ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER 9

EXPERIMENTS WITH A PASSIVE VENTILATION SYSTEM

JOHNSON K.A.[1] AND PITTS G.[2]

[1] Pilkington Brothers P.L.C.,
Research and Development Laboratories,
Lathom, Ormskirk, Lancashire, England, L40 5UF.

[2] Timber Research and Development Association,
Stocking Lane, Hughenden Valley, High Wycombe,
Buckinghamshire, England, HP14 4ND.

SYNOPSIS

The trend towards more tightly sealed houses is now well established and controlled ventilation is becoming a necessity; a simple method of ventilation is proposed comprising an extract system and air inlets. The extract system is effectively a flue connecting to vents in the kitchen and bathroom and it relies on thermal differences and the wind to create air flow; air enters the house via slot vents over windows. No maintenance is required other than cleaning the vents, there are no running costs and initial installation costs are low.

The proposed system has been installed in a timber framed house. Air has been extracted through the system up to the equivalent of 0.3 ac/h for the house volume, but this is less than expected.

The house needs to be tightly constructed, the extract tubes need to have very low air resistance and care is needed in siting the inlets for efficient operation. The effect of wind has not been measured, but a device may be necessary to prevent over extraction. Modifications to the system are proposed for future work.

1. INTRODUCTION

As insulation standards increase in houses, the transmission heat losses decrease and therefore the energy loss associated with the ventilation air becomes a greater proportion of the fuel bill. In order to attain further energy savings therefore, attention turns to reducing ventilation rates and a balance has to be found between a rate which represents high costs and one which keeps the air quality sufficiently high for comfortable, healthy living.

Many papers have been written on this subject and a suitable rate appears to be between 0.5 and 1 ac/h (air changes per hour). Having determined the necessary rate, the next problem is how to achieve it and again many papers have been written discussing various solutions using mechanical or natural ventilation.

Mechanical ventilation is attractive because the chosen ventilation rate can be easily controlled provided the house has a low natural air infiltration rate, but the cost of installation may be high, maintenance is needed and there may be a problem of noise from the fans. There may be other objections also such as that from one Local Authority who will not fit mechanical systems in its public sector houses because when breakdowns put houses at risk from condensation, the first complaint it would receive in many cases would be only when damage had already occured. The repair costs would then be increased because of the need for remedial work such as dealing with mould growth or redecorating. Whatever the reasons, although the use of such systems is increasing, they are not yet commonly installed.

Natural ventilation is seen as the alternative but it suffers from variability of rate depending on the weather; this means that if no intervention is expected from the householder, there may be times of excessive or insufficient ventilation. For example, if the design is for the 'correct' rate under 'average' conditions, then high wind will cause excessive ventilation and possibly even draughts.

It is a problem which must be faced and a solution found if energy consumption is to be reduced to a minimum without harmful side effects. There are many such effects but probably the most easily recognisable is that of surface condensation which ranges from that occuring on single glazed windows to extensive mould growth, peeling wallpaper and degraded plasterwork. Clearly if ventilation rates are reduced too much in a situation where moisture production is maintained, the risk of condensation is increased.

The current trend in British housing is towards timber framed construction which uses insulation extensively in walls and roofs: any problems of increased condensation risk in these houses is therefore the concern of TRADA (Timber Research and Development Association) and of Pilkington Brothers (Fibreglass) for although there should be no condensation problems associated with the use of timber or Fibreglass as such, any problems arising for other reasons might become associated with the use of these materials.

A passive system of ventilation was proposed as an inexpensive solution to control the ventilation rate in a tightly constructed house and TRADA and Pilkington Brothers have jointly carried out a preliminary investigation to determine if it is feasible; the results and conclusions of this initial work are presented here.

2. THE PASSIVE VENTILATION SYSTEM

2.1 Principles

One of the causes of high humidity and consequent condensation problems is claimed to be the demise of the open fire[1] and the absence of its associated chimney. The Local Authority referred to previously insists on having a flue built into each of its public sector houses and claims that it receives few complaints of condensation problems because of the effects of this policy.

The chimney forms the basis of the solution proposed here: if their removal has resulted in insufficient ventilation rates and the objection to their retention is excessive ventilation and draughts, then surely one built solely for the purpose of ventilation and which could therefore be fitted with a device to limit extraction, could provide a basis for house ventilation. The system would be cheap to install, free to run, and would be virtually maintenance free.

A flue will extract air from a building by virtue of the pressure differences created by a) wind and by b) the stack effect (the result of the difference in temperature between inside and outside). In a house, the stack effect can be relied upon throughout the winter and the effect will be greatest when the outside temperatures are lowest, that is, when most needed because then particularly, windows are kept shut. Consider a 200 m^3 house constructed tightly so that its natural air infiltration rate is low, say 0.25 ac/h under normal conditions. If the house is at 20°C with an external temperature of 0°C with no wind, then a single flue with a diameter of 165 mm, terminating at the roof ridge should produce an air change rate of 0.5 ac/h provided there is an equivalent diameter air inlet to the house; this air change would be in addition to the basic infiltration rate[2] producing 0.75 ac/h in total.

If the heating season is taken as October to April inclusive then using the warmest monthly mean temperature (for Manchester), the extraction rate produced by the flue would drop to 0.35 ac/h, giving 0.6 ac/h total for the house.

The effect of wind will be to increase these figures. Some spot checks have been made on air flows in unused house flues and these indicate that extraction rates equivalent to up to 0.6 ac/h might be expected with winds up to 6 on the Beaufort Scale, which is probably not as high a rate as is generally expected. However, this rate would not be fully additive to the stack effect rate[3] and so with this wind and 'full' stack effect the total rate would be less than 1.35 ac/h.

The proposed scheme of fitting a flue into a house should thus result in a total ventilation rate of between 0.6 and 0.75 ac/h during the heating season in the absence of wind; it should drop below 0.6 only when the outside temperature exceeds about 10°C. This will be for short periods in winter and will be followed by increased air change rates when the temperature drops again, and for longer periods in autumn and spring, but will again be compensated for, on average. During autumn and spring opened windows are more likely as the outside temperatures rise and the extraction rate drops. Wind will increase the ventilation, but it should be possible to design against an excessive rate if this is found necessary; presumably the basic infiltration rate for the house will also increase under the influence of wind and so from this point of view alone it is desirable to have that rate as low as possible.

The flue should extract direct from the kitchen and the bathroom where most moisture is created. If the kitchen has twice the volume of the bathroom and the flue divides in the proportion of 2:1, then for the 200 m^3 house, ventilation rates of about 3 ac/h can be expected for these rooms when the overall house rate is 0.5 ac/h.

A successful passive ventilation appears possible, particularly as with suitably positioned inlets, air movements will be encouraged into the kitchen and bathroom from the rest of the house, preventing the spread of moisture as well as removing it.

2.2 Practical Details

A system has been built into an experimental house owned by TRADA and situated at their premises near High Wycombe. It is of timber framed construction with the lower half externally clad with brick and the top with timber boarding; it faces east and there is extensive shading from the sun and wind by a building to the south and by rising ground with high trees to the west. The volume is about 200 m^3 and there are no internal doors fitted. The floor plan is given in Fig.1.

The flue or extract duct is made from components from the Marley Discharge Pipe System with 82.4 mm pipe to the bathroom and 110 mm pipe to the kitchen, which combine in the loft into a single 160 mm pipe. This is terminated at the ridge with a propriet ary ridge ventilator and at the lower ends with 90^o elbows to simulate fixing into casing, cupboards or the structure, Fig.2.

The lower ends were fitted with Marley self-regulating grilles rates at 40 and 30 m^3/h for kitchen and bathroom which are the nearest to the required 66 and 33 m^3/h for the 2:1 split of 0.5 ac/h for the whole house. The pipe in the loft is heavily insulated with Fibreglass to maintain the temperature of the air in the pipe, otherwise there would be a condensation risk and a loss of stack effect.

To allow the fresh air make-up into the building, Titon Trimvents were fitted to the main room windows, and these gave a total inlet area of 0.02 m^2; it was thought that with these the householder would need to close them to avoid draughts in windy weather. Later, vents of total area 0.05 m^2 were fitted to the external doors to increase the air inlet area for the experiments although it was realised that in practice these would create unacceptable draughts. A pipe through the lounge with an outlet was considered. The basic ideas are shown in Fig.3.

3. MEASUREMENTS

Air flow directions were determined using smoke tubes, and speeds using a thermistor bead air velocity meter. It was found that air flows varied significantly with time and so there was no point in attempting to measure the speeds in accordance with B.S. 1042; what apparently was needed was some form of full flow device, but it was thought than an anemometer fitted into the full diameter of the ducts might cut flow rates.

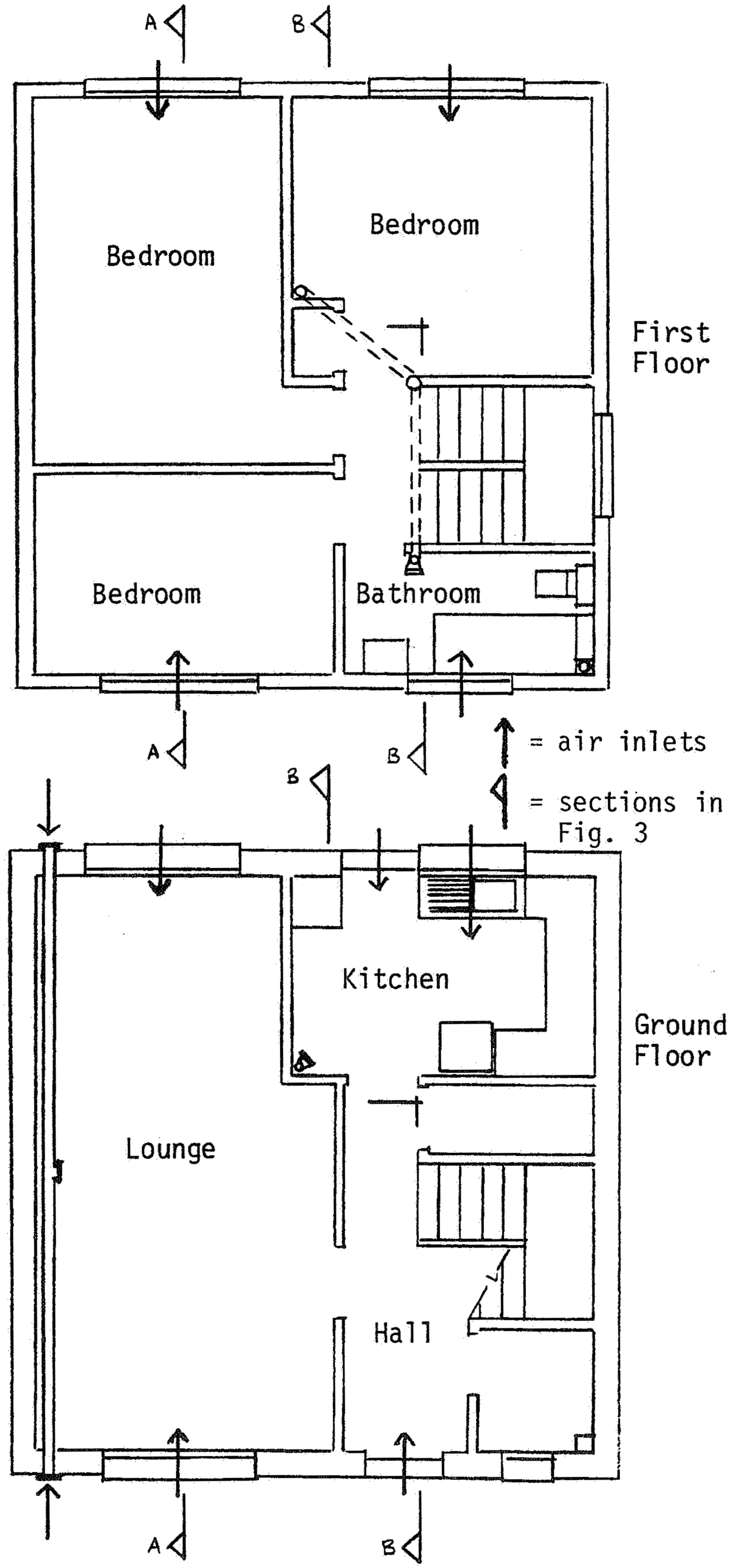


FIG.1 FLOOR PLAN OF TRADA HOUSE

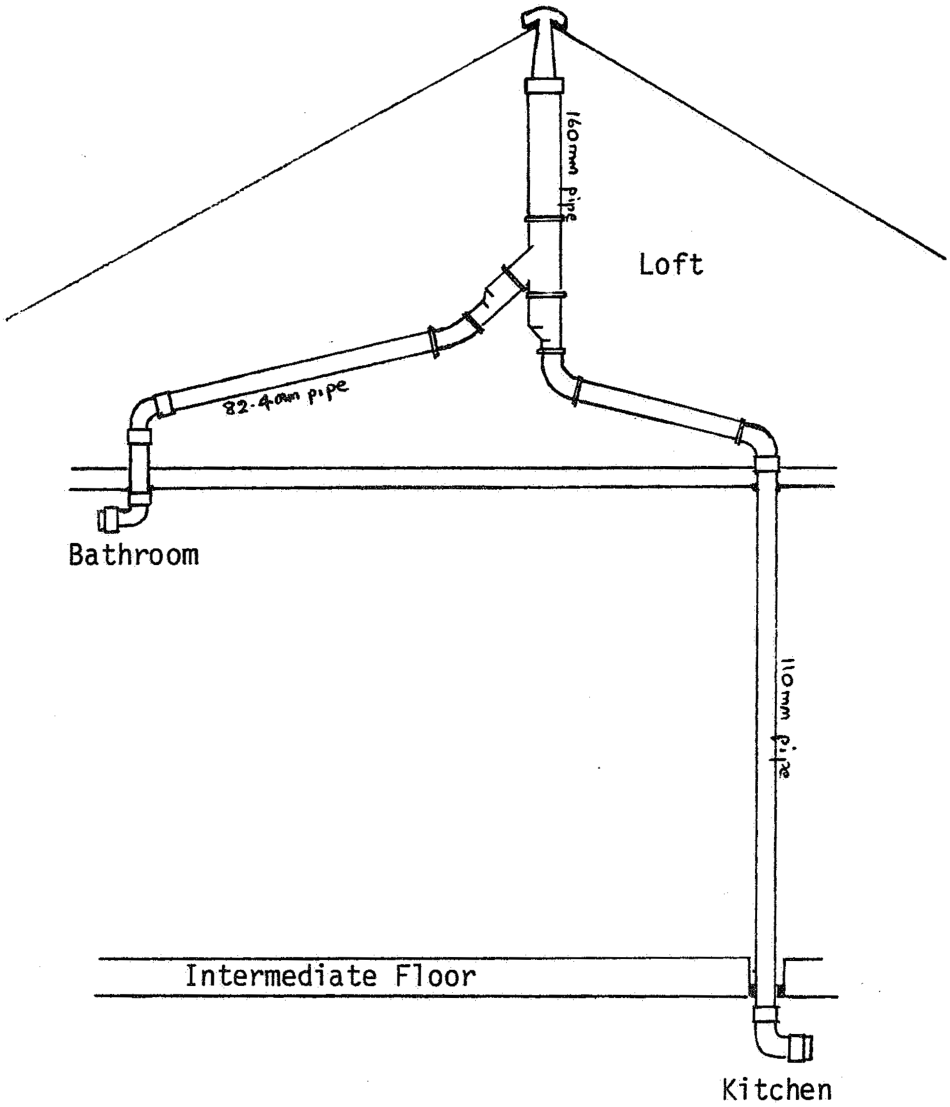
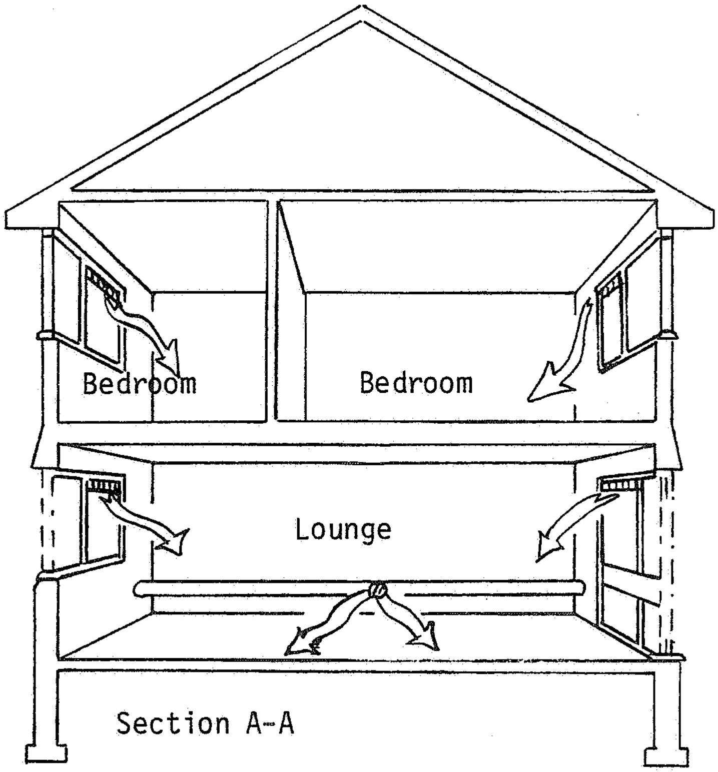


FIG.2 LAYOUT OF DUCTWORK



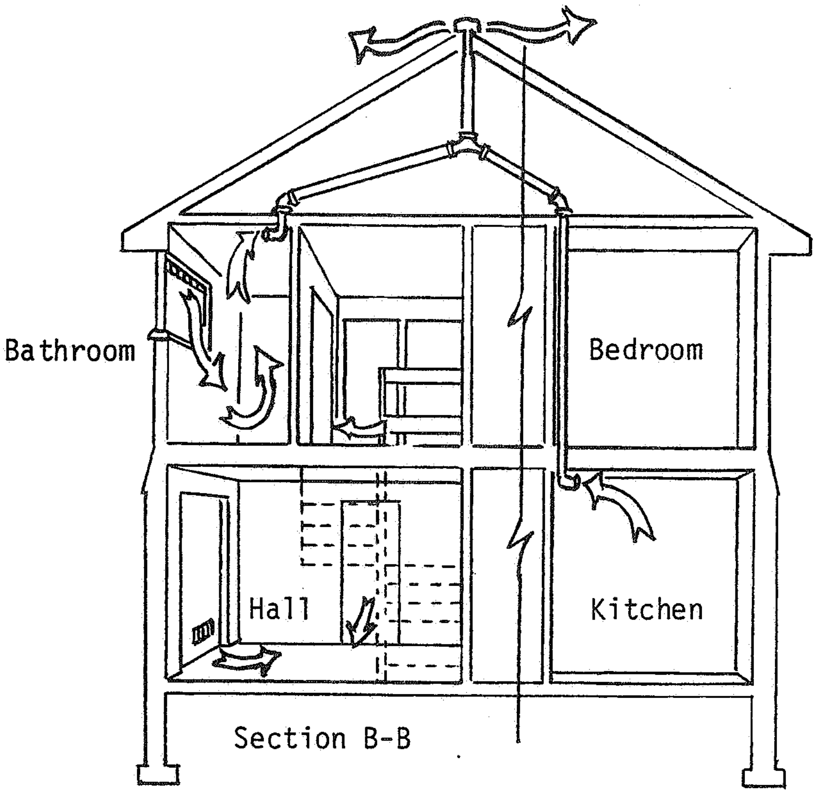


FIG.3 SHOWING POSSIBLE AIR FLOWS IN TWO SECTIONS (SEE FIG.1) THROUGH HOUSE

A figure for the flows was determined by taking a number of spot readings across the diameter of each duct, but these can only be very approximate.

Overall house air infiltration rates were determined using the CO_2 decay method.

4. RESULTS

The site was very sheltered from the prevailing winds; during the tests, nothing greater than a light breeze was encountered in the vicinity of the house and it is therefore thought that the extract rates achieved were mainly due to temperature effects.

Initially it was found that the house had a high air infiltration rate of between 0.8 and 0.9 ac/h, measured when the inside to outside temperature differences were between 9 and 16°C; the addition of the extract ducting and the opened window vents had no significant effect on the rate although it was shown that with the window vents open, there was a definite flow of air through the house. Total air flows in the ducts varied between 11 and 20 m^3/h and seemed to be independent of the status of the window vents. These flows represent up to only 0.1 ac/h for the house and the flow was split equally between the kitchen and the bathroom resulting in 0.4 and 0.8 ac/h for these rooms respectively.

With the self-regulating grilles removed, flows increased to between 27 and 55 m^3/h representing up to 0.3 ac/h for the house (average 0.2)and the split was nearer to that calculated giving up to 2 ac/h for kitchen and bathroom (averages of 1.3 and 1.5 respectively).

The building was then sealed by taping component joints and it was found that the basic air infiltration rate had dropped to 0.4 ac/h with inside to outside temperature differences of between 13 and 15°C, that is, with the window vents closed and the extract ducts sealed. The measured total air exchange rate increased to 0.7 ac/h with a temperature difference of 20°C when the window vents were opened, but dropped to 0.6 with a temperature difference of 13°C when the extract ducts were also operative.

With the building sealed and the self-regulating grilles removed flows measured in the ducts ranged from 25 to 46 m^3/h with the temperature differences between 4 and 15°C when the window vents were open; when they were closed flows were much less, but insufficient readings were taken to be sure of significance in view of the range of results. There was no correlation apparent between flows and the temperature differences.

With the house still in the sealed condition and no self-regulating grilles fitted, the window vents were shut and effectively replaced by the vents fitted to the front and back doors. With inside to outside temperature differences of 5 to 10°C, total flows in the ducts were between 31 to 40 m^3/h; however, it was found that the unconnected soil pipe installed in the house had inadvertently been left unsealed during this part of the tests. About 9 m^3/h of air was found to be flowing out of the house through this soil pipe and therefore it is likely that the figures of 31 to 40 for the ducts are lower than they would have been. No difference in air flows was noticeable whether just one door vent or both were open and again no correlation could be found between flows and the temperature differences.

The directions of the air flows in the ducts and at the window and door vents were determined in the tests. At all times, the flow in the extract ducts was out of the building, and the open window vents on the ground floor always had air entering the building through them. Upstairs, the flows through the window vents were complex, with some vents with air flowing in, some flowing out; there was no correlation with wind direction (but wind strength was between light and not measurable). There was a significant decrease in the proportion of the upstairs vents which were found to have air leaving the building after the house was sealed. The external door vents always had air entering the building.

5. DISCUSSION

The results have suffered because of the inaccuracy of the air flow measurements, but nevertheless trends are apparent, some conclusions can be drawn and suggestions for improvement made The tests using the CO_2 decay may be useful for determining the general level of tightness of a house, but the use of the difference between two tests to determine the flow into a ventilation system which is a minor proportion of the total flow is not suitable in view of the variation from test to test and the extended time of such tests; an accurate direct measurement of flow is required.

The initial test results with the house 'unsealed' suggest that in such a house the addition of ventilation openings will not significantly affect the overall ventilation rates at least under the conditions of little wind. If one accepts the suggestion that the total leakage paths in a house may add up to half the size of a door [4] then this is not surprising as the window vents are only 2% of this area.

Flows were insufficient for the self-regulating grilles to be called on to control the rate, but in any case they caused a considerable reduction in flow in the ducts under the conditions used, presumably because of the restriction of cross-sectional area, which is similar in both grilles used.

The restriction explanation is strengthened because the flows in the differently sized ducts became equal with the addition of the grilles. There is no criticism of the grilles however, as they are primarily designed for use in a forced extract system and not with the (presumed) very low pressure drops associated with this system.

Without the grilles, extract rates achieved were less than expected. The calculated rate for the ducts used and temperature differences encountered was between 38 and 77 m^3/h compared to 25 to 55 measured. This calculation assumes equal size of inlet and outlet and when the house was unsealed, it was thought than an inlet of at least this size would effectively exist; the window vents themselves provide this.

The sealing of the house made little difference to the flows in the ducts and thus if a house is made very tight and extra ducting installed, or the current system made more efficient, then it is likely that a high proportion of the air change will be via the duct system. The small number of results with the house sealed and the window vents shut are consistent with what might be expected: as the fortuitous openings are reduced it becomes necessary to deliberately let air in for the extract system to work.

The experiments with the door inlets are interesting. Calculations show that flows of 54 to 77 m^3/h were expected with one door inlet open and of 68 to 97 m^3/h with the two inlets open, compared to the 31 to 40 achieved.

It is significant that doubling the inlet area by adding a vent to the opposite side of the house had no effect on the measured flows, even though air was entering both door vents.

This result coupled with the direction of air flows at the window vents and the effect of the vent status on air flows in the ducts leads to the suggestion of a model for a house in the absence of wind, given below.

In a house the general flow of air is in near the ground and out near the top because of the temperature differences between inside and outside. If a duct system is introduced in a house which has a high natural air infiltration rate some of the existing air flow will travel via the ducts because there is less resistance to flow by that route, but the overall air change rate for the house will not be markedly affected because the increased area of flow path available through the outer structure is not significantly altered. If in addition to the ducts, extra inlets are introduced, again little change will be apparent because the increase in area is still insignificant.

If the house has a low natural air infiltration rate, the introduction of a duct system alone will again have little effect on the overall exchange rate because the existing fortuitous inlet areas are already feeding the fortuitous outlet areas, but with the addition of downstairs window vents flow will increase in the ducts because both inlet and outlet areas are increased and the flow path resistance is decreased. However if 'inlet' window vents are fitted upstairs as well, the duct system will be partially by-passed with air passing directly between the vents.

6. FUTURE EXPERIMENTS

The efficiency of the duct system itself needs increasing and this could be brought about by a series of measures. The less the natural infiltration rate of the house, the stronger will be the routing of air flows through the ducts, so further sealing is required. In view of the large effect caused by the self-regulating grilles on the flow rates, it appears that the system is very sensitive to resistance to flow and the following modifications are suggested: removal of the bottom end elbows with the pipes then terminating flush with the ceiling with simple grilles to make them visually acceptable; removal of other bends and junctions in the pipes and removal of the sloping sections, which means two separate ducts for the kitchen and bathroom; possible change of design of the outlet terminal to ones with less restriction to flow. The fitting of separate ducts will allow an increase of total cross-section of ducting.

In an area where the house is subject to winds, it will almost certainly be necessary to fit some device in the ducts to stop over extraction.

The details of how to allow air into the building causes some concern. On the ground floor, the through tube with an outlet may not be necessary as no cross flow of air between the window vents was recorded, but some form of large area inlet is needed which is draught free: window vents may be acceptable if the householder can be relied upon to open them. These should not be in the kitchen but in the lounge and the doors between the lounge and kitchen when fitted should have a deliberate air flow path. Upstairs it appears that no inlet vents should be allowed, otherwise the air flow will be diverted from the duct system; in particular, the kitchen extract efficiency would be reduced. Although the rooms would be ventilated if the doors had vents, there would be no control over the air flows. It is possibly useful to consider fitting small ducts from the bedrooms which feed into the bathroom duct with the doors fitted with vents. These ducts would not be very efficient as they would need bends and sloping pipes if the bathroom duct is straight, but relatively low extract rates for the bedrooms may be acceptable provided the flow is continuous and guaranteed.

In a final system, it will be advisable, if not mandatory, to fit devices to shut sections of the ducts in case of fire.

7. CONCLUSIONS

It has been demonstrated that a simple duct system will at least re-route some of the ventilation air in a house; if the extract points are situated in the kitchen and bathroom and the inlet points are in, say, the lounge, this re-routing will reduce moisture levels in the house.

If the house has a low natural air infiltration rate then the system should provide an extraction rate in the region of 0.5 to 1 ac/h throughout the heating season after suitable modifications.

ACKNOWLEDGEMENTS

This paper is published with the permission of the Directors of Pilkington Brothers P.L.C. and Mr. A. S. Robinson, Director of Group Research and Development, and of the Timber Research and Development Association.

REFERENCES

1. EURISOL-UK INSULATION FACT SHEET NO. 7. Condensation in Local Authority Dwellings. February 1982.

2. DICKSON D.J. Mechanical Ventilation. CIBS Symposium 'Developments in Domestic Engineering Services'. 1st December 1981.

3. B.R.E. DIGEST NO. 34. The Principles of Natural Ventilation of Buildings. September 1951.

4. EYRE D. and JENNINGS D. Air Vapour Barriers. Saskatoon Research Council, Canada. March 1981.