Natural ventilation in well-insulated houses

by D. J. Nevrala and D. W. Etheridge

Paper presented at International Centre for Heat & Mass Transfer, International Seminar, August 29th — September 2nd, 1977, Dubrovnik, "Heat Transfer in Buildings".

INTRODUCTION

Natural ventilation provides fresh air for a multitude of purposes, but it is also a source of heat loss from a building. In the past ventilation by natural means, either by infiltration through cracks or through purpose made openings, had been taken for granted. The only complaint at times had been of draughts; the energy loss caused by excessive ventilation rates had not attracted attention because the ventilation heat loss had been only up to 20% of the total heat loss from a typical house in the United Kingdom.

The energy crisis and the ensuing rise in fuel prices resulted in a range of energy saving measures, the most prominent being the adoption of higher insulation levels for new housing and it is probable that this trend will continue in the future. The application of high insulation levels disturbs the energy balance in a number of ways, one of the most important being the ratio of design fabric and ventilation heat loss, in a well insulated house. The ventilation heat loss can account for up to one half of the total loss under these circumstances. It has been realised that the law of diminishing returns applies to any further increase in insulation levels and therefore attention now has to be focussed on means of reducing the other component of energy loss - ventilation.

Measures have been introduced in prototype well-insulated dwellings to reduce the ventilation rate by specifying "tight" window designs or double glazing, and conventional ventilation heat loss calculations predict a substantially reduced design heat loss. However, experience has shown that where heating systems have not been fortuitously oversized, complaints of discomfort due to low temperature and draughts have arisen, which in turn suggests increased ventilation.

This paper presents an analysis of the mechanics of natural ventilation and describes a computer-based method developed by British Gas Corporation at Watson House for predicting ventilation patterns in houses. Calculations using the method are used to illustrate the basic reasons why natural ventilation is likely to cause problems in heating well-insulated dwellings. A detailed discussion of these problems is then given, particular attention being paid to the way in which ventilation could influence the sizing of appliances and the indoor thermal environment. Results of computer-based simulations of the thermal behaviour of a well-insulated dwelling are presented.

AIR INFILTRATION IN HOUSES

The natural ventilation of a house arises as a result of pressure differences generated across open areas by the action of the external wind (wind effect) and by bouyancy (stack effect). The open areas can take a wide variety of forms, and it is convenient to divide them into three groups. In the first group we have purpose-provided openings such as air vents, flues, chimneys and open windows. The second group consists of the cracks in and around room components (i.e. doors and windows). These cracks are such that they are readily identifiable and their dimensions can in general be measured. They have the important property that the spaces between which they communicate are also identifiable. In the third group, we have the open areas which remain when the two other types of crack have been sealed. This group is referred to here as "background leakage areas". Background leakage areas are often not visible as discrete cracks and the spaces between which they communicate are often not identifiable. Within this group will be cracks around electrical fittings and around the joints between ceilings and walls and also the porosity of room surfaces, which for certain types of floor can be very large.

Work carried out by the Government's Building Research Establishment(1) has shown that the infiltration of air into a house through background leakage areas can be very large. That is, when a house is pressurised by a large fan, and the cracks around doors and windows are sealed, a large flow out of the house remains and this is not due solely to the presence of purpose-provided openings. We have carried out tests to gain an idea of the magnitude of the background leakage area of individual rooms compared with the open areas of the components in the room. Both types of open area have been measured with the pressure/flow technique(2). Basically, a known pressure is applied across the area and the resulting flow rate is measured. By making use of the crack flow equations(2), the open areas can be obtained from the pressure/flow measurements. The values obtained in this way are accurate for doors and windows, which are considered as the areas of hypothetical equivalent cracks. Nevertheless, it is reasonable to consider the areas of these hypothetical cracks as an approximate measure of the background leakage areas, since they have been found to give a fairly reasonable description of the flows associated with them(2). Table 1 shows the results of tests carried out in a modern detached four-bedroom test house, The background leakage areas of the hall and the landing were not measured. For the tests, the lower suspended floor of the house was sealed with polythene sheet to simulate a concrete floor.

Table 1

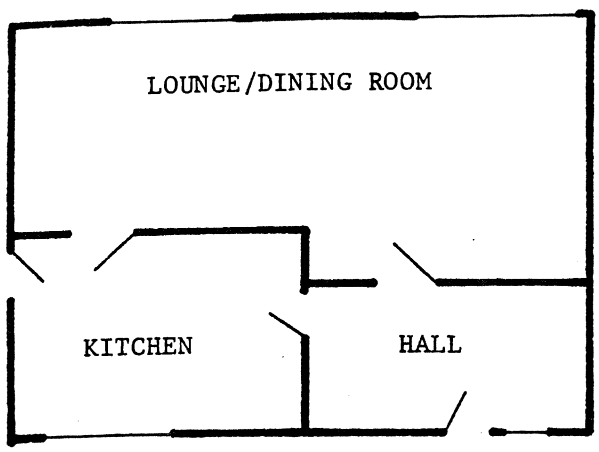
Comparison between background leakage areas of rooms and the sum of the open areas of the doors and windows in the rooms

ROOM	TOTAL OPEN AREA OF ROOM COMPONENTS m^2	BACKGROUND LEAKAGE area m^2
Lounge/Dining	0.073	0.031
Bedroom 1	0.025	0.037
Bedroom 2	0.020	0.031
Bedroom 3	0.026	0.036
Bedroom 4	0.022	0.032
Bathroom	0.022	0.025
W.C.	0.018	0.019
Kitchen	0.041	0.027

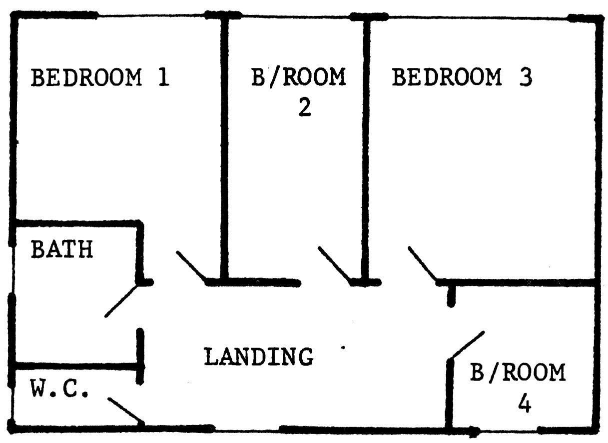
The main point to note from the results is that the background leakage areas of the rooms are of similar magnitude to the areas of the cracks around doors and windows in the rooms. Although the smaller background leakage areas occur for the smaller rooms (bathroom and W.C.), the largest background area does not occur for the largest rooms (lounge/dining room). Another point to note is that neither the room component areas nor the background leakage areas can be summed to give a total for the house. This is because some doors and some room surfaces are common to two rooms.

Account should be taken of background leakage areas when considering the ventilation of dwellings. This is likely to be more important for low-energy houses than for normal houses, since "weather-stripping" (e.g. reducing the open areas of

DOWNSTAIRS PLAN



UPSTAIRS PLAN



cracks by application of foam strip) of the windows and doors will tend to increase the proportion of the total ventilation associated with the background leakage areas. By the same token, the effect on the air change rate of a house due to weather-stripping is effectively reduced by the presence of the background leakage areas. The problem of background leakage becomes very apparent when one is concerned with the prediction of ventilation of multi-room dwellings with a mathematical model. This is because one would ideally like to know not only the magnitude of the background leakage areas, but also the manner in which they communicate, both between the exterior and the interior. Such information could be extremely difficult to obtain in full and for most purposes approximations will probably have to be employed. In the next Section a mathematical model which is being developed at Watson House is briefly described and the treatment of background leakage areas discussed.

PREDICTION OF VENTILATION

In essence the mathematical model[3] consists of the continuity equation coupled with the crack flow equations[2]. The latter equations are semi-empirical in nature, having been derived from laboratory tests but with a good theoretical backing. Measurements in a test house have shown that the equations describe accurately the flow through the cracks of real doors and windows. When a dwelling is being studied, the individual open are each allotted a crack flow equation and this system of equations is solved with the continuity equation, once the required meteorological conditions and dwelling characteristics are specified.

The required meteorological conditions are wind speed, wind direction and external temperature. In addition the internal temperature must be known so as to account for stack effect.

The pressure distribution generated by the action of the wind over the exterior of the dwelling has to be known. Strictly speaking this is as much a characteristic of the dwelling as it is of metrorological conditions, since it is determined by the shape and location of the dwelling as well as by the wind. The pressure distribution and its dependence on wind direction can be obtained conveniently from wind tunnel tests, but it is essential that the atmospheric boundary layer characteristics be simulated as closely as possible.

The dwelling characteristics which have to be specified are the geometry and physical dimensions of the various open areas. For open areas of the second group referred to above, this information can be obtained by direct measurement or by a combination of mensuration and pressure/extract measurements[2].

For background leakage areas this information can only be obtained from pressure/extract measurements. For general calculations with hypothetical dwellings, estimates would have to be made on the basis of experience of such measurements, and this is one area where further work is required. As well as estimates of the size of the background leakage areas, one also has to specify the spaces between which they communicate, but this is extremely difficult to do. However, the problem can be considerably simplified if one restricts the predictions to total air change rates of dwellings for the case with all internal doors open. For this case the internal open areas can be neglected and one is only concerned with the proportion of the background leakage areas which communicate with the exterior. By carrying out a fairly simple test on the house an estimate of this proportion can be made, This has been done for the four-bedroom test house referred to above.

Briefly, a large fan was used to supply air to the house at a known rate and the pressure inside the house relative to the outside was measured. Calculations were then carried out with the model using different distributions of background leakage area, and the distribution giving the best agreement with the measured pressure difference was found. For the house in question, this distribution was such that 50% of the background leakage areas of the downstairs rooms communicated through the external walls. In the upstairs rooms, 40% communicated through the external walls and 25% through the ceiling into the loft space.

ILLUSTRATIVE PREDICTIONS OF GENERAL TRENDS

The prediction method described above can be used in its present stage of development for illustrating some of the problems that could arise with the ventilation of low-energy dwellings. Calculations for this purpose are presented below. The calculations relate to a hypothetical detached house with four bedrooms, although the open areas of the various room components and the pressure distributions are values that have been measured for other houses. The size and distribution of the background leakage areas correspond approximately to those determined for the test house referred to above.

Fig. 1 shows the predicted variation of air change rate with wind speed for a westerly wind and for a range of values of the internal/external temperature difference, ΔT. The air change rate is defined as the volume flow rate of fresh air entering the house divided by the volume of the house. It can be seen that above a certain wind speed the predicted air change rate is independent of ΔT. This is to be expected, because the pressures generated by the wind increase as the square of the wind speed, so that as the wind speed increases, the pressures generated by the stack effect eventually become negligible. Below the critical wind speed, the predicted air change rate is virtually independent of wind speed and depends only on ΔT. In the prediction method the pressures generated by the stack effect are simply added to the pressures generated by the wind. As a result of this, one would expect the predicted behaviour, because on the windward face the positive pressure due to the wind will tend to increase the inflow to the house on the lower floor, but it will tend to oppose the outflow on the upper floor. The net effect will therefore tend to be small. The same argument applies to the leeward face. Hence the nett result of the wind effect and stack effect will be a tendancy for the total air change rate to remain constant, until the pressures generated by the wind become sufficiently large. The predicted behaviour in Fig. 1 can be observed in some recent ventilation measurements carried out in a terraced house of new construction (see Fig. 2). The wind direction is not the same for each measurement and the ΔT values range from 14°C to 20°C, nevertheless the predicted behaviour is still evident.

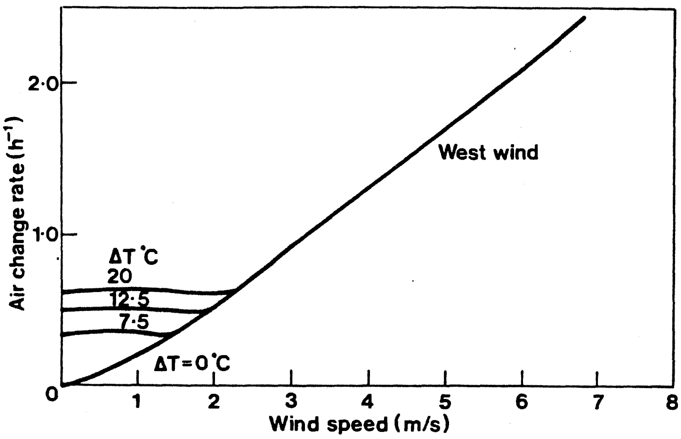


Figure 1

Predicted variation of whole-house air change rate with wind speed and temperature difference

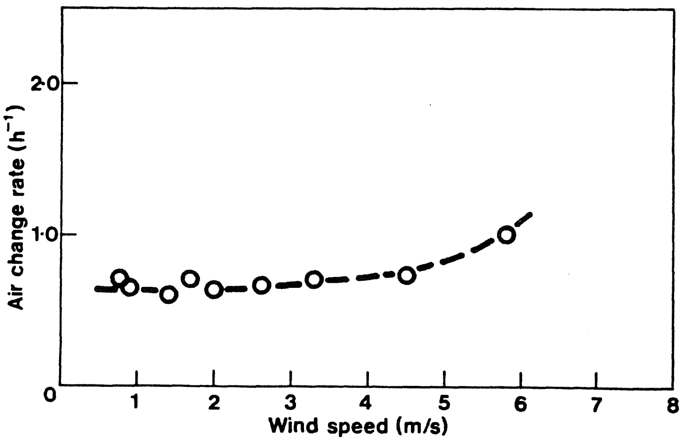


Figure 2

Whole-house air change rates measured in a terraced house, illustrating the importance of stack effect

Fig. 3 illustrates the large changes in predicted ventilation which can occur when the wind direction changes and when the wind speed is fairly high. The two wind directions shown represent the extreme cases and fluctuations in the direction of the real wind would tend to reduce their differences in practice. However, it still seems probable that certain changes of wind direction could lead to a doubling of the air change rate.

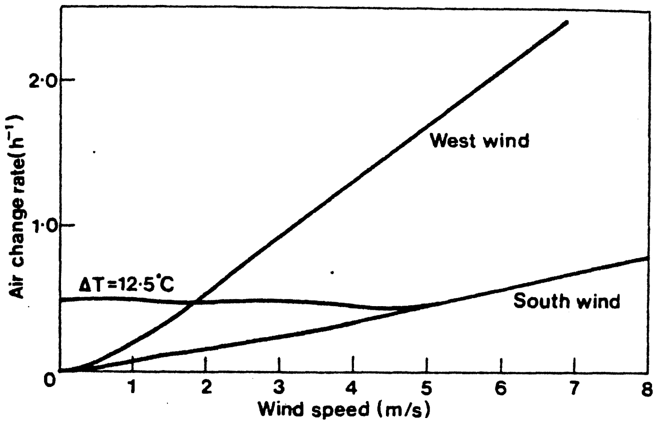


Figure 3

Predicted variation of whole-house air change rate with wind speed for two wind directions

Fig. 4 shows the frequency distribution of wind direction for a site in London[4] and it can be seen that the wind lies for a significant time in all the possible directions. Moreover the frequency distribution of the wind speed, also given in Fig. 4, indicates that large changes in ventilation rate due to changes in wind speed are likely to occur often.

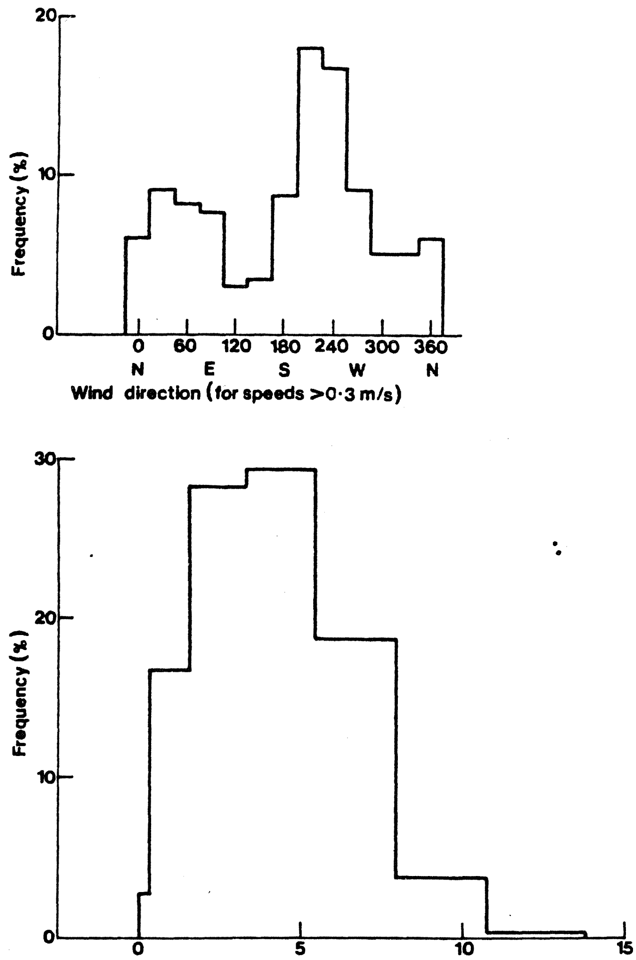


Figure 4

Frequency distributions of wind direction and wind speed at Kew, London

Fig. 5 shows the effect of neglecting the background leakage areas on the predicted air change rates. It is clear that the background leakage areas should be taken account of, since for this particular case they account for about 50% of the total air change rate. This is similar to the measurements for the semi-detached house given by Skinner[1].

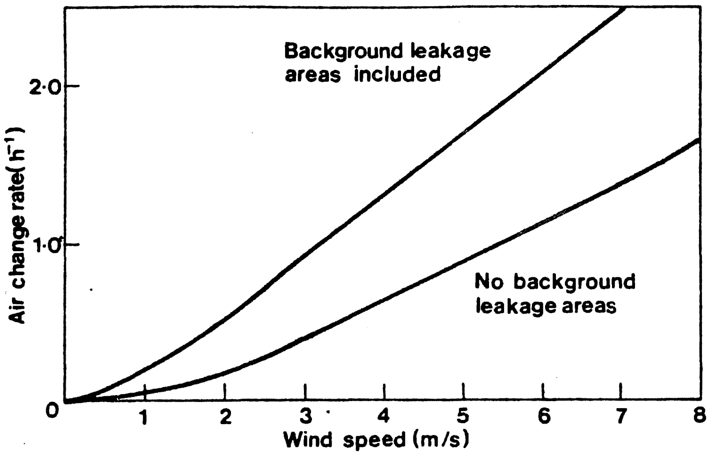


Figure 5

Predicted variation of whole-house air change rate with wind speed, illustrating the importance of background leakage areas

Fig. 6 shows the flowpaths taken by the ventilation air for one particular case (internal doors closed) where the wind effect is dominant over the stack effect. It can be seen that there is a strong tendency for the air to enter through one side of the house and exit through the others. The figure also shows the distribution of the background areas and their contribution to the ventilation rate.

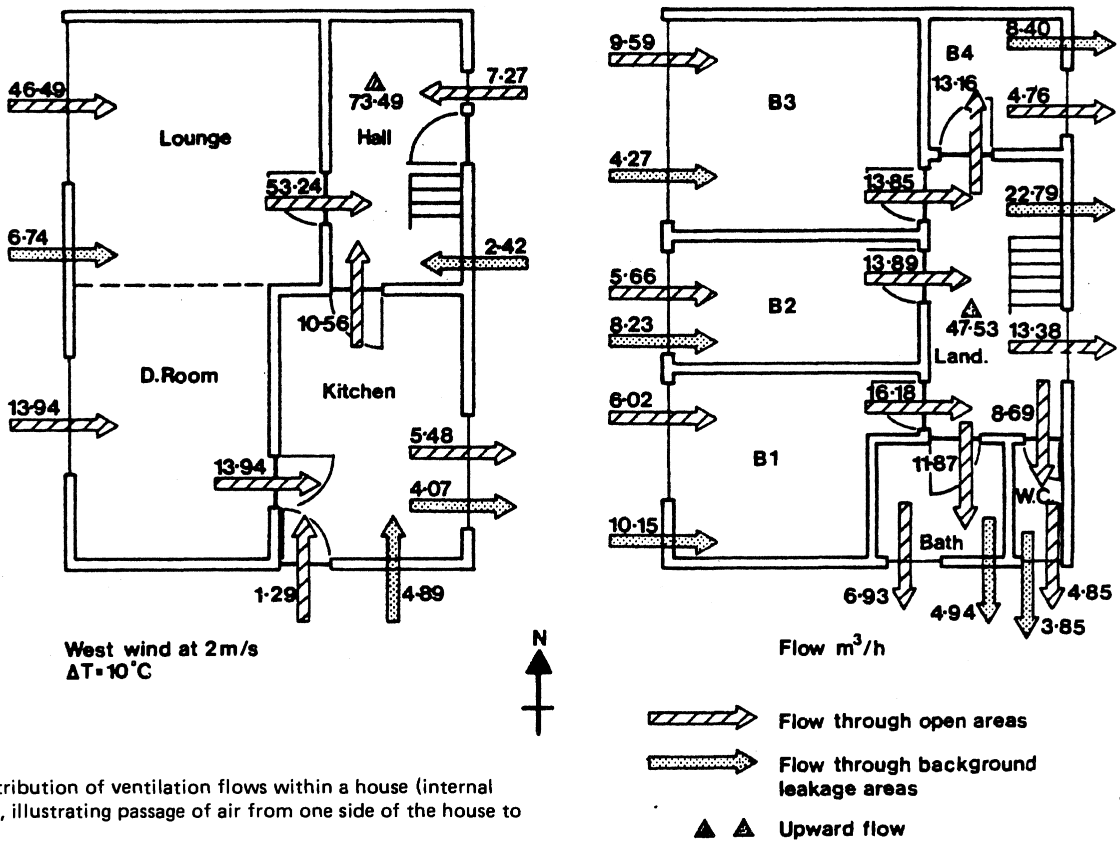


Figure 6

Predicted distribution of ventilation flows within a house (internal doors closed), illustrating passage of air from one side of the house to the other

IMPACT OF VENTILATION ON DESIGN AND PERFORMANCE OF SPACE CONDITIONING SYSTEMS

Natural ventilation or infiltration may have a significant influence on the performance of heating systems in a well insulated house. The discussion in this paper if focussed on the situation where mechanical ventilation is not provided. However, the following brief comments are worth mentioning here. Mechanical ventilation is one method of overcoming some of the uncertainties inherent in natural vantilation. Whole house mechanical ventilation, i.e. where both a supply and extract are provided, could permit heat recovery from the extracted air, but the extra capital cost involved has to be taken into account. In the United Kingdom, for mechanical ventilation to become a cost-effective energy conservation measure, the relative price of fuel would have to rise substantially[5]. Our studies indicate that in situations where mechanical systems are used, unless precautions are taken, infiltration will probably have a significant role, imposing a large fluctuating component onto the basic ventilation rate.

It is convenient to consider the impact of natural ventilation under two headings, i.e. in terms of total whole-house air change rates and in terms of the air supply to individual rooms (see following). Under the first heading the magnitude of the ventilation rate and heat losses are considered, and in particular the effects of variation of ventilation rates on the design of plant for the whole house. Under the second heading the way in which the ventilation paths in the house affect the sizing of emitters is discussed. Before proceeding to this however, some other points are worthy of mention.

Fresh air requirements[6] of a typical house having a floor area of $90m^2$ are in the region of 45 1/s, which represents an air change of circa 0.8 volumes per hour. Of equal importance is how the supply of fresh air is distributed throughout the house. The greatest need will be in the living room, especially if smokers are present. It is a reasonable assumption that occupants will take action, e.g. by opening windows, to ensure an acceptable environment. It would therefore be unrealistic in the pursuit of energy conservation not to take these needs into account.

The manner in which air enters a room can also be of importance. A well insulated room retaining a single glazed window could be susceptible to low level draught problems. The relative price of fuel would have to rise substantially for double glazing to be cost-effective in the British climate[5]. Cold currents generated by the window surface combined with infiltration could dominate the room air movement pattern in a well insulated enclosure, especially if for reasons of economy, radiators were positioned on inside walls. Subjective tests in a controlled temperature room at Watson House have shown that low level cold draughts can result in overall discomfort. For the tests, an optimum temperature of 23°C was maintained in the test chamber and subjects were exposed to simulated low level draughts at a constant velocity of 0.2m/s and varied temperatures. Results indicate that a draught temperature of 19°C in an otherwise optimum thermal environment would cause dissatisfaction of 30% of the subjects. The siting of heat emitters and their ability to respond to varying ventilation rates is therefore important. It is interesting to note here that by their very nature, background leakage areas are unlikely to cause detectable draughts.

Whole-House Air Supply Rate

Energy conservation considerations are the most obvious motives for trying to minimise the ventilation heat loss of dwellings. Fig. 7 illustrates how the ventilation heat loss becomes more important with higher insulation levels, constituting nearly one half of the total design heat loss in the well insulated house. The ventilation heat loss was calculated on the basis of empirical values in the 1970 IHVE Guide[7] Table A4.8 and is therefore identical for all three cases. A semi-detached house has been chosen as an example because it is the most numerous type of dwelling in the United Kingdom. Houses - detached, semi-detached and terraced - account for 78% of all existing dwellings and 70%[8] of new dwellings and this trend is likely to continue.

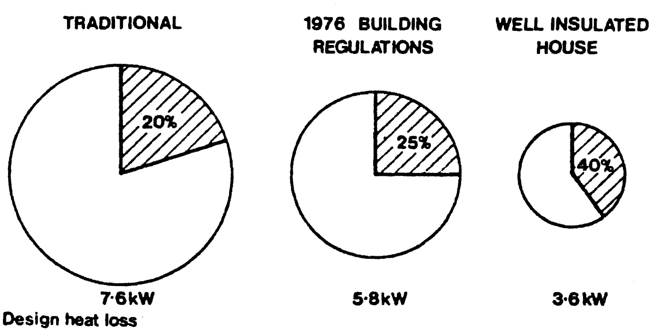


Figure 7

Ventilation heat loss as percentage of total design heat loss of a typical semi-detached house of $90m^2$ floor area for three insulation levels.

(The specific fabric heat losses are: Traditional $1.4W/m^{3\circ}C$; 1976 Building Regulations $1.0W/m^{3\circ}C$; Well-insulated $0.5W/m^{3\circ}C$).

The design heat loss is based on a mean internal temperature of 19.3°C, external temperature -1°C and a mean ventilation rate of 1.02 air changes per hour.

Higher levels of insulation have resulted in smaller heat emitters or other sources of heat being required, resulting in increased sensitivity to any imposed load such as ventilation. Two factors combine to reduce the heat emitter size even further. The first is an economic pressure to save capital cost and as a result, emitters are not being oversized as had been the practice. The second stems from an attempt to tackle the largest single remaining component of the overall heat loss - the ventilation heat loss. By specifying "tight" or "weather-stripped" windows without fully taking into account the fresh air requirements of the occupants significant reductions in the size of the installed plant can apparently be made. Hence, the variation in air change rate which can arise as a result of variations in wind speed and direction (Fig. 3) could lead to large changes in the heat demand of the house.

In practice, a building services engineer in the United Kingdom will probably use the IHVE Guide Section A4 to calculate the infiltration heat loss of weatherstripped windows. The method takes into account the actual crack length and is based on recommended window infiltration coefficients (*l*/ms at $1N/m^2$). Results of calculations of air change rates for a typical living room, as well as the usual recommended design air change rate* (Table A4.8), are summarised in Table 2. The recommended design value is identical for both the weather-stripped and the non-weatherstripped situation and is of the same order as the non-weatherstripped crack length value. The air change rate for the weatherstripped case shows a reduction by a factor of five. These values are applicable to single rooms therefore to sizing of heat emitters, and the Guide suggests that approximately only one half of the sum of the room values should be taken into account when sizing the central plant (outside air enters only the windward rooms).

Although the crack length method may be satisfactory for office buildings, factories or even flats, or where mechanical ventilation is employed, it is obvious that serious difficulties can arise if used for houses. The reason for the divergence has been discussed above, i.e. the significant influence of background leakage open areas and of the needs of occupants.

To examine the sensitivity of the thermal response of houses (and individual rooms) to ventilation rates different from those used in the heat loss calculations, a series of computer simulations have been carried out. A well insulated semi-detached house of traditional construction described in Table 3 was used for the analysis. To simulate a real life situation as near as possible clear and cloudy design days, having a mean temperature of -1°C, based on an analysis of 20 year weather data were used. Incidental gains and system operation are tabulated in Table 4. The computer program used for the analysis has been developed on the basis fo Rouvel's work[9].

* To be used when the window characteristics and building plan are not known or when calculation is impracticable or inappropriate.

TABLE 2

Air change rates of a typical living room - empirical and crack length method. Volume = 5.2 x 3.5 x 2.3 = 42m^3. Crack length 10m; Surburban site (normal exposure)

	WINDOW INFILTRATION COEFFICIENT (l/ms) AT 1N/m^2	INFILTRATION RATE PER METRE (l/s)	AIR CHANGE RATE RATE (h^{-1})
Empirical IHVE Guide Value			
Non-weatherstripped	–	–	1
Weatherstripped	–	–	1
Crack Length Method			
Non-weatherstripped	0.25	0.2	0.86
Weatherstripped	0.05	1.0	0.17

TABLE 3

Construction and heat loss of well insulated semi-detached house used in computer simulation studies

Construction

Internal Wall:

Plaster – 16mm
Lightweight block – 110mm
Plaster – 16mm

Ground Floor:

Carpet – 10mm
Timber – 20mm
Glass Fibre – 25mm
Concrete – 1000mm

External Wall:

Plasterboard - 16mm
Lightweight Block – 110mm
Polystyrene – 50mm
Brick – 115mm

Internal Floors/Ceiling:

Plasterboard – 10mm
Air Gap – 50mm
Timber – 20mm

Roof:

Plasterboard – 10mm
Glass Fibre – 100mm
Tiles – 10mm

Heat Loss

	AREA m^2	'U' W/m^2°C	'UA' W/°C
Roof	46.6	0.30	14.0
Wall	83.8	0.40	33.5
Floor	46.6	0.45	21.0
Window	14.1	2.50	35.3
Specific Fabric Heat Loss			103.8

As an example the results of two computer simulations are shown in Fig. 8, where the energy requirement and internal and external temperatures of a well insulated house (Table 3) on a cloudy design day are given. In both simulations the heating system was operated intermittently and a conventional plant size ratio of p= 1.2 (i.e. 20% was added to the design heat loss) was used. The design heat loss was based on a calculated air change rate of 0.2 volumes per hour; the Guide recommendation to halve the sum of room values having been disregarded, as it would have led to an extremely low value. In the first simulation the air change rate was kept to the design value of 0.2 volumes per hour and the temperature chart shows that the house required six hours to reach the design temperature of 20°C (test house results confirm this behaviour for similar plant size ratios[10]). In the second simulation the air change rate has been changed to one volume per hour (while all the other parameters remain the same) with the result that the internal temperature never reaches the design value although the plant operated at full capacity. The maximum temperature at the end of the heating period reaches only 18°C; the mean over the heating period being slightly below 16°C. Such internal temperatures would inevitably lead to severe complaints.

TABLE 4

System operation used in computer simulation studies

Occupancy

(i.e. time period when internal design temperatures should be maintained) — 8.00 - 23.00 hrs

Internal Design Temperature — 20°C

Lights — 300W

a.m. – on : 8.00 hrs — p.m. – on : 1 hr before sunset
a.m. – off : 1 hr after sunrise — p.m. – off : 23.00 hrs

Other Heat Gains

A weighted average of gains from people, domestic appliances, DHW, etc.

– day : 600W – night : (all occupants presumed : 667W in house (2 adults, 2 children))

Intermittent Operation

Heating System

– on : 6.00 hrs – off : 23.00 hrs.

Preliminary studies using the Watson House ventilation computer program indicate that the mean air change rate of a "tight" or "weatherstripped" house at design conditions is higher than conventional calculations would suggest (0.1 - 0.2 volumes per hour) and would be in the region of 0.5 plus, depending on the design and general workmanship of the house. The above example (Fig. 8) confirms that air infiltration through background areas (dependent on workmanship) has to be taken into account if complaints of discomfort are to be avoided.

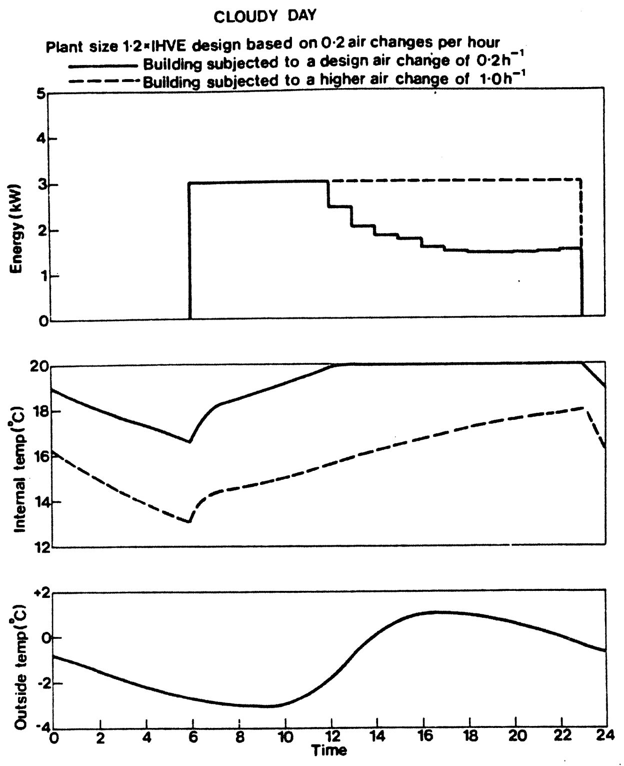


Figure 8

Energy consumptions and internal temperatures of a well-insulated house on a cloudy design day ($T_{MEAN} = -1^{\circ}C$).

Other simulations have shown that systems designed to operate continuously (plant size ratio = 1) would also fail to reach internal design temperatures. A system designed for an air change of 0.2 volumes per hour when subjected to an air change of one volume per hour would achieve only an internal temperature of 17 - 18°C.

The results of the study indicate that solar and miscellaneous internal heat gains cannot be relied upon to compensate for higher than design ventilation rates.

Distribution of Air to Individual Rooms

The flow rates and flow paths in Fig. 6 indicate that under certain conditions the bulk of the fresh air may be entering a house through one particular side. If this is so, then the overall air change rate for the house may be irrelevant to the conditions in individual rooms, although retaining its importance in determining the boiler size. Individual room flow rates are all the more important because with higher values the probability of dissatisfaction caused by draughts is greater. In this context it should be remembered that the situation in a home is different from that in an office. In an office a percentage of occupants will always be dissatisfied and such a situation is accepted,.in the home the space conditioning system has to satisfy the individual occupant.

A typical room (Fig. 9) was chosen for computer simulation studies of the consequences of a change in the direction of flow of air. As an example the internal temperatures for an inflowing and outflowing situation on a cloudy design day and continuous heating are shown in Fig. 9. The heat output of the emitter in this situation was varied with external temperature (graph in Fig. 9) as an external compensator control would do. The temperature chart shows that for the design ventilation rate the required temperature is attained. The outflowing situation results in a degree of overheating but the inflowing condition would create thermal dissatisfaction.

The situation on sunny and cloudy days as well as for north and south facing rooms for various ventilation rates was also explored. The results of the simulations are summarised in Fig. 10 where the mean internal temperature is plotted against the ventilation rate. The results show a high sensitivity of internal temperature to ventilation rate at the design condition of 0.2 air changes per hour. The graph indicates the desirability of individual room tempeature control and sufficient heat emitter output especially as the peak values of internal temperature for the south facing sunny day are significantly higher than the mean values.

Other modes of control of the heating system, except inividual room temperature control combined with sufficient flexible heat emitter output, would result in a worse disparity between conditions in individual rooms, especially if the inflowing condition were to coincide with a north facing orientation and the out-flowing condition with a south facing orientation on a sunny day. This is evidently true for the most widespread control system in the U.K. where the operation of the whole heating system is controlled by a single room thermostat either in the living room or in the hall.

The above computer simulation studies show that natural ventilation is one of the factors that will influence the choice of control systems for well insulated houses.

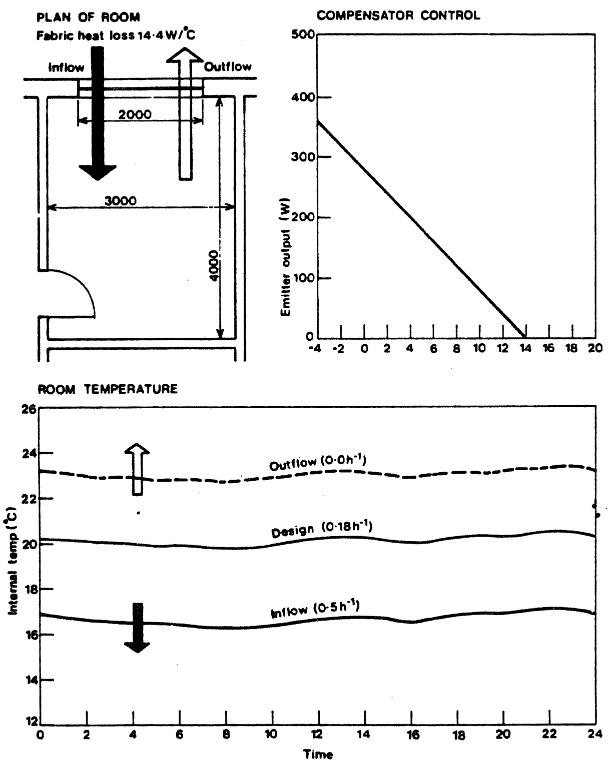


Figure 9

Internal room temperatures for an inflow and outflow situation on a cloudy design day ($T_{MEAN} = -1^{\circ}C$). Heat output varied with external temperature to sinulate an external compensator control.

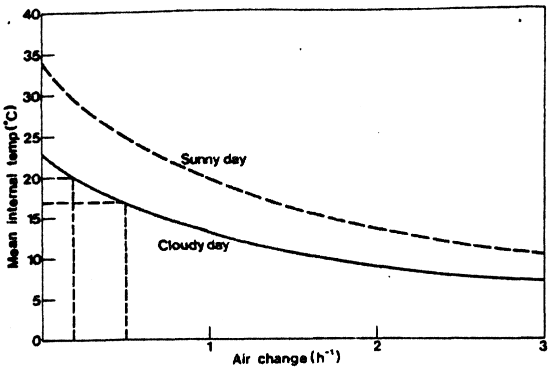


Figure 10

Effect of air change rate on the mean internal temperature for sunny and cloudy design days (T_{MEAN} = -1°C), continuous heating, simulated external compensator control. Sunny day = Sunny south facing room. Cloudy day = Cloudy south and north facing room and sunny north facing room.

CONCLUSIONS

The major conclusions to be drawn from the work described above are as follows.

When estimating the overall air supply to dwellings, allowance should be made for air infiltration through background leakage areas, which can be as large as that through cracks around doors and windows. Present day design procedures for estimating ventilation rates do not consider background leakage areas and consequently these procedures are likely to underestimate ventilation heat losses. For well-insulated dwellings, this could lead to a serious underestimation of the total heat requirement of the dwelling.

Large variations in ventilation heat losses, and hence total heat requirement can occur as a result of variations in wind speed and direction. This could lead to problems in sizing the appliance for well-insulated dwellings. In addition, a problem is likely to occur in sizing the heat emitters of individual rooms, as a result of the wide range of infiltration routes of the ventilation air. One solution to this problem might be the adoption of individual room temperature control.

Attention should be given to the avoidance of low-level draughts because it has been found that these can cause significant discomfort. With the small emitters of well-insulated dwellings, such draughts are more likely to occur, particularly if the emitters are placed on inside walls,

Careful consideration should be given to ventilation phenomena when designing space heating systems for well-insulated dwellings. It is believed that prediction methods, such as that described here, will be useful for predicting general trends and also possibly for application to specific types of dwelling.

ACKNOWLEDGEMENTS

The authors wish to thank the British Gas Corporation for permission to publish this paper, and their colleagues Mr. S.L. Pimbert and Mr. P. Phillips for their valuable contributions to the work described.

REFERENCES

1. Skinner, N. Natural Infiltration Routes and their Magnitudes in Houses. Pt. 2. Conference on Controlled Ventilation, Aston University, England, 24 Sept. 1975.
2. Etheridge, D.W. Crack Flow Equations and Scale Effect. To be published in Building and Environment.
3. Etheridge, D.W. & Phillips, P. The Prediction of Ventilation Rates and Implications to Energy Conservation. In preparation.
4. Penwarden, A.D. & Wise, A.F.E. Wind Environment around Buildings. Dept. of Environment, Building Research Establishment, HMSO, 1975.
5. A BRE Working Party Report. Energy Conservation: A Study of Energy Consumption in Buildings and Possible Means of Saving Energy in Housing. CP 56/75 June 1975.
6. Tipping, J.C., Harris-Bass, J.N. & Nevrala, D.J. Ventilation and Design Considerations. BSE, Vol.42, Sept. 1974, p. 132 - 141.
7. IHVE Guide, Book A 1970. Published IHVE 1971.
8. Housing and Construction Statistics HMSO.
9. Rouvel, L. Berechnung des warmetechnischen Verhaltens von Raumen bei dynamishen Warmelasten, Special supplement "FFE Berichte No. 2" to Brennstoff-Warme-Kraft 24 No. 6 (1972).
10. Nevrala, D.J. Heat Services for Future Housing Pt. 1 The Insulated House Design Requirements. Building Services Engineer, 45, Oct. 1977, pp 107–117.