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PAPER 4

A PASSIVE VENTILATION SYSTEM UNDER TRIAL IN U.K. HOMES

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SYNOPSIS

A passive ventilation system has been installed in four new houses: it comprises simple ducts which lead up from the kitchen and bathroom to outside near the house ridge and utilise the wind and the temperature difference between inside and outside (the stack effect) as driving forces.

During occupation the system provided a consistent background ventilation rate: the flows dropped only when it was warm and calm outside (when other ventilation measures might be taken by the occupier); when it was very cold and windy outside the system did not over extract but appeared to self-throttle. Window vents gave the occupiers the option of an increase in ventilation.

The occupiers made many favourable comments about the system. Cooking smells and steam had cleared quickly, there were no musty smells in the bathroom, nor stale tobacco smells in the living room after being closed up over night, and there were no significant annoying side effects: they had been able to 'forget' about the system.

The fitting of the passive system and associated window vents is recommended in new tightly built houses as a means of providing a continuous controlled level of ventilation, and thus reducing condensation risk. For older less tight houses draughtproofing would be necessary in addition to the system, to prevent over-ventilation.

1. INTRODUCTION

Condensation continues to be a major problem in U.K. houses with a total of 3.5 million dwellings affected to some degree[1] even though the mechanism of formation is readily understood. It occurs on surfaces or within structures when they cool to a temperature corresponding to the dewpoint of the adjacent air or, conversely, when the dewpoint of that air increases to the temperature of the structure, due to moisture gain. Clearly, the effect can be avoided completely by the correct balance of thermal and moisture properties of the structure, the heating regime, the moisture generation pattern and the ventilation rate.

In older properties the balance is difficult to achieve economically, due to the high natural ventilation rates and the poor thermal performance of the envelope; this means that the absolute moisture level of the air is low but the structure is cold and therefore any warmed air cools quickly. In new property the thermal performance will be much improved (although certain detailing may cause cold spots), but in a number of cases ventilation rates are now too low, and so condensation problems are again encountered - although the structure is warm, the absolute moisture levels in the air are now high.

In theory the problems can be reduced by insulating and draught stripping the older houses (making heating costs reasonable), and increasing the ventilation rate in new houses; however, in practice it is near impossible to predict the natural ventilation rate following any such remedial measures, so the end result may not be as desired. One solution therefore is to seal the house as completely as possible, and then introduce a ventilation system which will induce a particular air change rate.

In 1981-82 Pilkington Bros. and the Timber Research and Development Association (TRADA) installed an experimental passive ventilation system in a test house built at TRADA's headquarters at High Wycombe; this comprised ducts which utilised the stack effect and the wind to induce air flow through the ducts from the moisture-producing areas to outside at the house ridge. There were clear benefits for condensation control, although extraction of air through the system was less than expected; it was concluded that the basic house would need to be tightly constructed for the system to have a significant effect, and it was known that the test house was largely sheltered from the effects of wind which would certainly have affected the results. The work was fully reported at the 3rd AIC Conference in London.[2]

During 1982-83 the system was redesigned to be more efficient and detailed experiments carried out on the effect of internal/external temperature differences and of various air inlet configurations. Only a brief summary of the results has been reported[3] and so details are given in Section 2: conclusions were very encouraging, but were still without the effects of wind.

In 1984 Pilkington Bros. and TRADA joined with Laing Homes to install the system in four new houses near Southampton: these were sold in the normal way and the purchasers' views sought on the effectiveness or otherwise of the system following the winter period 1984-85. In addition, one of the houses was monitored for system extraction rates, and air tightness measurements and various experiments concerning air inlets, etc., were carried out. The results are fully reported in Section 3.

2. FURTHER EXPERIMENTS IN THE TRADA TEST HOUSE

2.1 The System

The redesigned system comprised two completely separate ducts: one duct (153mm internal diameter), lead up from the kitchen and the other (103mm internal diameter), lead up from the bathroom, both terminating at the roof ridge with a simple rain cover. The ends of the ducts in the rooms were flush with the ceilings, with no inlet cowls fitted. Sharp bends were avoided and the ducts were well insulated in the loft space.

Air inlets into the house were provided by Titon Trimvents in the main room windows and by ventilation grilles in the front and back doors.

2.2 Measurements

Air flows in the ducts were continuously monitored using a thermistor bead air velocity meter with a sensor situated at the centre of each duct, making correction for turbulent flow. Checks on the values obtained were made by introducing carbon dioxide and timing its passage through the ducts, and also by introducing a known bleed of carbon dioxide into the duct and measuring its concentration at the outlet, hence computing the volume air flow. All gave good agreement, giving confidence in the method.

Whole house ventilation rates were determined using the carbon dioxide decay method.

The main objective was to monitor the flows of air out of the house via the extraction system and to see how these varied with changing internal/external temperature differences: these were measured with downstairs window vents and door vents open, and with all air inlets closed.

Information on whole house ventilation rates was needed to determine what proportion of the ventilation was provided by the duct system.

2.3 Results

Results are presented graphically in figs 1 and 2. Air movements are quoted as velocity in the appropriate duct and also as volume flows: from the latter, the appropriate air change rate per hour for the whole house, kitchen and bathroom attributable to the ducts can be calculated using the respective volumes of 240, 20, and $20m^3$.

Whether the inlet vents were open or closed, the extraction rates increased with the increase in temperature difference, as expected.

In the kitchen duct, flows at $20^{o}C$ difference were $55m^3/h$ with all inlets closed and $75m^3/h$ with downstairs window and door vents open. These flows correspond to as much as 3.8 ac/h (air changes per hour) for the $20m^3$ room. In the bathroom duct a flow rate of $20m^3/h$ at $20^{o}C$ difference would be expected irrespective of the inlet conditions, corresponding to 2.0 ac/h for this $10m^3$ room. Thus, the flow out of the house via the complete system at 20^{o} C temperature difference varied from 75 to $95m^3/h$ depending on whether inlets were open or closed. This represents 0.3 to 0.4 ac/h for the whole house. It seems likely that these rates were influenced by the wind, at least at the small temperature differences, even though the house was protected from the direct effects of wind by adjacent structures.

These figures become particularly interesting when compared to the corresponding whole house ventilation rates measured at the same time at temperature differences in the range $12-15^{o}C$, which is typical for an average winter day and heating level:

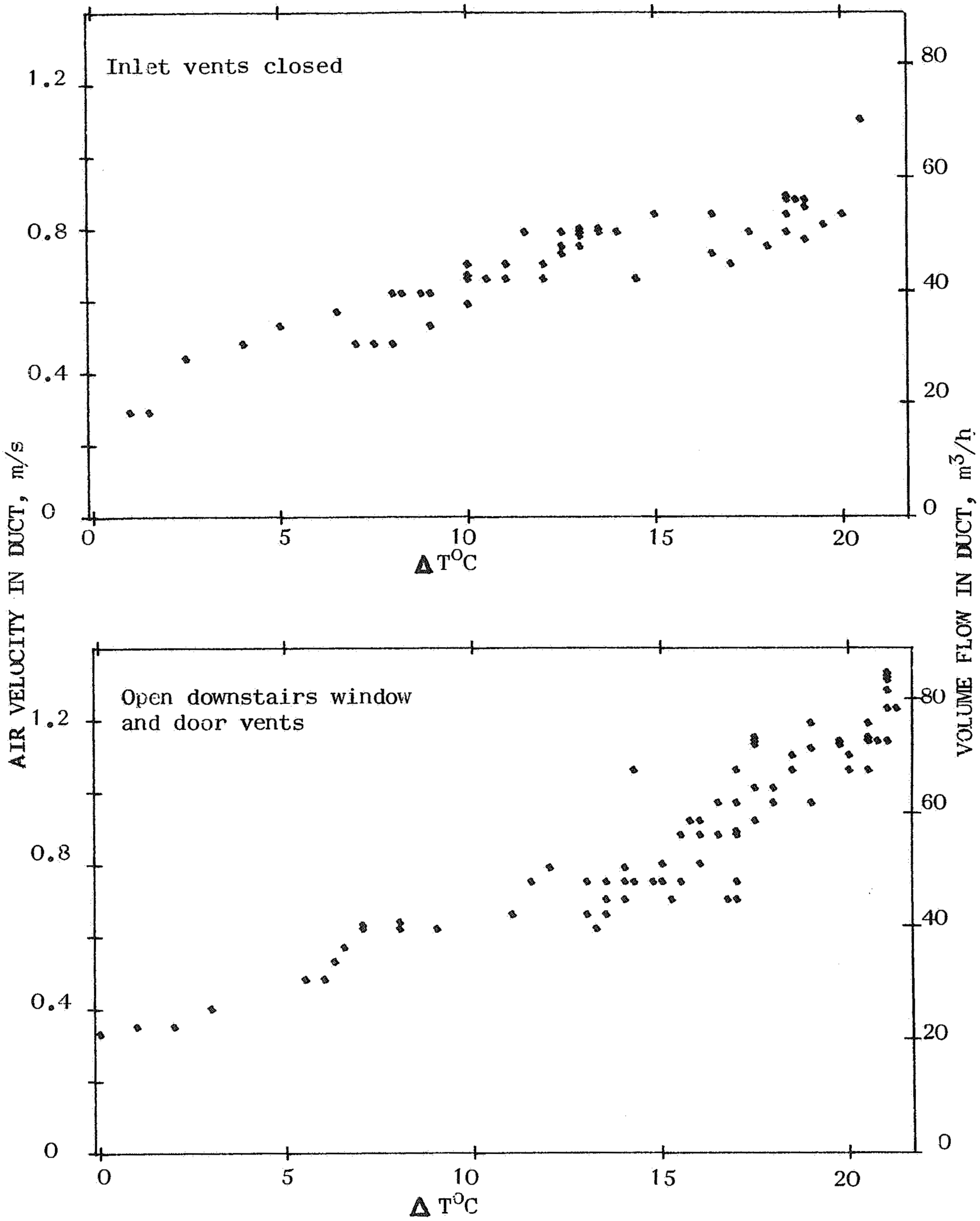

Fig 1. Flows in TRADA house kitchen duct.
(House - 240m^3; kitchen - 20m^3)
ΔT is the difference in internal/external temperatures.

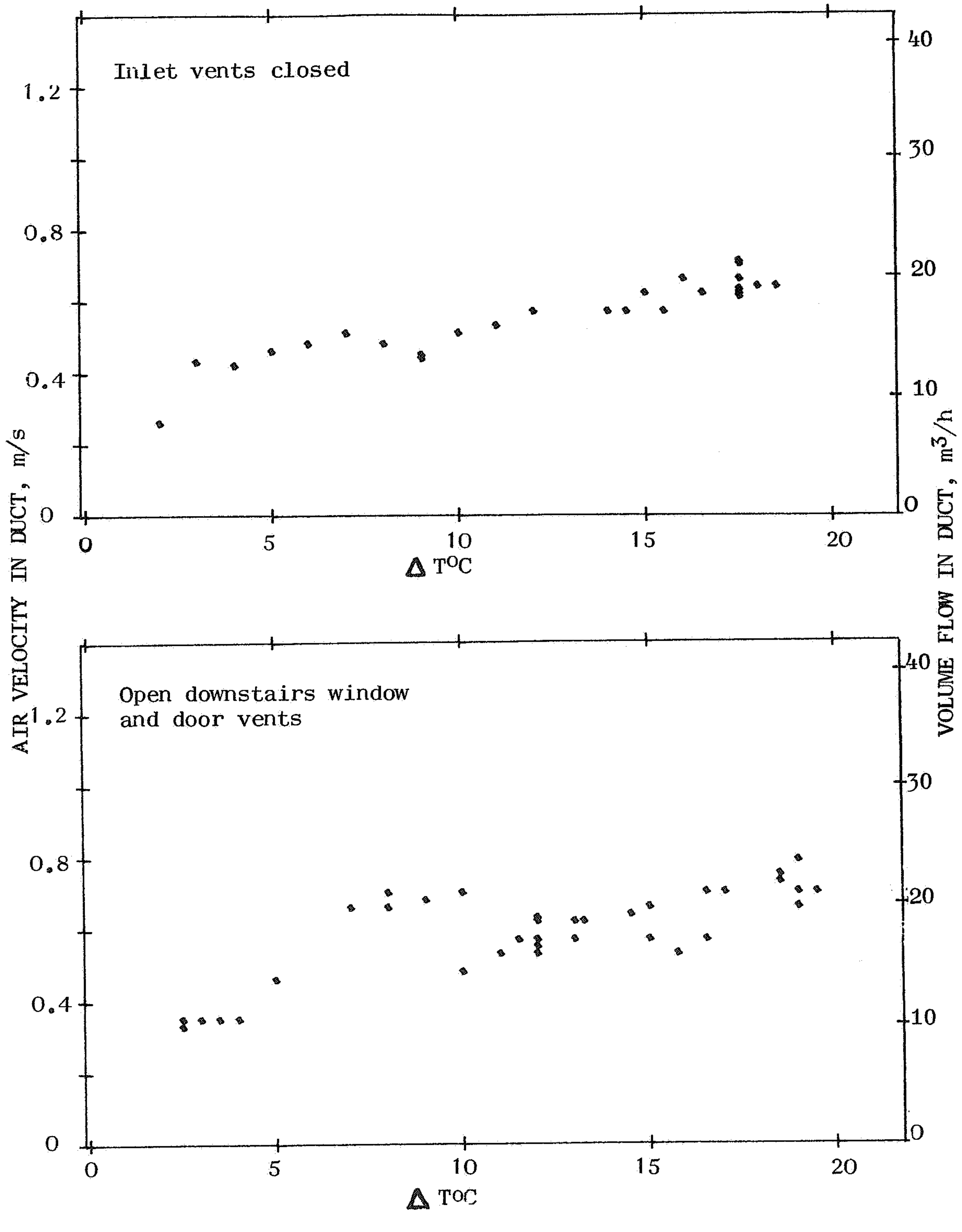

Fig 2. Flows in TRADA house bathroom duct.
(House - 240m^3; bathroom - 10m^3)

ΔT is the difference in internal/external temperatures.

TABLE 1. Ventilation rates in the test house

	Kitchen ac/h due to duct	Bathroom ac/h due to duct	House ac/h due to ducts	Total House ac/h
Downstairs window vents and door vents open	2.8	1.8	0.3	1.3
All inlet vents closed	2.7	1.8	0.3	0.6

2.4 Discussion

Under the conditions used, with the window and door vents closed, a total air change rate for the house would be 0.6; this compares to 0.4 ac/h found for the house without the ventilation system and inlet vents. Half the air left the building via the ducts, resulting in more air movement generally towards the moisture producing areas: this was confirmed by smoke tests. An increase in the ventilation level was achieved by opening the inlet vents giving a total air change rate of 1.3, whilst maintaining the 0.3 ac/h extracted by the ducts from the moisture producing areas.

The house with its natural ventilation rate of 0.4 ac/h (without the system) is considered to be fairly "tight" but when the air inlets were closed the flows in the ducts did not reduce at the typical winter day conditions. It is suggested that the explanation for this is that even at 0.4 ac/h a house has a considerable number of gaps in the structure, which would allow sufficient air inlet to "feed" the system.

As outside temperatures fell, the extraction rate through the system increased at the very time that an occupier would be likely to close the inlet vents (and windows).

2.5 Conclusions

The passive system provided 24-hour background ventilation to the house, with relatively high air change rates in the moisture producing rooms. It provided a better air flow pattern when windows and vents were closed, with the facility of increasing the ventilation rate by means of opening the vents in the windows - the use of the door vents is considered undesirable because of the likelihood of low level draughts. The major unknown was the effect of wind and of occupation of the house.

3. UNDER TRIAL IN LAING HOMES

3.1 The houses

The four houses fitted with a passive ventilation system were built near Southampton by Laing Homes, fig 3, and were all "Richmond" one-bedroom, two-storey, back-to-back, end-terrace houses. A site plan, block plan, and floor plan of the houses are given in figs 4, 5 and 6. The houses are timber framed and are well insulated with 97mm of mineral fibre in the wall cavities and 120mm in the loft; windows are single glazed and draught stripped and the entrance door is a foam-filled steel panel type, with a magnetic draught seal and "double" letterbox.

The houses have a floor area of $39m^2$ and a total volume of $92m^3$; the kitchen and bathroom have volumes of 11 and $8m^3$ respectively. Separate ventilation ducts were fitted to these two rooms and both were 103mm internal diameter, fig 7. These finished flush with the respective ceilings and were terminated with Bahco exhaust registers, which will automatically shut in the event of fire; the registers were adjusted to maximum opening. In the monitored house these exhaust registers were later removed.

Sharp bends and low angle ducts were avoided in the monitored house and the adjacent one, but in the other two the duct route through the loft was less than satisfactory due mainly to the roof pitch orientation. The ducts were well insulated in the loft spaces and were terminated just below a Glidevale tile vent situated near the top of the roof. It was suggested that the gap between the ducts and the terminal would "decouple" the system somewhat from the effects of strong wind and thus prevent excessive over-extraction.

Air inlets were provided by Titon Trimvents, fitted to each of the four windows of the houses. The total inlet area of these vents was approximately one and a third times the total cross-sectional area of the ducts.

3.2 Experimental Procedure

In the three non-monitored houses the principles of the system were explained to the occupiers, with a recommendation that the air inlets were in general left open. They were then left to use the system as they wished and their reactions sought at the end of the winter period.

For the monitored house, again in general, the occupiers were left to use the system as they wished, except during specific periods when they were asked, for example, to have the window vents permanently shut, or have the ventilation ducts sealed off.

During the full winter period the flows of air out through both the ducts were continuously monitored as before, using thermistor bead air velocity meters. Air flows were found to vary considerably: sometimes the flow would be very steady when

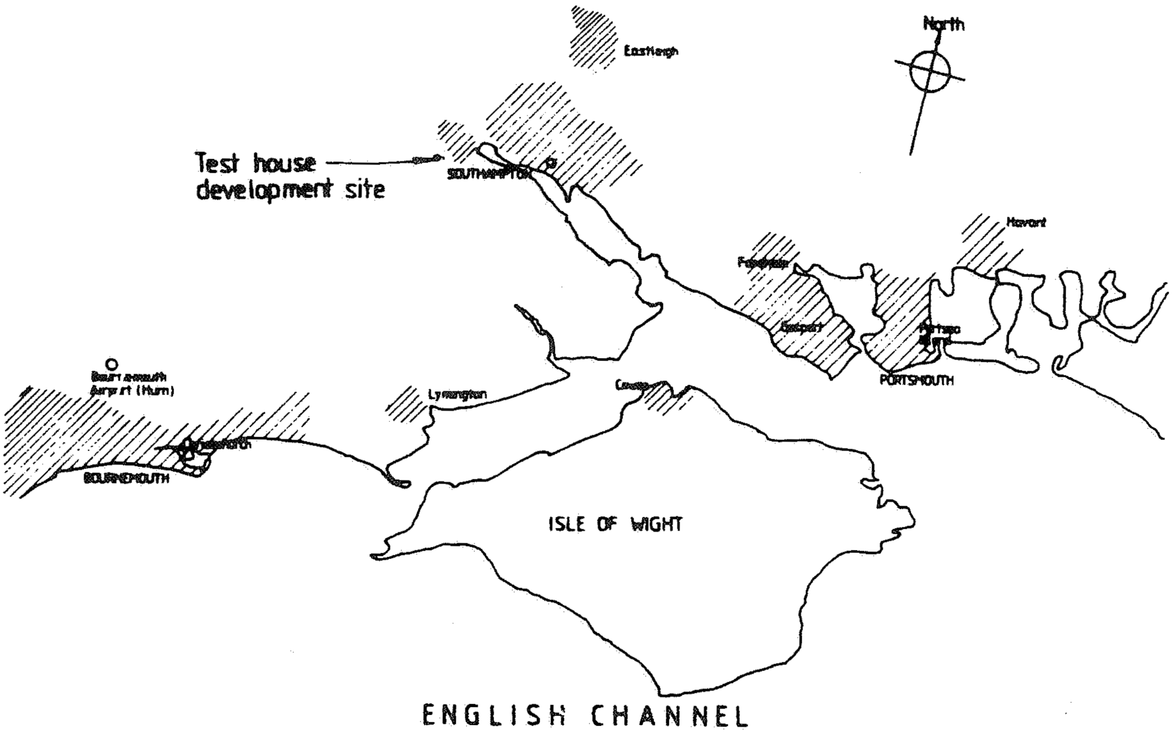

Fig 3. Location of the Laing development site

Fig 4. Site plan showing positions of houses fitted with the passive ventilation system.

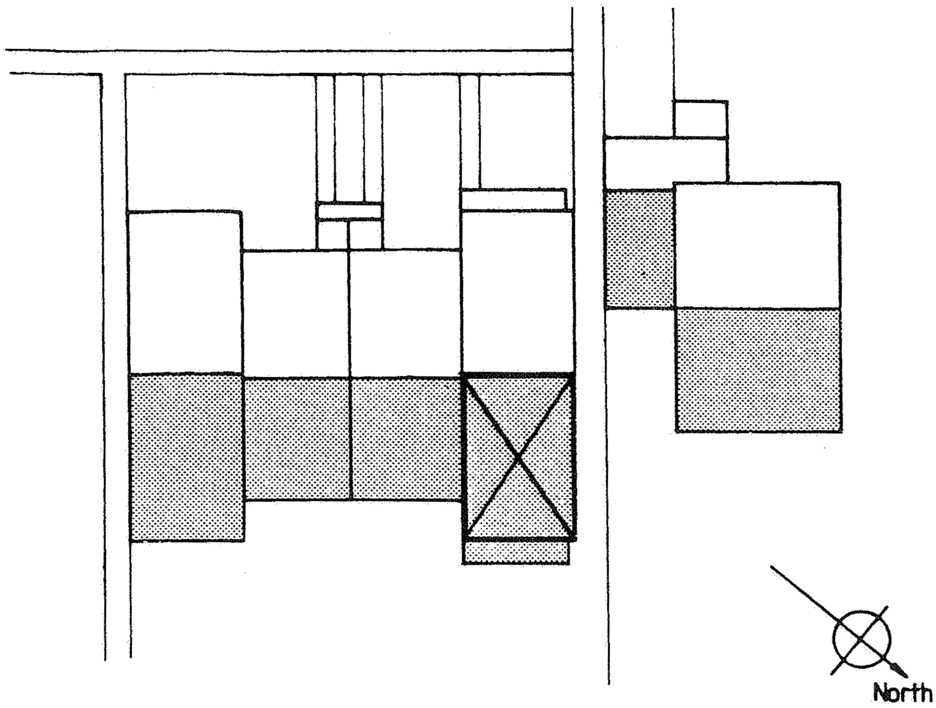

Fig 5. Block plan of the monitored house.

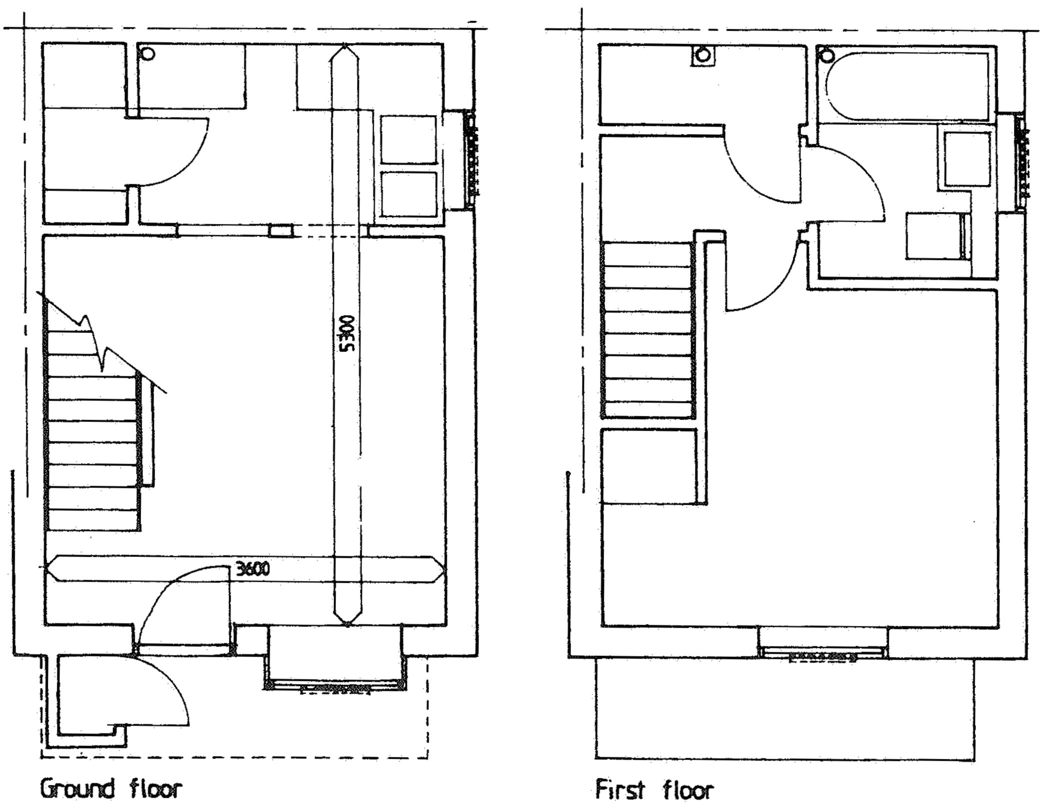

Fig 6. Floor plan of the 'Richmond' house.

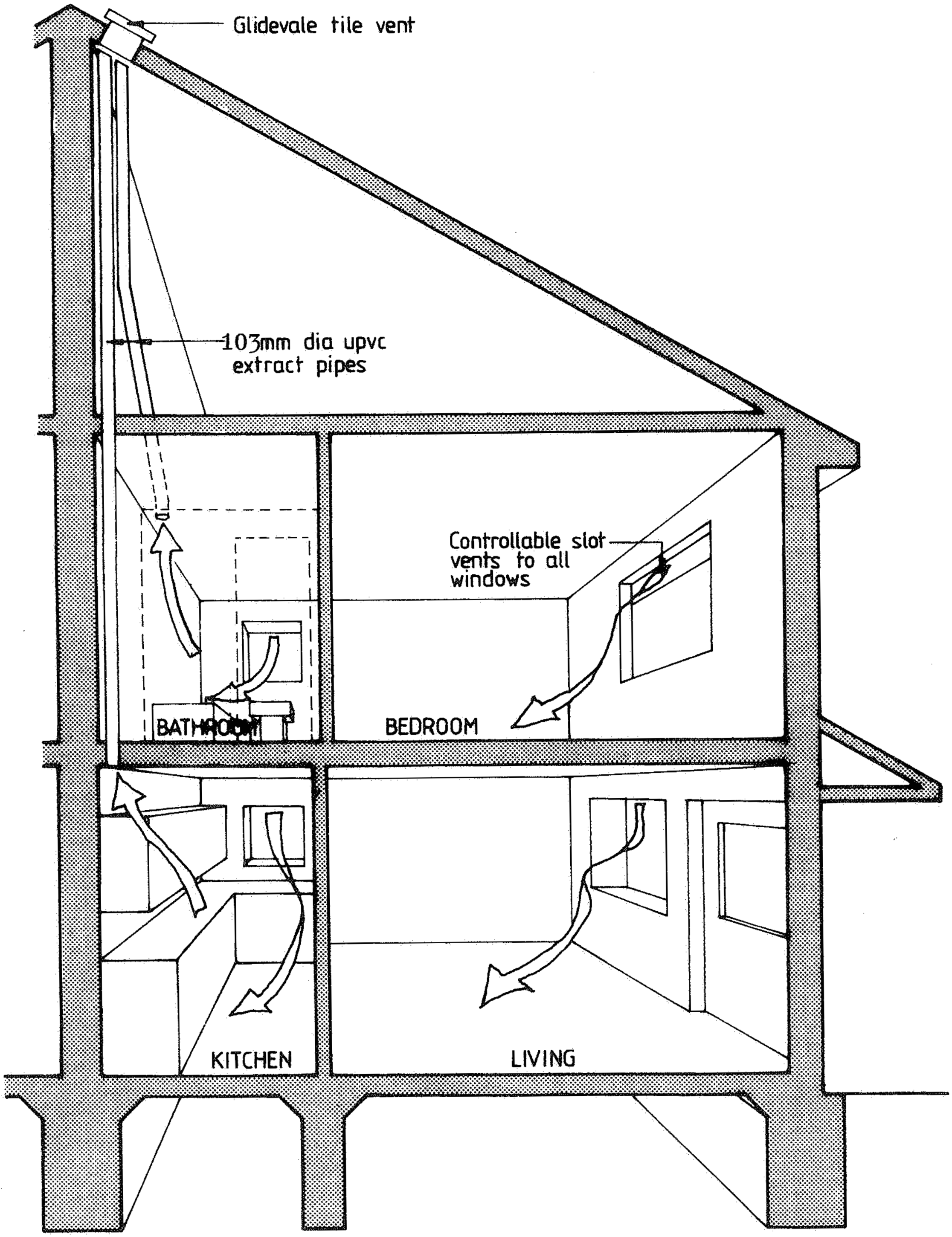

Fig 7. The ventilation system fitted in the 'Richmond' house.

indicated by direct connection to the recorder, e.g. fig 8a, and sometimes the flow would have fluctuations of the type and extent as in fig 8b (the reason is discussed in Section 3.6.1). For the long term recording, with its necessarily compressed time scale, the oscillations were damped by using a resistance/capacitance filter network (with a time constant of 100 seconds) fig 8c: this avoided wear of the paper by the pen, and made averaging easier. It is necessary to remember throughout interpretation of the results that the traces are damped.

Internal temperatures in the vicinity of the duct intakes were also monitored; external temperatures for nearby Southampton, and wind data for Hurn, were obtained from the Meteorological Office. Unfortunately Hurn is 17 miles away and so the data will not exactly match the area of the houses. However, it is a reasonable guide and spot checks confirmed this.

House tightness was determined by air pressurisation tests and air infiltration rates by carbon dioxide decay tests: these were carried out before occupation, September '84, and during the occupation period, February '85.

3.3 Air Pressurisation Tests

The September '84 tests were substantially confirmed by the February '85 tests (except that the house appeared to be a little tighter at the later date) and so the later tests are described here.

The house was pressurised and depressurised in the range 15-60 Pascals and the air leakage characteristics taken as the mean of the pressurisation and depressurisation tests. That rate at 50 Pascals can be used to compare the various conditions and other dwellings.

The results for the various air inlet and duct configurations are given in table 2.

TABLE 2. Air pressurisation tests

House Condition		
Vent. ducts	Window vents	Mean ac/h rate at 50Pa
Closed	Closed	7.4
Open	Closed	9.0
Open	Open	12.1
Bahco registers removed	Open	13.4

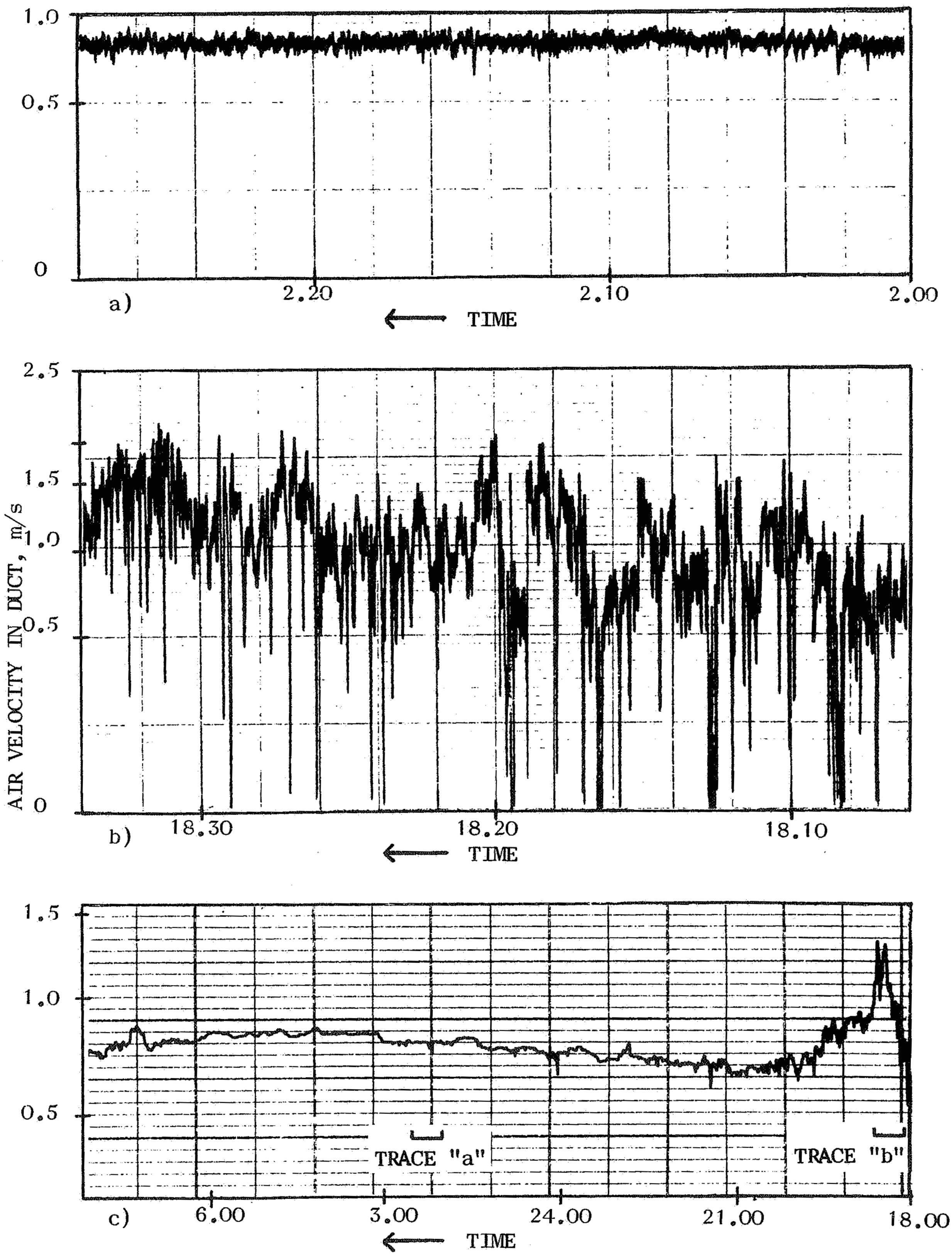

Fig 8. Typical air velocity traces (kitchen duct)
a) undamped trace - steady flow
b) undamped trace - irregular flow
c) damped trace - including periods of traces 'a' and 'b'.

3.3.1 Discussion

Without the ventilation ducts and window vents the dwelling would be under-ventilated[4], especially at times of high moisture production. The installation of the passive system would increase the ventilation rate by a useful amount and would be particularly beneficial in inducing air change to take place for the moisture producing areas. The window vents would give the occupier the opportunity to control the rate over a useful working range - for example, by opening the vents to increase air exchange rates during moisture production. Finally, it was seen that the inlet registers were throttling the flows somewhat.

3.4 Carbon Dioxide Decay Tests Before Occupation

The tests carried out before occupation were with the house unheated and consequently with small or zero internal/external temperature differences. Results are given in table 3.

TABLE 3. Decay tests

House condition		$\Delta T\,^{o}C$	Wind m/s	Ac/h
Vent. ducts	Window vents			
Closed	Closed	0	3	0.1
Closed	Closed	0	10	0.3
Closed	Open	1	10	0.6
Open	Closed	3	9 dropping to 4	0.3
Open	Open	5	4	0.4

ΔT is the difference in internal/external temperatures.
Wind speeds are for Hurn.

3.4.1 Discussion

Without the ventilation ducts or window vents, the house appears to be very tightly constructed (more so than indicated by the pressurisation tests) and it would be seriously under-ventilated: the minimum rate usually accepted is about 0.5 ac/h. The low figure might be explained to some extent because of the small internal/external temperature difference, but this does not appear to be the case in view of later tests in the occupied house.

Still without ducts or vents, and with a wind blowing stronger than the average 5 m/s, the ventilation rate increased, but still not to a satisfactory level. The use of window vents during the strong wind resulted in a satisfactory level, but it can be argued that occupiers would close at least some of the window vents during such conditions.

The introduction of the ventilation ducts did not have a significant effect on exchange rates, which is not surprising at the low temperature difference; it is likely that opening the window vents would also be more significant with bigger temperature differences.

In the two tests with the ventilation ducts open, air flows measured in the ducts represented about 0.2 ac/h for the house, that is, with window vents shut, about two-thirds of the air leaving the building did so via the ventilation ducts, and with window vents open about half of the air leaving was via the ducts.

During the tests the wind was blowing from the side to the front of the house (west to east); smoke tests showed that with the ventilation ducts closed and the window vents open, air entered the house via the side windows and left via the front - with the ventilation ducts open as well as the window vents, air entered the house through all window vents. Although the wind was less during the latter condition and there was only a small temperature difference, the introduction of the ventilation ducts had altered the air flow through the house, which would be beneficial in controlling moisture removal and spread, and hence condensation problems.

3.5 Carbon Dioxide Decay Tests During Occupation

The carbon dioxide tests were repeated some months after occupation, to check on the very low basic infiltration rate found and to compare the effects of opening the ventilation ducts and window vents. At the same time, air flows leaving the house via the ventilation ducts were monitored to see how relatively significant these were. The house was, of course, now heated with temperature differences of 14-16^{o}C throughout the tests. Results are given in table 4.

TABLE 4. Decay Tests During Occupation

House Conditions		Wind m/s	Ac/h	Ac/h through vent ducts
Vent.ducts	Window vents			
Closed	Closed	4	0.15	-
Closed	Open	4	0.3	-
Open	Open	6	0.6	0.4
Bahco registers removed	Open	5	0.6	0.6
Bahco registers removed*	Open	3	0.6	0.6
Bahco registers removed	Closed	4	0.4	0.5

*Short check test.

Wind speeds are for Hurn.

Clearly one cannot have more air leaving the house via the ducts than indicated by the total air exchange rate, and so the results do indicate some inaccuracies in measurement techniques.

3.5.1 <u>Discussion</u>

The very high tightness of construction is confirmed by these results. Looking at both sets of carbon dioxide tests, it can be seen that in the absence of the duct system the window vents will only produce satisfactory air exchange rates when there is above average wind blowing - the stack effect alone is not sufficient.

It can be seen that the exhaust registers are throttling the flow, and so following these tests, that is, for the main results printed below, the registers were removed, so the ducts simply ended flush with the ceilings.

The introduction of the combination of the ventilation ducts (without the Bahco registers) and window vents appears to provide a very satisfactory system. With the window vents closed, most of the air leaving the building is via the ducts, with consequent re-routing of the air (confirmed by smoke tests) and under the typical winter's day conditions, flows were just below the minimum that would be acceptable. If the window vents are opened the overall ventilation rate is increased by about 50%, but apparently still with most of the air leaving the house via the ducts, continuing the beneficial conditions for the removal of moisture at source. This is very different from the effect of opening window vents in the TRADA test house which caused a big increase in the amount of air bypassing the ducts - this may be because of the difference in air tightness of the two houses and to the different window (and window vent) positions.

Conditions of high wind were not encountered whilst the house was heated for the carbon dioxide tests: this is important as it is possible to have too high an infiltration rate for the house due to air bypassing the ducts under these conditions (significant over-extraction through the ducts themselves due to wind was not encountered - see Section 3.6.1). However, the first set of carbon dioxide tests showed an air exchange rate of 0.6 ac/h under high wind conditions with window vents open (ducts closed), so it does not seem likely that too high a total figure would be produced: it could again be argued that with high wind, the window vents are likely to be closed by the occupier, with a reduction of air exchange rate to 0.3 for the cross-ventilation without ducts.

3.6 Continuous Monitoring of Air Flows in the Ventilation Ducts

Monitoring took place over the winter period from September 1984 to February 1985.

As a result of failures of chart drives and air velocity probes (and the occasional collection of fluff on the air velocity sensor in the kitchen duct) incomplete sets of data were collected. Fortunately, the internal temperatures for the house remained fairly consistent throughout the period, as a result of the occupier leaving the main heater on 24 hours a day and controlling it with its thermostat and also because there was little direct solar gain.

3.6.1 9th March to 24th March 1985

A 16-day period has been chosen for evaluation assuming that the internal temperatures were as during the previous 22-day period, that is, downstairs at 20^{o} C and upstairs at 16^{o} C, both temperatures measured near to the duct inlets. During the 16-day period external temperatures varied from -3 to 14^{o}C and wind from 0 to 10 m/s, and both duct sensors worked continuously and at the end of the period were checked and found accurate.

The most significant result from the monitoring is the overall consistency of the duct flows throughout the 16 days: an average 0.9 m/s in the kitchen duct and 0.6 in the bathroom duct representing 2.5 ac/h and 2.0 ac/h for those two rooms, and together representing 0.45 ac/h for the house.

If one takes lower limits of 0.6 and 0.4 m/s for the flows in the kitchen and bathroom ducts and upper limits of 1.2 and 0.8 m/s, corresponding to two-thirds and one-and-a-third of the average for the period, and which represents a range of 0.3 to 0.6 ac/h for the house, flows were within these limits for 91% of the period; more than half of the remaining 9% was attributable to low flows in the bathroom duct on two particular days, which are discussed below. It must be remembered that the flows referred to are from the damped results: actual flows would be varying greatly over time periods of a few seconds but, provided that there are no undesirable side effects caused by the rapid fluctuations, it is the flows measured over time scales of a few minutes which are appropriate to removal of moisture.

An example of the results for 10th March is given in fig 9, which is typical, and is now discussed in detail: note that the time sequence is from right to left.

The pattern of variations of flow is the same in the kitchen and bathroom ducts, the flow being lower in the bathroom ducts almost certainly due to the shorter duct length, and hence smaller stack effect. Fig 9 also shows the corresponding wind results from Hurn and internal/external temperature differences.

Initially, flows in the ducts and the temperature difference are steady, and there is virtually no wind. As the temperature difference decreases flows start to drop, but then the wind starts to pick up, apparently having more effect than the continuing drop in temperature difference, as the flows in the ducts increase. Then the wind steadies, temperature difference continues to fall, and hence so do the flows. Temperature difference then starts to increase again but accompanied by a drop in wind, again the wind apparently predominating, with a continued (general) fall in flows. Then the wind again increases accompanying the increase in temperature difference and the flows increase again. The effect of the subsequent drop in wind is only really apparent in the bathroom duct flow.

The definite change at 09.00 hours from fairly steady flow to flows varying on the few minutes time scale, is almost certainly associated with reaching a certain level of wind, and there is some evidence throughout the results that this threshold value is higher the greater the temperature difference at the time.

There are a number of variations imposed on the general changes due no doubt to internal activities in the house, or local variations in wind and external temperature, but the patterns described above are generally to be found throughout the monitoring.

It was stated that a significant part of the period when flows were outside 0.3 to 0.6 ac/h for the house, was due to low flows in the bathroom duct on two particular days. The results for the worst day, March 12th, are given in fig 10. There was a dip in the kitchen duct flow, and the flow in the bathroom duct dropped significantly. The drop in performance corresponds to a low temperature difference of 6.5^{o}C and a below average wind of 3 m/s. However, the drop in flow in the bathroom duct is much greater than on 10th March, on which day conditions of 4.5^{o}C and

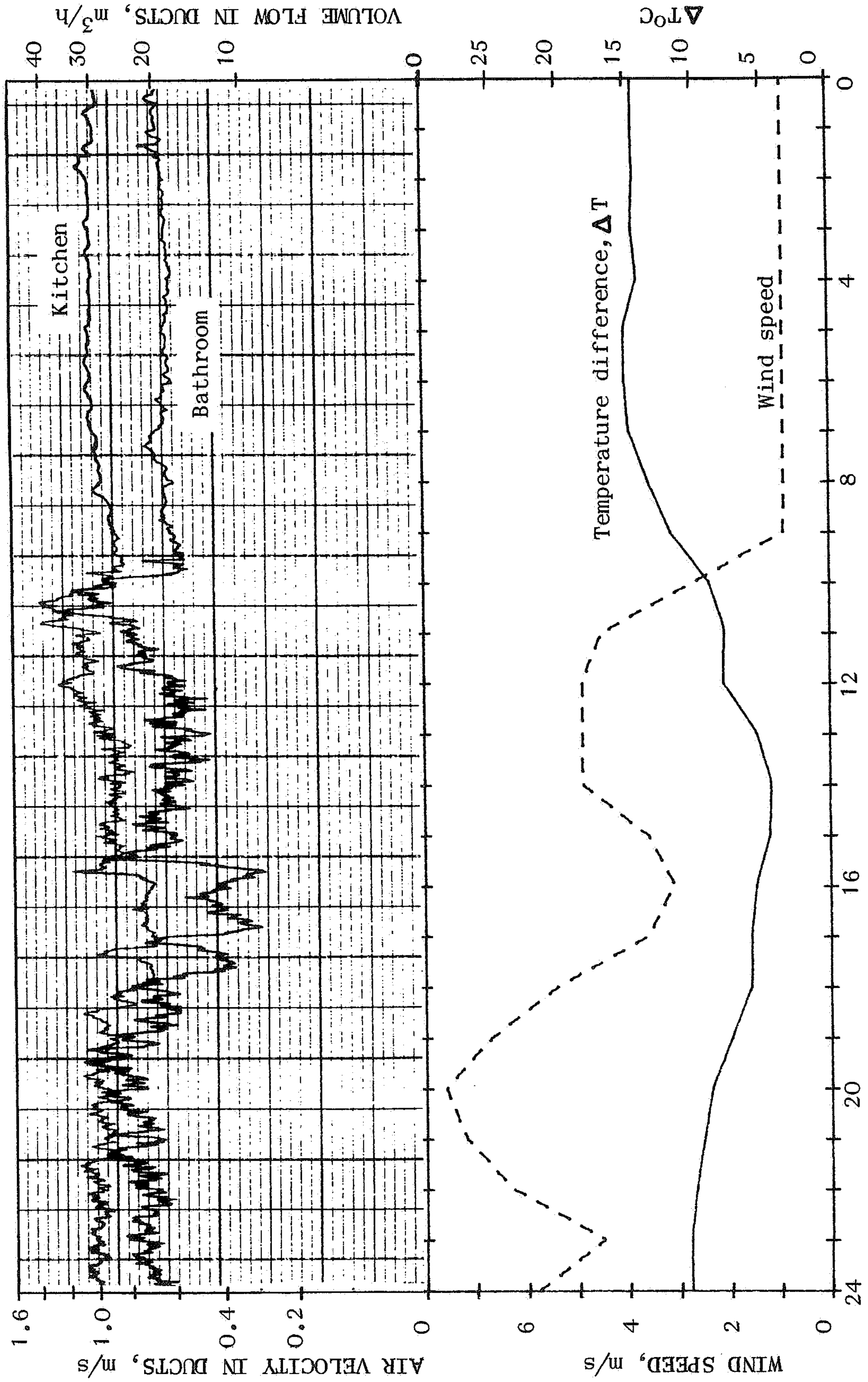

Fig 9. Flows in kitchen and bathroom ducts, wind speed and internal/external temperature difference (ΔT), 10th March 1985.

Fig 9.

Fig 10.

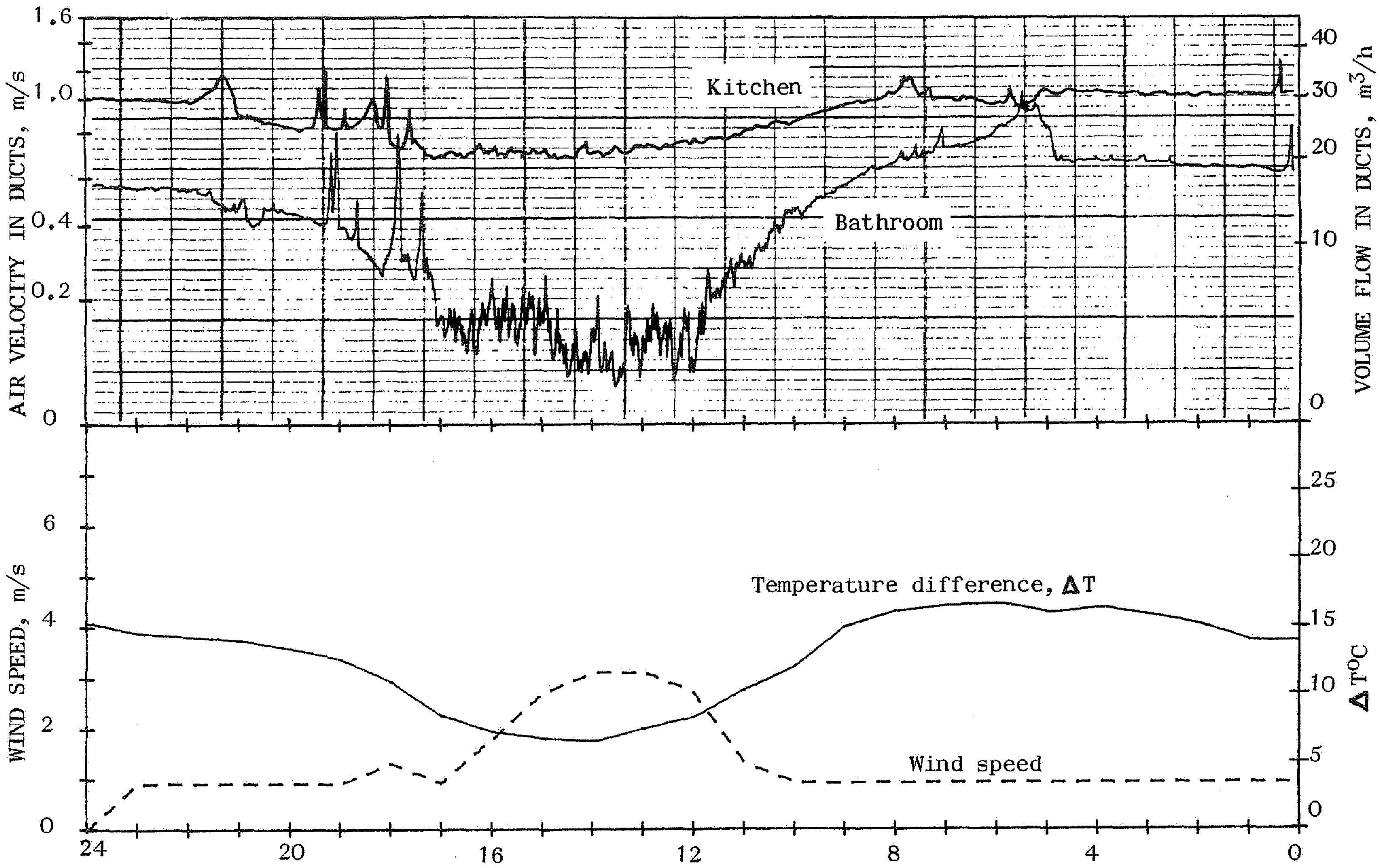

Fig 10. Flows in kitchen and bathroom ducts, wind speed and internal/external temperature difference (ΔT), 12th March 1985.

3.5 m/s were encountered. The known difference is the status of the window vents, open on 10th March and closed on 12th March, as part of the experimental programme and not under occupier control. Since generally over the test period no large difference was noticed in duct flows, whether window ducts were open or closed, the answer appears to be that the bathroom duct is particularly sensitive to the window vent status when both stack and wind driving forces are low - other low results seem consistent with this.

At the other end of the scale, the day with the greatest driving forces logged was 15th February (when only the kitchen duct was successfully monitored): the flows are given with internal/external temperature differences and wind data in fig 11. A temperature difference of 23.5°C combined with a wind of 7 m/s resulted only in the average flow in the kitchen duct - the status of the window vents is not known but it is likely that they were closed.

3.6.2 <u>3rd May to 30th May 1985</u>

A 27-day period in May was also successfully monitored. During this period flows in the ducts were reducing and, especially in the bathroom duct, becoming more variable. This corresponds to the much warmer weather but the data has not yet been evaluated. It is probably of much less practical interest, as windows are likely to be opened with the improved weather and, in any case, condensation risk reduces as winter is left behind.

3.6.3 <u>Other Periods</u>

The other data collected during the winter period, although not complete, is all consistent with the 16-day period and so overall the system appears to give a reliable background ventilation rate to the house. This must be due to the fact that usually at least one of the driving forces, stack and wind, is present. When both are reduced it will usually be mid-day and then only the bathroom ventilation is significantly affected, possibly only when the window ventilators are shut. A reduction in ventilation in this room at this time is not likely to have a significant effect on moisture spread and condensation problems.

The average flow recorded during high wind and large temperature difference is particularly interesting. The fact that extraction rates were not excessive confirms the prediction[3] that the system will self-throttle in a tightly constructed house (helped presumably by the decoupling of the pipes from the roof ventilator).

3.6.4 <u>Short Experiments</u>

A series of experiments was carried out to determine the effect of air inlets. Opening the window vents caused an increase of flows in the ducts of something like 20%. This is different

Fig 11.

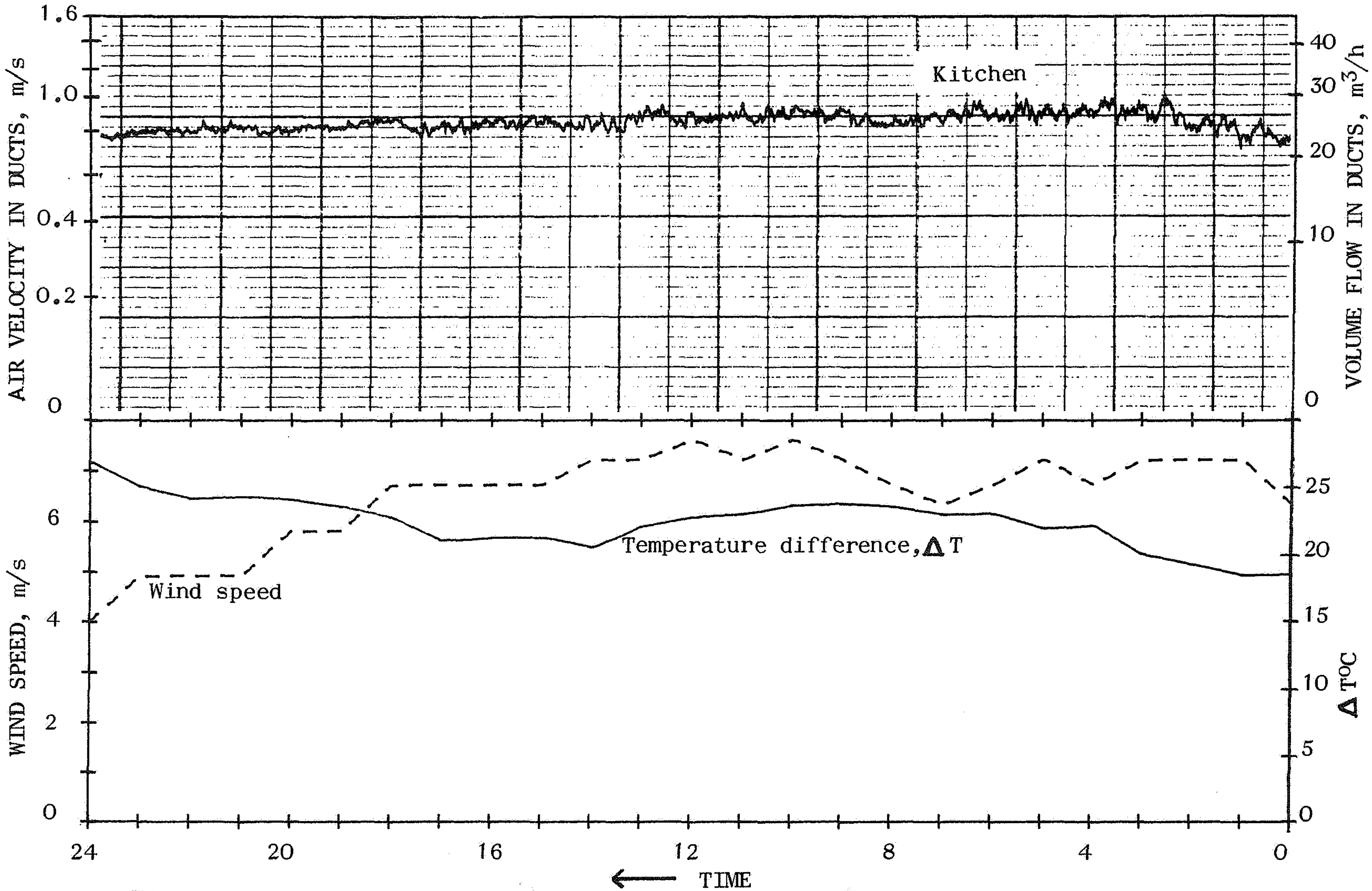

Fig 11. Flows in kitchen duct, wind speed and internal/external temperature difference (ΔT), 15th February 1985.

from that indicated during the carbon dioxide tests, and may be attributable to different stack and wind conditions. Subsequent progressive opening of windows caused increases of up to another 40%, mostly achieved on the night latch position, with little change thereafter. Opening the external door wide, in addition to all windows fully open, resulted in a duct flow from the kitchen of 1.2 m/s - the upper limit which was exceeded for only 2% of the time in the 16-day March period. Admittedly these short tests were carried out during low driving forces, but a picture does emerge of a system which has ducts which throttle at flows corresponding to about 0.6 ac/h for the house.

3.6.5 Doors

All the tests referred to were carried out with internal doors open. The effect of shutting the bathroom door (there was no kitchen door) was to decrease flows in the bathroom duct - say perhaps 10%. However, if the room window vent was also shut this had a marked effect on the duct flow in that room, especially during low driving forces. Under these conditions there would be little cross house ventilation through the bathroom, so moisture removal would still be quite effective. Indeed after baths or showers it should be noted that the passive system continues to extract, which will be more effective in practice than an extract fan, which runs only for a limited period, in clearing moisture left on tiled and bath/shower surfaces.

It is suggested that a kitchen door would act in a similar manner, but with less overall effect, due to the greater stack effect in the kitchen duct.

3.6.6 Cooking

Previous tests showed that the local heat from the cooker increased the extraction rate in the kitchen. It now seems likely that this effect would only occur under conditions of low driving forces: under high driving forces extraction would be high and already throttled.

3.6.7 Inlet Registers

The tests confirmed that the Bahco registers throttle the flows by something like one-third: a check on the dimensions showed that the free area through the register was only about half that of the duct area, so this is not surprising. It is still felt that some device is needed that will both collect any debris which may fall down the duct, and also which will positively shut the system in the event of fire. A redesign is therefore obviously needed here, such as an increase in duct end diameter to accommodate a larger register, or a redesigned register (the registers are designed for a mechanical system, so no criticism of the product is implied).

3.6.8 Dirt and Condensation

At the end of the tests a check was made for deposited dirt in the ducts: all that was found was a thin layer of dry dust on the walls of the kitchen duct.

No condensation was found on the roof tile, nor was there any evidence that there had been any. There were no signs of condensation having occurred in the ducts themselves.

3.7 Occupier Reactions

The overall reaction from the four households was that they had not really noticed or thought about the system until the interview which on investigation meant that they had rarely considered opening or shutting window vents or opening windows to reduce cooking smells or steam and that there were no significant annoying side effects: they had generally "forgotten" about the system - these are very encouraging comments.

In interpreting the views it should be remembered that in the three non-monitored houses the system was not working to full capacity because the inlet registers were restricting flows, and in two of those houses the ducts in the loft had a number of restricting bends which would also tend to reduce flows.

In detail it was apparent that window vents had generally been left open except during very cold or very windy weather following which the occupiers had reopened them. Just one window vent had caused problems - the one in the lounge had resulted in draughts to people whilst sitting, for example watching TV so this one was frequently closed. No back draughts had been noticed from the ducts nor had any dirt fallen or blown down. Some noise had been apparent: for example the occasional aeroplane had been noticed and heavy rain (presumably on the plastic of the tile vent) had been heard "through the kitchen duct" and there was a "whispering" noise during windy weather. However none of the occupiers had found these noises annoying and had only offered the information in response to the direct questions.

In particular they all thought that cooking smells and steam had cleared quickly (without window opening) with no musty smells in the bathroom after the room had been closed overnight. One pair of occupiers who smoked remarked on the quick clearance of smoke and lack of "stale tobacco" smell in the morning and commented that the clearance was much more effective than in their previous older and presumably leakier house.

Specific comments were received from the occupiers of the monitored house appertaining to certain test periods. They said they had noticed more condensation on windows during periods when the window vents had been shut (ducts open) and particularly when the ducts had been closed off. They commented on lingering cooking smells and "smokey" conditions with the ducts closed off whether or not the window vents were open.

Condensation had generally been encountered on the single glazed windows and in some cases had run off into pools on the sills: this would be expected during winter months due to the changing external environment.

3.8 Discussion

The simple passive ventilation system provided a continuous background ventilation rate averaging at about 0.45 ac/h during the winter conditions in a tightly constructed house which would have been otherwise under-ventilated. The driving forces for the system were the wind and the internal/external temperature difference, and it appears that in the winter there was usually sufficient of one or these to produce a reasonable extraction rate. If both driving forces were high, the extraction rate did not become excessive, as the ducts appeared to self throttle.

Window vents alone would have left the house under-ventilated except during strong winds, when they were likely to be closed anyway.

The effect of window vents in addition to the ventilation system was more complex. It appeared that if there was a good flow of air being extracted through the system due to one or both of the driving forces being high, then opening window vents had no effect or caused only a small increase in flows. However, the opening of the vents increased the natural cross house ventilation (as it would in the absence of the ventilation ducts) giving the occupier some control over the total ventilation rate. On the few occasions when both driving forces were low, air flows out of the house via the ducts dropped, especially that in the bathroom duct. Under those conditions it is thought that opening the window vents would tend to counteract this drop: both driving forces were low when it was relatively warm and calm in the middle of the day when ventilation levels in the bathroom least mattered.

Thus, if the occupier tends to close window vents in windy or cold weather and opens them during the better weather, the best from the system will be obtained. At worst, if the occupier leaves window vents shut all the time the house should still have, at minimum, an air change rate of 0.4 and so, with reasonable indoor activities, should not have too many condensation problems. There appeared to be no significant disadvantages and the occupiers were able effectively to "forget about" the system.

4. OVERALL ASSESSMENT AND CONCLUSIONS

The extent of the effect of fitting passive ventilation ducts into a house depends particularly on the basic tightness of that house.

If the house is very tight, as the monitored Laing house (about 0.1 ac/h) the introduction of the system is very beneficial.

It provides a continuous background ventilation rate, extracting from the moisture producing areas. If the window vents are kept shut this ventilation rate should be, for most of the time near to the minimum considered to be satisfactory, even when it is very cold with a strong wind blowing outside. If the window vents are opened the background ventilation continues but there is an increase in the total rate for the house: this will increase as wind increases, but is unlikely to be excessive, as the vents will probably be shut during strong wind to prevent draughts. During warm calm weather, flows in the ducts will reduce, especially that from an upstairs room (e.g. bathroom) but this reduction will be minimised if window vents are opened, which is probable under these conditions.

If the house is less tight, as the TRADA test house (about 0.4 ac/h) the introduction of the system is again beneficial. However, there will be higher cross house ventilation than if the house was very tight. The window vents will have the same effects, but the magnitudes will be different: overall there must be a tendency to higher ventilation rates than in the very tight house.

In an older type house with a basic ventilation rate of about 1 ac/h or greater, a passive ventilation system would still work, but the total levels of ventilation would be too high.

The idea of building tight houses and installing passive ventilation systems, similar to those described in this paper, to provide controlled background ventilation rates, is commended. The system would only be suitable for older property if extensive draught-proofing was carried out, and would only contribute to condensation control if the property was made thermally efficient and properly heated.

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