which could not be wondered at when the amount of dirt and dust that every day collected on the floor in a Board School. This, together with the emanations from the children, should not be allowed to rise and pollute the air above, but should be removed before it could do harm. An interesting installation, which he had recently erected conjointly with Dr. Haldane, F.R.S., was that at the musical club room at Oxford University. It was on the plenum system and the air was heated by electricity. Dr. Haldane had written—"The whole seems now to work excellently, and the secretary of the club has simply to turn on the switch to get whatever amount of air and whatever temperature seems desirable. The room is kept clear of tobacco smoke, &c., and the complaints about headaches after the concert have disappeared. The allowance of air is about 1,000 cubic feet of air per person per hour."

Mr. A. T. Walmisley remarked that in large dining-rooms, with only natural ventilation, when lighted by electricity and several persons smoking tobacco, the smoke hung about the table or centre of the room, whereas if the air was heated at the top by a gas sun-
Mr. Walmisley. burner or other means, and proper ceiling exits provided, the room was kept clear and comfortable. As to air space, in hospitals 1,000 cubic feet per patient was an approved minimum to allow in a ward, and this volume should only be reckoned 10 feet in height, so as to provide ample floor-area or space of 100 square feet. He would be interested to know the Author’s opinion of the tunnel leading from the King’s Cross (Metropolitan) station to the King’s Cross suburban station upon the down line. It was the foulest tunnel that he knew, and worse than the Penge and Sevenoaks tunnels. The latter must be full of oscillations of foul air driven first in one direction and then in another by the passage of up and down trains. Would not a thin partition in the Penge and the Sevenoaks tunnels, centrally and longitudinally, in the central way, separate the tunnel into two tubes, so that the trains help to push the foul air always in the same direction? This partition needed no great strength; it would serve purely as a screen. The Central London Railway engineers were wisely adopting separate tunnels.

Mr. Wilson. Mr. Joseph M. Wilson, of Philadelphia, stated, as an example of what he would suggest for special tunnel ventilation, that it had been his province as consulting engineer for a prominent railway company to recommend a ventilation system for a tunnel on a subway line in a large city, where the surface above was to be occupied as a street. The tunnel had a length of nearly 3,000 feet and was for four lines, having an area of cross-section of 1,022 square feet and a total content of about 3,000,000 cubic feet. It was practically a portion of a terminal yard in which shunting was carried on, and one or more engines might be in the tunnel almost constantly. The line was nearly level and there was no opportunity for natural ventilation, so that in murky, damp weather the smoke and gases from the engines would remain in the tunnel for a long time. Extraordinary precautions seemed necessary, not only for the comfort of the employees and passengers, but also to make it possible to work the tunnel without danger to life or damage to the property of the Company. It was recommended that four 20-feet diameter exhaust fans be located in pairs at two fan stations, so as to divide the tunnel into four equal parts of about 600 feet each, each fan therefore clearing one-fourth of the tunnel. Seventeen outlets were proposed for foul air, located in the roof of the tunnel, about 150 feet apart, each outlet having an area of 33 square feet, these outlets to connect with four main air-ducts, one to each fan. Upon the opposite side of the tunnel, midway between the outlets to the fan conduits, inlets were to be provided
to deliver fresh air from the street above to the bottom of the tunnel, the distance from an inlet to its adjacent outlet, across the tunnel, being approximately 80 feet. The conduits to the fans and the outlets from the tunnel were to be proportioned to equalize the flow from all parts, and the inlets were to be protected by automatic louvres opening inwards, so as to prevent the possibility of the escape of foul air from the tunnel to the street, the outlets from the fans to discharge into tower-shafts 108 feet in height above street grades. Possibly at times both ends of the tunnel might be blocked with cars. The air inlets would then be largely depended upon to furnish fresh air. With a velocity of air in the fans of, say, 15 to 20 feet in a second, a full supply of fresh air would enter at distances of 150 feet apart, the fans emptying the tunnel every 6 minutes. The fans were to be operated by electric motors supplied with current from a central plant which also had other work to provide for. The tunnel was constructed under a joint arrangement between the City and the Railway Company; but the ventilation scheme, while fully elaborated in detail and approved of as the proper one for its purpose, was not adopted on account of its expense, and an arrangement was concluded between the Company and City for a series of longitudinal openings, aggregating in all about 6,500 square feet in area, constructed from the roof of the tunnel to the street on its centre line, this being a very wide avenue. These openings were walled up about 3½ feet in height above the street level, and were surrounded by beds planted with shrubbery so as to conceal them from the drives on both sides. It was not believed that, even under the most favourable circumstances, the adopted arrangement would accomplish all the fan system promised, and there would be times when it would undoubtedly be found ineffective; but, under the circumstances, it was the best that could be done. A number of anemometer readings had been made in the tunnel to determine, if possible, the action of the vent openings; but they were not very satisfactory, nor was it possible to arrive at any very definite conclusion. With many cases to the contrary, the following general conclusions had been reached. With strong currents in the tunnel there was less current in ventilating openings, while with a weak current in the tunnel there was a stronger current in vent openings. A weak current in the tunnel generally induced a reverse current in the vent openings. The current was generally weaker in the tunnel in the direction of its axis under the openings than between them. He had experience in the heating and ventilating large buildings,
Mr. Wilson. hospitals, schools and other public structures, but in such cases each building had its own conditions and must be worked out as a special problem. For private residences, heated by steam, low pressure indirect radiation was generally employed, fresh air being drawn from the exterior of the building to radiator-boxes located in the cellar or basement, directly under the various vertical heat flues discharging to the different rooms. Flues for ventilation were provided to the rooms, occasionally connected to a common flue, where the draught was accelerated by a steam coil, and the windows were also available. Such a system brought in the heated air always fresh. In the Presbyterian Hospital of Philadelphia, which he had designed, nearly all the wards were of a single storey. Fresh heated air was admitted to the wards and rooms by indirect radiation, supplemented with direct radiation in some cases where specially needed, and foul air was taken off by flues from the floor under each bed, carried to a common flue. Open fireplaces were provided, and ridge ventilation in the ceiling or roof for summer use, or even in winter if desired. These ridge ventilators extended for nearly the whole length of the ward like the ventilators in an American Pullman car. The windows had a double-hung sash with a transom above, all movable, and the sashes were double glazed, there being ½ inch air-space between the inside and outside glass, so as to keep out the cold in winter and prevent down-draughts. The best practice had been followed as to square feet of floor surface, cubic content of rooms, etc., per patient. The best system for heating and ventilation was one with plenum fans driving in fresh air previously warmed to a certain temperature, say 70°F, by passing over steam coils; any extra heat required to be supplied in the rooms by direct radiation and controlled by thermostats operated electrically. The heated fresh air was introduced to the rooms by flues at a considerable elevation above the floor, and the foul air was taken out at, or close to, the floor, to exit shafts, the draught being induced preferably by exhaust fans. The fans were best operated by electric motors, and where engines were in service in the building the exhaust steam was utilized in heating. In such cases, while the dynamos were running, the heat costs practically nothing. Vacuum pumps were often used to promote circulation.

Mr. Worthington. Mr. Edgar Worthington thought that the method of ventilating tunnels on mountain railways by completely closing the mouth after the entrance of a train might be found useful in many cases. It had several advantages over other systems, such as reliability, simplicity and cheapness, especially in eastern countries where
labour was so plentiful. In the summer of 1893, while in- Mr. Worthing-specting the Usui-Toge rack railway in Japan, for the purpose of designing the large four-cylinder locomotive engines, which had since been constructed and were now working this heavy traffic up the long 1 in 15 gradient, he had been requested by the Director of Railways to advise how to ventilate these tunnels, as all known methods had been tried without success. The locomotives on this section of the railway pushed the trains up the incline at a speed of about 5 miles per hour, and the carriage windows were all closely shut. He had observed, from the locomotive foot-plate, that the products of combustion gathered in the top of the tunnel, travelling both forwards and backwards, and being very little disturbed by the slowly travelling train. This dense mass of smoke and steam gradually increased in volume, and breathing became impossible, except through some filtering material; and before the end of the tunnel was reached the water-gauge lamp, which had previously burned brightly, went out, and the two Japs on the foot-plate were kneeling with themselves with their faces as low as possible to breathe what little oxygen there might be left at the bottom of the tunnel. After this experience he had recommended the Japanese Government to erect a canvas screen at the lower end of each of the worst tunnels, this screen to be closed after the entrance of each train to prevent any air following the train. This was soon done, and proved successful. The new locomotives were designed so that the engine-men could also breathe air from the rail-level, in case the screen arrangement proved inefficient.

13 December, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President,
in the Chair.

The President said that for the third time since he had been President of the Institution it was his painful duty to have to announce a gap in the ranks. In his experience, and in that of the Council, no President had ever been so unfortunate. He had to announce, what perhaps the members already knew, the sad and irreparable loss sustained by the Institution in the death of Sir William Anderson. The Council had, of course, taken the matter into consideration at once, and had passed the following