ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

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PAPER 2

USE OF NATURAL VENTILATION

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SYNOPSIS

Ventilation needs are outlined to show that odour dilution and moisture control are the major winter factors. Detailed studies on 24 well insulated houses show that the window opening habits are clearly linked to the outdoor temperature. More windows are opened in milder weather but even in the coldest weather some windows are open. Moisture measurements inside the house confirm this trend.

Energy input analysis shows that space heating only provides a quarter of the total heat, the remainder comes from casual sources. Analysis of energy loss suggests that a third of the losses are attributed to ventilation, the remainder through the building fabric. This ventilation loss is equally divided between infiltration and window opening. Average house seasonal ventilation rate is half an air change per hour.

1. INTRODUCTION

The five factors which influence space heating energy are:

1. Fabric insulation
2. Infiltration losses
3. Internal temperature
4. Free heat from sunshine and occupancy
5. User ventilation

The energy loss through fabric insulation is well recognised and insulation standards in Britain have been rapidly improving. Infiltration is an active research area. Ventilation rates vary according to wind and stack effects but average values for a house with closed windows and doors vary between one-third of an air change each hour to one and three-quarters. Internal temperature is assumed to be under the control of the occupant. In practice it is more usual for the living room to be controlled and for the temperature of the rest of the house to float somewhere between the living room and the outdoor temperature. The free heat comprises sunshine and internal heat. The influence of sunshine is mainly a function of the prevailing cloud cover and of the window sizes and directions. The internal heat is a function of the number and activity of the occupants themselves and of the number of electrical appliances in use, such as lighting, television and refrigeration.

The major unknown is the energy loss due to the ventilation behaviour of the occupants. This paper describes a study to estimate this energy cost.

2. PREVIOUS WORK

The minimum ventilation requirement in a room is determined by the permissible carbon dioxide concentration. Carbon dioxide is exhaled during respiration. This limit is not normally reached because infiltration is more than adequate. The usual criteria are comfort and absence of smell. More generous ventilation is needed for this. A less clearly defined criterion is moisture control. The air in Britain is near saturation for the duration of winter. If the internal environment is to be controlled then more air will be needed in milder weather to dilute the moisture. The relative importance of these factors is illustrated in figure 1.

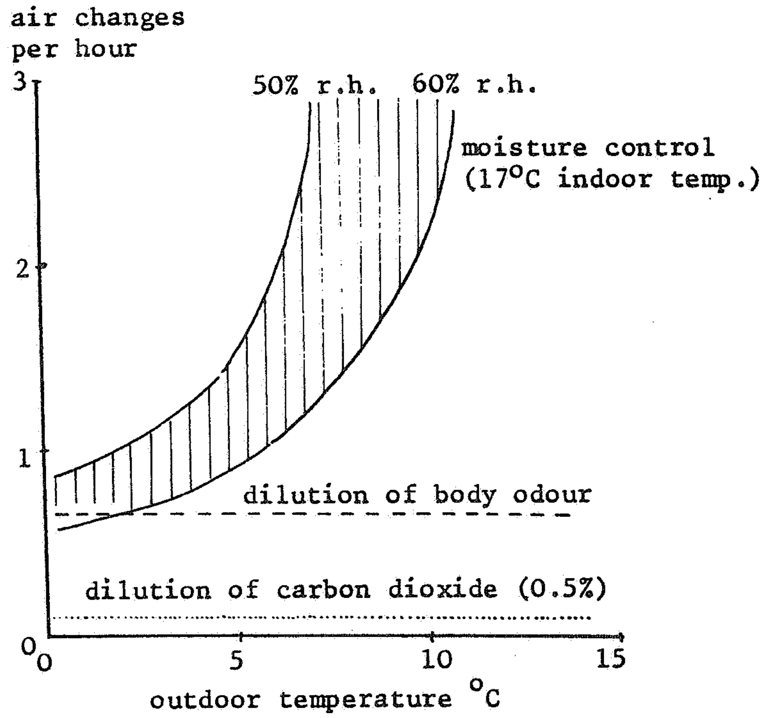

Figure 1 Ventilation needs for a living room
(2 sedentary adults, $30m^3$ volume room)

Behavioural studies have identified the link between window opening and outdoor temperature or moisture. Monitoring studies have resolved temperature and energy flows within low energy dwellings. The Electricity Council have made particularly comprehensive measurements on a group of twenty-four houses in Scotland and these form the basis of this analysis. The user window opening behaviour was also recorded.

3. FIELD TRIALS

3.1 The Houses

The houses are situated in an open and fairly exposed area 12 miles west of Aberdeen. Around 500 were built here by Gordon District Council to meet the urgent need for accommodation in north-east Scotland. The test houses are all prefabricated timber construction with high levels of thermal insulation and weatherstripping. Double glazing is standard throughout the houses. Each house has three bedrooms. Three house types were selected: detached, end-terrace and mid-terrace. An unusual feature is the party wall between the terraced houses. This is a double wall which is constructed and insulated as if it was an external wall to each house. It is therefore doubly insulated and house to house heat transfer will be negligible.

Electricity is the sole form of energy supplied to the houses and was charged at the normal domestic tariff. Space heating is provided by direct acting, proportional control, wall mounted heaters, supplemented in each of twenty of the houses by a radiant log-effect electric fire. This system is controlled by a two zone time clock programmer.

A central hot water storage system is provided, with the cylinder (114 litres) in a first floor cupboard. The cylinder is heated by a 3 kW immersion heater and is factory insulated with (22mm) polyurethane foam.

Each kitchen is provided with a manually operated extractor fan. Each window has a manually controlled ventilation slot.

Dimensions and thermal properties of the houses are listed in Table 1. Twenty-four houses were monitored. Results were incomplete in one house because of equipment problems.

The results given apply to the period 25th October, 1977 to 23rd May, 1978.

3.2 Monitoring

Each house had three electricity recorders. One continuously measured the space heating energy, one the water heating and one the remaining energy used by cooking, lights and appliances.

Thermographs were used to record living room, hall and bedroom temperatures. Some moisture measurements were taken in bedrooms by recording thermohygrographs. Market researchers interviewed the occupants to establish family size and the reported use of the heating system. Ventilation habits were also noted. A spot check of rooms with an open window was made each weekday for each house, between either 0009-1230 or 1400-1630 h.

Systematic recording of the weather included wind speed and direction, outdoor air temperature and humidity, rainfall, and solar irradiance on the horizontal surface.

3.3 Measurements

The average temperatures and energy consumption figures for each house type are included in Table 1. There was little difference in space heating energy between the different house types but there was a systematic difference in house temperatures. Mid-terraced houses were generally warmer than end-terraced houses, which in turn were warmer than the detached houses.

Table 1 House details: Summary 25th October 1977 - 23rd May 1978

House type		Det-ached	End-terrace	Mid-terrace
Number in sample		9	11	3
Floor area m^2		109	99	99
Fabric heat loss (18^{o}C Δt)	kW	1.88	1.61	1.38
Ventilation heat loss (18^{o}C Δt)	kW	1.68	1.62	1.62
Specific heat loss Watts/^{o}C		102.4	86.0	78.8
Heating equipment (direct electric)	kW	8.4	6.6	6.6
Average winter temperature: outside	^{o}C	4.4	4.4	4.4
Average bedroom temperature	^{o}C	14.2	15.1	16.2
Average hall temperature	^{o}C	13.9	15.3	15.7
Average living room temperature	^{o}C	17.1	18.0	18.4
Average bedroom relative humidity	%	61	59.3	58.5
Space heating	kWh	2021	2194	1995
Electricity for hot water	kWh	2459	2175	2162
Electricity for cooking, etc.	kWh	2208	2253	2258
Useful electrical gains	kWh	5377	5158	4782
Useful energy from people	kWh	917	930	930
Solar gains	kWh	1355	1365	1365
Total useful energy in house	kWh	7650	7454	7077
Mean internal/external Δt^{o}C		9.6	10.5	11.0
Average open windows over winter per house		1.66	1.14	1.03
Average total ventilation rate	ac/h	0.49	0.51	0.50
Average ventilation due to window opening	ac/h	0.24	0.26	0.25

Ventilation calibration of one empty detached house showed the ventilation rate to be mainly a function of the outdoor wind speed. This relationship is shown in figure 2. The average wind speed was 2.3 m/s over this heating season and therefore the average infiltration was taken to be 0.25 ach. Pressurisation tests on representative houses showed the mid- and end-terrace houses to have similar characteristics to the detached one, and therefore the average infiltration was taken to be 0.25 ach for each house.

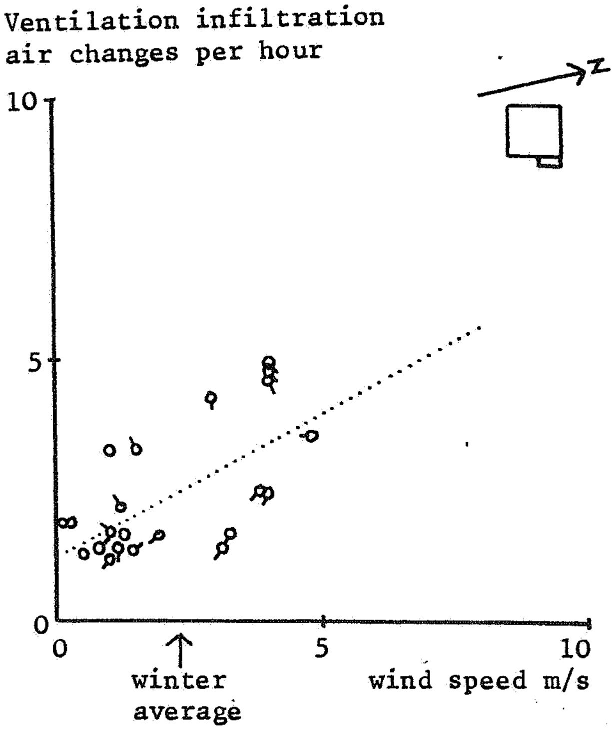

Figure 2 Ventilation characteristics of an empty detached house (Dickson, ECRC: personal communication)

The window opening behaviour was related to the weather according to the following relationship (correlation coefficient $r = 0.75$)

$$\text{Number of rooms with an open window/house} = 1.2 + 0.1 \times T - 0.14\ V\ \text{m/s} + 0.14\ R$$

where T = mean outdoor daily temperature ^{o}C
V = wind speed m/s
R = solar energy on the horizontal kWh/day

This is illustrated in figure 3. The earlier results of Dick and Thomas 1951, and Brundrett 1977 are included for comparison.

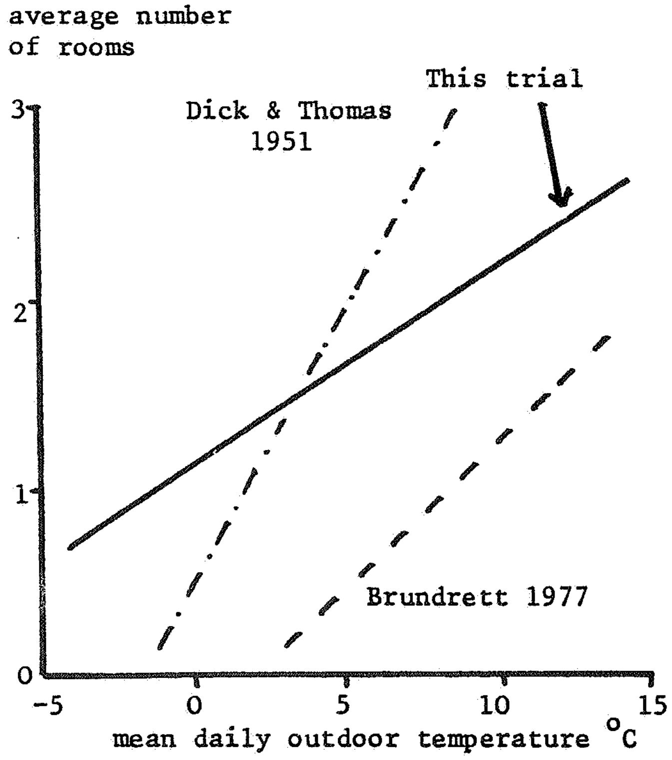

Figure 3 Relationship between open windows and outdoor air temperature

The windows which were found to be open are recorded in figure 4 as a daily average over the winter. This shows that the upstairs windows are the ones usually opened.

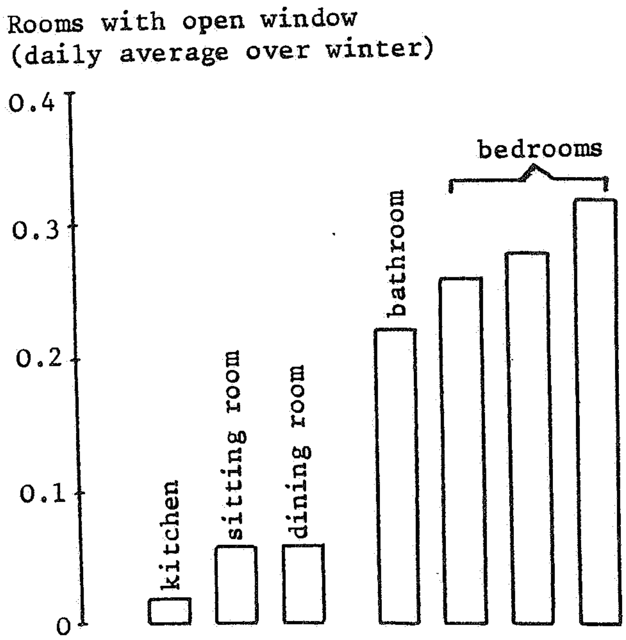

Figure 4 Distribution of windows opened

The thermohygrograph records of moisture in the main bedrooms showed a seasonal average of 60% r.h. This seasonal average varied between 54 to 67% r.h. for different houses. A particular study for part of the heating season was made for the bedrooms of the terraced houses. This is shown in figure 5. The indoor air moisture content was only influenced to a small extent by large changes in the outdoor air moisture content. This confirms the increase in ventilation rate in warmer weather as suggested by the pattern of window opening.

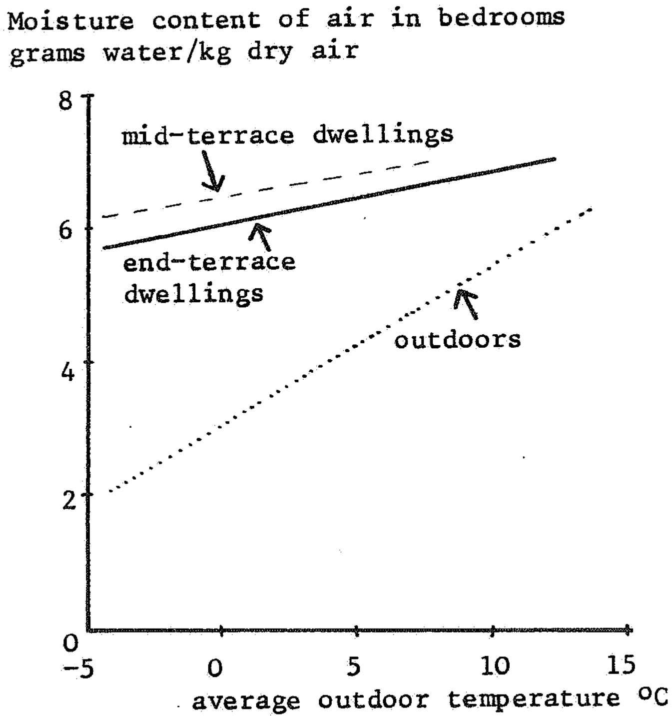

Figure 5 Moisture in bedrooms relative to outdoor air

4. ENERGY BALANCE

The four energy sources heating the homes are:

(a) Space heating. This is mainly by panel heaters but with an occasional use of the living room radiant fire.

(b) Other electrical gains. An approximation of the sensible heat gain from electricity is taken as 30% of the domestic hot water energy (15% through the lagging and 15% through the piping) and 87% of the rest of the electrical energy.

(c) The occupants themselves. This is a function of the number in the family and the time they spend at home. Four people at 90W per person will add up to 2000 kWh to the house over winter, depending on their time at home.

(d) Sunshine. The net solar gain was computed monthly for each face of three houses. The horizontal solar radiation was converted into incident radiation to vertical planes from empirical relations derived from measurements at Kew. Corrections were made for sky radiation loss and orientation sensitivity of the glass transmission coefficients. General solar gains, based on these three houses, were applied to all the houses.

The energy input for each house type is summarised in figure 6. This shows that the space heating energy only contributes a quarter of the total released in the home. The relationship between energy and house temperature was explored for the nine detached houses and this is illustrated in figure 7.

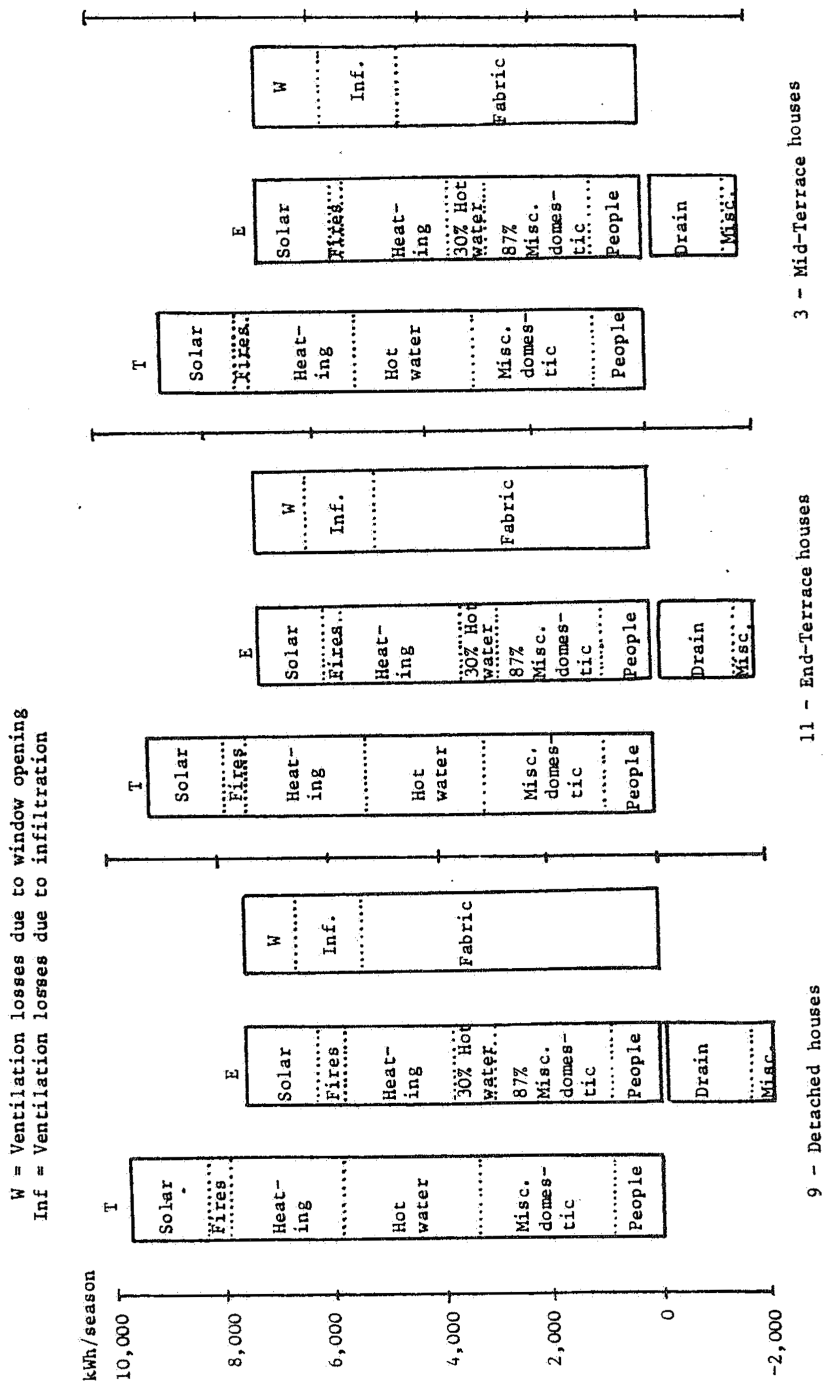

Figure 6 Energy input and losses in the houses over the heating season

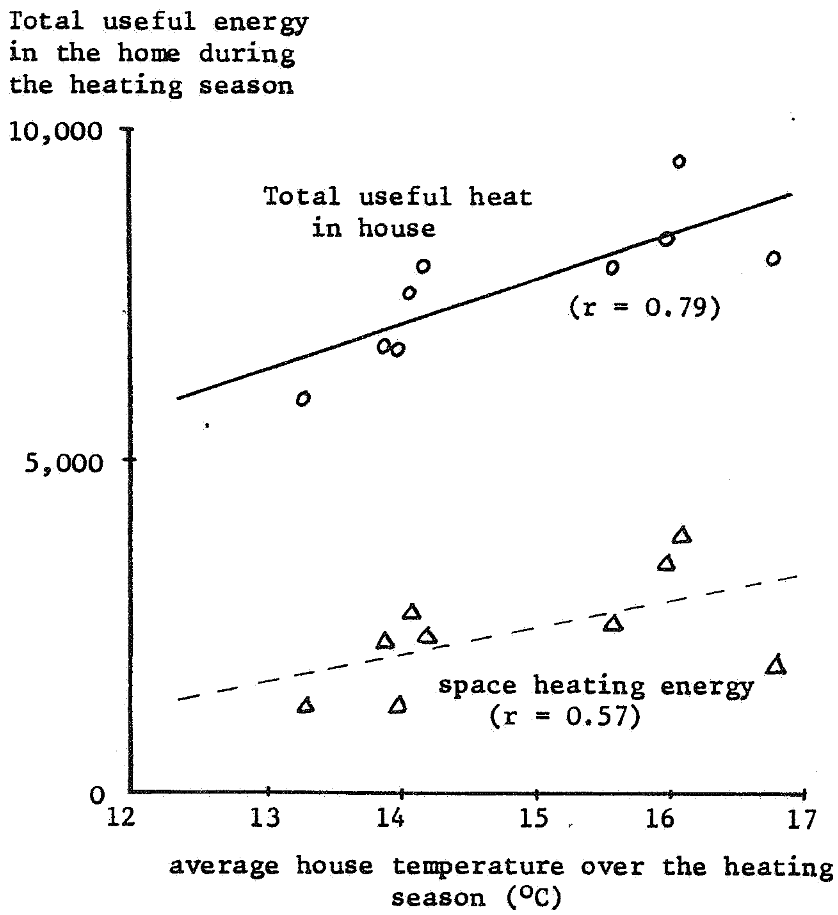

Figure 7 Energy into the homes as a function of house temperature (nine detached houses)

The four energy losses are:

(a) Fabric heat loss. This can be calculated from a knowledge of the internal temperature, the external temperature and the thermal transmittance of the building components.

(b) Ventilation heat loss. This cannot readily be calculated directly. It can be estimated as the difference between total useful energy released in the house, less that energy lost through fabric conduction. This estimate will also include all error terms.

(c) Hot water to drain. Since the losses from the domestic hot water systems are estimated at 30% of the total drawn, then the remaining 70% is assumed to go down the drain.

(d) Evaporative losses. Latent heat losses from moisture in the building fabric over the heating season are ignored. Minor losses from cooking will be lost as latent heat.

These loss routes, matched against the total energy supplied, are also shown in figure 6.

The detailed energy analysis was continued on the nine detached houses. This illustrates the loss mechanisms and shows ventilation to be a surprisingly constant energy loss, despite differences in average house temperature. The ventilation losses were calculated on the assumption that the ventilation route was into the house downstairs and from the house through the upstairs rooms. The ventilation loss was therefore taken at bedroom temperature (figure 8).

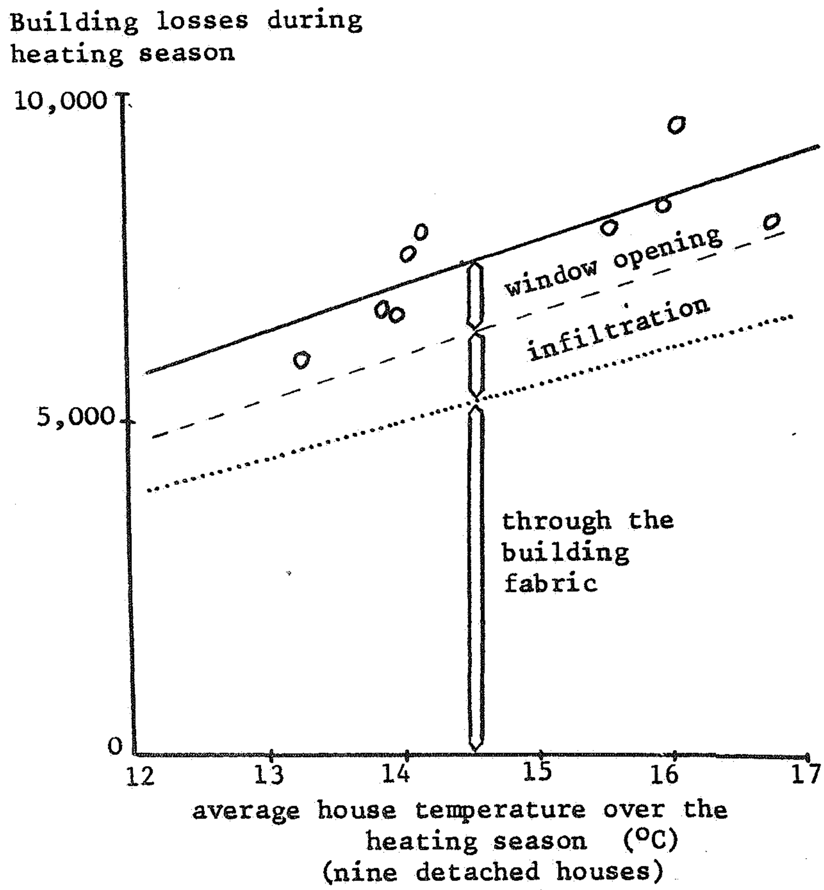

Figure 8 Allocation of energy losses in nine detached houses
(An additional 2,000 kWh is lost through drains and latent heat during cooking)

5. CONCLUSIONS

1. Studies of window opening behaviour in houses show that windows are seldom all completely closed. In average conditions houses have one or two rooms with an open window and the number reduces in colder weather and increases in milder weather.

2. Energy analyses for these houses show that only one quarter of the thermal energy in the home comes from the space heating equipment. The remaining 'free' heat comes from appliances, losses from hot water, sunshine and the occupants themselves.

3. Analysis of losses from the houses suggests that about a third is due to ventilation. The remainder is through the building fabric. Half of this ventilation loss is casual infiltration and half is attributed to window opening habits.

6. BIBLIOGRAPHY

1. AGIUS, P.J.V.
A Warmer house at lower cost.
Watt Committee Report, May 1979.

2. SIVIOUR, J.B.
Energy flows in six experimental houses.
CIB Second International Symposium on Energy Conservation, Copenhagen 1979.

3. GUNST, E. van.
Ventilation and infiltration in dwellings.
CIB S17 Symposium, Holzkirchen, 1977.

4. LIDDAMENT, M.
A survey of current research into air infiltration.
Air Infiltration Centre Technical Note TN-2-80, 1980.

5. WARREN, P.R. and WEBB, B.C.
Ventilation measurements in housing.
CIBS Proceedings, December, 1980, pp 22-34.

6. BS 5925: 1980.
Code of practice for Design of buildings: ventilation principles and designing for natural ventilation.

7. HEAP, R.D.
Heating, cooling and weather in Britain.
ECRC/M731, Electricity Council, 1973.

8. BRUNDRETT, G.W.
Window opening in houses.
ECRC/M801, Electricity Council, 1975.

9. DICK, J.B. and THOMAS, D.A.
"Ventilation research in occupied houses".
JIHVE, 19, 306-326, 1951.

10. BRUNDRETT, G.W.
"Ventilation: a behavioural approach".
Energy Research, 1, 289-298, 1977.

11. HARTMANN, P.
Fenster-Luftungsverhalten der Bewohner zweier Mehrfamilienhauser in Abhangigkeit vom Aussenklima. EMPA N39400/b Kurzfassung, April 1981.

12. LYBERG, M.D.
Energy losses due to airing by occupants.
CIB W77 Symposium, Dublin, pp. 6A 54-6A 65, 1982.

13. ENVIRONMENTAL ENGINEERING, ELECTRICITY COUNCIL
Heating in well insulated houses of lightweight construction at Kemnay, Aberdeenshire, by direct electric heating during 1977/78. ECR/R1304, 1979.

14. ENVIRONMENTAL ENGINEERING, ELECTRICITY COUNCIL
The domestic space heating field trials at Kemnay, Aberdeenshire. ECR/R1101, August 1977.