THE STUDY OF AIR FLOW, VENTILATION AND AIR MOVEMENT IN SMALL ROOMS AS EFFECTED BY OPEN FIREPLACES AND VENTILATION DUCTS

By T. C. ANGUS, D.F.C., D.Sc., A.M.I.E.E., F.I.E.S. (Associate Member)
The Department of Applied Physiology, London School of Hygiene and Tropical Medicine.

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Synopsis.

The numerical importance of the solid-fuel fire, owing to the increase in families in this country in recent years, has justified an extensive enquiry into the efficiency of open fires—particularly as influenced by ventilation. Comfort in the home may be increased by attention to draughts (which have been found prevalent even in new houses).

The paper describes part of a research on the influence of environment on physiological reactions and thermal comfort inaugurated by the Ministry of Works and carried out by a team of workers from the Ministry of Works and the London School of Hygiene and Tropical Medicine.

Experimental rooms and apparatus are described and the imperfections in some of the instrumental methods—especially in respect to the measurement of air change by tracer substances—are noted.

A brief description of a method to measure air change is given in which CO_2 is used. The importance of limiting the rate of air change in rooms heated by fires—as a means to save heat—is stressed. A method to measure the rate of air flow into a fireplace is described, also the use of the Chattock gauge to measure the static pressure difference produced by chimney and fire in a room when the windows are shut. A relationship between this slight negative pressure and the infiltration through cracks and porous materials is discussed with results of experiments shown in graphs and tables. The possibility of developing a method by which the air-tightness or otherwise of a building may be measured, and perhaps specified, is suggested.

Experiments were made with fresh-air ducts designed to draw air from the ceiling-roof space and deliver it into the flue without mixing the air of the room. It was found that to do this successfully it was necessary that the ducts should discharge near to the top of the fire rather than down near the hearth. By reducing the area of the chimney throat and utilising two air ducts of reasonable size it was found possible to reduce the air turnover by one half and still be within a satisfactory standard of ventilation for four persons.

It is believed that it will not be practicable significantly to reduce the draughts from under doors of ordinary construction by admitting air through ventilating ducts. Suggestions for two methods in which air ducts might be combined with fireplaces of popular type are illustrated.

Appendices give particulars of the calculations by which the experimental ducts were designed ; a description of the method used to deduce the rate of air flow through these experimental ducts by measurements of the static pressure between the room and the ceiling-roof air space ; and tests of the experimental ducts in terms of their efficiency in converting static pressure into air flow. It is suggested that some such method may be employed in the standardisation of " natural " ventilating devices.

Introduction.

To-night I have the honour to address this inaugural meeting of our Institution upon phenomena to which every heating and ventilating engineer in this country has been subjected during much of his life, but to which phenomena he has in all probability paid very little attention : I refer to the ventilation that takes place where usually no special provision for ventilation is made—in the home.

I feel that some justification is needed for bringing before the Institution a paper on a subject so commonplace and so homely—and justification must rest upon the great building programmes envisaged; upon the inherent connection between ventilation and warming during the cold weather; upon the increasing value set upon fuels; and upon the undoubted wastefulness of most of the early types of solid-fuel domestic heating appliances. With these must be considered the fact that there must be in this country a very much larger number of separate families than, say, twenty years ago, and that each family will in all probability use at least one solid-fuel appliance during the heating season. In 1911 there were 7,943,000 private families and 7,691,000 structurally separate dwellings (which include flats). In 1931 there were 10,233,139 private families (an increase of 23.3 per cent.) and 9,400,000 structurally separate dwellings. The last census from which there are figures taken was in 1931.

An estimate of the increase in the number of families since the war may be made from the official housing return for June 30th this year, from which we learn that 574,136 houses of all kinds have been built since the war and 25,179 blocks of flats in England and Wales; we are also told that 218,000 houses were totally destroyed during the war. This leaves a balance of 336,136 houses (supposing that flats do not number amongst the destroyed houses) and again assume one family (and consequently one fire) to each house. On the somewhat doubtful assumption that the average number of dwellings, or families, per new block of flats is 38 this would mean that there are some 356,000 new families in houses and 916,000 new families in flats since the war—or very approximately one million two hundred thousand more fires.

We know that there are already certain more or less experimental sites in this country where district heating has been installed, and also that certain houses and flats are equipped with central heating, or with electrical or gas appliances for heating as well as for cooking, but it appears to be pretty certain that for a long time to come the open fire, or the solid-fuel closable fire, will be the principal heating agent in our houses, and it is with the ventilation of rooms so equipped that I shall be dealing.

In an official publication (Post-war Building Studies No. 10)[1] it is stated ". . . . out of a total of 63 million tons of coal required for all domestic purposes, 51 million tons (approximately 80 per cent.) were used in solid form." In terms of national economy then it will be apparent that even a slight increase in the effectiveness of heat retention in dwellings will be of importance.

In the Report of the Royal Commission on Population, 1949; 677, the statement occurs :—" The application of scientific research to the problems of house design and equipment has lagged far behind its application to industrial and agricultural techniques. The enquiries of the Ministry of Works in this field should be developed, and a special study should be made of the needs of families with three or more young children."

Then there is the human aspect of the problem. Rudyard Kipling wrote :—

"England is a cosy little country,
Excepting for the draughts along the floor.
And that is why you're told,
When the passages are cold:
Darling, you've forgot to shut the door!"

The problem of draughts is both old and new. We know how old houses offend in this respect, but in an investigation made into the thermal and humid conditions in a large selection of pre-last-war Council houses in five municipalities about the year 1944 many complaints of draughtiness in the living-rooms were made, moreover the thermal and humid conditions in what are still new types of houses were found to be far from ideal.

Table I.—14 Council Houses—S.E. London.
9-in. Solid Brick Walls

	Living-Room			First Bedroom
	Temp. excess, °F.		Humidity excess	Temp. excess, °F.
All houses	median	13	17 gr. per lb.	3
	maximum	23	51 "	9
	minimum	3	3 "	0
End houses ...... (5 in all)	median	6	4 gr. per lb.	3
	maximum	13	13 "	6
	minimum	3	3 "	0
Intermediate houses (9 in all)	median	15	26 gr. per lb.	3
	maximum	23	51 "	9
	minimum	10	10 "	2

Table I shows the temperature excess (inside room to open air) in one group of Council houses on days when the outside temperature was below 50° F. There was in every instance a fire in the living-room but no heat in the bedroom. The observations were taken approximately at noon.

All these houses were built with 9-in. brick walls. The large range of the temperature excesses and absolute-humidity excesses in the living rooms is notable, and although this will be to some extent controlled by the habits of the occupants (Mason, 1947)[2] there is a marked difference shown between the houses at the end of a block and the intermediate houses. The former indicated not only a greater heat loss through the walls, but also a greater rate of ventilation as shown by the decreased absolute humidity, where the moisture due to occupation appears to be kept down by a greater rate of ventilation. The point at issue is that there is a large divergence in thermal and hygrometric states in similar houses which to a certain extent appears to be fortuitous and so indicative of losses of heat which might be prevented. The bedroom temperatures were very low and probably some of these rooms felt damp. Complaints of draughts in living-rooms were rife.

In 1946 a small team comprising doctor, engineer and technicians from the London School of Hygiene and Tropical Medicine, ably assisted by scientists from the Ministry of Works, started upon what is termed an "extra-mural research contract" on behalf of the

Ministry of Works to make investigations into the influence of house design upon the physiology of the inmates—experimental living-rooms being made available at a Field Test Unit near Barnet. Although the evaluation of the effects of environment upon man was to be essentially a medical problem the necessity to be able to express this environment in measurable terms immediately became apparent—and with this the imperfections of some of our instrumentation. So yet again has the need for a close liaison between the doctor, the physicist and the engineer been demonstrated.

Many of the medical aspects of these problems are still obscure and are still under investigation, whilst the physical side of the work is anything but complete. It is in the hope that our findings in some of the simpler problems of domestic heating and ventilation, particularly those connected with air change, are new and of possible value that the present paper is presented.

Experimental Rooms.

To enable the relationships between physical environment and physiological reactions to be studied three full-sized models of a present-day kitchen-living-room have been built inside a standard Ministry of Works hut. The rooms conform to the A.T.P.L.A.R. designs and are each 14 ft. × 12 ft. × 8 ft. high. The arrangement is shown in Fig. 1.

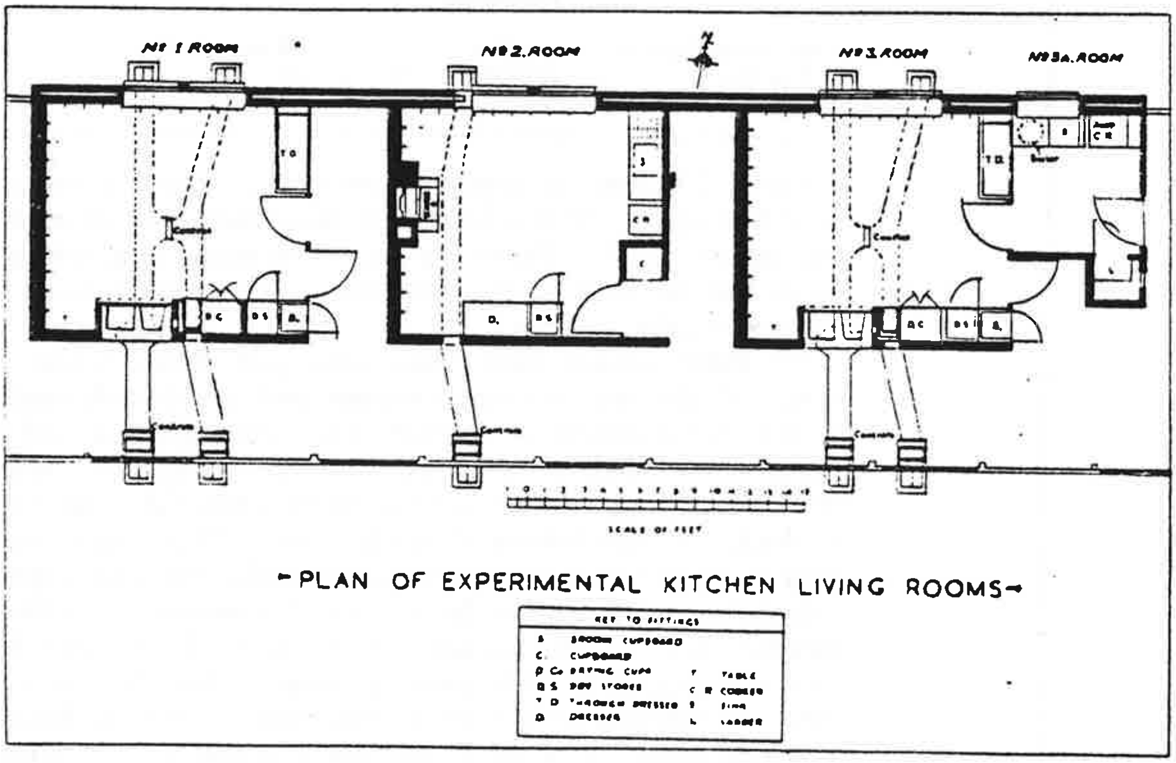

Fig. 1.

The advantage of this arrangement is that it is possible to use one room as a control when testing conditions in one or more of the others: because any variation brought about in one room by changes in wind and weather during an experiment may reasonably be expected to be shown in the control room. The middle of the three rooms shown was used in these experiments, the room on the left being used as the control. This test room is fitted with modern type of fireplace with a throat 12 in. × 4 in. opening to a brick chimney 12 ft. high. The fireplace is fitted with dampers by which air may be directed into the space below the firebars from an under-floor duct open to the air at both ends through the walls of the hut, or up through a grille in the front of the fireplace and so into the room. During most of the experiments to be described the openings to this duct were carefully sealed off.

Amongst the measuring instruments employed are the following :

Hales' radiometer,
Assmann psychrometer,
Recording thermo-hygrograph,
Globe thermometer,
Kata-thermometers,
Silvered thermometers.

The three last-named instruments were used in sets of three at three different levels in the rooms, to determine thermal gradients and distributions of radiant heat. This arrangement is shown in Fig. 2.

Measurement of Air Change.

One of the first difficulties encountered was to measure with any degree of accuracy the ventilation rate, or rate of air change in rooms " naturally " ventilated. It was obvious to the experimenters that it would be best to employ one of the tracer substance methods, but preliminary experiments made at the London School of Hygiene showed that there are many pitfalls for the unwary when employing these well-known, but seldom employed methods which should be avoided if any reasonable degree of accuracy is to be obtained. These preliminary experiments were so fraught with doubt that they led to a considerable research into the use of CO_2 in a practical technique to make these measurements in living rooms (Renbourn, E. T., *et al.*, 1949)[3]. The immediate findings of these experiments were that with certain precautions we are able to measure the rate of air change in such rooms, up to rates not exceeding 7 changes per hour, with an accuracy of 15 per cent. CO_2 is blown into the room from rubber bags (so as to be near air temperature) to a concentration of some 3 or 4 per cent. and the rate of decay is measured by taking air samples in evacuated sampling tubes ; taking a sample every five minutes over a quarter hour. These samples if analysed in the standard Haldane gas analyser will give the degree of accuracy stated above, but it is absolutely essential to stir the air not only during the introduction of the CO_2 but also during the sampling. Three disc fans were used which produced a velocity of not less than 40 ft. per min. in any part of the room. If this precaution is not taken the incoming air may find its way to the top of the room whilst the CO_2 concentrates nearer to the floor, a kind of stratification taking place which greatly reduces the likelihood of accuracy. We are indebted to Mr. Merlin Stephen Jones of the Ministry of Works Chief Scientific Adviser's Department for mathematical treatment of this part of the problem. His conclusions are in the paper cited above.

Pettenkofer on the Measurement of Air Change.

When considering this subject of the measurement of air change by CO_2 it is natural to think of Pettenkofer from whom this method takes its name. On enquiry it appeared that no copy of Doctor Max von Pettenkofer's book (Munich, 1858)[4] is available in this country, but eventually we were able to obtain a photostat copy from Munich itself, from which a translation has been made by Mr. L. M. Croton of our Department at the School. It is extremely interesting reading and for my own part I often find a salutary lesson in referring to the " Old Masters " in the light of ideas we think are new.

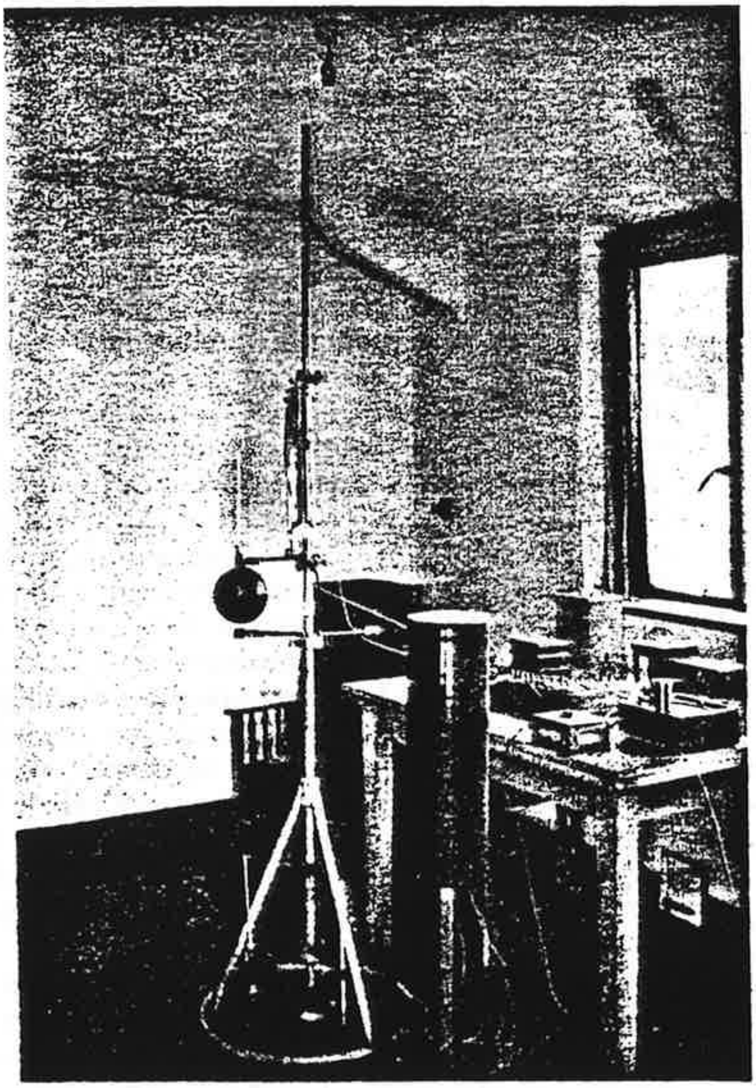

Fig. 2.

Pettenkofer investigated the CO_2 produced in rooms by respiration, and in a maternity home ward found 0.38 per cent. CO_2 near the floor and 0.71 per cent. near the ceiling. You will note that the gradient was reversed in our experiments, where the CO_2 was cool and in greater concentration (in Pettenkofer's observation the expired CO_2 would have been warm and mixed with water vapour from the lungs). He writes :—

> "Therefore on purely theoretical grounds we can see the importance of really good mixing of the air in occupied rooms."

Pettenkofer found that a "natural" ventilation system in a Munich maternity home was "useless"—the air very often flowing along the ducts ("arteries" he terms them) in the wrong direction and from one room into another. But he found that the mechanical ventilation in a Parisian hospital was satisfactory. As a ventilation standard (and Pettenkofer was careful to point out that CO_2 *per se* is not harmful but is a good index of general vitiation) he concludes:—"I will prove that we have no right to say that an atmosphere is good which contains more than one part per thousand of carbon dioxide following natural respiration and perspiration." This, be it noted, corresponds to a ventilation rate of 1,000 cu. ft. per person per hour which is the L.C.C. statutory requirement for cinemas today.

Pettenkofer produced CO_2 by burning charcoal in a room whose air change he wished to measure, and on one occasion his experimental fervour carried him into oblivion under the influence of the carbon monoxide so produced. He measured the decrease in CO_2 by drawing samples of the air into flasks into which he afterwards introduced lime water whose loss of alkalinity he was able to measure by titration—thence deducing the amount of CO_2 absorbed.

Air Change due to Open Fires.

A primary object of our investigation was to determine the extent of natural ventilation in this modern type of room when heated with a modern type of fireplace, to find out whether this ventilation may be excessive and if so to explore means by which it may be controlled. and to study the draughts arising in such a room and if possible how they may be prevented. The importance of such an investigation as a guide tc future design may be seen from Mason's paper[2] already cited in which he states :—". . . that as more attention is paid to improving the insulation (of houses) the relative importance of ventilation as a source of heat loss increases ; thus in a well-insulated house the ventilation loss may account for as much as half the entire heat input, and out of every pound spent on fuel some ten shillings may be carried away on the breeze."

Air Flow up a Chimney.

It became necessary to find some ready means by which to measure the flow of air into a fireplace, and this without adding any resistance to flow. The device shown in Fig. 3 is a metal box to which is attached an orifice flowmeter supplied by a variable-speed fan. This arrangement will not allow continuous readings to be taken, but "spot" observations are easily made by putting the whole apparatus over the fire and removing it immediately afterwards. The fan motor is run up until the manometer attached to the box gives a null reading—when it may be assumed that the fire is getting all the air it needs. A proprietary type of diffuser is provided so that there is no local disturbance of the fire by concentrated draught.

Static Pressure Difference.

When air is extracted from a room by the pull of a chimney, for instance, the necessary replacement air must be sucked in through window cracks, under doors and through such fortuitous openings—unless one of the windows is open or there is some other source of supply with negligible resistance. With a room completely shut-up by closed doors and windows, as is not unusual in winter time, a means of exhaust ventilation such as a hot chimney must produce a measurable negative static pressure from inside to outside in order to overcome the not inconsiderable resistances of the various cracks. We were able to measure this static pressure by means of a Chattock gauge manometer, sensitive to 0.0006439 inch of water gauge. One end of this manometer opened into the room and the other was connected to a rubber tube opening into the space between the ceiling of the room and the roof of the hut. It was found that this space gave a good datum which was but little influenced by wind effects on all but stormy days, but this may not apply to houses of different construction differently sited.

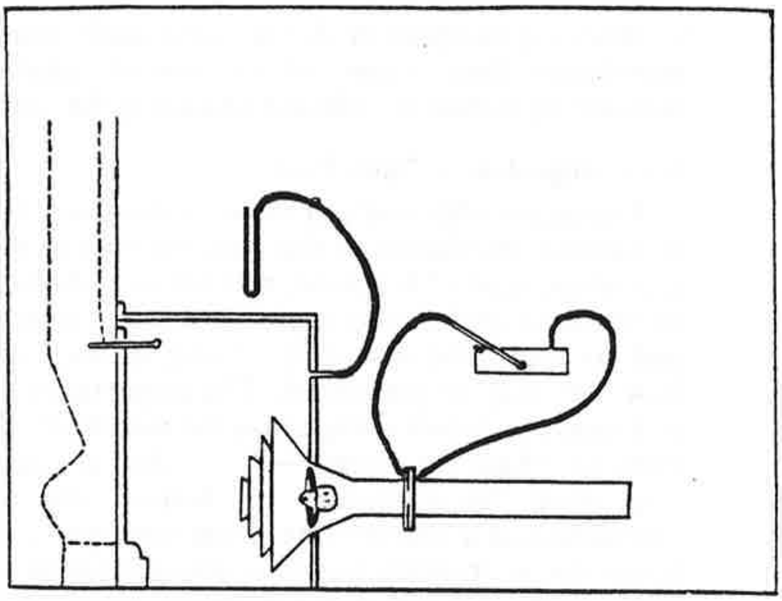

Fig. 3.

Measurement of Floor Draughts.

An empirical measure of this disagreeable quantity was made by placing a Velometer on the floor with its inlet at a fixed point just nine inches inside the door and near to its opening end. The velocities so measured were considered to give a measure of the quantity of cold air coming in over the floor and finding its way to the fire.

The Relationships between Chimney Draught, Air Change, Static Pressure and Floor Draught.

Ventilation Rates.

In the Egerton Report[5] the minimum fresh-air requirement for dwellings is given as 600 cu. ft. per hour per person (compare Pettenkofer and the L.C.C. standards of 1,000). Because the accepted occupancy for these rooms is four persons the minimum fresh-air requirement would be 2,400 by the Egerton standard. With the fire burning normally and fuelled every fifteen minutes at the rate of 3 lb. of coal per hour the flowmeter showed that 8,100 cu. ft. per hour were going into the chimney—or nearly 3½ times the minimum requirement. An improvised register was fitted in the chimney throat with which it was found possible to reduce this flow to 5,790, but it should be noted that for efficient flue design the throat and flue terminal should be the seat of the major part of the total flue resistance (Commander and Hales[6]).

In this experiment all windows (steel-framed) and the door were shut, as in cold weather, but no attempt was made to seal the cracks.

Table II

17th March, 1947 — Kitchen-Living-Room No. 2

Time (approx.)	Register opening (inches)	Air change by CO_2 Room 1 (Control)	Room 2	In terms of c.f.m. Room 2	Air into fireplace (c.f.m.) (flow meter)	Static pressure (milinches) h	$\sqrt{h}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
11.00-11.15	1¾	3.85	4.29	81.5	97	7.5	2.74
11.40-11.55	4½	4.27	6.31	120	135	17.7	4.21
13.40-13.55	1¾	4.22	4.39	83.5	96	7.7	2.77

Table II shows the effect on both the static pressure and air change of alterations in flue width by a register. The air change was measured simultaneously in the control room (Room No. 1); the very small variations here indicating that the changes in Room No. 2 are unlikely to have been caused by winds, etc.

It being supposed (erroneously as it now appears) that the flow of air through the various cracks into the room would follow a square-root law, this relationship between air infiltration and static pressure was tested by comparing the means of the rates of air change with narrow register opening with the air change with wide register opening, and square roots of the corresponding static pressures when measured in milinches (thousandths of an inch). In this instance a close relationship was found, thus :—

$$2.75 : 82.5 :: 4.21 : 124.5$$

this last figure being the ventilation in c.f.m. that should result from a static pressure of 17.7 milinches. The air change by CO_2 (Col. 5) gave this as 120 c.f.m., which is easily within limits of experimental error. But later experiments have shown that the index is generally nearer to 0.65 than to 0.5; that is flow is proportional to static pressure to the 0.65 power, and this appears to be nearly true for very different cracks or leaks in our building.

An important deduction appears from this and from similar experiments :—

> In a room whose pneumatic parameters are known it should be possible to measure the combined ventilation rate through all fortuitous openings in terms of the static pressure difference

between the inside and the outer air, by measuring this with any known quantity of impressed air flow into or out of the room, provided that such pressure difference is substantially above local fluctuations and variations due to wind or to temperature gradient.

It may be possible with the aid of not too elaborate apparatus to measure the air-tightness of buildings, by blowing in measured quantities of air and observing the corresponding rise in internal pressure, and even to establish building standards on such a basis.

Supplementary Ventilation.

It being apparent that unnecessarily large volumes of air were being taken into this fireplace, even with the throat reduced by a register to the point of smoking, the desirability of finding some workable means to introduce a large part of this air in an inoffensive manner became evident. When these experimental rooms were built provision was made for 12 in. square ventilation ducts in the solid concrete floors. These ducts opened into the outside air at both ends, but were carefully sealed from the room during the first part of our experiments.

At this stage experiments were made by opening a grille with 22 sq. in. free area in the hearth in front of the fire from this duct, but it was found that this only dropped the static pressure in the room from 20 to about 16 milinches whilst its effect upon the air change was inconsiderable. In another experiment air from this duct was led up and discharged into the room from an opening in the wall to one side of the fire, but this produced considerable draught over the floor just where the feet of anyone sitting before the fire would be resting. Various " thin plate " orifices were then fitted into the top surface of the under-floor duct, the static pressure across these orifices measured, and the air flows into the room calculated from the usual formula. The opening of such orifices reduced the static pressure and from such data it was decided that if 100 c.f.m. of air were taken by the chimney and 80 c.f.m. of this could be supplied directly into the fireplace without admixture with the room air a considerable saving of heat would result.

In view of the little effect of the grille in front of the fire and the probable unwillingness of builders to interfere with the solid floors with their damp courses (to which construction there appears to be no alternative at the present time) it was decided to experiment with vertical ducts, using the space between ceiling and roof as a source of supply. In the official publication (" Solid Fuel Installations ",[1] p. 16) various recommendations are made for supplying combustion air, amongst which is " by a suitably disposed down flue from the ceiling or roof level ". In 1944 Mr. Martin Henry, M.R.C.S., L.R.C.P., patented a ventilating system in which vertical ducts were used not only to supply air to an open fireplace, but also other vertical ducts were used as outlets for vitiated air. This system was tested in 1945 by the Building Research Station and reported upon favourably.

It was decided from preliminary experiments and measurements that two ducts should be designed to supply together 80 c.f.m. under a static pressure of 12.5 milinches ; it was also found that to ensure the air from the duct going straight up the chimney it was of little use to bring the ducts down to near the hearth, but rather that they should deliver their air as high up and as near to the throat as possible, where the entering velocity is greatest. The problem was to design two ducts 8 ft. long each to supply 40 c.f.m. under a pressure of 12.7 milinches. The calculations used are given in the appendices, and it was found that two circular ducts of 5¼ in. diameter, or two rectangular ducts 5 in. ×4½ in. would suffice, if these were designed without bends and with a flanged evasé inlet, also with expanding area turning vanes at delivery. The total area of these two circular ducts would be 43.3 sq. in., and it may be noted that a recent publication by the Ministry of Fuel and Power[7] recommended that the cross-section of double-ended ducts designed to supply combustion air to fires should not be less than 60 to 80 sq. in. But it is unlikely that such under-floor ducts could be made without bends.

In consideration of the rather theoretical nature of the initial treatment of this problem and the very small quantities involved—values of speed and pressure much lower than generally encountered in ventilation engineering—it was decided to make two rectangular ducts one larger and one smaller than the calculated size and to try them out. Two ducts were made and installed, one 6 in. × 4½ in. and the other 5 in. ×3½ in. It was found in actual test that under the static pressure of 12.7 milinches these ducts discharged 51.5 and 38 c.f.m., respectively, or a total of 89.5 against the calculated 80 c.f.m. for the two 5¼ in. ducts postulated. But it was also found that with a very reduced chimney register the static head fell to 7 milinches and the flow through the ducts to 60 c.f.m. In Appendix I is given a method by which it may be possible to measure the efficiencies of " natural " ventilation appliances in terms of *conversion efficiency*, if the static head between entry and exit and the mean air velocity in the duct can be measured.

The Influence of Air Ducts on Air Change and Floor Draughts.

It was found that when these ducts were put in so that they rested on the floor and discharged across the ash tray they had very little effect on the air change in the room as shown by CO_2, but when they were raised some 12 in. (Fig. 4) so that the air came in to the top of the fireplace the result was important.

Table III shows a range of different ventilation rates ; the greatest being with the full register throat and no ventilation other than through cracks and the smallest with the register just at smoking

Table III

Register inches	Air change per hour	
	Ducts closed	Ducts open
4½	6.04	4.70
2½	5.34	3.46
2	4.86	3.60
1½	4.59	3.01

point and the vertical ducts open. An air change of 3.01 corresponds to an air supply of 860 cu. ft. per hour per person (four people), which is between the recommended minimum of 600 and Pettenkofer's 1,000.

The effect of the drop in static pressure on floor draughts when this extra air was admitted through the ducts is disappointing.

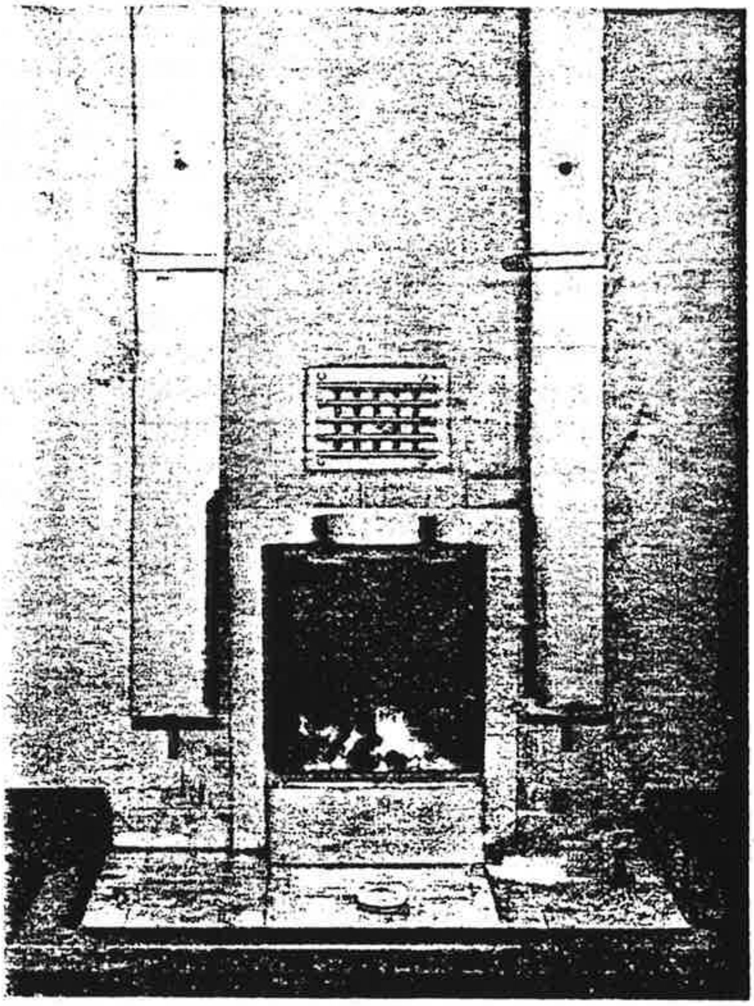

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Fig. 4.

In Fig. 5 are plotted the speed of floor draughts at 9 in. from the door with varying static pressures produced in the room by a fire. and various conditions of natural ventilation—the highest pressures are with air coming in through the cracks only, then with small duct open, large duct open, both ducts open. It will be seen that the points lie on two lines ; the upper one representing the p.m. readings and the lower one the a.m. readings on the same day. The weather changed from morning to afternoon, so it will be seen that local weather conditions will have a big influence on local draughts, which after all is common knowledge. Extrapolating these curves and taking a mean point it will be seen that to reduce the floor draught to 50 ft. per minute will necessitate a reduction of static pressure to 4 milinches, and this is less than the pressure due to a temperature difference of 20° between the inside and the outside

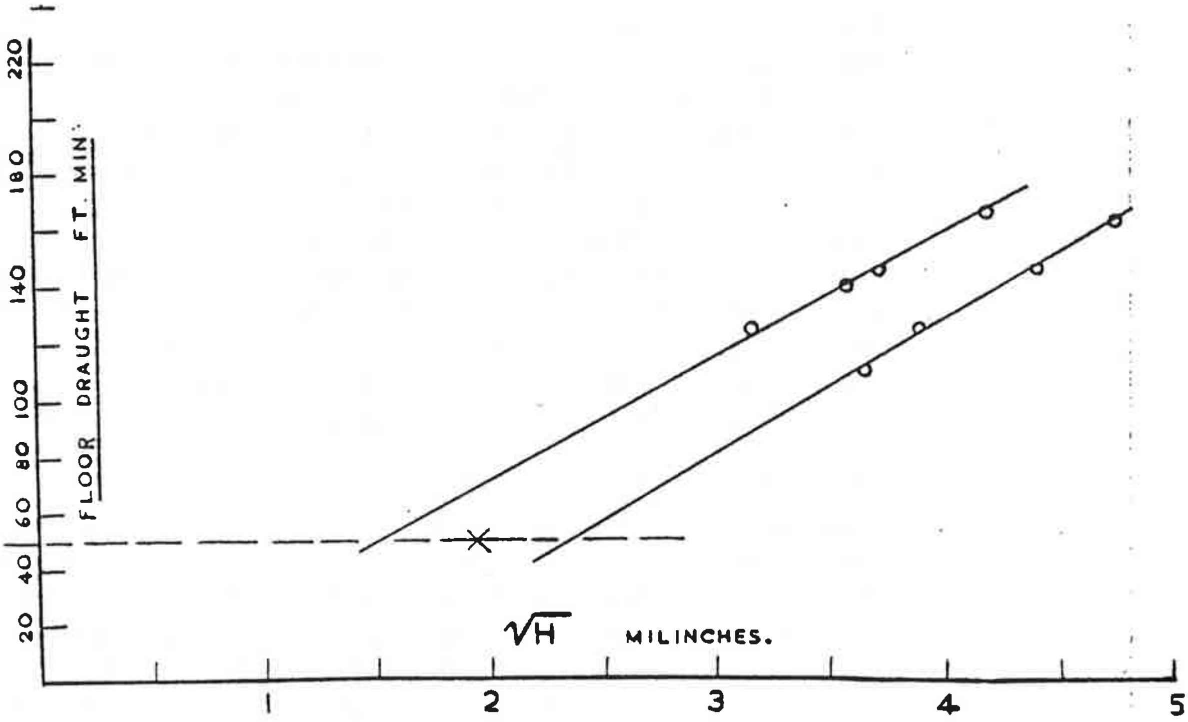
FLOOR DRAUGHT FT. MIN.
20
40
60
80
100
140
180
220
√H MILINCHES.
1
2
3
4
5

Fig. 5.

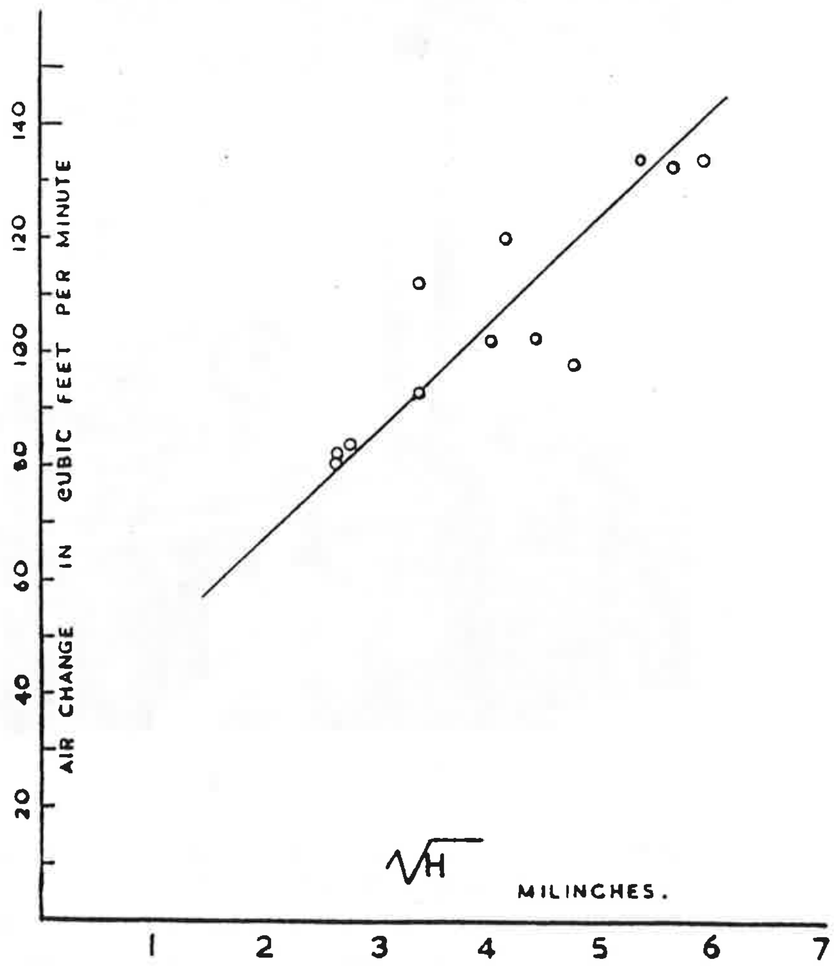
AIR CHANGE IN CUBIC FEET PER MINUTE
20
40
60
80
100
120
140
√H MILINCHES.
1
2
3
4
5
6
7

Fig. 6.

of a room 8 ft. high. This is too low a pressure to operate any kind of a ventilating duct. An attempt was made to obtain a relationship between static pressure and air change (Fig. 6). A square root law was assumed, but this was not justifiable as we found out later on. The air change is expressed in c.f.m. through cracks only. Taking the above value of static pressure of 4 milinches this curve indicates a ventilation rate of 3,900 cu. ft. per hour as the result of this very small static pressure. This means 3.5 changes per hour (nearly). These figures, although by no means beyond criticism indicate, I believe, that with rooms and doors of ordinary construction it will not be possible to reduce floor draughts to negligible proportions by providing air ducts of reasonable size.

The Characteristics of Air Leaks in Rooms.

The above results have been worked on the assumption that air flowing into a room through the cracks inherent in building construction will behave as if these cracks were orifices in the aerodynamic sense of the word where a square-root law holds, or where flow is proportional to pressure to the power of $\frac{1}{2}$. The dimensions of some of these cracks are so large as to make this assumption

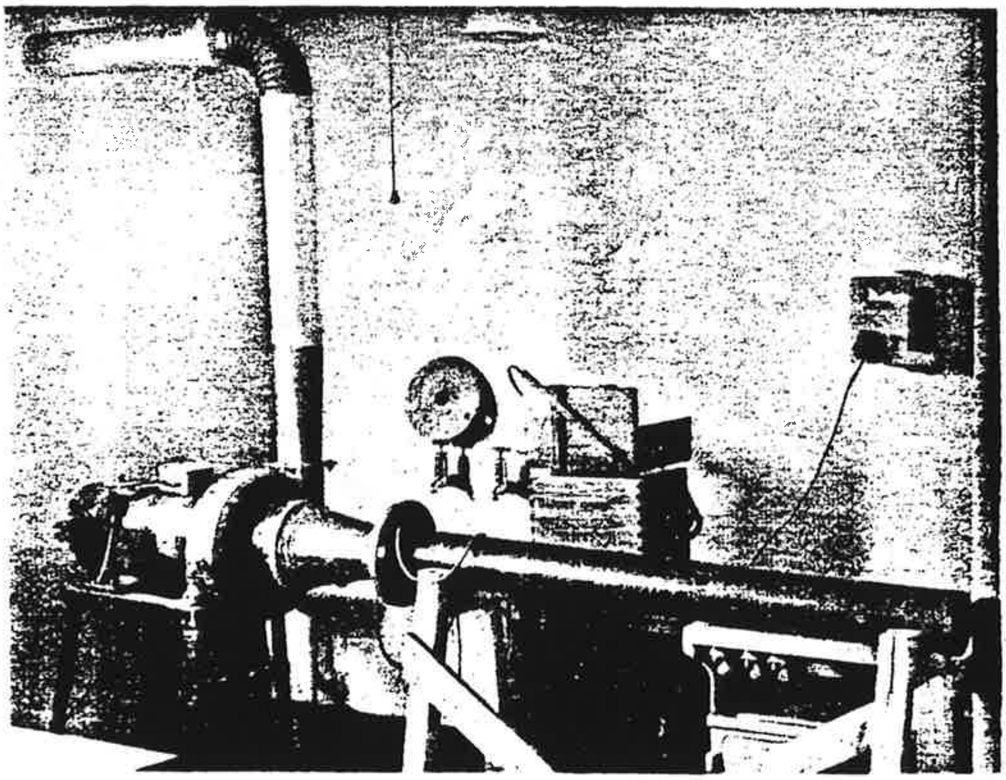

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Fig. 7.

appear reasonable ; as an instance the crack between the door and the floor was calipered and found to have an average width of just over $\frac{1}{4}$ in., giving a free area of $6\frac{3}{4}$ sq. in. It is interesting to compare this free area with the areas given by the perforated building bricks put into walls to aid ventilation. A terracotta air brick was found to have 3.1 sq. in. and a cast-iron air grating 7.59 ; it may not be generally realised how these various sources of air entry compare.

Up till now we had been using the hot chimney as a source of aeromotive force, but of course this aeromotive force could not be relied upon as constant. The next step was to introduce a mechanical "chimney" by sealing up the fireplace and drawing air at known rates from the room through a calibrated flowmeter (Fig. 7). In

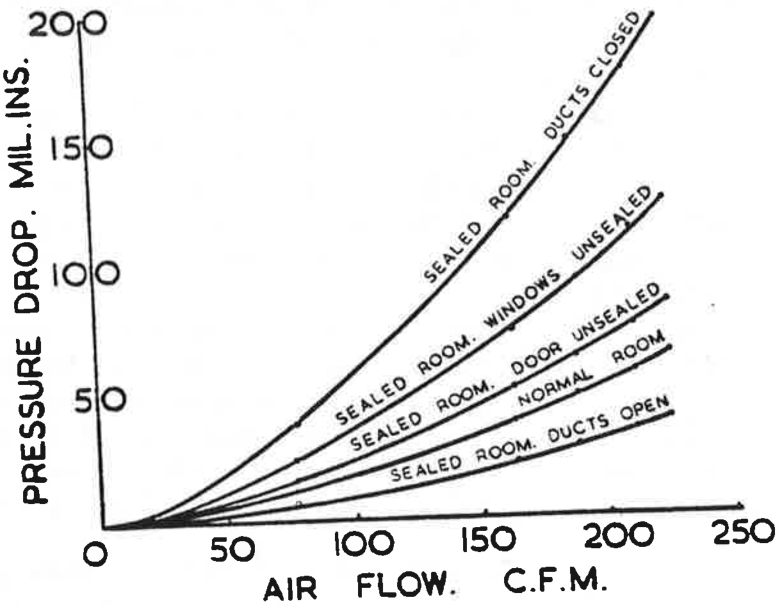

Fig. 8.

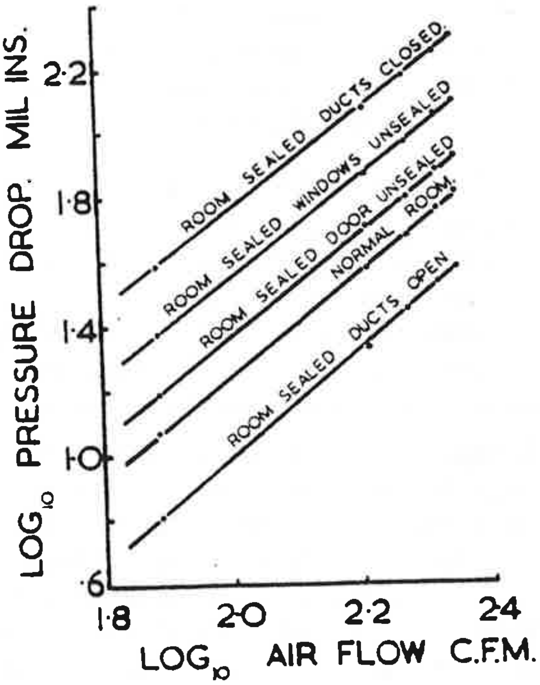

Fig. 9.

this way not only could constant flow be assured, but higher ventilation rates with their attendant static pressures could be obtained which among other advantages would give a greater degree of independence of the outside wind. An examination of the various sources of leak was made in a number of experiments in which the flowmeter was set to give five definite rates of exhaust with various conditions of air-tightness—attained by opening ducts or windows or by sealing the door or other obvious sites of cracks. We were surprised to find that the index in the formula $Q \propto h^n$ was much nearer to 0.6 or 0.7 than to 0.5; and that this was equally true when every obvious crack had been sealed with gummed paper; when all these cracks were left open; and also when the vertical ducts were open but the rest of the room sealed.

Figs. 8 and 9 show this relationship, plotted both directly and logarithmically.

The indices derived from the slopes of the last curves are given in Table IV. It will be noted that the controlled air-change rates vary between 11 and 4 changes per hour and that with the room completely sealed over the obvious cracks the large ventilation rate of 11 changes could be brought about by a head of less than a $\frac{1}{4}$ in. of water gauge.

Mr. D. E. Hickish, of the Department of Applied Physiology in our School, has worked out the indices for the flow of air through windows and building materials from the data that appear in the "Guide"[8] of the American Society of Heating and Ventilating Engineers, where tables connecting wind pressure and air infiltration are given. These figures are given in Table IV for comparison.

Table IV—Values of "n" in formula $Q \propto h^n$

Room sealed, ducts closed	0.676
Room and ducts sealed	0.658
Room sealed, door unsealed	0.649
Room normal (no ducts or sealing)	0.644
Room sealed, ducts open	0.611
From A.S.H.V.E. "Guide":	
24 in. shingles on shiplap	0.745
16 in. shingles on 1 in. × 4 in. boards	0.652
Rolled section steel windows, $\frac{1}{32}$ in. crack	0.625
Rolled steel section sash windows $\frac{1}{64}$ in. crack	0.55
Double hung wood sash window, unlocked	0.507

Although there is a steady fall in the index with decreasing static pressure in our room it was unexpected to find so little change in the value of the index from a well-sealed room to a room ventilated by ducts with very little resistance. The American figures are interesting by comparison and it would appear to be of little value further to surmise on the significance of these figures without a good deal more data obtained from other rooms. The porosity of the walls is one factor of which we have no knowledge, and this was one of the subjects dealt with by Pettenkofer.

Possible Applications.

It would be regrettable if no suggestion for immediate application or further investigation could be drawn from these early experiments. It appears to me that in rooms heated by open fires no provision for admitting air into the room short of opening a window (and few people will do this in really cold weather) will drop the static pressure in the room sufficiently to prevent floor draughts from under a door with ¼ in. clearance, and it is doubtful whether in practice doors can be made to clear the floor by much less. On the other hand the provision of extra air to the fire without mixture with the air in the room would appear to be well worth while if only as an aid to keeping the room warm with less fuel.

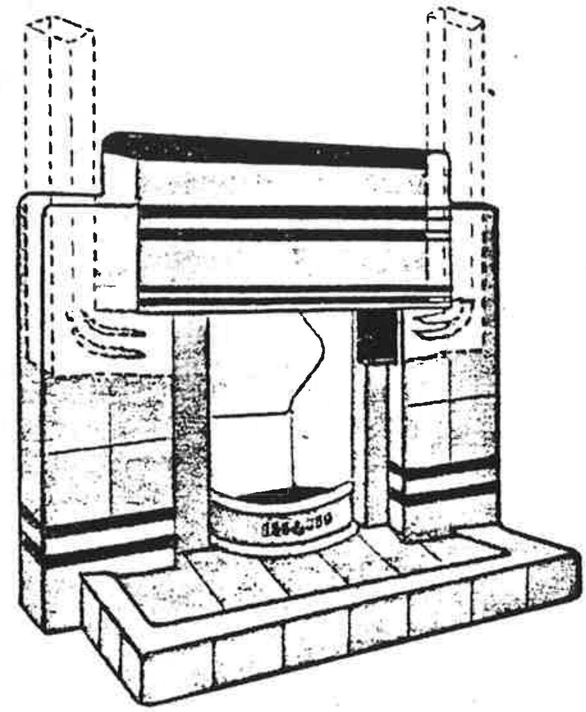

Fig. 10.

It should not be very difficult to design some kind of sliding contact under a door, or fixed to it which would make an effective and durable seal against draughts—and if there was a realisation of how much cold air may be drawn in from under doors no doubt the necessary public demand for such an extra refinement would be forthcoming. In Figs. 10 and 11 are shown two suggestions how ducts of reasonable size may be constructed that may not be too difficult or costly to build into houses. To supply air to the fire near to the throat it will either be necessary to bring in two converging streams from either side (as in Fig. 10) or to arrange the streams to meet above the canopy of the fire and descend over the front of the fireplace as in Fig. 11. These sketches are prepared in the realisation that fireplaces have to be sold, and that the public are a little inclined to be guided by fashion rather than by efficiency tests—it is hoped that it may not be impossible to incorporate what is believed to be an improvement in fireplaces with the "tiled surround" which appears to be a *sine qua non* in to-day's houses.

Acknowledgments.

I have pleasure to express my indebtedness to the Ministry of Works for permission to publish this paper and also for help and encouragement in the experimental work on which this paper is

based, and to the staff at the Field Test Unit at the Thatched Barn, Boreham Wood, Herts.

To Professor G. P. Crowden, under whose direction the research is being conducted for the Ministry of Works, and to the other members of the team from the London School of Hygiene and Tropical

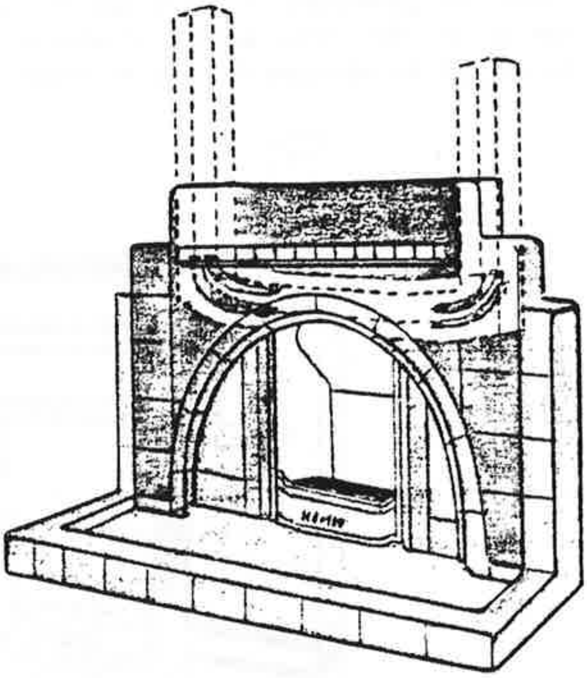

Fig. 11.

Medicine who have been my colleagues. Also to Mrs. George Bambridge for permission to quote from her father's work, " Brazilian Sketches."

Appendix I.

The problem is to design a duct 8 ft. long to supply 40 c.f.m. of air under a static head of 12.7 milinches of water gauge. The velocity in the duct to be 267 ft. per minute. To find the velocity head corresponding to this speed use the formula in general use for " standard " air :—

$$V = 3960\sqrt{h}\,;\; h = \frac{V^2}{15{,}670{,}000}$$

where h = velocity head in inches of water
V = velocity in feet per minute.

So if $V = 267$, $h = 0.00455$ in. w.g.

Assume that one velocity head is lost on entry and one on the air leaving the duct. Then the head available to overcome duct friction will be :—

$$0.0127 - (2 \times 0.00455) = 0.0036 \text{ in. w.g.,}$$

which is the greatest allowable value for duct friction loss.

If the speed of air is 267 ft. per min. the area of a duct to deliver 40 c.f.m. will be $40 \div 267$, or 0.15 sq. ft., or 21.6 sq. in.—corresponding to a circular duct of 5.24 (say $5\frac{1}{4}$ in. diameter).

What will be the resistance of an 8 ft. duct $5\frac{1}{4}$ in. diameter to air travelling at 267 ft. per min. ?

By Fritzsche's formula :—

Where d = diameter of duct in inches.
h = the friction loss in inches w.g.
L = length of duct in feet.
V = velocity in feet per *second.*

$$h = \frac{0.0001577 \times V^{1.852} \times L}{d^{1.269}}$$

$$h = \frac{0.0001577 \times 4.45^{1.852} \times 8}{5.25^{1.269}}$$

= 0.00203 w.g. = which is less than the limiting value for friction loss (above).

Note.—By actual tests at a static head of 12.7 milinches
duct 6 in. × 4½ in. (equivalent circular diameter 5.56 in.) delivered 51.5 c.f.m.
duct 5 in. × 3½ in. (equivalent circular diameter 4.59 in.) delivered 38 c.f.m.

Appendix II.

CONVERSION EFFICIENCY.

The testing of the actual ducts to find their conversion efficiency in terms of friction loss and entry losses.

With a rectangular duct 8 ft. long and 6 in. × 4½ in. in section it was found that 60 c.f.m. of air passed with a static pressure of 0.0150 in. water gauge. This corresponds to a velocity of $\frac{60}{0.177}$ = 339 ft. per min. or 5.65 ft. per *second*, and a velocity head (by preceding formula) of 0.007330 in. w.g. To apply Fritzsche's formula for duct resistance it is necessary to find the diameter of a circular duct which will have the same resistance. This is found from the formula :

$$d = 1.265\sqrt[5]{\frac{(ab)^3}{a-b}}$$

where a and b are the sides of a rectangular duct and d is the diameter of an equivalent round duct.

This gives an equivalent diameter of 5.544 in. for a circular duct. Applying Fritzsche's formula for friction loss again, with V = 5.63 ft. per sec.

$$h = \frac{0.0001577 \times 5.65^{1.852} \times 8}{5.54^{1.269}} = 0.00355 \text{ in. w.g.}$$

The property of a duct to convert a difference in static head between entry and outlet into an equivalent air velocity may be expressed as a *conversion efficiency.*

In a perfect duct the velocity of the air would be equivalent to the static head with no friction loss ; in a real duct the velocity of the air will be equal to the total static head less the entry and exit losses, less the friction losses. The friction losses are inevitable, and can be calculated, so the balance of static pressure available to produce velocity should, if conversion were perfect, be :—Static Head − Friction loss = Velocity head of air in the duct. Any further loss would represent an inefficiency due to entry and exit losses.

In the present instance the total static pressure is 0.0150 in. and the calculated friction loss is 0.00355 in., so the theoretical velocity head, were conversion from potential to kinetic energy to be 100 per cent. perfect, would be 0.01500 — 0.00355 = 0.01145 in. But by experiment the actual velocity head is 0.007338 in., so the conversion efficiency may be said to be 0.007338 × 100 ÷ 0.01145 = 64 per cent.

This shows how very important it is to make all air ways for "natural ventilation" as aerodynamically perfect as possible in order to conserve the very small static pressures. Apart from internal friction the forms of the inlet and exit terminals are most important.

Considering the experimental figures found on testing the smaller duct (5 in. × 3½ in.) and treating them in the same way it was found that a static head of 0.0150 in. w.g. produced a flow of 41 c.f.m. An equivalent round duct would have a diameter of 4.594 in. and if 8 ft. long a friction loss of 0.00450 in. w.g. the velocity in the duct having been found to be the same as in the larger duct—339 ft. per min. with equivalent velocity head of 0.007338 in. w.g. The conversion efficiency, by similar calculation, comes to 0.007338 × 100 ÷ 0.01500 — 0.00450 = 70 per cent.

I am greatly indebted to Mr. Merlin S. Jones and to Mr. J. McK. Ellison for checking these figures. Mr. Jones applied a new and a more elegant treatment to the first and second parts of these Appendices in which he was able to dispense with the assumption of an initial air velocity deduced from volume ÷ area. Mr. Jones's final values for duct dimensions and velocities are not very different from those which appear above.

Appendix III.

The method by which the quantity of air delivered by the ducts was measured may be of interest. It was realised that the placing of any of the usual kinds of anemometer in ducts where the aero-motive force was so small would have been inadmissible, and that traverses with a Pitot tube would be too slow. Duplicate ducts had been constructed, and in each duct a half-inch testing hole had been cut, centrally and some 42 in. downstream of the inlet (see Fig. 4). The duct to be calibrated was laid horizontally, the outlet with the turning vanes removed and an exhaust fan delivering through a flowmeter carefully fitted to the outlet and of the duct so shortened. A standard Pitot tube connected to a Chattock gauge was then inserted into the test hole and carefully centred. A number of centre velocity pressures—corresponding to a series of air discharges, measured by the flowmeter, were then measured by the Pitot tube and a graph obtained.

When the duct was fixed in position it was possible by the centrally fixed Pitot tube to read off the velocity pressure of the air at the axis and obtain the corresponding volume, in c.f.m., from the curve. Because the test hole was some 30 in. upstream of the exit opening with the turning vanes it was most unlikely that the addition of this in the final set up would vitiate the initial calibration. But it was soon realised that from first principles these centre velocities and volumes would be a function of the static pressure existing between the two ends of the duct.

As already remarked, this static pressure was measured by a Chattock gauge, one end of which opened into the room, the other being connected to a static tube in the ceiling-roof space near to the entrances to the ducts. By taking a series of simultaneous readings of static pressures and the corresponding volumes in c.f.m.—as deduced from the centre-line Pitot-tube calibration, it was possible

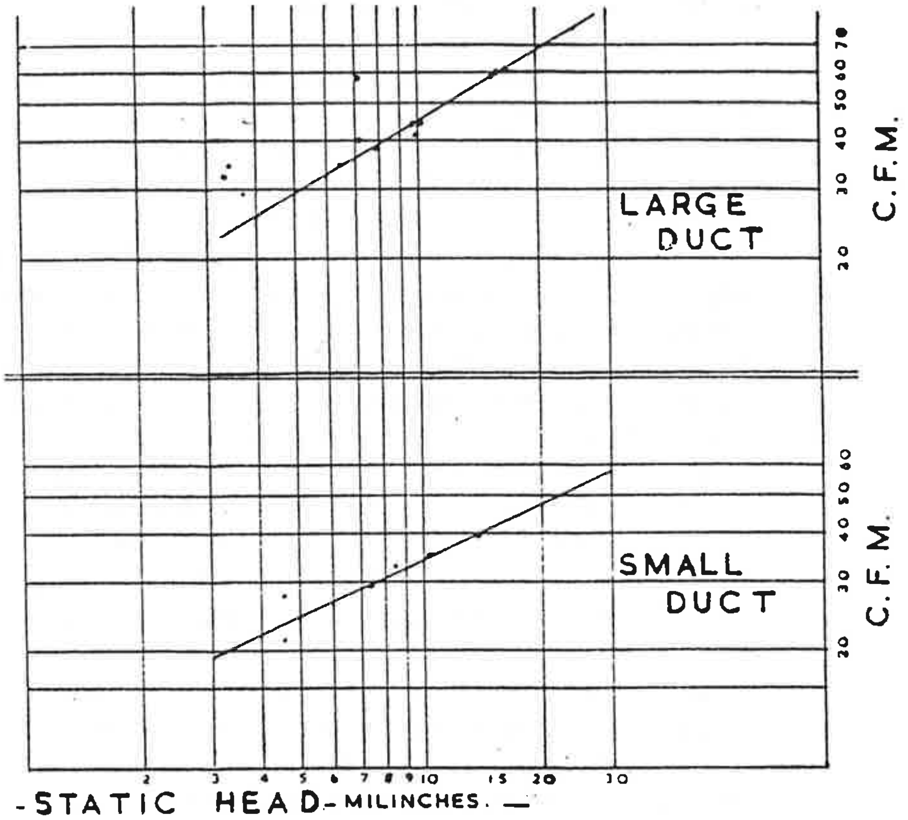

Fig. 12.

to plot, on logarithmic paper, two graphs from which the quantities of air being delivered from both ducts could be read off from a single observation of static pressure.

This graph is shown in Fig. 12 to give an idea of the order of accuracy to be expected from the use of such a technique. It will be seen that below 40 c.f.m. for the larger duct and 30 c.f.m. for the small duct these measurements are unreliable, but that at 50 and 40 c.f.m. there is little reason to mistrust them.

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Discussion.

The President invited Professor Crowden to open the discussion.

Professor G. P. Crowden said that he would like, at the outset, to say that the experimental studies dealt with by Dr. Angus were in their early stages, but that they were related to the very important subject of comfort in the home.

An attempt was being made to assess the relationship between the physical environment, namely the indoor climate, and the physiological reactions and subjective thermal sensations of the occupants of rooms of ordinary construction. For such studies it was essential to be able to assess the physical factors concerned. One of these was the ventilation of occupied rooms.

Although progress had been made in this direction, the methods which had so far been devised for the measurement of domestic ventilation were by no means convenient for general application. If studies of the kind carried out by Dr. Angus ultimately led to some simpler method which could be readily applied in occupied rooms they would facilitate studies on a much larger scale.

The co-operation of the physicist, the heating and ventilating engineer, the architect and the medical scientist in studying such problems would probably lead to improvements in the ventilation of ordinary dwellings. He hoped that the paper would lead to a very fruitful discussion on the important subject of domestic ventilation.

The President said he believed Mr. J. B. Dick, who was to give a paper next month on a very closely related subject, was present, and was engaged in some work with the Building Research Station. Perhaps he would join in the discussion.

Mr. J. B. Dick said he would like to make two points on Dr. Angus's paper.

First, he was very interested to learn that Dr. Angus found the index of air change very different from the theoretical value 0.5. Some work had been done at the Building Research Station in measuring the air infiltration through windows, and it had been found in these experiments that the index could vary quite appreciably. As far as could be seen the variations of the index were mainly due to actual movement of the windows. When, for instance, there was pressure outside a window which opened outwards, as that pressure increased the window was forced home against the frame, thus narrowing the gap and effectively reducing the index.

Secondly, there was the question of the efficiency of under-floor ducts in reducing floor draughts. The experience at the Building Research Station was similar to that of Dr. Angus. In a house in which a 6 in. under-floor duct was installed, the amount of air coming through the duct was never more than 25 per cent. of the total air passing through the room. That reduction was not very significant if one was interested in floor draughts : one required something of the order of four or five before it became effective.

In this particular case, the floor draughts were not conspicuous, as air entering under the door came from a partially-heated hall, and in the hall the external doors had been weather-stripped so there was no entry of cold air along the floor. Dr. Angus's paper had shown clearly that where there was a source of cold air outside a door, for comfort one must take positive action at the door. This could either be by the temporary expedient of, possibly, a doormat or by other means, such as using a metal weather-stripping on the door, or by the use of a threshold.

Mr. L. Gordon Davies said he had followed the experiments of Dr. Angus and Mr. Dick very closely for some time and had found them extremely interesting.

He was in some doubt as to whether 600 cu. ft. per hour per person, which had been laid down as a minimum, was sufficient. If one went into a normal house where people had been sitting for two or three hours—perhaps four people in a room, playing cards—the condition of the air inside that room would, he would imagine, need a good deal more than 600 cu. ft. per hour per person. Whether one would every get windows which were sufficiently sealed to overcome Mr. Dick's objection to incoming air was very problematical, so that it was difficult to see what the regulations were likely to be in the future from the point of view of air change in public rooms. Perhaps Dr. Angus would say something about that.

Mr. L. Gordon Davies (communicated) *:* Dr. Angus in his lecture discussed ventilation only in so far as it is effected by the open fire, and he shows that about half the air changes created by that fire can be reduced by the supply of an adequate quantity of air to the fire. The other half of the air changes may be due to atmospheric pressures outside the building. To me, one of the important points resulting from the tests is the emphasis on the necessity to carry out further similar experiments embodying such pressure releases as were mentioned by Dr. Angus, but over the whole house, and to find out to what extent weather disturbances have upon each room in relation to each other.

Dr. Angus states that air must be sucked in through window cracks and under doors and through such fortuitous openings to replace the "pull" of the chimney. We all know, too, that the negative pressure due to the wind over a house can easily cause air to be sucked out of the window cracks at a sufficiently high rate to overcome the "pull" of the chimney with most unpleasant results. If the doors and windows were made to fit with as little leak as possible, then these alarming conditions would be worsened. It appears to me, therefore, that if provision is made for an automatically regulated supply of air to enter on the pressure side of the house and a similarly automatically controlled extract prevents undue extraction on the negative side extremely interesting and informative tests could be carried out. It may be found that, with all windows closed and with the sometimes helpful pumping action of normal opening and closing of doors, a drop in static pressure would occur preventing those unpleasant floor draughts from under doors to which Dr. Angus has referred. This would make the almost impossible task of making perfect fitting doors and windows unnecessary.

With regard to heat loss which may occur as a result of the higher air change, it is pointed out that it is reasonable to suppose that the door into the room in question would, in normal circumstances, be open for a period equal to about one-third of the time that the fire is alight. A considerable proportion, therefore, of the heat is entering the house from the room to distinct advantage and, if the house is treated as a whole, represents a saving of fuel as against a loss. I have often wondered to what extent fuel economies can be made, even though the rate of air change in a room is dropped by one-half, by reason of good fitting windows and doors and a separate air supply to the fire, since the number of times a door is opened while the fire is alight could ordinarily be so great as to easily offset any saving made.

It may, therefore, be true to say that it is more important in the interest of the health of the nation as a whole to educate people to live in a fresher atmosphere rather than in one where a slightly lower air change exists with its somewhat doubtful effectiveness in the saving of fuel.

Mr. J. S. Hales said Dr. Angus had rightly pointed out that the usage of fuel for domestic purposes formed a very large proportion of the total coal output of this country. A more recent figure than that quoted in the paper gave 52 million tons as the figure for all domestic purposes at the present time, including gas and electricity. Of this amount some 28 million tons was supplied as raw coal for domestic use, and probably about 80 per cent. of this, or some 23 million tons, represented the amount used for open fires.

Assuming means could be found for increasing the efficiency of the open fire by 100 per cent., which was not unreasonable, and allowing for the fact that people would then enjoy a higher standard of heating, one arrived at a figure of potential saving of at least 8 million tons—a larger figure than any other industry could show. This served to emphasise the importance of the figures that had been mentioned.

As to how this saving was to be effected, that was another matter. Although Dr. Angus had given some interesting data in connection with excess ventilation, the solution was still a long way off. The trouble was the twelve million odd existing houses which formed the core of this particular difficulty. The solution, of course, lay in the supply and installation of improved appliances. These had to be cheap and attractive, and they had probably to be tenants' fixtures—a feature sometimes overlooked, though a very important point.

Dr. Angus had emphasised that one of the most important improvements was in ventilation and the reduction of excess ventilation on the score of both fuel economy and comfort. He had indicated the advantages and disadvantages of ducts, both under-the-floor and over-the-floor, in order to satisfy the demands of the chimney. He had not—incidentally—mentioned one other purpose of under-flow ducts—to control combustion and deal with difficult fuels by concentrating such draught as was available on to the fuel bed.

Dr. Angus had noted in his paper that the seat of the major resistance of flow should be in two places—at the throat and at the flue terminal. By that method one did ensure a more satisfactory stable flue. He was not sure whether a stable flue could be produced by the introduction of large volumes of air at an unrestricted throat and it was possible that by bringing in such large volumes at that point one might introduce unstable flow conditions which would give rise to smoke.

Another point : the name of Mr. Martin Henry had been mentioned. In an experiment using air from the loft space, there had been some difficulty with reverse draught, and the downgoing air-supply duct acted as an upgoing smoke supply ! There was a reversal of the flow conditions when the duct was warm and the flue draught was not very high, and the same difficulty might arise in connection with one or two of the suggestions that had been mentioned in the paper.

Some of the points that had been made appeared to ignore that it had been known for many years that room ventilation could be reduced merely by restriction at the flue throat. The flue throat could in fact be reduced to approximately 5 sq. in. only, burning about 2 lb. an hour and cutting down the ventilation rate in terms of the amount going up the flue to as low as 1,500 cu. ft. an hour. With such a restricted flow, suction at the throat of the order of 0.1 in. water gauge was obtained, a very considerable figure. This gave very stable flue conditions which were able to overcome down-draughts, one of the difficulties experienced with many types of open-fire appliances.

The reduction of ventilation rates might, therefore, be better tackled by greater attention to the reduction of throat area, which had other advantages, rather than to the introduction of large volumes of air which would involve structural and other difficulties.

Mr. Merlin Stephens Jones said Dr. Angus's interesting discourse was no exception to what appeared to be the general rule that papers dealing with fires and natural ventilation were fruitful in leading us back to fundamentals and reminding us of the astuteness of such early workers as Rumford, Pettenkofer, De Chaumont and Napier Shaw.

In quoting the error of measurement of air change by the CO_2 method as 15 per cent., Dr. Angus should have made it clear that this was *twice* the standard deviation.

He would like to put rather more emphasis than Dr. Angus had done on the importance of register control at the throat of the flue, and to give strong support to the contention of Mr. Hales that both throat and terminal may with advantage be constricted to a far greater extent than was customarily supposed.

Table II of Dr. Angus's paper immediately invited an attempt to evaluate some of those constants of the room that he had so aptly named "pneumatic parameters." Columns (5) and (6) of this table provided two estimates of the volume rate Q at which air entered the room through miscellaneous cracks and adventitious orifices, the first derived from the measurement of air change by means of a tracer gas, and the second from direct measurement of the flow into the fireplace through a guard-box. Assuming (despite the somewhat contrary evidence afforded by Table IV) the approximate validity of the quadratic law of resistance, and allowing for the fact (supported by Fig. 6) that a portion of the inflow appeared to be independent of the pressure drop, it was possible to utilise Column (8) to calculate the pneumatic resistance of the cracks and chinks in the room. To facilitate appreciation of the geometrical magnitude of the leak, he (Mr. Jones) had adopted the convention of expressing this in terms of the area of an ideal orifice (i.e. one whose coefficient of discharge was unity) which would offer the same resistance to flow. The results from Columns (5) and (8) and from Columns (6) and (8) were concordant, being respectively 29.5 sq. in. and 30.3 sq. in. These figures were not unreasonable, since a one-eighth inch crack around the whole periphery of a 7 ft. × 3 ft. door would have an area of 30 sq. in.

Thus encouraged, Table III might be examined. For various register settings the table gave a measure of the air flow through the room, (*a*) when the cracks offered their normal impediment to the flow (Column (2)), and (*b*) when the cracks were by-passed by a pair of vertical ducts connecting the hearth to the roof space (Column (3)). A simple theory of the mode of action of heated flues, akin to that elaborated by C. A. Masterman in 1930, led to the conclusion that if Q was the rate in cu. ft. per min. of air flow through the room and d the width in inches of the register opening, then the graph of $1/Q^3$ against $1/d^2$ should be a straight line. This was confirmed to within 1 per cent. by the data in Table III Column (2) which yield

$$Q = 68.5d^{\frac{2}{3}}/(1 + 0.158d^2)^{\frac{1}{3}}$$

It might hence be inferred that under these conditions the maximum value of Q would be 127 cu. ft. per min. (when the register was taken right out) and that the area of ideal orifice equivalent to the combined resistance of the room cracks, chimney terminal and chimney length in series was 30.2 sq. in. Column (3) of the table was clearly somewhat irregular, but by doing our best with the graph one finds (with a maximum departure from the observations of 10 per cent.) the flow through the room to be

$$Q = 41.3d^{\frac{2}{3}}/(1 + 0.050d^2)^{\frac{1}{3}},$$

with a maximum Q of 112 cu. ft. per min. By combining the data of Columns (2) and (3) it was further possible to calculate separately the equivalent ideal orifice areas of the ducts and of the room cracks. For the two vertical ducts in parallel (total cross section 43 sq. in.) the equivalent area worked out as 19.3 sq. in., while that of the room cracks was 29.3 sq. in. The agreement between this latter figure and those already derived from Table II (namely 29.5 and 30.3 sq. in.), seemed too good to be true in a statistical sense! It was now evident why the small vertical ducts were not very effective. The fact that the area (30.2 sq. in.) equivalent to cracks, terminal and chimney in series was so close to the value for the cracks alone suggested also that the resistance of terminal and chimney must be small compared with that of the cracks.

For convenience he had based the above calculations on the quadratic law of resistance corresponding to a value of $\frac{1}{2}$ for the index n in Dr. Angus's Table IV. In view of the values of the index there quoted, it might seem somewhat surprising that the parameters he had deduced should form so coherent a picture. The analysis could, of course, be carried out for other values of n, although at the cost of some algebraic complexity and computational tediousness ; but he was inclined to think that analysis based on the simple quadratic law could, with care, give very useful and even quantitative guidance on the behaviour of complex ventilative systems. Incidentally, the values given in Table IV all seemed to be rather high, indicative of a large proportion of " capillary " resistance in the leaks concerned, and it might be of interest to note that in a 1940 report of the United States National Bureau of Standards an index as low as 0.52 was encountered in some experiments on window infiltration.

The Secretary read the following communication from *Miss Flora W. Black :* On page 385, Dr. Angus says " One end of the manometer opened into the room and the other was connected to a rubber tube opening into the space between the ceiling of the room and the roof of the hut. It was found that this space gave a good datum which was but little influenced by wind effects on all but stormy days . . ."

The factual basis of this statement is, I think, that, while the static-pressure difference between the inside of the room and the outside was subject to erratic short period fluctuations on all but the calmest days (or periods of very steady wind), the pressure difference between the roof space and the room was not subject to these short-period fluctuations except on days of stronger changing winds. In other words, a fairly steady reading of the pressure between the roof space and the room could often be obtained when a steady reading of the pressure between the outside and the room could not be obtained. If during such a period, the rate of flow through the room were altered, while the ventilation channels to the room remained unaltered, plots of the static-pressure difference between the roof space and the room, against the rate of flow would lie on smooth curves. With this (cf. Fig. 8) I agree.

What is not apparent from the paper, however, is that the value of the " steady " reading obtained for a given rate of air change in the room, even when doors windows, etc., remain unaltered in position, may vary very considerably with wind speed and direction. Thus, although smooth curves may be obtained (*a*) on a calm day, (*b*) on a day with a steady north wind of, say, 10 m.p.h. and (*c*) on a day with a steady west wind of, say, 5 m.p.h., these curves would in all probability be quite different and differ from the curves obtained with any other steady wind. The reason for this is that the different winds produce different pressure distributions about the building, and the difference in pressure between one external point and another may not be small compared to the difference in pressure between either of them and the interior of the room. Although the effect of short-period fluctuations in the wind may, to some extent, be damped out before appreciably affecting the pressure in the roof space, the pressure induced by prolonged alterations in the wind are transmitted to it, even when the magnitude of the change is not great. Now the total flow of air through the room is the sum of the flows through the individual channels to it, and, although the flow through any individual channel depends on the pressure across it, a knowledge of the pressure across any one channel, or between the roof space and the room, will not necessarily determine the pressure across, nor the flow through, any other channel, and hence will not necessarily determine the total flow through the room.

Thus, although when wind speeds are known, or are known to be constant, static-pressure measurements may provide useful qualitative indications of the effects of various modifications to a room, considerable discretion and probably a considerable amount of additional data, is necessary for their quantitative interpretation.

Mr. D. R. Wills, referring to the large appetite of the domestic flue for air and to feeding it from sources other than the room itself, said this would seem to be the wrong approach. As Mr. Hales had pointed out, it should be far easier to control the flow of air into the flue and hence the air change in the room by the use of a restriction at the entry or the throat, but the important factor was that attention should be given to the application of aerodynamical principles as far as is possible. Pushing across a flat-plate register could not produce the same desirable effect; more careful design was necessary.

The domestic flue was probably the most common form of ventilating duct in use, yet it appeared to be designed not on aerodynamical principles but around the sweep's brush!

He was interested in the contribution from the speaker from the Ministry of Works. He had himself attempted to analyse the logarithmic curves shown in Fig. 9. These are of the form:

$$\log Q = \log k + n \log h$$

where Q is the quantity of air flowing

k is a factor of the form $C_d \times A$ (C_d being an overall discharge coefficient and A an equivalent area of the flow stream)

If one assumed the overall coefficient of discharge remained constant for the collection of openings involved under the different test conditions and this was a reasonably valid assumption (a check on the measured flow and total pressure loss for the ducts from figures given in the paper showed the overall coefficients for the two ducts were between 0.6 and 0.7 which compared with normal orifice coefficients), the equivalent area of the various openings could be estimated. For instance, if one considered two cases such as "room sealed, ducts closed," and "room sealed, ducts open" and assuming the area of the adventitious openings to be A_1, the areas involved in these two conditions were A_1 and $(A_1 + 43)$ sq. in. respectively. From the known values of Q, h and n in each case, A_1 could be evaluated. Similarly for other conditions.

The results of these calculations showed the following equivalent areas to be involved.

Room sealed, ducts closed = 15.5 sq. in.
Room sealed, ducts open = 58.5 sq. in.
Equivalent additional area by unsealing the window = 6.45 sq. in.
Equivalent additional area by unsealing the door = 15.35 sq. in.
Equivalent total area for normal room = 37.95 sq. in.

These figure showed the great difficulty of restricting the air change by adequate sealing. For instance, when the room was supposedly sealed there was an equivalent area of about one-third of the open duct area.

With regard to the likely value of " n " it would be incorrect to suggest the values obtained from these experiments could be universally applied and it was not surprising that it differed from 0.5.

The flow was quoted in the paper as proportional to h^n. This law was more fully $Q \propto C_d h^n$. Both the coefficient C_d and the index n varied with Reynolds number and characteristics of the flow through the large number of openings involved would no doubt vary widely. The flow, for instance, through a permeable partition such as a porous wall would be more nearly proportional to the pressure difference rather than the square root of the pressure difference as was the case of a sharp-edged opening of short length. Thus an overall value of n could vary between 0.5 and 1.0 depending on preponderance of one or other type of opening.

He was interested to note the comparison drawn between the size of the opening beneath a door and the free area of a terra-cotta air brick. The significant feature was the closeness of the size of what should be a well-designed ventilation opening, with a stray opening ! An additional ventilating opening in particular rooms was often necessary and a well-designed ventilator should be fitted, rather than something which was apparently designed to resemble a solid brick ! Here, surely, was the need for a ventilator which would not only introduce a controlled sufficiency of air, but would diffuse it so that no uncomfortable draughts were produced.

He had hoped Dr. Angus would have mentioned kitchen ventilation. Although the kitchen was not regarded as a conventional habitable room, many housewives would disagree, for they spent much of their time there ! The modern tendency seemed to be to make kitchens smaller and yet do more jobs in them and there was a real need for increased rather than reduced ventilation there. Random tests showed that if the question of adequate ventilation was overlooked, uncomfortably high levels of dry-bulb temperature and humidity could be reached. It must be remembered that during her busier days the housewife was continually moving into and out of this zone and discomfort must result.

There was a need for a closer study of this problem, so that the provision of an adequate amount of ventilation could be assured and discomfort avoided.

As a general comment he thought that Dr. Angus would have some difficulty in persuading Housing Authorities that in order to provide one open fire they must provide three flues or ducts ! Flues were now apparently regarded as expensive luxuries.

Dr. F. J. Eaton said that Fig. 3 of the paper showed that the chimney was restricted by a moveable horizontal plate at the level of the top of the fireplace opening. The paper stated that the free space could not be reduced to less than 1¾ in. without getting smoke into the room. It was his experience that much smaller openings were practicable if the restriction was arranged some 12 in. above the top of the fireplace opening. In his own living-room fireplace he had used a piece of sheet metal of which the lower edge rested on the front of the firebricks and the upper edge was about 1 in. from the back wall of the builder's opening. The slope of the sheet metal was about 60°. It was noticeable that whereas before fixing the metal plate his family gathered round the fire now they were content to be in other parts of the room. Further windows were opened on days when previously care would have been taken to keep them shut. Anyone could try this device which was simple and effective. No quantitative experiments had been made but he suggested that before expensive ducts were introduced to control the ventilation in living-rooms the much simpler expedient of adding resistance to the chimney above the fireplace opening should be tried.

Many of the new houses were being equipped with convector open fires and some with openable stoves. Such appliances had smoke nozzles of 5 in. to 7 in. diameter and generally a short length of flue pipe connected the appliance with the 9 in. × 9 in. brick chimney. Dr. Angus had so far confined his attention to the traditional open fire and it was suggested that his experiments should be extended to cover these new appliances, which could possibly be modified to control ventilation. It was also suggested that experiments might be made with an open fire designed in the down-draught principle. One such fire, the Maxra, was now nearing the production stage and was obtainable for test purposes. In this open fire which incorporated a back boiler, a damper in the chimney was used to control the combustion rate and as it also restricted the excess air drawn through the appliance ventilation was controlled to some extent. The amount of ventilation depended on the position of the chimney damper ; the minimum being obtained with the damper set for maximum hot-water production when practically all the products of combustion and excess air in the chimney gases originate from the air passing through the fuel-bed.

On the question of air leakage into rooms, he said he had had considerable experience of the installation of coke grates in houses of all types. It was rather significant that only in a handful of cases had it been found that the fire would not burn when the door was closed, but would burn when it was open. In one such case, the room had a fitted carpet ; the house was of the Victorian period and it had sash windows. Arrangements were made for a small opening not at floor level but at the top of the door, and that gave satisfactory results.

Mr. H. C. Jamieson said he was puzzled to hear that underground ducts would apparently not work. They did not appear to suffer from the disadvantage of vertical ducts which, as had been suggested, created a negative static pressure. They could easily be used in the two suggested fireplaces. He was not sure that they had been fairly treated under the test conditions as set out in the paper. The underground duct was 12 in. square with a 22 sq. in. opening, while the two vertical ducts had an area of at least double that size. In the tests, again, the two vertical ducts were apparently going into the roof space of a hut and normally in a house they would go up two stories into the roof space of an ordinary house with a pitched roof. Was it known that the pressure in such a roof space was equal to the outside pressure ?

Dr. Angus's suggestion that a method of blowing air into a room or taking it out of a room might be used for determining the over-all air-tightness of the room was interesting. It could only be applied to small rooms, but it was of considerable interest in the question of general leakage into a room. Members of the Institution would be more interested if it could be applied to the determination of the natural air change of a room, and in that case it was not the over-all airtightness that was of interest but the differential airtightness, which was the airtightness of the windward side as compared with the leeward or interior side.

Mr. J. R. Kell said it occurred to him as a matter of interest to ask whether Dr. Angus had any idea of the air changes which went on in our forefathers' times, when chimneys were not 9 in. square, but something like 18 in. or 2 ft. and the sweep's brush, of course, was a small boy. He remembered once sitting in an old farmhouse in front of some such flue on a cold winter's night. The fire was built up with logs to keep the room warm, and the more logs were put on in the middle of the fire, the colder the room became. It would be interesting to draw a curve of what the ultimate result of that must eventually be. One was becoming very nice as to the problem of a few square inches of flue opening and little cracks round doors and so on, and he supposed this problem of what happened in a flue had been under investigation right from the days of Rumford—should be say ?—onwards. Tredgold had dealt with the subject in his book. Now the Department of Scientific and Industrial Research were on it. And a solution seemed to be no nearer. Although the paper was extremely interesting and a great deal of work had been done, he did not think there was much of a clue yet to the solution.

He gathered the opinion was held that to introduce air by means of ducts was in some ways difficult and opinion of some was doubtful whether it was wise, in any case. Mr. Hales had rather plumped for reducing the flue aperture which appealed to him (Mr. Kell) as being along the right lines—a cheap simple thing that could be done even with existing fireplaces. It did call to mind the type of cast-iron fire he had had in a house some years ago—and they probably existed in large numbers—in which there was a thing called a canopy. In the summer this canopy was pushed in and shut the flue off. In the winter it was pulled out and one could adjust it nicely to give 1 in. or $1\frac{3}{4}$ in. or whatever one wanted. He seemed to remember it was possible to get a better draught and a better fire if the thing was pushed in. In nine out of ten modern designs of tiled fireplaces that were sold in the shops—and Council houses had them—one would find a colossal area of flue with no sort of restriction whatsoever. He would suggest that this was going miles back into the past.

He realised that a great deal was being done, but was it being used by the people who ought to be using it ? In his local paper only last week he had seen a statement that the City Surveyor had been called upon to do something about complaints received from a large number of tenants on a recently constructed housing estate who were apparently quite unable to get their living rooms warm last winter with the fireplaces which the Council had provided. That sort of thing was a crying scandal in the twentieth century, with all the knowledge now in the possession of the Ministries and what not. Yet ultimately one found these matters were left to the local borough surveyor or county architect, and he was cut down on cost by the Ministry of Health and was forced to put in the barest minimum which as everyone was aware was—from the national. fuel and every other point of view—quite undesirable.

With regard to the importance of stirring the air up when testing for CO_2, if one forgot one was testing the air and imagined a room full of people exuding CO_2, one would find that the CO_2 fell to the floor and the highest concentration was near the bottom. Bearing in mind that the open fire gave a bottom extract, it was presumably a good way of ventilating the room. What was Dr. Angus's opinion on that?

In his conclusion, which he had not given in his verbal summary, Dr. Angus had referred to the possible means whereby draughts under doors might be stopped or reduced. He had suggested some device attached to the door. It might be common knowledge, but he himself certainly remembered having one on the door thirty or forty years ago and then there was an improved model with a cam action which put a piece of felt down neatly as one closed the last inch of door. There was quite a variety on the market.

Mr. R. C. Ching said his firm used to manufacture all types of appliances for natural ventilation including a mica flap. If properly made, this mica flap was noiseless and no smoke would pour from the chimney and pass into the room. If fitted in the higher part of the chimney breast, it would take the air from the upper part of the room, which was often laden with smoke and heat and natural gases arising from the body. (It was best, for this reason, to take the ventilation from the higher part of the room as a rule).

The mica flap would also have the automatic effect that when the fire was first lighted and the flue was quite cold, the draught up the flue would be very little and the flap would keep shut. As soon as the flue began to get hot, the mica flap would begin to open gradually until it was right open. Quite a considerable amount of cold air would be taken into the flue by that means, and there would be automatic regulation of combustion. Instead, therefore, of choking the throat of the flue, as had been suggested, one could obtain automatic regulation in this way. He wondered whether under really scientific conditions a case could not be made for this appliance which had come into disrepute when it had been copied in a cheap and unsound fashion. Perhaps it might be used again to give a result which appeared to be so necessary.

Dr. R. S. Silver (communicated): The feature of Dr. Angus's very interesting paper is that his concern is with the causation of draughts, mainly those particularly annoying ones which creep along the floor. He shows rightly that the most important quantity affecting such draughts is the difference between the static pressure in a room and the outside atmosphere. This static-pressure difference is produced by the convective action of the chimney and strictly speaking could be made zero only if the chimney were blocked.

Since a chimney has, however, to remove waste products it cannot be blocked and some static-pressure difference must exist in the room. This pressure difference can be made smaller if the resistance at the entry to the chimney is increased, the practical limit being when the resistance becomes so great that combustion products are not completely drawn away. For some time it has been tacitly assumed that the modern type of chimney throat construction gives as high a resistance to air entering the chimney as is reasonably possible combined with complete offtake of combustion products. It has been known, however, that even with this the amount of air passing from the room through the chimney throat was nevertheless considerable, and Dr. Angus's paper gives definite information as to its magnitude, and to the magnitude of the floor draughts which are consequent upon it.

It is perhaps not made sufficiently clear in the paper that most of this air is excess air, i.e. does not pass through the fire and does not take part in combustion. The total amount of air flowing into an ordinary chimney throat is of the order nine to ten times that which takes part in combustion. This is a point which has special relevance to those designs of appliance in which the combustion air is taken from channels underneath the floor. It should be clearly realised that reduction of room draughts is not necessarily assured, since unless the design of the fireplace is also suitably modified, the excess air drawn in through the chimney throat will still be as great. In actual fact, in a good room when furnished, carpeted, and curtained, so that wall cracks and door apertures are as small as possible, an underfloor-air fire can produce a considerable static-pressure difference in the room because the combustion air is no longer cut down along with the reduction in excess air. In a normal fire with combustion air taken from the room, the two go together. There are advantages and disadvantages in each, which must be carefully weighed for whatever purpose is in hand. In good design of underfloor fires these are also arranged to supply excess air into the room as well as the combustion air.

The methods by which Dr. Angus tried to reduce floor draughts can now be seen more clearly in the pattern of development. Instead of ducting the *combustion* air to the fire from outside, he has attempted to duct the *excess* air and to deliver it at the entrance to the chimney throat. Now the essential requirement if this is to have any chance of success is that the total aerodynamic resistance in the duct must be small compared with the total aerodynamic resistance through all room cracks and openings. The system provides a parallel path and it is essential that resistance in this parallel path be small compared with the alternative flow through cracks and openings in order that it should provide a preferential path. The second point is that in order to be successful it must discharge on the same side of the throat resistance as does the alternative path through cracks and openings, i.e. it must discharge on the room side of the chimney throat. Looking at Dr. Angus's Figs. 10 and 11, I rather feel that these openings are coming a bit too high and a portion of the air may enter on the wrong side of the chimney throat. Such portion can only have a secondary effect in so far as it reduces the temperature of the chimney. I feel that the disappointing results to which Dr. Angus refers may have been caused by this. Obviously, if the aerodynamic resistance of the duct were sufficiently small and if it discharged through a large area into the room itself, one could expect that leakage through cracks and floor openings would be negligible. The flow of air from the duct opening across to the fire might, however, be equally objectionable. Hence the duct openings have to be put near to the fire as Dr. Angus has done, but better results should be obtained if they discharge at hearth level, or just above fuel level in the fire. They would then be unmistakably on the right side of the chimney throat and, always providing the duct aerodynamic resistance is sufficiently small, floor draughts should be considerably reduced. Dr. Angus's conclusion that it will not be possible in ordinary construction to remove floor draughts by providing air ducts of reasonable size, would therefore, appear to imply that in fact the duct resistance cannot be made small compared with crack and opening resistances, without going to unreasonable size and cost.

Mr. G. S. Horne (communicated) : Dr. Angus believes that with rooms and doors of ordinary construction it will be impossible to reduce floor draughts to negligible proportions by providing air ducts of reasonable size. It may also be worth bearing in mind that even if it were possible to do it with ducts of reasonable size, the extra cost would be largely wasted because people persist in keeping their windows open. It is certainly quite impracticable to make ducts less in aerodynamic resistance than opened windows.

Mr. J. C. Longley (communicated) : I have read with considerable interest the draft of the paper to be given by Dr. T. C. Angus in London on October 12th, 1949.

The idea of reducing and to some extent controlling the rate of ventilation in rooms induced by the stack effect of open fireplaces is not new, but has probably never been scientifically approached until recently.

Numerous specifications for Patent Application, including one by the writer, have been filed dating back to 1909, almost exactly 40 years ago, in connection with improvements to domestic fireplaces. Many of these envisage a quite simple form of air duct between the hearth and the very common ventilated space under the ground floor, but as far as is known none of these have been developed commercially.

The author has indicated the possible objection by the general public to the incorporation of air ducts into new fire surrounds, but for new property or even modern surrounds fitted to older houses it should be feasible to overcome this by good design. By far the more difficult problem would be the provision of extraneous air ducts to the many existing dwellings where no major expense is contemplated, but the probable saving of something in the nature of 5 million tons of domestic coal annually should be a definite spur in this direction.

The President said that before calling upon Dr. Angus to comment on the discussion, he would ask Mr. Duncan Wallace to propose a vote of thanks.

Mr. Duncan Wallace said the paper given that evening had been of great interest and Dr. Angus would have realised that he had no need to start with an apology in view of the discussion that had taken place. He had himself been particularly interested because he would have a living room in the coming winter with a fireplace and some under-floor ventilators. He had come to the conclusion during the evening that he would have to go round with sandbags and mats and probably sealing tape as well, in view of the size of the ventilators, in order to prevent air from coming through the cracks instead of through the small ventilators provided. However, it would be interesting to see how it worked out in practice.

The main trouble seemed to be that the Englishman was still going to insist on having his open fire. From what they had heard that evening, it seemed perfectly " daft " for him to do so, but that was that ! There would be open fires, and everything possible must be done to reduce the losses involved.

They were all very grateful to Dr. Angus for his paper and he had great pleasure in formally proposing a vote of thanks.

Dr. T. C. Angus said he was pleased to see there was some controversy as well as obvious interest in his paper, which was perhaps of a type not usual at the Institution.

Mr. Dick had raised the very interesting point that the 6 in. ducts were only able to reduce the ventilation turn-over by 25 per cent., and had dealt generally with floor ducts. It would seem to be a serious matter to put a duct big enough to do what was required of it through a solid floor with a damp course in it. It would be a source of extra expense and everybody was anxious to avoid that at present. On the other hand, pre-fabricated cement rectangular ductings might be let vertically into walls at comparatively little cost. Bricks and mortar were expensive and such ducts might well save a certain amount of material if designed to be incorporated in walls, the only extra expense being the labour involved. He was open to conviction, however. If floor ducts were preferable to vertical ducts there was no reason why they should not be made to come up beside the fireplace. The air, instead of coming out of the hearth, might come where it encountered the higher suction from the flue. He was indebted to Mr. Hales for pointing out not only to him personally but in a publication the great difference in the suction effect at the top and bottom of the fireplace.

Mr. Gordon Davies had run into the realm of the doctors, and it was to the doctors that one turned when they said that 600 cu. ft. was the minimum allowance for people. Many people thought that was not enough and the figures quoted in the paper were on the safe side in referring back to their origin, the Egerton Report. He did not for a moment think the last word had been said upon this subject. In a publication by Mr. J. B. Carne (1946, *J. Hyg.* **44**, 315) the natural ventilation of houses was considered taking the house as a whole, with the internal passages and staircases considered as a sort of ventilation chamber of neutral pressure. He believed that the experiments proposed by Mr. Gordon Davies using one-way air bricks to break down excessive wind influxes would be interesting and might be valuable. Mr. Davies suggested that it might be well to educate people to live in fresher atmospheres : he was afraid that during the last eight years they had been only too well educated in the art of existence in chilly houses !

Mr. Hales's figures on fuel wastage were most interesting as well as his suggestion that fires could be controlled by regulating the air going in underneath the grate. Presumably there was no particular reason why the air for that purpose should go through a floor duct. It might well be taken through a duct or other opening above floor level : there would seem to be no special virtue in an air supply from under the floor to below the grate to control combustion. He was open to conviction on that point, too.

The register used, which was illustrated in the diagram, was a poor one. It was put in in the middle of a number of other experiments and was not the sort one would recommend. Mr. Hales had pointed out that one did not want to increase the horizontal distance between the front of the flue and the inside of the room. We should narrow it down so that the velocity was brought forward in the room. He had himself expressed that rather badly, but other speakers had said the same thing—that the obstruction should come from the back of the fireplace rather than the front.

It was a great pity that the old-fashioned practice of fitting registers to fireplaces had dropped out. He could not think why that was except for the obvious reason of price-cutting and the fact that people did not ask for them. A newly-produced heating and cooking combination unit had been tried out at the Experimental Station and had a register. It took quite a while to find out that there was a register at all. There was a canopy which pushed in and out and gave three or four different register openings. It had no handle. Fifty per cent. of the people probably did not know it was there and it burned one's fingers to use it. Otherwise, it was a very good fireplace but the register tended to be entirely overlooked.

Mr. Jones had given a great deal of help during the course of the work and his analysis was new and interesting. He (Dr. Angus), was very pleased indeed that Mr. Jones had confirmed instead of falling heavily upon his mathematics !

Dr. Bedford who was unfortunately unable to be present had confirmed the suggestion that one could very well go back to Shaw's calculation of the equivalent area. That was an attractive plan. Dr. Angus had thought at first that the difference in index from the square root, or 0.5 power, would vitiate the use of Shaw's method of calculation here, but apparently he had been wrong in that instance and the difference was not great enough to make the new method of measuring useless. He was in agreement with the general assumption given in Miss F. W. Black's communication that the use of the ceiling-roof air space as a true no-pressure datum is open to question ; this was shown in Fig. 12 where two similar curves at different levels on the graph were obtained at different times on the same day, when using the very small static pressures induced by a fire. But the excellent curves in Figs. 8 and 9 were obtained from the data on a day with a wind of Force 3 or 4 blowing obliquely on to the closed windows. Such winds were never steady around groups of trees and buildings. It would be seen that the inevitable fluctuations of such a wind did not make for unsteady readings when working up to pressures of 0.2 in. w.g. Very stormy days would be unsuitable for such experiments. Should further work on this subject be contemplated attempts would be made to employ a method based on Shaw's work.

Both Dr. Eaton and Mr. Hales had suggested there was a lot to be done with new designs for fireplaces and that one had also to consider putting improved fireplaces into old houses, which seemed to be a good idea. Unfortunately, as he had indicated, there was little demand from the public. After all, these things had to be sold, and if people demanded " tiled surrounds " to the exclusion of all other considerations, he did not see what fireplace makers were to do about it. In reply to Dr. Eaton, and other contributors, he would point out that the 50 per cent. reduction in air flow was achieved by combined use of register *and* ducts (Table III).

He had been glad to hear Mr. Kell's views. Talking of air changes in the old days, one could even go back, perhaps, to the days when one had a fire in the middle of the house and a hole in the roof without any chimney at all. No doubt people were very cold in those days, though probably they were able to eat a great deal more than was possible now. He agreed with Mr. Kell that in many of the modern " tiled-surround " fireplaces the design had gone miles back into the past—but the Public (who pays) did not seem to realise it. He had seen a description, quite recently, in the daily press of a self-acting device to seal the objectionable leak under room doors, but doubted if there was yet any demand for such an inconspicuous improvement.

As was pointed out in the paper, Pettenkofer found that the CO_2 concentration was higher at the ceiling than towards the floor, and that was presumably because the rooms were not very hot, and the CO_2 mixed with the moist and warm air naturally went up to the ceiling before it found its way down and mixed with the air of the room. Where the main quantity of CO_2 did not come from the people, but where CO_2 was more or less forced into the room, the concentration went down to the bottom of the room. In either case, stirring was equally necessary.

He had been pleased to hear Mr. Ching's reference to the mica flap. This would seem to have been treated in much the same way as the old-fashioned adjustable register which had been allowed to drop out because people had not bothered about it and it had, perhaps, been badly constructed and misused. It was in the interest of everyone that good designs should be selected and that people should know about them. Otherwise very little would be done in practice. As Mr. Kell had said, there had been some very bad fireplaces in quite new houses. This was entirely wrong and something should be done about it.

Mr. Wills's assumption of a value of about 0.6 for the discharge coefficients of the various leaks and orifices encountered in this room was interesting, and he (Dr. Angus) had considered it rather venturesome: but the striking and, to him, surprising agreement in the values of " h " for openings so very different in nature might indicate that his assumption was by no means unjustifiable. If that was so problems of this kind would be simplified.

Referring to the top and bottom curves in Fig. 9 one would have expected the curve for the room with every obvious crack sealed to have the characteristic of the permeable partition or porous wall, with *h* near to unity—it was in fact 0.676.

The bottom curve—for the room sealed except for two large, carefully designed ducts, might be expected to show *h* nearer to 0.5—it was in fact 0.611. He still found this hard to explain.

He might say that the ventilation of small kitchens was one of the problems on which they were now working at the Thatched Barn.

In reply to Mr. Jamieson, when the actual comparison was made between the effects of the two vertical ducts and the under-floor duct in reducing air change, a rectangular orifice of area exactly equal to the combined areas of the two vertical ducts had been provided in the floor duct just in front of the fireplace. The total resistance of this orifice and the two-ended 12 in. floor duct would have been slightly less than that of the two 8 ft. ducts of smaller area throughout their length, so the comparison was fair. The use of vertical ducts in two or more storied houses, with fires on each floor, would certainly provide new problems.

The theory behind the use of the ceiling-roof space as a ventilation chamber was that the roof usually had many small leaks all round it so that entering winds lost their velocity in the large space, but that static pressures were likely to adjust themselves to a fair mean value, except on stormy days.

He agreed with Dr. Silver that sufficient distinction had not been drawn between combustion air passing through the fuel and " induction air," if it might be so-called, drawn into the chimney above the fire. He did not see that air coming into the fire from beneath through the firebars would be any more effective in blowing up the fire if it came from a duct running below the floor to the outside, rather than from a hit-and-miss grille in the front of the fireplace, as was so often seen. Should the floor duct open on the lee side of the house with a very strong wind blowing it was possible that a negative pressure would be produced beneath the fireplace.

He could not agree that better results would be obtained by allowing the air from the ducts to enter at hearth level : they tried out the two ducts illustrated in Fig. 4 with the bottoms resting on the floor; the effect on the air change when measured by CO_2 was then negligibly small.

In reply to Mr. Horne he thought that persons of limited means would keep their windows shut in really cold weather ; that in doing so they might create worse local draughts under certain conditions of door leaks or the like might easily be overlooked. What was intended was to provide air for the chimney in an inoffensive way when a room was closed in hard winter weather.

He agreed with Mr. Longley that many good devices for fireplaces and draught prevention had been introduced from time to time and that perhaps a change of fashion—in such things as " tiled surrounds" would have neutralised any public demand for material improvements. He could remember that not long before World War I there was a motor-car fashion for what was termed the "clean dash"—that meant that there were no instruments to help drivers to take an intelligent interest in their engines. Purely fashion and, one might say, purely silly; but fashions were like that sometimes.

Mr. Duncan Wallace, in proposing the vote of thanks, had referred to open fireplaces. It would be a great pity ever to drop the open fire, but it would be a greater pity if it could not be improved upon and made more effective and economical. One might conclude with G. K. Chesterton's reference to our open fires as "the veritable flame of England, still burning in the midst of a mean civilisation of stoves."

The President said it only remained for him to say that Mr. Duncan Wallace's vote of thanks did represent the views of the Institution. Quite apart from the interest of the paper and the discussion it had provoked, these occasions were of great importance because they tended to give members of the Institution a livelier interest in heating and ventilation in the domestic field. If the units were very small, it was nevertheless in the national interest that the experiments and technique developed in other fields of heating and ventilation should be applied to the advantage of the millions.

Mr. N. S. Billington (communicated): Dr. Angus's paper is of some considerable interest, not so much for the originality of the ideas, as for the quantitative data which it presents to us. The notions themselves are not new: the value of restricting the throat and the introduction of fresh air close to the fire are discussed in two books published 70 or 80 years ago* and they were also considered by the 1857 Commissioners. Numerous attempts to popularise these ideas have been recorded, but generally with little success. Mr. Edwards in his book says "how gradual must be the process by which any real improvement can be effected, and that all he can do . . . is to leave (his labours) to produce results in the slow and gradual manner which is inevitable from all solitary endeavours."

It was in 1939 that another attempt was made at the Building Research Station to revive interest in fresh-air ducts. These experiments† showed that the speed of the floor-draughts in the neighbourhood of the fire (whether coal or gas) could be reduced from 70 to 100 ft. per min. to less than 50 ft. per min. The general air movement in the room was also reduced. The duct employed was 5 in. in diameter and had an opening 9 in. × 2 in. cut in the side to face the fire. When used with a gas fire, the velocity of the air leaving the duct was around 250 ft. per min., corresponding to a volume flow of nearly 2,000 cu. ft. per hr.

Dr. Angus found that the use of a fresh-air duct gave no appreciable reduction in the rate of air change in the room. This might have been due to the use of a fan for stirring the air; and to the small area of the duct in relation to the inlet openings. I note that the vertical ducts which he used successfully had double the area of the under-floor duct. Under-floor ducts were also employed in some of the Abbots Langley houses, and here too, they seemed to be

* "Our Domestic Fireplaces," F. Edwards (London, 1870; Longmans, Green & Co.).
"The Open Fireplace," J. P. Putnam (Boston, 1882; Osgood).

† The Ventilation of a Warmed Room: *I.H.V.E. Journal*, 1939, 7 (79), 328.

of much less value than in the 1939 tests. I believe that the comparative failure here, as in Dr. Angus's experiments, was due to the ease with which air could enter the house by alternative paths, and not at all to the fact that the ducts were horizontal instead of vertical. This brings me to a point which Dr. Angus has missed, namely that as well as making the throat of the appliance smaller, one must also reduce the available inlet area by weather-stripping. In fact, I hold the view (and I have done so for many years) that all doors and windows should be weather-stripped, and if any openings are needed to admit ventilating air or air for combustion, they should be specially provided. Only by such means will it be possible to ensure that the air entering the room is tempered, and that there is freedom from draughts.

But I take comfort from my old friend of 1870. "The great difficulty . . . is to get (a system) authoritatively tried and its advantages established. We are so accustomed for any new suggestion to be talked about for many years before there is the slightest chance of its being adopted, that such a fate seems almost inevitable for this . . . We may therefore be content for the present moment to cast the seed upon the ground with a reasonable expectation that it will not have been thrown away." These seeds have already been dormant for 70 years : when may we expect them to germinate?

Dr. T. C. Angus (communicated) : Mr. Billington's contribution to my paper of last month is very much to the point. I was unaware that yet another two voices had cried in the wilderness and will read the books he mentions with considerable interest. I have no especial prejudice against ducts beneath the floor and believe they may be made to operate as well as vertical inlet ducts bringing air from the ceiling-roof space to near to the top of the fire, if carefully sized and designed, and if they can be protected from local side winds. The objection to the making of floor ducts seems to be based on the construction of modern solid floors. In the experiments cited it was not found possible to reduce to negligible proportions the draughts from under a door with ¼ in. clearance by anything less drastic than opening a window, when the fire was alight : the static head from a really cold passage to a really warm room will produce a considerable floor draught under such a door ; the curve on Fig. 5 shows that on the floor 9 in. from the door a static-pressure difference of 4 milinches will cause a draught of about 50 ft. per min.

Care was taken when comparing air-change rates with stirred air to protect the fireplace from the turbulence so produced. The entire fireplace was covered by a large hollow-box screen that left a 6 in. space around the periphery of the fireplace at sides and top for the entry of air but prevented any serious local disturbance by the fans of the air-flow from ducts or floor opening to the fireplace. When the comparison between air changes with floor-duct opening and vertical ducts was made, the floor duct was provided with a rectangular plate orifice opening in the hearth just in front of the fire of exactly the same area as the combined areas of the two vertical ducts. The fact that this orifice communicated with a two-ended duct of 144 sq. in. cross-section means that the total resistance of the floor-duct system was less than that of the two vertical ducts.

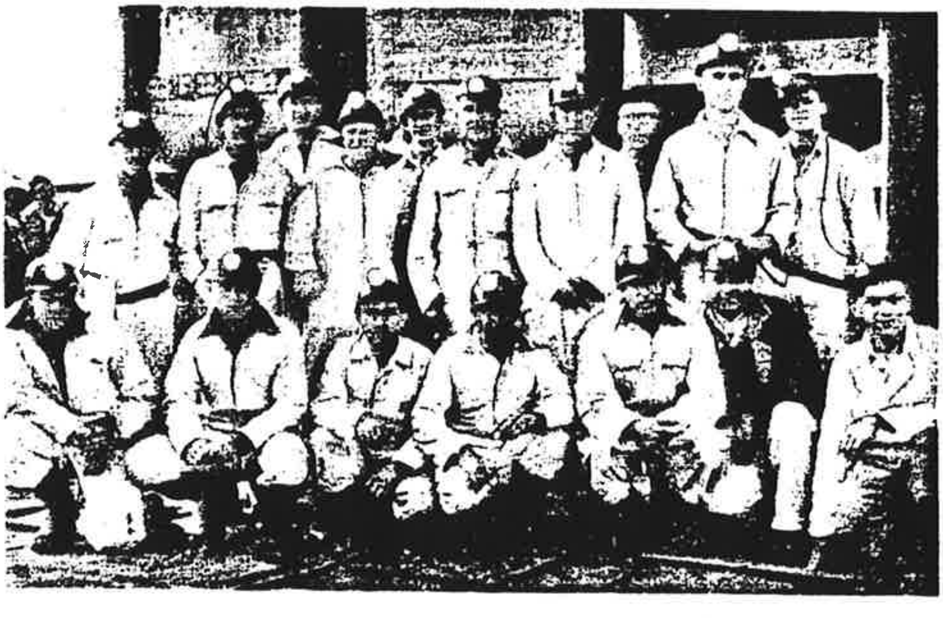
The comparison was, therefore, more than fair to the floor ducts.

I am fully in favour of weather-stripping and of taking every means to obviate unlawful entry of air into rooms in cold weather: provided that appropriate means are also taken to give adequate ventilation with doors and windows shut.

In one of our experiments where air from a floor duct was led into the room horizontally along the floor through an opening to one side of the fireplace it was found that a floor draught of 75 ft. per min. was produced, with a kata-cooling power of 10.2, just where the feet of a person would be when he or she would be sitting in front of the fire. With an opening of the same area from the same duct made to deliver air across the hot front of the heat service unit fireplace (much, presumably, as recounted in Mr. Billington's second paragraph) the speed of the floor draught fell to 10, and the kata-cooling power to 6.6—the air temperature having risen by 5.6°.

SOUTHERN AFRICA BRANCH

On Saturday, 23rd July last twenty-four members and friends of the Southern Africa Branch of the Institution paid a visit to the Robinson Deep Gold Mine, near Johannesburg. The visit, conducted by one of the members of the South African Mine Ventilation



Officers' Society, was naturally mainly concerned with the ventilation and cooling works, and over two hours were spent underground inspecting these and other workings, the greater part of the time at depths of over 9,000 ft. The surface cooling plant was also seen but as time was restricted the gold reduction works had to be missed. It is hoped to make these the subject of a future visit.

The photograph was taken by the Branch Hon. Secretary (Mr. N. H. Baines) and shows some of the party on their return to the surface. The Branch Chairman, Mr. H. C. Cawood is in the centre of the group at the back.