VENTILATION OF HOUSING SYMPOSIUM: SECOND PAPER

Adventitious ventilation of houses

by J Harris-Bass PhD, MSc (Eng), BSc, DIC, ACGI
B Kavarana PhD, BSc (Tech), BSc, MIGasE MInstF
P Lawrence

SUMMARY
This paper describes the research being undertaken by the British Gas Corporation on adventitious ventilation of houses. It outlines a test house programme which has quantified adventitious open areas for both room components and progressively sealed rooms in dwellings of varying age and construction. It also describes a model scale approach to natural ventilation aimed at predicting room air movements and ventilation rates. This work is compared with full-scale results and theoretical models.

1. INTRODUCTION
The Gas Industry has always been concerned about adequate ventilation of rooms containing gas fuelled appliances that take their combustion air from within the rooms concerned. Adequate ventilation is essential for the safe operation of appliances and was given particular emphasis in the Morton Report on 'The Safety of Natural Gas as a Fuel'[1]. Following the publication of this report, the sections of the Building Regulations dealing with ventilation requirements for gas fuelled appliances were revised and now specify the ventilation areas that are required; these are dependent on appliance type, rating and room volume. These two events were the major factors that caused the current project to be started in 1971. At that time it was thought, however, that modern building techniques combined with the growing use of weather stripping, was resulting in houses having increasingly lower levels of adventitious ventilation. As this adventitious ventilation had in the past been relied upon to provide all the air needed for normal habitation, combustion and flue dilution, the trend towards 'tighter' house construction would in itself mean that a re-appraisal of ventilation requirements was necessary.
At the time the project commenced a decision was taken to maintain a balance between short term ventilation tests in dwellings of different ages and construction and fundamental support work. The support work involves the comparison of ventilation rate measurements in model and full scale rooms and a mathematical technique for predicting ventilation rates. This latter technique was thought to be important as it can be used to evaluate the implication of installing any combination of appliance type in dwellings of various constructions. In this way it would complement the site measurements of adventitious ventilation and provide the industry with a method for determining realistic levels of ventilation in the design of future heating and indoor environmental control systems.

2. TEST HOUSE PROGRAMME
2.1 Adventitious Ventilation
The Morton Report[1] stressed the need for ensuring adequate ventilation openings into rooms in which gas fired appliances were situated, to ensure an adequate supply of air for combustion and flueing requirements. The problem in implementing such a recommendation is to know what allowance (if any) to make for adventitious ventilation, since excessive ventilation can lead to unnecessary heat loss as well as discomfort of the occupants. The problem is complicated by the known variation of such adventitious ventilation with the age and type of property under consideration, and with the possibility of changes being applied (deliberately or otherwise) by the occupant.
The programme of work presented here deals with a series of test house studies to quantify the adventitious open areas of the room components and the relative reduction in total area caused by the application of typical methods of draught-proofing. The programme of work was divided into two parts:—
(a) The measurement of the areas of the adventitious openings associated with the various room components and the effect on them of the application of draught-reducing techinques such as weather-stripping the doors and double-glazing the windows.
(b) Observing the effect of progressively reducing the total adventitious open area on the ventilation rate of the room.
Dwellings that have been tested are listed in Appen-

dix I and include conventionally and system built houses of various ages.
For a typical room, pressure sensing heads were installed on either side of the door and window, and in the centre of the room. The central room pressure was taken as a reference. Air was extracted from the room using a centrifugal extract fan discharging either up the flue or through some suitable vent (ie: air-brick, central heating duct, window ventilator, letter box, etc). The volume of air extracted was calculated from the pressure drop across on orifice plate situated immediately after the fan outlet. By setting up a flow rate and measuring the pressure drop across the component in question, a value could be calculated for its open area from equation A2.3 in Appendix II. This is known as the pressure/extract technique.
Starting from the condition where there was no sealing of the room components or floor, each component was partially or wholly eliminated in turn, either by the application of draught-reducing technique or by sealing off completely with polythene sheeting and PVC tape.
Where it has been possible to compare open areas of adventitious ventilation openings as determined by the pressure/extract technique and by direct measurement of crack width, the results show a reasonably satisfactory agreement and therefore validate the theoretical reasoning upon which the pressure/extract technique is based. With most rooms in their least sealed condition, the open area of the cracks around the doors as measured by the pressure/extract technique was within 15 per cent of that measured directly. In the case of windows this figure was slightly higher at 25 per cent, possibly due to the effect of the wind on the outside pressure readings.

TABLE 1. Effect of Draught-Reducing Techniques

Dwelling	Average room volume (m^3)	Average open area before weather stripping		Average open area after weather stripping (internal doors treated)	
		m^2	in^2	m^2	in^2
Conventional	30·0	0·0357	55·3	0·0101	15·6
System built	28·0	0·0262	40·6	0·0106	16·4

TABLE 2. Range of open areas measured during tests; effects of weather stripping (w/s)

Doors	Non w/s	0·021–0·004 m^2	32–6 in^2
	w/s	0·0045–0·0003 m^2	7–0·5 in^2
Windows	Non w/s	0·011–0·001 m^2	17–1 in^2
	w/s	0·0014–0·0003 m^2	2–0·5 in^2
Floors	Non w/s	0·0062–0·0025 m^2	9·5–4 in^2
	w/s	0·015–0·0052 m^2	23–8 in^2

The act of weather stripping had a pronounced effect on the value of open area for individual components. A reduction of approximately 80 per cent in open area could be attained by the fitting of a foam-backed weather strip around the doors and windows of a room and a draught-excluder to the bottom of the doors. But by far the largest reduction in open area as regards the whole room was obtained when a suspended floor was covered by a well fitted foam backed carpet. In a room with a suspended floor this could account for, on average, 50 per cent of the open area of the room.
These results clearly demonstrate that large quantities of adventitious open areas are able to be sealed with very little effort by the householder but as the table below and Appendix III show, even after the application of draught-reducing techniques the open area still available is quite large. Table 1 below shows an average result for those taken with the exception of the system built property which is shown alone.
It was expected that this latter property would display lower characteristics in view of its supposedly 'tighter' construction. However, as the results convey this particular property seemed no 'tighter' than the conventionally built dwellings.

2.2 Ventilation Rates

Ventilation rates have been obtained for all the properties in most of the conditions of sealing. As a check, ventilation rates for some of the conditions of sealing have been determined from the measurement of pressure difference across the open area of relevant components in the room. The technique used to

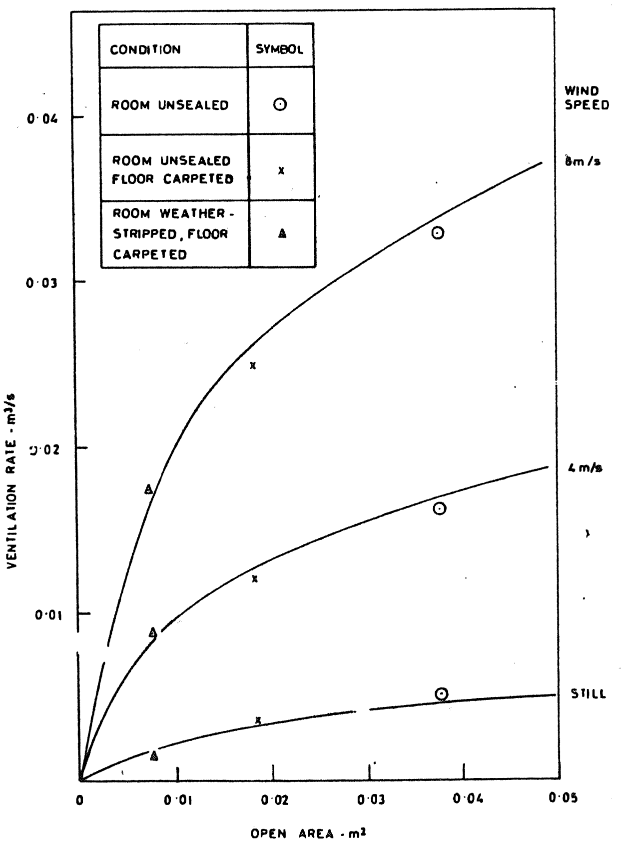

Fig 1: Effect of progressive sealing on ventilation rate within a room.

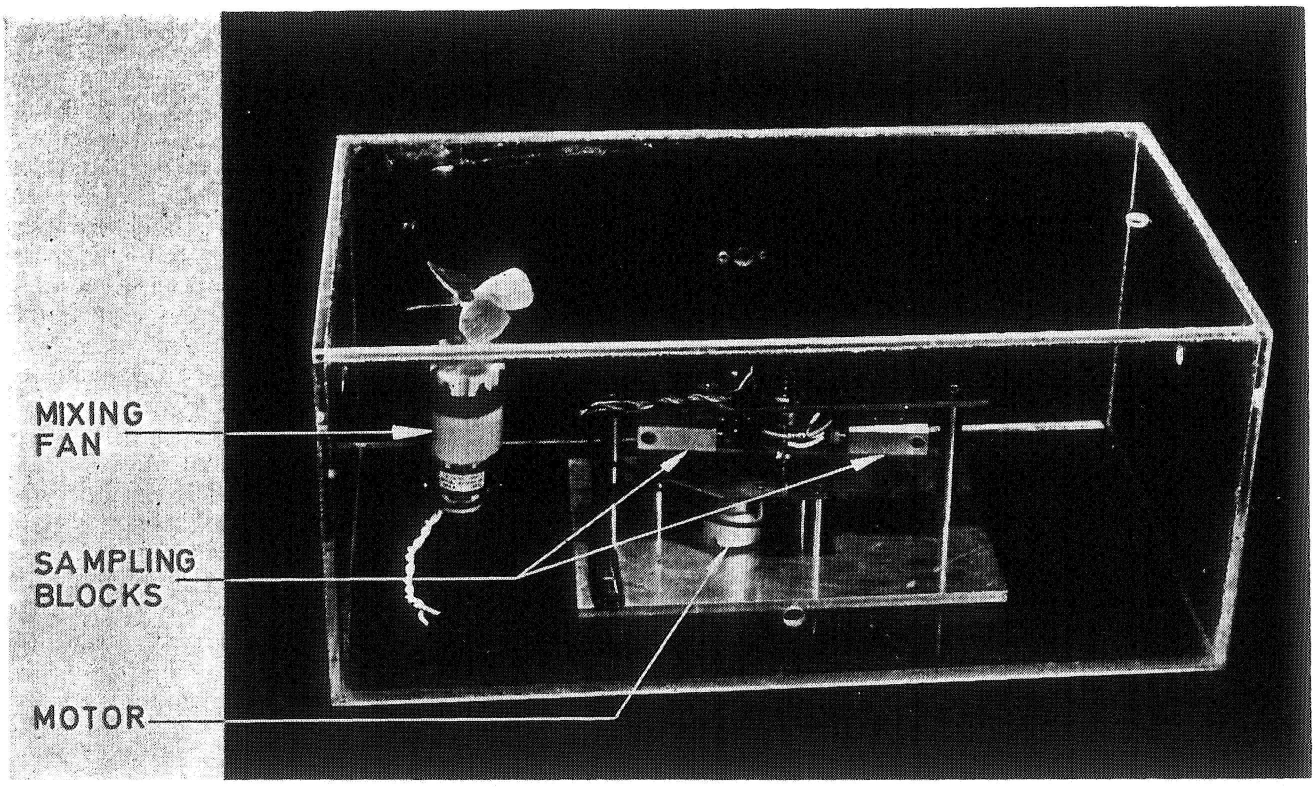

Fig 2: Whirling arm Katharometer within model in wind tunnel.

measure ventilation rates is that of tracer gas decay. A full explanation of this technique is given in Appendix II. The gas used was helium because (a) it is an inert gas and therefore unlikely to react in any way, (b) when mixed with air it gives a large change in thermal conductivity and (c) it has the ability to homogenise quickly. The advantage in (b) is that this is the quantity which is monitored by the katharometer used for measuring the decay and thus only a small amount of tracer gas (usually about 1 per cent by volume) is required to register a reasonable response from the instrument.

For the purpose of using data for the natural ventilation studies, mean values of adventitious open area were taken. Most results were determined for average wind speeds about 5 m/s (12 mph) and all results are dependent upon the wind speede at the time. However, on average, a reduction of 60—70 per cent in the ventilation rate could be achieved by applying draught-reducing techniques such as weather-stripping and by the fitting of a carpet. Figure 1 shows the effects of progressive sealing on ventilation rate within a room for property 2. These results are typical for the test house programme where draught-reducing techniques were applied.

3. WIND TUNNEL MODELLING

As described earlier, dilution techniques using a katharometer and helium as a tracer gas have been used to measure the ventilation rates in rooms. In model tests the necessity to take a continuous air gas sample to the analyser excludes this technique since the katharometer requires a sample rate of approximately 0.03 m^3/h. (1 cu ft/h). This rate is insignificant in full-scale tests, but in a model of approximately one tenth full-scale it would induce an air change rate of about two per hour. Thus a technique which dispenses with the need to draw a sample from the model is required. Several possible techniques, including the use of a radioactive tracer gas, were investigated. Finally, a method which utilized a hot wire katharometer type instrument, whose sensing elements are mounted inside the model, thus obviating the need to draw a sample from the model, was adopted. A prototype instrument of this type has been developed and used in some initial ventilation research with a one twelfth full-scale model.

3.1 The Whirling Arm Katharometer

Figure 2 shows a picture of the instrument in position inside the model. Four heated filaments are mounted in aluminium blocks and are connected to form a bridge circuit. The two reference wires, which to some extent compensate for changes in ambient temperature, are mounted in sealed cavities, whilst the cavities containing the sample wires are connected to the outside of the blocks by circular passages. The blocks are rotated by a small geared electric motor so as to impose a fixed flow velocity at the filaments. This also has the added advantage of aiding the mixing of the air/helium mixture within the model by generating a turbulent motion within the model.

The calibration curve for the instrument was obtained using an accurately calibrated helium analyser to set up known concentrations of air/helium mixtures in an enclosure which contained the instrument. When measuring ventilation rates the absolute calibration of the detector is not important, as if the calibration is linear, any calibration error cancels in the ventilation rate calibration. (re: Appendix II). Zero errors are important however, due to the lograithmic nature of the decay curve. Small zero errors caused by tem-

Fig 3: Portakabin structure on site (showing mast for measuring wind profile and turbulent intensity).

perature drift have been observed, but if the instrument zero is checked at frequent intervals, these errors can be made insignificant.

3.2 Natural Ventilation Measurements

In order to obtain some correlation between full-scale and model results, the initial studies of this approach to the natural ventilation problem have taken the simplest form, that is the investigation of ventilation in a single rom situation. For the full-scale tests

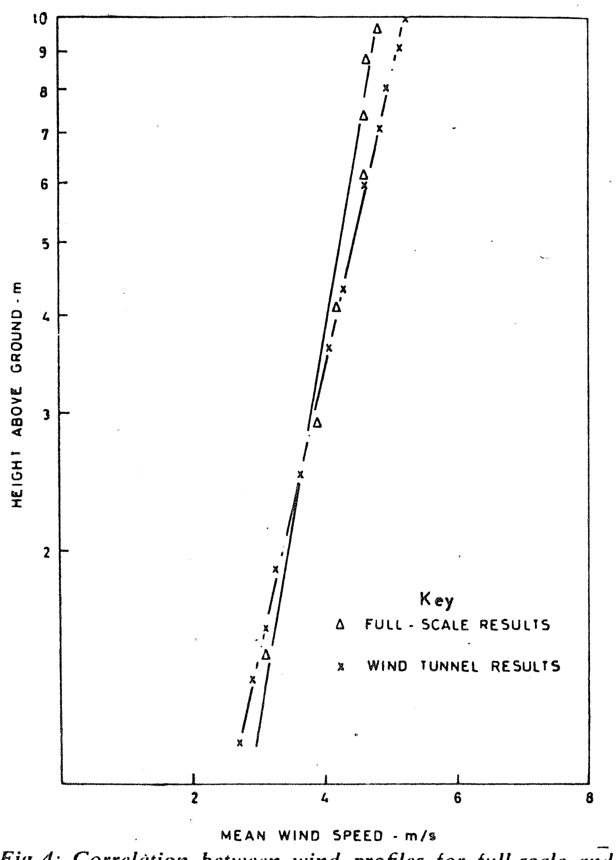

Fig 4: Correlation between wind profiles for full-scale and model Tests.

a Portakabin structure has been obtained and set up, as shown in Figure 3, in a typical urban environment. Work in this structure has been similar to that described in Section 1, except that the ventilation rate measurement has been read automatically using a data-logging facility.

Before the ventilation work commenced in the Portakabin structure, a careful study of the wind profile and turbulent intensity were made at the site. The resulting profile corresponded well with that predicted in the literature[2, 3, 4] for an urban area. By using slats positioned in the entrance section of the wind tunnel, the profile has been reproduced for the model investigations as shown in Figure 4.

The results from tests made for natural ventilation rates through the structure due to two purpose made ventilation openings are shown in Figure 5 and 6. Figure 5 shows the variation in pressure across the two ventilation holes as the wind direction is varied and demonstrates the range of pressures that each hole experiences. Flow visualisation has shown that at $\alpha = 90°$ the wind causes the air to flow into the model to pulse regularly through the holes. These model and full-scale results have enabled an empirical result to be formulated for this case. This result has led to a more accurate theoretical model being evolved. Figure 6 shows the correlation between the full-scale, model-scale and more accurate theoretical model results.

3.3 Modelling and Flued Gas Appliance

The correlation finally obtained in Figures 5 and 6 has given hope to the ultimate aim of being able to predict ventilation rates and air flow patterns by model techniques. The next step in the programme has been to extend this study by looking at the open flued gas appliance. For convenience a simulated heat source was used. A maximum of 6 kW was available but in practice it was found that enough draught was

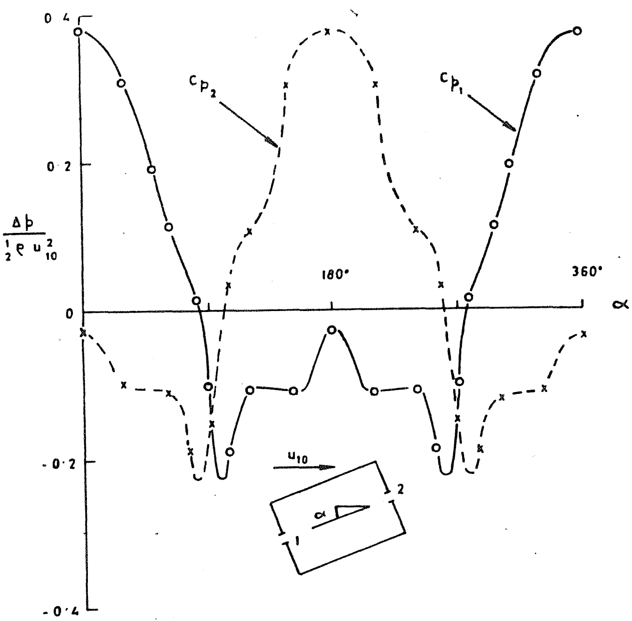

Fig 5: Results of model tests for two hole ventilation case.

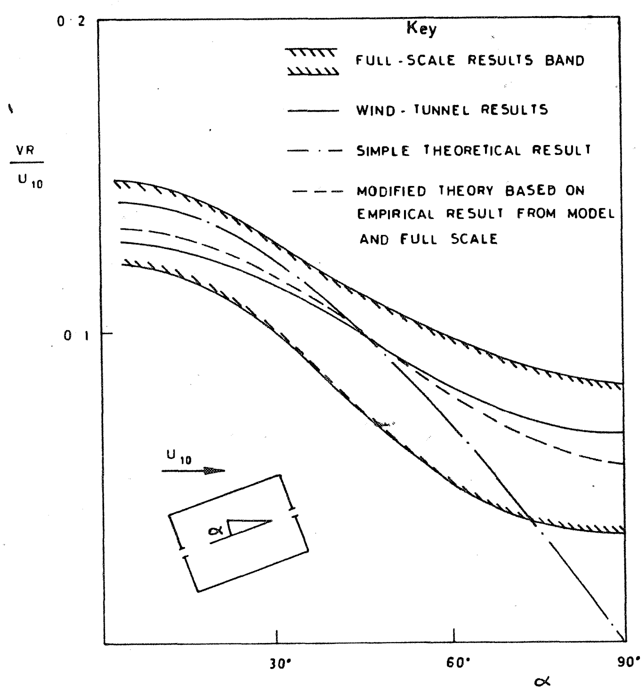

Fig 6: Correlation between full-scale model and theoretical results for two hole ventilation.

obtained in the flue by using only 1-2 kW. The pressure and temperature differences across the flue and the flow rate were monitored and ventilation rates were obtained using one purpose made ventilation opening.

In the wind tunnel, the one twelfth full-scale model was adapted to take a model open flued gas appliance. This was also a simulated model being built such that the flue volume flow rate was correct when compared with that in the full-scale tests. The model, as shown in Figure 7, used a small centrifugal fan to obtain the simulated volume flow rate but on this scale the modelling of temperature would have required a heat input in excess of 100 kW. This is not to say that the modelling of temperature gradients cannot be satisfactorily attained, but to be practical, a model of approximately one quarter full-scale would be required and this would necessitate a very much larger wind-tunnel.

Results for this part of the programme are shown in Figure 8. They demonstrate that whilst the trends from this type of approach show some correlation, the magnitudes of the results are not all that could be desired. This was undoubtedly due to the lack of temperature gradient of the model tests, but with a larger wind tunnel and thus a larger model it is hoped that a better correlation may be obtained.

Also shown in Figure 8 are the results from an iterative theoretical model developed to simulate the open flued gas appliance within a room. The correlation between the theoretical and full-scale results is very encouraging and further work on the theoretical model is being undertaken.

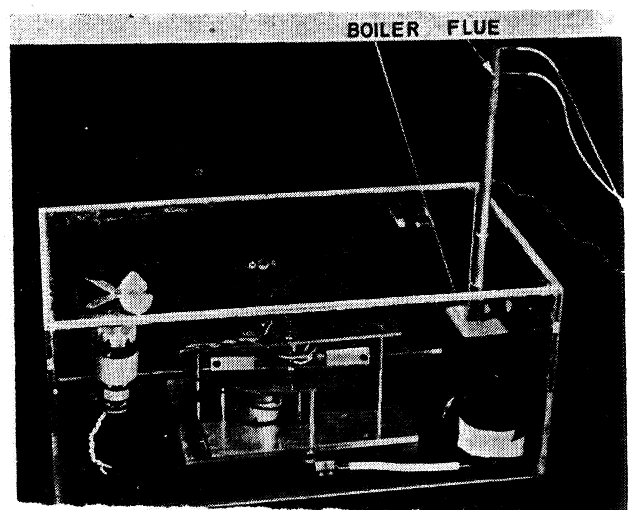

Fig 5: Results of model tests for two hole ventilation case.

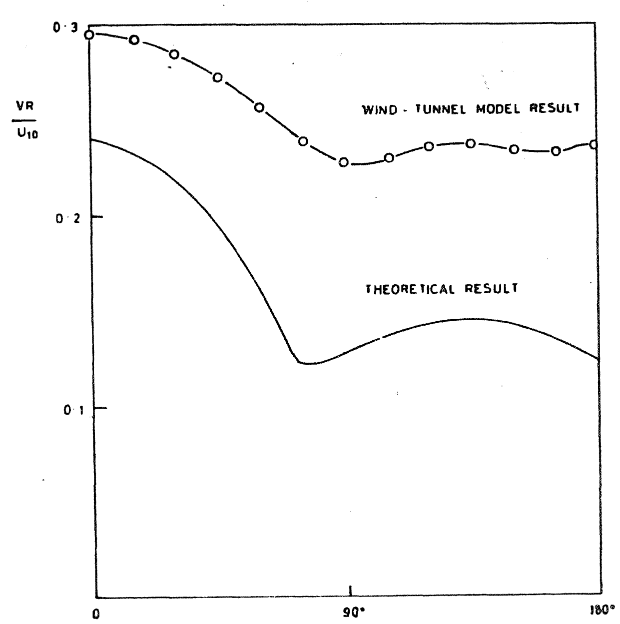

Fig 8: Correlation of model and theoretical results for open flued gas appliance.

4. CONCLUSIONS

1. Results from the test house programme have shown that a reduction in room adventitious open area of 50 per cent may be achieved by the fitting

of foam-backed carpet where there is a suspended floor. Reductions of up to 80 per cent in individual components such as doors and windows may be made by careful use of foam-backed weather stripping. These results clearly demonstrate that large amounts of adventitious open area are able to be sealed by the house-holder with very little effort, but, as the results have shown, even after a determined effort by the house-holder in the application of draught-reducing techniques, the adventitious open area still available is quite large and very significant. These results are an average of those taken for a number of dwellings with the exception of the system built property which is shown separately.

2. The minimum adventitious open area to which a householder could seal, in any dwelling, will not be less than 5 sq inches.
3. The effect of progressively sealing a room was to reduce the natural ventilation rate. On average a reduction of 60-70 per cent in the ventilation rate can be achieved by applying draught-reducing techniques to doors and windows. The results are obviously dependent on the wind speed at the time.
4. Results from the model investigations are a great encouragement to the ultimate aim of predicting ventilation rates and air flow patterns by model techniques.

ACKNOWLEDGEMENTS

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APPENDIX I

Brief description of properties tested

Property 1. Early 1930's, 6-8 room luxury flat with sash windows and suspended floor. No gas appliance fitted, simple sealing undertaken no weather stripping.

Property 2. Early 1930's, 5 room semi-detached house with metal casement windows and a solid ground floor. Gas fire/back boiler fitted, weather stripping and double glazing fitted.

Property 3. 1968, 5-6 room detached house with casement windows and suspended floors. Gas fire/back boiler fitted, weather stripping and double glazing fitted.

Property 4. Early 1900's, 7-8 semi-detached house with sash windows and suspended floors. No gas appliance fitted, general survey of ventilation rates with various sealing undertaken.

Property 5. Early 1930's, 5-6 end-of-terrace house, sash windows upstairs and casement windows down. Gas fire/back boiler fitted, weather stripping and double glazing fitted.

Property 6. 1967, 7-8 room system built maisonette with metal casement windows and all solid floors. No gas appliance fitted, general surveys of ventilation rates.

The measurement of adventitious open area is based on the equation for turbulent flow through an orifice plate as derived from the Shaw[5] resistence concept, whereby the flow through any path is equated to that through an orifice of equivalent area.

For SI units, the resistance R of an area A m^2 is given by:-

$$R = 1.4 / A^2 \qquad \text{A2.1}$$

The volume flow rate, Q m^3/s through that area is given by:-

$$\Delta p = RQ^2 \qquad \text{A2.2}$$

and thus

$$\Delta p = 1.4 \left[\frac{Q}{A}\right]^2 \qquad \text{A2.3}$$

where Δp is the pressure drop across the orifice in N/m^2. The constant 1.4 includes a discharge coefficient of 0.65, a figure which is discussed later in Paper 3 of this symposium.

For ventilation rates, a tracer gas decay technique has been used. If one assumes complete mixing between the room air and fresh air, the concentration of the tracer gas is given by:-

$$x.C = -v \frac{dC}{dt} \qquad \text{A2.4}$$

where

C = concentration of tracer gas at time t

x = volume of air entering the room in unit time

v = volume of room

Initially, $C = C_o$ and $t = o$

thus $C = C_o e^{\frac{-x}{v}t} = C_o e^{-Rt}$

where R = number of air changes per unit time.

$$\text{thus } \log_e C = \log_e C_o - Rt \qquad \text{A2.5}$$

Hence knowing the initial concentration C_o and the concentration C after time t,

$$R = \frac{\log_e C_o - \log_e C}{t} \qquad \text{A2.6}$$

The air change rate is normally expressed in air changes per hour and multiplying this by the room volume will give the volume air change rate per hour.

DISCUSSION

Mr W S Trenhaile (GLC): I am grateful to Mr Tipping for his paper. Quite a lot of work has obviously gone into it and some very useful results have been obtained.

I see that the window ventilator was developed commencing in 1972. During that particular time many ventilators of various types were installed in dwellings both in the County and in expanded towns. Problems arose not so much with the distribution of air as the amount of cold air entering during the colder months of the winter when winds were blowing. I do not know whether you have any idea how much cold air can come through an opening approximately four inches square when the wind is blowing quite strongly. We had complaints from tenants resulting from the installation of these ventilators and many tenants in fact blocked them up. Within the Inner London area, under the Building Acts, there is a requirement, as many meople know, that there shall be three square inches of permanent ventilation to each room, and to accomplish this we have been using for some time the Bon air vent which is fitted into the transom of a window and is adjustable from three square inches up to fourteen inches. We had this particular ventilator tested by North Thames Gas at the request of our Director of Housing. I have photographs and the test report here, and they say at the end, 'This ventilator appears to be an attractive solution to the problem of securing draught-free ventilation', but I think this was largely because of the ability to adjust this ventilator.

I rather feel that the whole question of ventilation wants to go much further than Mr Tipping has said in his paper. As many people will know, gas appliances are installed either in kitchens or where they take their combustion up from kitchens, and not only are there gas-producing appliances but in many instances now extraction fans are fitted to windows to extract the moisture generated at source, to prevent it drifting through into other parts of the dwelling, with mould growth and condensation.

A lot of work needs to be done in recommending the type of ventilator considered necessary to cope not only with combustion air but this matter of extraction from the kitchen. This ventilator does not appear to have any justification, and I feel that adjustment is necessary, even if it is a pre-set adjustment, to control the right amount of air in the right localities throughout the country—because we are talking now countrywise.

Dr J C Tipping: The question of extraction of moisture from the kitchen has concerned a lot of people, and the prime concern has not been for us in the Gas Industry. A draft cond of practice recommends ten changes of air when moisture-producing appliances are in operation.

I sympathise with the idea of having some pre-set adjustment on ventilators. The reason that the British Gas ventilator does not have any adjustment is that we had difficulty in obtaining the diffusion of air that we required, and it would have made the problem greater and perhaps more expensive to have pre-set adjustment of area. These are some of the thoughts behind having a fixed single area ventilator such as we have at the present time.

The Chairman: Could you elaborate a bit? Are you to go on with it? What about the future and any possible adjustment?

Dr J C Tipping: At the present time there are no plans to look into a design having pre-set adjustment, but it is possible that we may look into it, the point having been raised.

Mr D S Hawes (Technical Director, HH Air Power Engineering Limited): With regard to the question about adjustment to ventilators, there exist now on the Continent devices which compensate automatically for wind pressure. They consist usually of a long thin slot which has a plastic vane inside, and this vane will automatically partially close up when the wind blows. If we look to the Continent, where this kind of appliance is widely used, particularly in France, the answer to some of these questions could be found. In France over half a million dwellings have been fitted with mechanical ventilation systems, which are usually fairly comprehensive, in that they comprise not only air inlet devices but also comprehensive extraction devices. I am in the process of installing such devices in my own home at Cobham, so that I can make a personal appraisal of the system and how well it works, particularly in view of Mr Tipping's comments about gas boilers operating in kitchens, sucking air out, and the risk of interaction of the boiler flue and the air that is being introduced or extracted. I immediately think in terms of self-compensating devices as fitted to most boiler flues, which have these balanced swinging plates which automatically partially close off when an excessive amount of air is being drawn up the flue.

The chairman: You are welcome to try one of these devices in my house, too!

Dr Tipping: I have actually seen a strip ventilator with this flexible vane in it and the unit does not keep an exactly consistent volume flow. I was a little concerned about the robustness of the vane and whether it would flutter in the wind. However, we have not done a detailed evaluation but do intend to assess the feasibility of constant volume flow ventilators.

With regard to dampers, I am not happy about a device with a moving part, particularly, when these are in contact with flue products. There is too much chance to the damper sticking of fluttering and giving rise to noise complaints.

Dr J B Siviour (Electricity Council Research Centre):

I agree with the previous speakers who said that ventilation must be controlled. There is not much point in providing a ventilator which people will close over when the wind blows strongly.

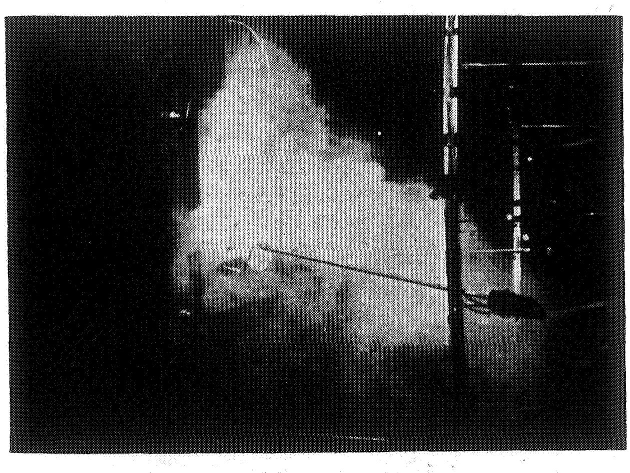
I have a question on Fig 1 in the first paper, where air is shown to be entering through the vane and rising. What temperature conditions are prevailing in this photograph, and has the performance of the ventilator been investigated with various outside air temperatures, for example 5 C and 0C.

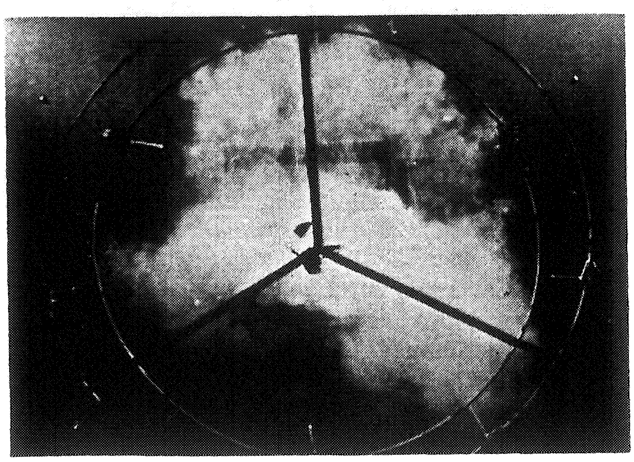
Dr Tipping: These photographs were taken at room air temperature during the original development work there was a temperature difference of 20°C between air entering through the ventilator and the room as there was provision for cooling the incoming air. Temperature effects were taken into account during the development of the ventilator.

Dr Siviour: But this photograph covers isothermal conditions.

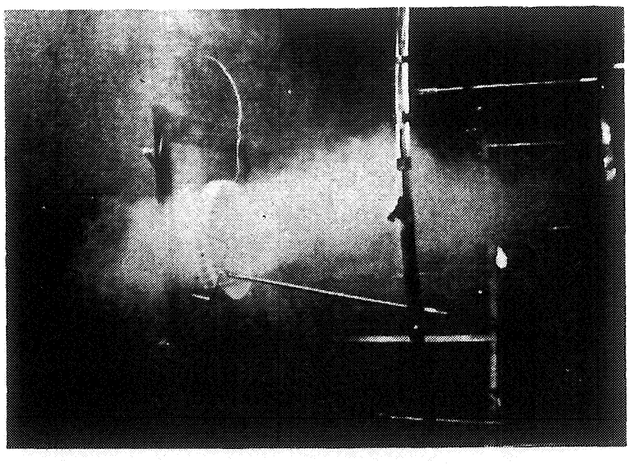
Dr Tipping: Yes, but it demonstrates the correct type of flow pattern. In fact, when you have got this temperature difference you are obviously concerned that the incoming air will fall due to buoyancy effects. The angle of the vanes has been set to ensure that the incoming jet of air does not drop down at low velocities but travels horizontally, and at high velocities the air tends to diffuse upwards.

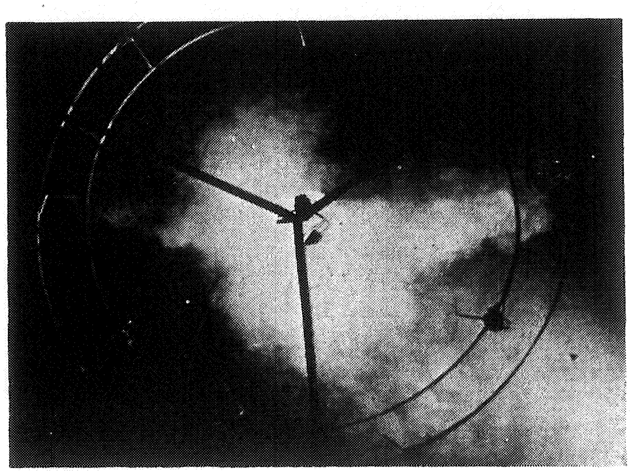
The following four photographs show the diffusion of air entering through the ventilator when the incoming air is at a temperature of 20°C below the air in the room.





Airflow rate—0.017 m³s. Maximum velocity—0.28 m/s. Tests of developed ventilator: Airflow rate—0.017 m³/s. T—20°C.





Airflow rate—0.024 m³/s. Maximum velocity—0.35 m/s. Test on developed ventilator: Airflow rate—0.024 m³/s. T—20°C.

Dr Siviour: Would it be possible to include in the published discussion some photographs showing a typical differences in the temperature of air entering?

Dr Tipping: I think we can show photographs where there was a difference in temperature of 20°C.

Mr Emerson (South Eastern Gas Board): We have been privileged to exchange opinions with Dr Harris-Bass and his colleagues on the question of adventitious ventilation and I may be able to fill you in on some of the data on Property 3 in Appendix 3. The modern house, the 1968 house, was in fact our test house for the laboratories. We did similar work to his work on the other houses in measuring adventitious ventilation areas in the living room, and with similar surprising results. The completely unsealed adventitious opening amounted to 0.2 m². This is a fantastic area. All lumped together in the right shape one could crawl through it. Most of this was made up of the gaps between floorboards, which were butted rather than tongued and grooved. Sealed, this area was reduced to 0.08 m², or 12 in², still quite a fair and quite adequate for any reasonable boiler or central heating appliance which might be installed. It took real effort to reduce this to 0.008 m², about 1½ in², and to do this we had to seal over such things as electric light switches, because air was creeping down the conduit. We checked on the performance of the back boiler and found that even with the ventilation area reduced to some 4½ in² we were still getting adequate clearance of the products up the flue. It underlines the fact that the adventitious ventilation is a figure to be contended with and to be accepted as part of the normal ventilation of a house which in fact cannot be reduced.

I noticed that in Dr Harris-Bass's description of the Portakabin he talked about an urban environment. I do not think this is quite true, since the houses appear to be about 100 yards away, and I imagine would have been rather different from that suffered by a street of semi-detached or terraced houses. In his correlation diagram with the ventilation as a function of the angle of incidence of the wind, he uses the vector VR/U10 as an ordinate. This assumes that the ventilation is proportional to the wind speed at that height. Could he confirm that this is really so?

Dr Harris-Bass: With regard to the urban environment situation, the Portakabin structure is on the Gas Board's playing field at Acton. I think it is fair to regard it as an urban environmental profile, in as much as for seven or eight miles in prevailing wind conditions the wind has to travel over housing and small office blocks, and only for a few hundred yards are there clear country surroundings. One needs to do the sort of test that has been done by BRE at Aylesbury, where they have a test house literally situated in the country.

With regard to the second point, the ordinate was taken as being the ventilation rate divided by the velocity at 10 metres. I think this is justified as long as there is no 'stack effect' in the experiment.

Mr J Peach (IHVE): With regard to controlled ventilation, it has been mentioned that there is necessity for control from the point of view of varying wind pressure, and I agree, but there is another need for control. These days, the rooms in houses tend to be multi-purpose, and as the purpose of a room changes so does the amount of ventilation air necessary for supplying the needs of varying numbers and activities of occupants. I have been a little worried sometimes that from the energy conservation point of view, the necessity for reducing adventitious air change in a room may lose sight of the comfort considerations. As the years go by I think there will therefore be an increasing use of controlled ventilators.

In the paper you have mentioned a sound-attenuated ventilator. It is mentioned also that the tests were made with a lead-lined prototype ventilator. I appreciate the reason why lead would have been used—the high density, etc—but it seems to me that lead is a rather scarce raw material, and I would hope that further work is proceeding in regard to the use of other materials and so on. If we arrive at a situation where large numbers of ventilators are going to be used—and they will be, as more and more houses are built near motorways and airports—we should ensure that scarce materials such as lead are not used if it can be avoided.

Mr Tickner (Watson House): On the question of the sound-attenuate ventilator, we did use lead obviously for testing, but in addition we also used a stainless steel casing. Since these prototypes were made we have gone some way to producing what might eventually be a production model of this ventilator, and in this for most of the metal work we have used a zinc-coated steel, which is considerably cheaper than lead. We still use some lead inserts in the form of baffle plates.

Dr D Fitzgerald (University of Leeds): With regard to the grille ventilator mentioned by Mr Tipping at the start of his talk, is this grille not going to get very dirty in use?

Dr Tipping: This is a problem that has been pointed out from time to time. All I can say is that at the time we were designing the ventilator to get optimum air diffusion, there were dimensional factors which made it difficult, though not impossible, to enable the ventilator to be taken out of the window for cleaning. The inside can be cleaned out, depending on the location, it may not be possible to clean outside. This was a problem of constraint on size that had to be faced with regard to a compromise between design, and installation requirements.

Dr P R Warren (BRE): I have a small question for Dr Tipping on the first paper concerning the performance of the sound attenuating ventilator. I believe he states in the text that this has an effective free area of 35.5 cm^2 and would therefore satisfy Building Regulations for 15 kW or so. Am I not right in thinking that there is a further constraint in Building Regulations that the free area must be above that of the flue? I think the 4 in flue, which is probably the minimum size, will give 81 cm^2. It is only a small point but it may be worth bearing in mind. It comes up later this afternoon.

With regard to Dr Harris-Bass's paper, he mentions modification of his theory to take into account the effect of fluctuating pressures when the wind is 90° to the plane of the openings. Could he amplify that statement a little? Is this theory applicable to other situations where one has not the advantage of wind tunnel results?

Dr Tipping: With regard to the first point about the interpretation of Building Regulations, this has been brought to my attention on more than one occasion and I had a long discussion on this topic prior to the meeting to try to clarify the situation in my own mind. As Dr Warren is well aware, the particular clause in the Building Regulations is a clause which, although giving guidance, is not mandatory. Also attached to that clause is the requirement of the equivalent of 1 in^2 for every 1,000 Btu/h input. As you well know, the more logical approach is to associate a given free area with the heat input rate to an appliance.

Dr Warren: I was just wishing to point this out.

Dr Harris-Bass: We were faced with what amounted to a no-ventilation rate situation when the structure was at 90°, due to our simple theory. This was not the case when we got the result from full-scale and model tests, and we thought the best thing would be to form a semi-empirical relationship by using the results from the model and the full-scale tests and to employ these in a modified theory.

Dr Warren: Could you give some indication of how you did this? Have you any theoretical prediction which may be based on some measure of the fluctuations in pressure?

Dr Harris-Bass: No.

Dr Warren: To what extent can this empirical theory be used for ventilation where you have not measured the rate?

Dr Harris-Bass: One cannot do it.

Mr Churton (DOE): If I may quote the requirement mentioned by Dr Warren, it is an area equivalent to, first, the cross-sectional area of flue connection, that is, the entry into the main flue, and, second, 550 mm^2 for each kW or part thereof of the maximum output per hour of the appliance, whichever is the greater. I have two questions, both concerning the draught-diffusing ventilator. I would like to know whether, within the hemisphere around the tested appliance, there is any isothermal and non-isothermal conditions complete mixing or, if not, at what distance from the ventilator complete mixing could be expected.

Secondly, following the question about dirtying, would it be possible to re-design the ventilator so that it was not circular but oval, which would allow the householder to take out the three component sections from the inside of the house and clean them?

Dr Tipping: With regard to the first point, very simple tests were done. No measurements were made on the rate of mixing other than measuring velocities around the hemisphere, and the position of maximum velocity was obtained on the hemisphere by using a hand held anemometer.

With regard to the second point, I think it is quite possible to redesign the ventilator in an oval form. However, one of the constraints we placed on the design was that the ventilator should fit in the normal transom window, and this dictated to some extent the dimensions of the unit. If we went to an oval shape it might be a little more flexible, in application. I wonder how easy it is to cut this type of hole in a window? Perhaps somebody could tell me?

Mr Hayes (Domestic Heating Society): This would be an appropriate platform for making rhetorical appeals but it is so rarely that one finds such a vast assembly of academics that I cannot resist the urge to ask something. As Dr Gray has said, British Gas has probably the most advanced and effective research organisation in the world. We do not doubt this. What we doubt and what we can mathematically claim is that communication to the lower levels of chaps who install ventilators and gas appliances is by no means as effective as it should be. People still die in bathrooms. People still die, or at least become adversely effected, from warm air heaters pushing flue products around the house. Mothers are still reluctant to put their children to bed because the bed linen is so damp because of condensation in cold bedrooms, so they put them to sleep in front of the fire in the lounge. These are the sorts of facts I encounter in my daily activities with the Society. We hear about all these things. We hear about ceiling paper festooning down because the rooms are full of water vapour causing condensation. Can you please get in touch with your counterparts in the world of communication, with all your excellent and no doubt progressive enterprise in improving the way we live, so that the men who fix ventilators and gas appliances and the other things we are talking about here may do it in a way that will comply with your findings and your recommendations?

The Chairman: I think one has to agree with every word of it. Watson House do not build houses. They can only influence the design and type of construction, etc. The whole question of communications, as we have seen, is under continual review, certainly by the Marketing Division of British Gas and especially the Service side of it. This has all been very much improved, and I was quite surprised only yesterday by a domestic incident in the South East Gas area. We had a fault on an appliance and I suggested that my wife ring the local Gas Board and ask them to come. A chap actually came at 5 pm the same day. She said she wanted it put right but she did not want him to have to come back because of needing spare parts and tools, and asked if he wanted to use the telephone. He had got all the tools and spare parts and did not need to telephone. He has his van outside. This is a symptom of the improving standard of service that the industry is aiming at, but I take your point particularly about communication, and that is one of the things we are aiming at in this symposium today. Would one of the Watson House people like to comment further on it?

Dr Tipping: On the matter of communications, I think every one of us involved in a research and development organisation is conscious of the responsibility for ensuring effective communications. There are internal contacts and committees which ensure that the results of our research work are communicated to the various operating divisions of British Gas. Also the existence of the Confederation of Registered Gas Installers, should help to improve external communications compared with the situation that existed three or four years ago. We are all very conscious of the need to communicate our results, otherwise the work becomes ineffective.

Mr J Peach (IHVE): We have in the last year published some practice notes relating to combustion and ventilation air. This particular booklet concerns installations of less than 45 kW and includes recommendations to installers and appliance manufacturers in regard to labelling, etc. I just mention that point in regard to what the previous speaker was saying about communication.

Mr R D Bruce (Watson House): I should like to say a word in reply to Mr. Hayes. John Tipping has already mentioned this matter of communications. Enormous efforts have been made in recent years through CORGI. For their members there are regional symposia, literature suitable for their needs is especially produced and each month the technical press carries a feature headed CORGI Installer with specific advice on safe and sound gas installations. I hope it will be accepted, then, that although a number of things are still far from right, considerable effort is constantly being made to get this information to the people who actually need it. Though today you will be hearing mainly from those who, through their practical training and experience are able to pass on this information in a form suitable for practical application in the field.

Mr Binns (DoE): One of the basic premises of everything we have heard so far this morning is that combustion air supply is going to be drawn from within the room where the appliance is situated. There are room-sealed appliances, as you know. Does not a room-sealed appliance answer a lot of the problems? How much development is going on in regard to other such appliances? We are concerned with building new houses, and I feel that there should be a lot more research work done into avoiding combustion air supply problems.

Dr Tipping: I agree that an obvious solution with regard to the problems of drawing combustion air through a room is to have the appliance room-sealed. There are a large number of such appliances. However, one of the main problems we face with the flueing of gas appliances is that restrictions on siting are sometimes dictated by the associated flue system. This is an area which for many years to come we shall be searching for alternative and better ways of flueing appliances, as we have in the past. During the past two or three years we have put quite an effort into ways and means of extending flues using fan assistance. If this is possible the current method of fitting balanced-flue appliances on the outside wall can perhaps be modified so that the appliances can be sited away from the outside wall. There are a number of ways of getting air to appliances and they all play their part. We do not want to say unilaterally that all appliances should be room-sealed as there will be need for open flued appliances and I think that for a long time to come we are faced with taking air through the room.

Mr E A K Patrick (Watson House): May I spring to the defence of the chaps who evolved the draught-free ventilator? It must be put in its context. It was intended to replace existing ventilators installed in a certain size of hole through pieces of glass. It was wanted fairly quickly because the Gas Industry was putting in a lot of these ventilators at the time. We wanted a ventilator which was better than we already had and which would fit into the existing holes. The ventilator was developed in the context that it must not be too expensive. It is indeed liable to get dirty but so were the others. I have always felt that in new construction the ventilator should be built into the walls. The corresponding 'through the wall' ventilator has not yet been fully developed. It could be made to any size that is required, but we think this is a development for the longer term.

With regard to the cost of the acoustic ventilator, I understand that to use lead is no more expensive than using stainless steel, although it is of course dearer than zinc coated steel.

I am sure that Mr Hayes knows quite well that communication is a difficult problem for all of us, and that the industry he speaks of is not an easy one with which to communicate. It is a very diffuse industry. Communication is quite a headache and we put a lot of effort into trying to communicate.

Mr Hayes also knows I am sure, that the Gas Industry is only very indirectly responsible for worrying about condensation. Condensation is caused by not building a house correctly and not designing it correctly. That is the cause, and it is not primarily our concern. We are concentrating on providing the air for combustion and it is not for us to take primary responsibility for building.

An important point from the point of view of a fuel industry is that at any one moment it is the existing buildings that provide the majority of the market, and therefore of the problems which we as an industry have to concern ourselves. This leads me back to the need that we often have to develop things that can be used in existing premises at low cost and with convenience. This always has to be in the forefront of our thinking, though we do not forget new housing because this creates the buildings population of the future.

Dr D Fitzgerald (University of Leeds): I think Mr Patrick said that the purpose of the meeting was to discuss the provision of air to combustion appliances. But the preprints are entitled 'Ventilation of Housing: Research by British Gas'. It does not mention the provision of air for gas appliances. This field includes a great deal more than the mere provision of air for combustion appliances.

Dr Tipping: We as a Gas Industry have a prime interest in the supply of combustion air for appliances. However, in studying ventilation, which is necessary for this particular area of concern we gain a lot of insight and information concerning general levels of ventilation that is of wider interest.

***A speaker** (North Thames Gas Board): I should like to make one comment about Mr Patrick's statement. He said that the Gas Industry was not responsible in some way for the operation of gas equipment. He did not quite phrase it in that way but I think that is what he intended to say. If that it the case, it should in my opinion completely eliminate such things as apparatus which is flue-less. I had a wall heater put in some years ago and it has been responsible for all sorts of condensation and has eventually been replaced. We should not be to complacent about these matters.

The Chairman: No research organisation can be complacent.

* *Name not clear.*

Mr Patrick: I certainly did not say that the Gas Industry was in anyway trying to absolve itself from the responsibility for the operation of gas equipment. I would not like anyone to feel that I would say a thing like that. My point was that condensation troubles arise from the fact that some parts of the building are colder than they should be or do not get enough air change. This is a matter of building construction. In the great majority of cases condensation is due to things which have not been taken account of when the house was built.

With regard to the flueless heater, if there is very restricted ventilation its use can lead to condensation. It is a matter for debate whether that such very restricted ventilation should be permitted. We have stopped the sale of portable heaters entirely. We have a responsible attitude here, yes. Flueless heating can give rise to condensation, I agree.

† **A speaker:** Why not a twin-console on the internal flue liner, to draw out combustion air down the external flue?

† *Name inaudible*

Dr Tipping: We are aware of this method of supplying combustion air. I personally have had very little experience of the operation of this type of system. I am well aware of flues like the U-duct system used on all blocks of flats where there is a special duct taking the air up the appliance without going through the room.

Mr D G Oliver (Bromley): I come from the Housing Department of a London borough and I am responsible for the maintenance of the housing, so that I get all the problems when other people have finished their design. I have to try to keep things going.

I get a lot of problems with condensation. When I look at the dwellings I am really shocked sometimes. I see some of the problems arising in construction now. There are properties being built in my borough which will have condensation problems as soon as they are occupied. The person designing the dwelling does not design the heating unit. The person who designs the heating unit has his own ideas and the two do not meet.

With council housing the Department of the Environment cannot be entirely eliminated from blame because they are concerned with the original capital cost. I have some maisonettes with a warm air ducting system under which, due to cost cutting, air has to find its own way up to the bedrooms from the heating unit. If a fan is put in the kitchen to remove moisture it will stop a lot of the warm air climbing up to the bedrooms. Putting in a fan also means relying on tenant cooperation. There are great problems here because they do not really understand what is going on. I had a fan ventilator fitted in a kitchen recently to try to stop condensation problems and carefully explained that it would only consume 20 watts, and that the tenant should run it during washing and cooking hours only.

Two months later I received a letter from the secretary of the Tenants' Association saying that it was costing the tenant a great deal of money to run it. It was just ridiculous. At least 30 per cent of the people on the estate in question have had their gas cut off because they think it is uneconomical.

Many years ago I carried out a minor survey and found that every ventilator on the estate on Midsummer's Day was sealed off by the tenant! When people design these things they should remember that to a large extent they have to be passive measures. If you rely on tenant co-operation by using positive measures you will have only limited success.

You spoke of putting a ventilator into a window. I wonder if you have really done a full financial appraisal on this. I had a complaint recently that in a certain dwelling there was insufficient ventilation. Nothing was done about it and it eventually got into the hands of a Member of Parliament. Finally he said, 'I will pay for it myself'. We obtained an estimate to put this ventilation into two rooms. In the end he paid out of his own pocket about £30 to have one room done. At the same time I am getting wall ventilators fitted through cavity walls at about £10 each.

Dr Tipping: Where were these window ventilators being installed?

Mr Oliver: They were in fact in large picture windows.

Dr Tipping: We had in mind the thinner type of glass.

Mr Oliver: We couldn't get a contractor to do this without reglazing.

It depends on the size of the window and who is doing the job.

We have dwellings including high-rise blocks of flats with large picture windows and no other form of ventilation. I am in a borough which is not one of the original metropolitan boroughs, an outer one, and under the Building Regulations there is no necessity to have a permanent vent. The only way of providing ventilation is by opening a large window by a small amount, but the tenants complain of draughts and say that it is totally unsatisfactory.

Dr Tipping: I agree that we ought to talk more in terms of the combined performance of a heating and ventilating system. We are aware that this is an area requiring further development and investigation.

On the final point, with regard to draughts, this was one of the motives behind designing the type of ventilator I described. It was an attempt to get to a situation where sufficient air would come through the ventilator without people feeling the need to put polythene sheets over it.

Mr Chambers (Scottish Gas): Have the committee given any thought to having a permanent ventilator behind radiators? that would help the draught situation, and also the sound-attenuating aspect. I remember a paper by Mr Oliver in which he commented on permanent ventilation incorporated in the building, to coincide with the latest design position.

Dr Tipping: If you are putting a ventilator in a property built from scratch, and know at the outset that you are having a radiator installed, a possible place to put the ventilator is behind the radiator In fact, you will probably see a slide this afternoon showing the type of system commonly used in Sweden and also in France, where there is a mechanical ventilation system and the exhaust registers are located behind the radiators. This is the obvious place to put them.

Mr Newhouse (North Thames Gas Board): Although not on the sales side, I did give a lecture last week on comparative costs, bringing them right up to date. We have a projected cost increase coming up for March, and in regard to the price of fuel oil, etc., there is no doubt whatsoever that gas is by far the cheapest gorm of heating. I was also discussing the use of flueless heaters during this lecture.

Points have been raised concerning window ventilators, of which we have installed very many in North Thames. Some years ago we had problems with an Essex borough trying to improve ventilation. There was a complaint of draughts from window ventilators. We made arrangements with a firm to produce a plastic cone-shaped device which clipped on to the inside of the window ventilator and deflected the air stream parallel to the window surface, and this reduced the complaints of draughts.

Dr Tipping: All I can say is that the philosophy of approach to the kind of unit we designed was somewhat different. The idea was to leave the forward flow substantially unaffected but make sure it diffused rapidly so that one could stand 7 or 8 in from it without experiencing an undue draught.

Mr W S Trenhaile (GLC): We have been talking about this ventilator and the lack of draught. When I made my first comment I did say that the draught aspect was not such a major one as the amount of cold air that came into the room through these ventilators when the wind outside was high. That is why I feel that some control or even variable size ventilators are an essential factor.

For heaven's sake, do not put the ventilator behind a radiator. These beautifully fluted radiators with ventilators fitted behind are as old as the hills. These days radiators mostly operate with thermostatic valves, so that when the appropriate temperature is reached the radiator is shut off, and in many cases when it is frozen outside you will get a frozen radiator. If there are individual systems many people tend to turn their system off during the day and put it on a time clock from 4 to 10 and on again for two or three hours in the morning. If there is a permanent ventilator behind there you are really asking for trouble.

Dr Tipping: I was referring to the mechanical system where the air has been recirculated. It would not be freezing cold and it was introduced behind the radiator.

Mr Strudwick (Basingstoke Borough Council): You said that your window ventilator was designed to replace the original simple one which gave rise to complaints of draughts and I am wondering if you mean that literally. Basingstoke was converted (in the gas sense!) in 1968 and I would not like to count how many thousands of these simple ventilators were installed. I would like even less to calculate how many have been blocked up by tenants. If I go to my area Gas Board could I get them replaced with new vents.

Dr Tipping: I sincerely hope so. All regions are aware of its existence and it has been made available in each region.

Mr Strudwick: I did actually mean 'at the Board's expense' as the ventilators were installed by the Board as part of the conversion programme.

Dr Tipping: I would not have thought so.

The Chairman: I am sure that Watson House will take note of these comments about the draught-inducing ventilator and the quantity of cold air that comes into the room in cold weather, but it is not a simple problem. Any device that is to be installed has to be foolproof and reliable and not under regular servicing. Ideally it should be fail safe. If it does not it leads to all these counterproductive requirements. Above all it must be cheap, so it is a very difficult problem.

* **Speaker** from a Development Corporation: We have properties seven months old which are running with condensation. We are having to spend £25 000 on adjustable air vents. We cannot take it out of the capital cost. I support my friend on the right. I think that at the beginning when gas installations are going in an approach should be made to the architect to look over these schemes, because they are affected by the gas central heating. There are windows which do nothing at all. The tenants will not open them either because the children can throw things out of them or they cause draughts.

* *Name and place inaudible.*

† **A speaker:** I have experience of one or two problems of condensation. Gas warm air has been blamed for mould growth in the corner of the room. When an examination was made the flues were found to be inadequate. In another instance again the gas had nothing to do with it, although there was heavy condensation. It was a ventilation problem. It would seem that you should look elsewhere than at the gas appliance in these properties.

† *Name not given.*

Professor J K Page (University of Sheffield): I am becoming increasingly worried that the role of ventilation in condensation control has been given an exaggerated position, and the importance of adequate thermal insulation has not been discussed. At a meeting I chaired at the Lancaster Hotel for the Department of the Environment a few years ago the BRE presented an interesting paper showing the relationship between thermal insulation, heating costs and condensation. It was brought out very clearly that first of all there was an optimal ventilation rate, and that if this was exceeded there was more trouble, rather than less, with condensation. Secondly, if the right thermal insulation decisions were made, not only was a great deal of energy saved but also the risk of condensation was substantially reduced. Therefore in looking at this problem we must consider the total system and examine condensation in a much more rational way, instead of going for make-believe solutions. We have to apply science to the design of buildings, and I am very concerned that this conference, which was supposed to deal with the ventilation of housing, is so limited. I have not heard anything yet that Jimmy Dick could not have told us in the early 'fifties. I am very concerned at the limited concept of the ventilation of houses that has been presented so far.

The Chairman: What we are discussing this morning are the first two papers. Many of the broader questions may well be brought out in the discussion of the two papers this afternoon, especially the last one. Are there any other contributions specifically on these papers, rather than the broader issues?

Mr A Cole (South Eastern Gas, Housing Development Section): With regard to the conclusions concerning adventitious air through the building, it does not state very much finally. Are you saying that we might be reverting to using this adventitious air only within the near future, owing to the fact that we have more or less said in the paper that the requirements to shut out adventitious air have to be so finely allowed for that the normal domestic householder would not have the facilities for doing the things detailed in the paper?

Is there any chance that certain size boilers will require non-ventilation of the actual compartment or house in itself?

Dr Tipping: This is one interpretation. We have shown that there will be some adventitious area left after measures have been taken to seal the room.

Mr Cole: We do not really say as a conclusion whether it is to be used in the future.

Dr Tipping: We will definitely use it. Just how is a matter for consideration.

Mr R Gross (London Borough of Harrow): Mention has been made of gas-burning appliances in kitchens; also of the extract fans which are available in kitchens to get rid of moisture-laiden air when cooking, washing, etc, has been carried out. I have recently seen a new vent and I wonder whether Watson House have seen it. It is a centrifugal fan working on a thermal basis which not only extracts air but brings in fresh air at the same time. The manufacturers claim that this will save 40 per cent of the heat which would normally be lost when using an ordinary extract fan. Would the members of the panel say whether or not this has been looked at and, if so, what conclusions have been reached?

Dr Tipping: We have not done laboratory tests ourselves. We are aware of the ventilator and have had discussions with the manufacturers of this type of unit. It is an alternative way of providing ventilation levels required in the kitchen which is more economical in regard to the use of fuel. It would seem to be a valid alternative and perhaps a better one than the use of the extract fan.

Dr J B Siviour (Electricity Council Research Centre): Does the mechanism just by-pass air from inside to inside or outside to outside, or does it take air from the inside and eject it outside, and take air from the outside and bring it inside? That is really the kind of evaluation which is required.

* **A speaker:** Have you attempted to evaluate or consider any other means of heat recovery instead of having heat exchange?

* *Name not given*

Dr Tipping: Not in detail at this point in time. There is one approach which we intend to evaluate and that is the use of heat pipes, which are heat transfer elements for transferring large quantities of heat from an evaporator to a condensor. This may well be an answer to some sort of heat recovery. Heat pipes are at present under development and being used in the United States.

* **Speaker:** It is fairly complex. I was thinking of concentric tubes. If there were tubes of this tube which were concentric one could achieve a certain amount of heat exchange.

Dr Tipping: The device I mentioned is a passive device, fairly simple in construction, and also robust. The required heat transfer could be obtained in a fairly small volume, although large surface area would be needed.

The Chairman: In closing the morning session I should like to thank the authors and the contributors. I am sorry that our papers this morning have not met Professor Page's desire but we would like to have an input to any work that goes on whereby communications may be improved. We must try to improve the general links between installers, architects and builders, and attempt particularly in the R and D field to look at total systems rather than at little bits separately.

The vote of thanks was carried by acclamation.