OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER 3

A PRELIMINARY STUDY OF WINDOW OPENING IN 18 LOW ENERGY HOUSES

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Synopsis

An energy efficiency monitoring programme was carried out from 1984 to 1986 by the South London Consortium Energy Group, United Kingdom Department of Energy, with assistance from British Gas, Watson House, as part of a demonstration project funded by the United Kingdom Department of Energy, the EEC and SLC Energy Group. 18 occupied low energy houses were thoroughly instrumented in order to monitor energy usage and occupant behaviour. Data collected included temperatues in each room of the house, window usage determined from microswitches on every openable window, individual energy consumptions for heating, hot water, cooking and electrical appliances, and detailed weather monitoring. Humidity measurements and ventilation tests were also performed.

Data was stored as hourly averages of 2-second readings over the entire monitoring period. This enables a comparison to be made between window opening patterns of occupants recorded on daily, weekly and seasonal timescales. These window opening patterns are discussed with respect to the levels of occupancy, building energy consumption, occupant activity, comfort, perceived need for ventilation, and external weather conditions.

The discussion of these preliminary results leads to a critical assessment of the installed warm air heating and supply ventilating system, and the differing reactions of some occupants to energy conservation and air quality.

Suggestions are made concerning changes in system design to maximise the air quality within the building whilst minimising ventilation heat losses for differing levels of occupancy.

The data collected reinforces the established criteria for window opening behaviour. The detailed level of data collected should, on more thorough analysis, provide a further contribution to these criteria, as indicated in the text.

Introduction

The energy efficiency monitoring of 18 low energy houses by the SLC Energy Group was designed to record the performance of the house design with respect to occupant behaviour. The logging of window opening times was an integral part of this exercise. The amounts of data produced as hourly summaries over a period of greater than 18 months provides a level of detail which will take a considerable time to analyse fully. This paper looks at the overall trends in window opening behaviour with respect to current knowledge on the subject, and includes examples of more detailed data, which will no doubt produce further information in the future. This information is used to consider the occupants' perception of the quality of air in the dwelling, and how that perception is likely to be influenced by modifications to the ventilation system. Future analysis will look at the energy implications of the opening data and how the energy losses are affected by mechanical ventilation systems. This is the ultimate objective of this work.

Previous work by DICK, BRUNDRETT et al,[1,2,3] has related domestic window opening behaviour to prevailing weather conditions and social grouping, which is well reinforced by other researchers. More recently, the window opening behaviour patterns and reasons behind the specific behaviour of the occupants is attracting more attention. This is important because if energy savings are to be made by reducing occupant window opening with mechanical ventilation systems, the reasons behind existing behaviour need to be investigated (MEUNIER et al [4]). Such work has already been started, and preliminary results from instrumentation of a large block of naturally ventilated flats have been analysed (PHAFF et al [5]).

These detailed analyses are required because although window opening correlates closely with prevailing weather conditions, the reasons behind the frequency of window opening is likely to be a balance between the external weather conditions and the perceived need for ventilation of the occupants.

The SLC/British Gas study was carried out in 18 low energy houses with warm air heating systems providing partial ventilation during the heating season. Comparison of window opening behaviour in these houses with different building types should result in the identification of the motives and range of responses to those stimulae that are the source of motivation for occupants changing their requirements for ventilation.

The Test Houses

The 18 test houses are energy-efficient 3-bedroom designs with a high level of evenly distributed insulation. They are built in three North-South oriented terraces to maximise solar gain to the living rooms and solar panels. Double glazing and draught-stripping is used throughout, and a draught lobby is included for both the front and rear doors. The warm air heating system is designed to give even house temperatures, redistributing solar gains throughout the house by recirculating air. A fresh air supply to the heating system is provided from a loft air intake, giving about 0.5 air changes per hour. There are no return air paths from the kitchen or bathroom, ventilators in these rooms providing an exit for stale air. Floor plans of the houses are shown in Figure 1, together with a list of the energy saving features of the design.

The logging system consists of microprocessors in each house taking two second readings of all the parameters in the house, from which they produce hourly averages when interrogated by a central computer. The measurements taken in each house are as follows:

(i) 7 room temperatures
(ii) central heating "on" time
(iii) gas consumption (cooking, heating and hot water)
(iv) electricity consumption
(v) window opening times (microswitches on all 10 openable windows)

In addition, weather data is collected including:

(i) air temperature
(ii) ground temperature
(iii) solar gain
(iv) wind speed
(v) wind direction
(vi) relative humidity

Close contact is kept with the occupants of the houses, and their reactions are informally monitored. A questionnaire regarding window opening attitudes will be circulated when monitoring has ceased, to avoid any influence on window opening behaviour patterns.

The infiltration rates of the houses were measured, and are shown in Figure 2. When the heating system is on, this gives typical ventilation rates of 0.8 air changes per hour. (ETHERIDGE)

Window Opening Patterns

This preliminary study reviews the annual window opening characteristics of the houses on a monthly basis, and compares the simple statistical correlations with those of Brundrett [2]. The window opening data for individual houses is then reviewed and examples of obviously different bahaviour of different occupants is looked at in more detail. These behavioural examples are then looked at from weekly intervals over a three month period, and some are further looked at using daily data. More detailed investigation including detailed statistical analysis will be reported at a later date when a thorough computer analysis of the large amount of available data is completed

Mean Annual Window Opening Patterns

Figure 3 shows the mean window opening hours per month for all 18 houses plotted over an 18 month period. Also plotted are mean ambient temperature, solar gain, relative humidity and energy consumption for all the houses. The correlation coefficients between window opening, ambient temperature, solar gain and mean house energy consumptions are all relatively good, as would be expected from previous work. The correlation coefficient and regression equations are as follows:

TABLE 1

VARIABLES	CORRELATION COEFFICIENT	REGRESSION EQUATION
Window opening (hrs) vs ambient air temperature (°C)	0.90	HRS=-120+63x°C
Window opening (hrs) vs monthly solar gain (MWm^{-2})	0.84	HRS=0.96+0.26 MWm^{-2}
Ambient air temperature (°C) vs mean energy consumption (kWh)	-0.97	kWh=2475-106x°C
Window opening (hrs) vs mean energy consumption (kWh	-0.84	HRS=1282-0.54kWh

Individual House Annual Window Opening Patterns

Figure 4 shows a selection of the mean annual window opening patterns for some chosen individual houses. These particular curves have been chosen to show the large range of window opening activity between different houses over the logging period.

House number 28 only has any significant window opening in the lounge alone during the summer of 1984 (the hottest Summer in England for many years). The only other window opening in House 28 was in the bathroom in Winter - this never exceeded 2 hours total per month. At the other extreme, house 18 used all its openable windows extensively, many of the windows staying open virtually all the time outside the heating season. The exceptions were the lounge, kitchen and bathroom windows. The lounge window was only opened in the peak of summer, and the bathroom window was used extensively during the heating season and particularly in Spring and Autumn. The kitchen window was used to a variable extent throughout the year, with little use in winter months.

Between these two extremes lie a large range of window opening behaviour, with many patterns which deviate significantly from the trend which correlates well with ambient temperature. For example, the peaks are indicated on the graphs for houses 19 and 25. These examples are looked at in more detail in the next section.

Individual Window Opening Patterns for Chosen Houses

Figures 5 to 8 show the relative window open times for each room in some chosen houses in order to show the variation in window opening behaviour during the 18 month period considered. Also shown on these graphs are the houses' energy usage on a monthly basis, for comparison.

Figure 5 shows the pattern of house 18, which used all the openable windows extensively. The general trend follows external temperatures well, but there are several notable features throughout the seasons. The warm summer of 1984 encouraged all the bedrooms to have at least one window open for greater than 50% of the time.

It is expected that analysis of daily window opening patterns would reveal overnight opening to cool bedrooms at night. Then the window opening generally decreases with the approach of the heating season, with the exception of the bathroom window, which peaks in the intermediate seasons, probably due to the low heating on times and higher ambient atmospheric water vapour levels causing increased condensation. The highest levels of window opening in the winter are in the bedrooms and bathroom, most likely stimulated by occupants perception of air quality.

Figure 6 shows the window opening pattern for house 28. This house had a very low energy consumption throughout the year, and associated low average internal house temperatures of down to 10°C in winter. The heating system was not used, and casual gains from cooking and other electrical appliance operation was the only source of heating, averaging 400 kWh per month - equivalent to the other houses' casual gains. The only significant window opening was in the lounge and one bedroom during summer 1984. A small amount of bathroom window opening occurred in the spring of 1985.

Figure 7 shows that the pattern of window opening in house 19 is dominated by bathroom window opening between the heating seasons, when the heating system was not on. This either demonstrates the householders' reluctance to open windows in the winter, or it may be a reflection that the supply mechanical ventilation combined with the heating system provides adequate ventilation for the bathroom in winter and spring seasons.

Figure 8 shows the inconsistant window opening patterns of house 25. The windows in the kitchen and bedroom 2 follow a predictable seasonal pattern, but bedrooms 1 and 2 and the bathroom are inconsistant. These radical changes in behaviour during the year may be due to long term visitors to the house who have different window opening habits, or who stimulate a desire for increased air quality by the occupiers. Such inexplicable peaks occur in several of the monitored houses, and fall into no identifiable pattern.

House number 33 is worthy of comment, as the bathroom window is opened to a similar level all year round, averaging 3 hours per day, apparently independant of weather conditions and other stimulae.

Window Opening - Autumn 1985

Figure 9 shows the 18 house weekly mean window opening hours and prevailing weather conditions for autumn 1985. The window opening reduces consistantly with temperature, apart from week 5, where the wind speed increased substantially, although the mean temperature rose 1.5°C. For three weeks in November, the mean temperature was below 4°C, relatively cold for the time of year. The next three weeks in December were mild, about 10°C, but window opening did not follow this temperature increase, even though ventilation supplied by the heating system reduced. Perhaps the cold period in November had provoked the belief that winter had begun, and occupiers were reluctant to increase window opening behaviour as a result of this expectation.

However, the occupants of house 27, whose window opening behaviour correlates closely with ambient temperature throughout the 18 month period monitored, appeared to respond to the increase of temperature with an increase in bathroom window opening (See Figures 10 and 11).

Daily Window Opening Patterns

Presented in this section are some patterns of window opening on a daily basis. These are presented as examples which show how the window opening behaviour and energy consumptions can be linked to occupant activity. Examples only are presented because the vast amount of data available will require extensive computer analysis before detailed results are obtainable. (Approximately 10,000 daily behaviour pattern graphs are available.) Variations in these daily patterns are expected to correlate with family size and activity (BRUNDRETT[2]).

Figure 12 shows some 24-hour window opening patterns for house 27. Figure 12a shows the central heating system fire for an extended period prior to the bathroom window being opened and a peak in electrical consumption. This pattern is typical of washing activity, the central heating providing the hot water for bathing, the electricity consumption rising for a supplementary bathroom heater or hair dryer, and the bathroom window opened in the mild March weather to encourage moisture removal.

Figure 12b shows the kitchen window opening after the start of a peak in electricity consumption (2.5 kW) at 1300 on a mild Sunday. Kitchen window opening continued through the evening with lower peaks in electricity consumption of 1 kW. In Figure 12c on a cold February day, kitchen and bathroom window opening coincides with electricity consumption peaks of up to 4 kW, and also long central heating on times indicating near simultaneous cooking and bathing, although a 2 kW electrical peak results in no window opening later that day.

Summary of Preliminary Results for Chosen Houses

Several characteristics of window opening behaviour have been described, together with probably stimulae for the behaviour. The four main stimulae appear to be energy conservation, perception of air quality, moisture dispersal and cooling in Summer. Some of the houses' occupants behaviour patterns can be categorised according to their apparent primary concern. This, of course, alters with the seasons. Table 2 shows the correlation and regression equations for external temperature with respect to window opening and energy consumption of some individual houses.

House number 18 had the highest frequency of open windows with 1100 window open hours per month on average. All windows were used and the opening patterns follow seasonal variations in temperature, apart from the interseasonal bathroom window opening. The regression equation suggests a linear increase of 114 hours window opening per °C abgove 2°C per month. In practice, a linear curve fit is not an accurate reflection of behaviour, as different stimuli for window opening are likely to be relevant in different temperature ranges (BRUNDRETT [2]). It does, however, give an impression of the sensitivity of the householders behaviour to external temperature.

House 25 also used windows extensively. This, and the high mean indoor temperature, probably represents the highest ventilation heat loss through the windows for the dwellings monitored. This house has a very irregular pattern of annual window opening behaviour, as already described, with isolated peaks of window opening in guest bedrooms and the bathroom. The energy implications of this behaviour will be reported in future work.

Houses 19 and 33 have a relatively low frequency of window opening. The correlations with temperature are low, and their regression lines have low gradients. This implies, along with their lower energy consumptions, that the window opening in these houses is less temperature dependant. Windows will tend to be closed unless there is a specific need for them to be open. In both houses, the bathroom window is the most frequently opened. The occupants may well be more concerned with condensation than the degree of freshness of the air in the house. (House 19 also appears to have minimal window opening habits at ambient temperatures below a threshold temperature of 10°C -see Figure 13).

The mean level of window opening is lower than that measured by Brundrett [2,3] and the sensitivity to temperature is also lower. This is to be expected as partial mechnical ventilation is supplied to the test houses. Care will be required on more detailed analysis because of the non-continuos nature of Brundrett's data.

Conclusions

From a combination of annual, seasonal and daily window opening patterns, many types of behaviour pattern have been observed. Some of these patterns can be associated with responses to different stimuli such as energy conservation, perception of air quality, moisture dispersal and thermal comfort. The following list of characteristics have associated with them the identification numbers of the houses whose window openings appear to be influenced by them.

1) Nearly all the houses opened windows in the height of summer for cooling, particularly in bedrooms overnight.

2) Large inconsistancies of window opening pattern occurs in some bedrooms (assumed to be guest bedrooms)(e.g. houses 25, 28, 33). These have associated peaks in bathrooms in some houses.

3) Some houses close all windows through winter (e.g.house 19)

4) Some houses reach a minimum window opening level in winter, which can be associated with a threshold temperature. (e.g. houses 18, 20, 25, 27, 33)

5) Some houses have high levels of window opening in intermediate seasons, particularly in bathrooms. (e.g. house 18)

6) Lower levels of window opening than previous work [1,2,3] were encountered which is possibly due to the partial mechanical ventilation supply system in the houses monitored.

The data produces good correlations between external temperature, energy use and window opening frequency, as expected from previous work, but more detailed analysis is required of the conditions under which different stimuli result in window opening for different inhabitants.
A more detailed analysis of the energy consumptions associated with the window opening behaviour will be done in the future. This work will have to take into account the fact that in common with most surveys the extent of window opening was not measured.

The supply ventilation provided by the heating system was not adequate all year round for most of the households. The variations in window opening may correlate with the size and ages of the families living in the houses. (A questionnair should resolve this question at a later date.) It appeared that The ventilation provided by the heating system in the intermediate seasons was not capable of fully controlling bathroom humidity/condensation. In winter, the reduction in bathroom window opening may be due to occupants not tolerating draughts, or the heating system providing adequate ventilation through higher supply flow rates of ambient air with lower water contents. Ventilation for bathrooms in intermediate seasons would probably result from supply ventilation being provided through the heating system whenever the time clock is "on", rather than whenever the room thermostat calls for heat.

Acknowledgements

We wish to acknowledge the cooperation of British Gas and SLC Energy Consortium for permission to present this paper at the 7th AIC Conference.

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TABLE 2 : PRELIMINARY STATISTICS FOR CHOSEN HOUSES

HOUSE NUMBER	MEAN INDOOR TEMPERATURE °C	MEAN MONTHLY ENERGY CONSUMPTION (kWh)	CORRELATION COEFFICIENT	REGRESSION EQUATION (kWh = a + b x Ta)	MONTHLY MEAN HOURS WINDOW OPEN (hrs)	CORRELATION COEFFICIENT	REGRESSION EQUATION (hrs = a + b x Ta)
18	19.6	FULL 18 MONTH DATA NOT AVAILABLE			1100	0.87	-203 + 114 Ta °C
19	19.6	1163	-0.85	2003 - 73 Ta °C	205	0.63	-159 + 32 Ta °C
25	22.5	1442	-0.91	2674 - 107 Ta °C	830	0.91	-142 + 85 Ta °C
33	19.4	862	-0.94	1714 - 74 Ta °C	298	0.61	6 + 25 Ta °C
34	21.4	1685	0.96	3562 - 164 Ta °C	492	0.88	-461 + 83 Ta °C
MEAN OF ALL 18 HOUSES +	-	-	0.97	2475 - 106 Ta °C	-	0.90	-120 + 63 Ta °C *

Ta is Ambient Temperature.

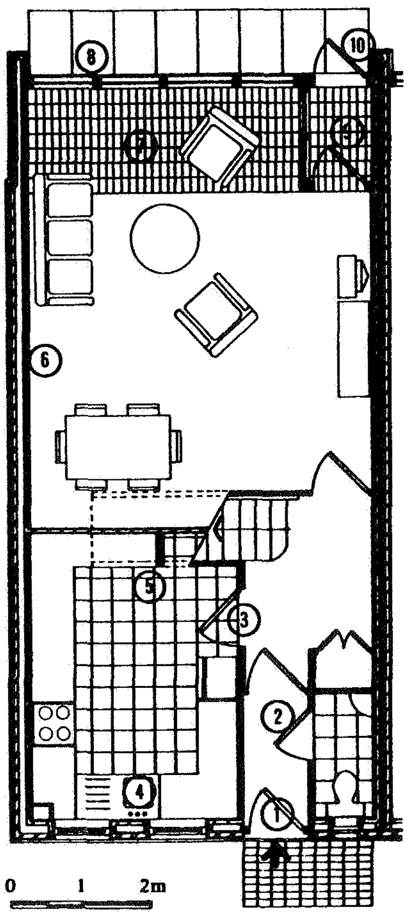
* This compares with Brundretts [2] of - 150 + 97 Ta°C.

\+ Mean includes night-time window opening which is a significant proportion of total not included by Brandrett [2].

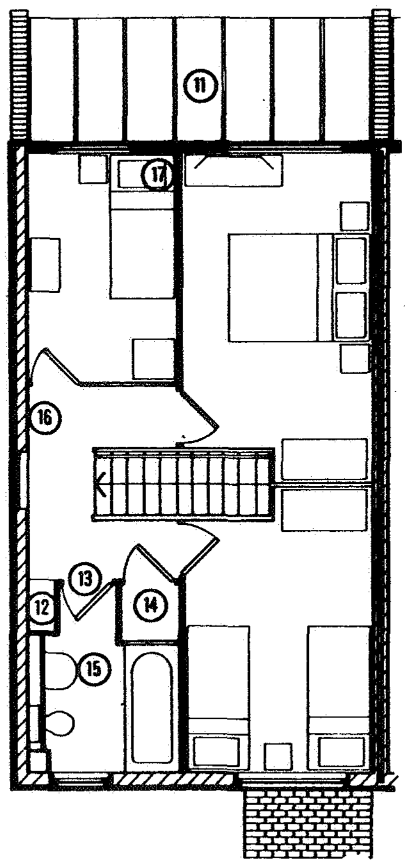
Fig.1 FEATURES OF THE DESIGN

Features of the Energy Saving Design which can be identified within the Demonstration House – 6 Colvin Close, 68-72 Lawrie Park Road, London SE26.

1. Draught-stripped front door.
2. Draught lobby.
3. Draught-stripped kitchen door to reduce water vapour entering rest of the house.
4. Three taps on sink – tap with yellow top supplies solar heated water.
5. Warm air outlet.
6. External wall-cavity insulation plus Thermalboard dry-lining.
7. Passive solar gain here. Some heat stored in floor and wall and released later. This area could be turned into Conservatory by addition of internal wall.
8. Draught-stripped windows. Double glazing.
9. Rear draught lobby.
10. Draught-stripped back door.
11. (View from outside or above.) Solar panels for water heating. Solar heated water stored in cylinder in roof space.
12. Warm Air Heating/Ventilation unit. Takes in fresh air, mixes with recirculated air, heats and distributes through ducts.
13. Draught-stripped bathroom door to reduce water vapour entering rest of the house.
14. Gas water heater. Fed from Solar cylinder so as to reduce amount of gas required to achieve required temperature.
15. Three taps on bath and washbasin. Taps with yellow tops provide solar-heated water.
16. External wall-insulating blockwork with Thermalboard inside and cladding externally.
17. External wall-insulated timber frame, cladding externally.



GROUND FLOOR



FIRST FLOOR

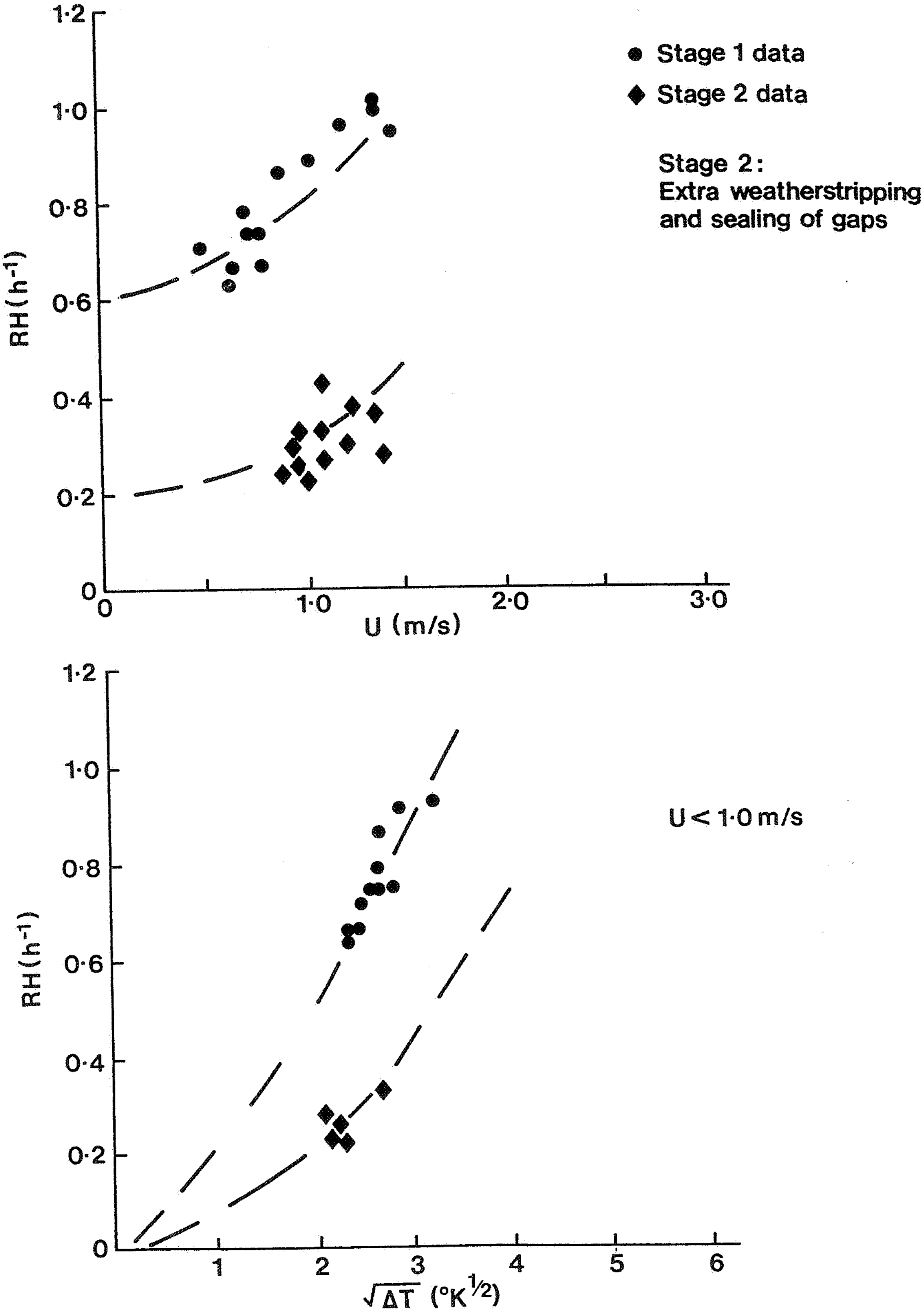


Fig. 2 VENTILATION RATES-PRELIMINARY DATA (VENTS CLOSED)

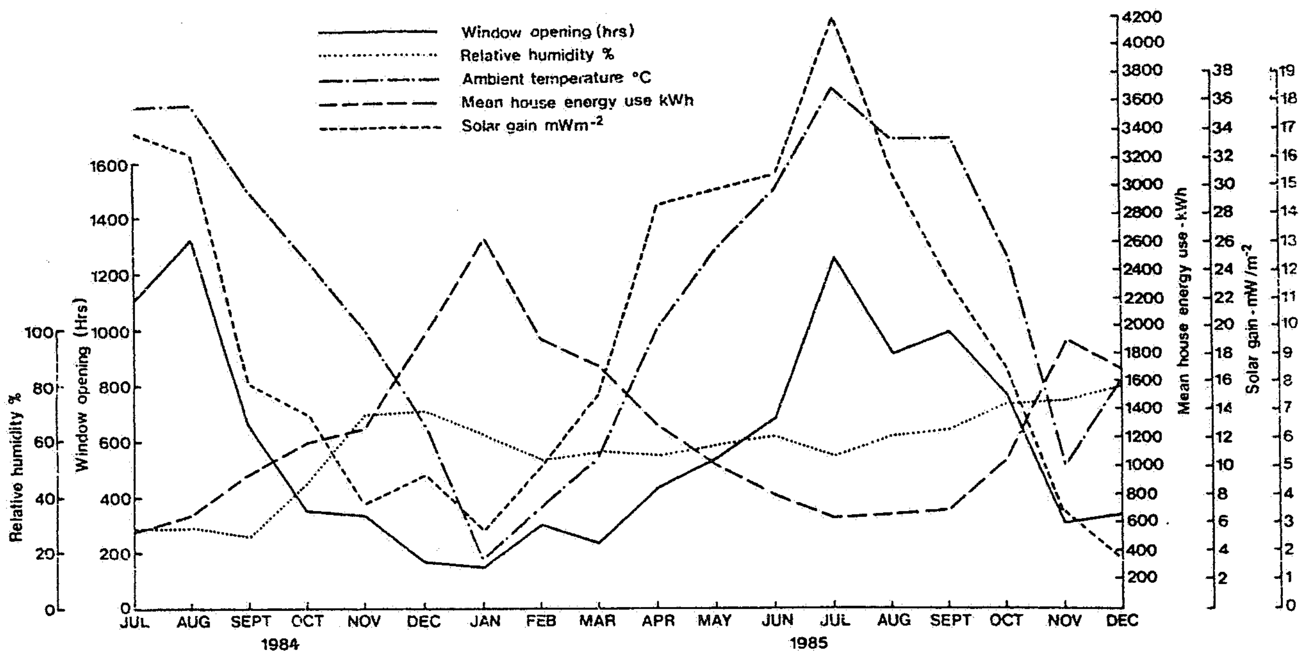


Fig.3 MEAN MONTHLY WINDOW OPENING TIME 1984/5 COMPARISON WITH AMBIENT TEMPERATURE, SOLAR GAIN, RELATIVE HUMIDITY AND MEAN ENERGY USE

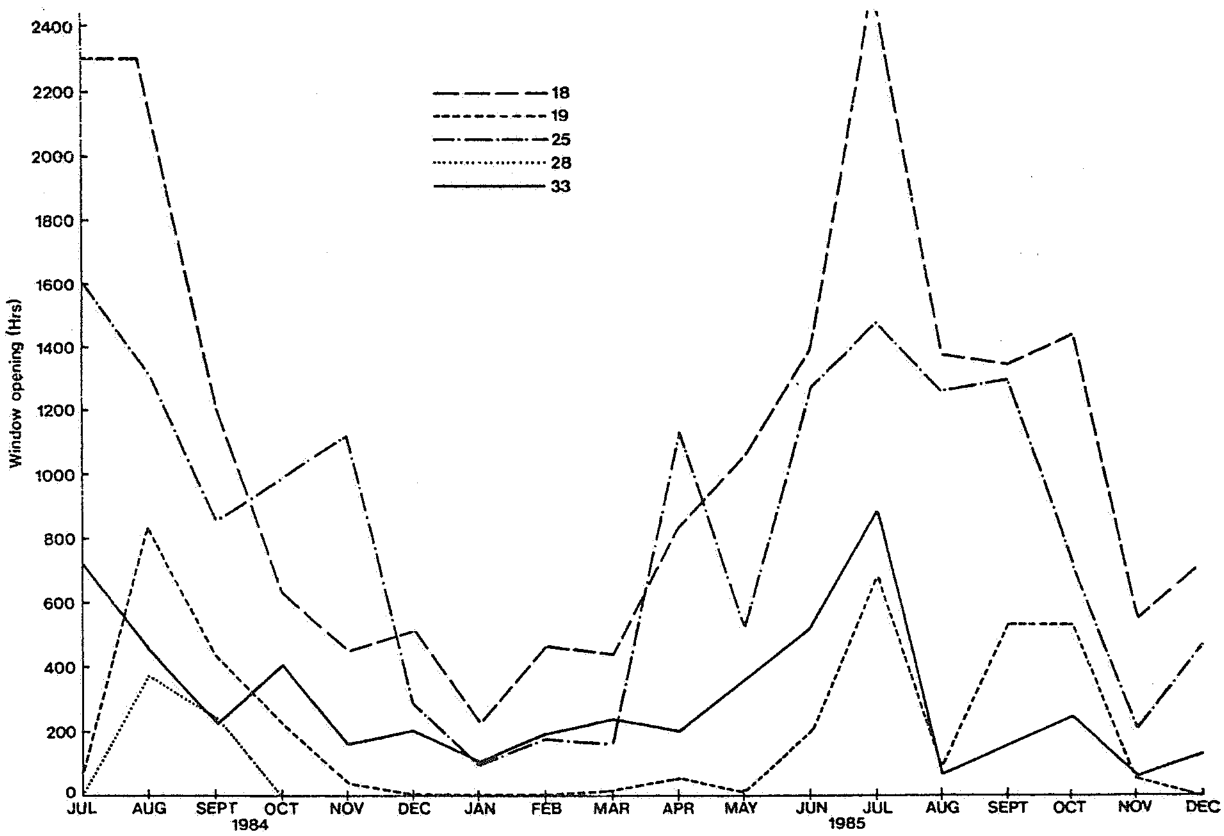


FIG.4 MEAN MONTHLY WINDOW OPENING - INDIVIDUAL HOUSES

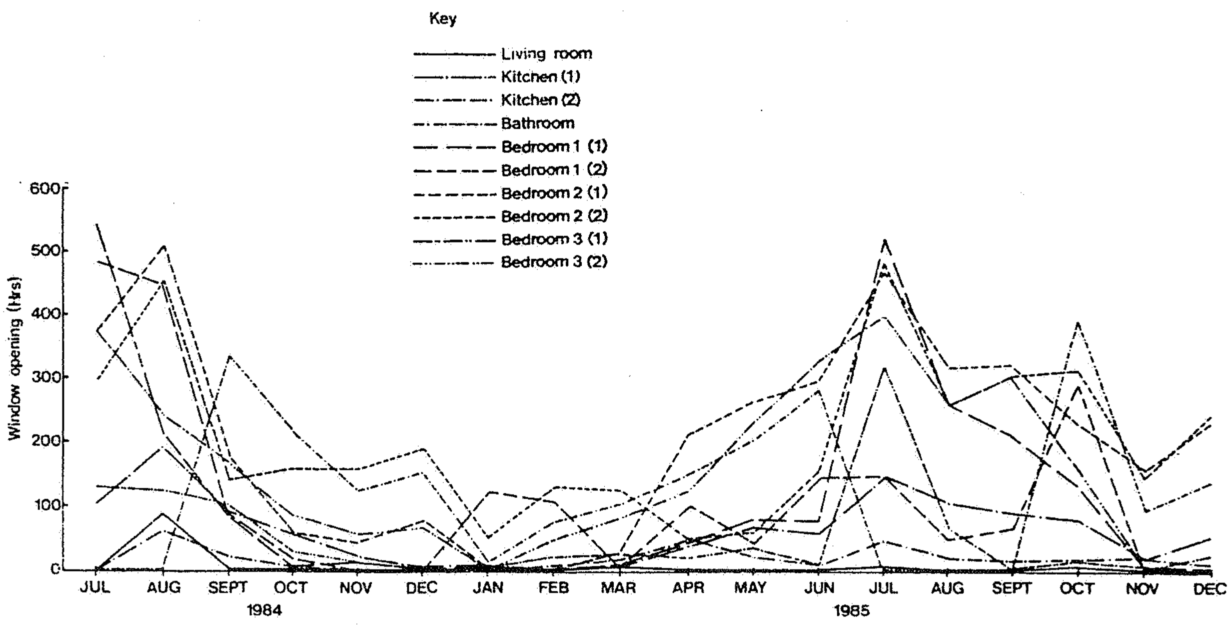


FIG. 5 INDIVIDUAL WINDOW OPENING PATTERNS FOR HOUSE 18

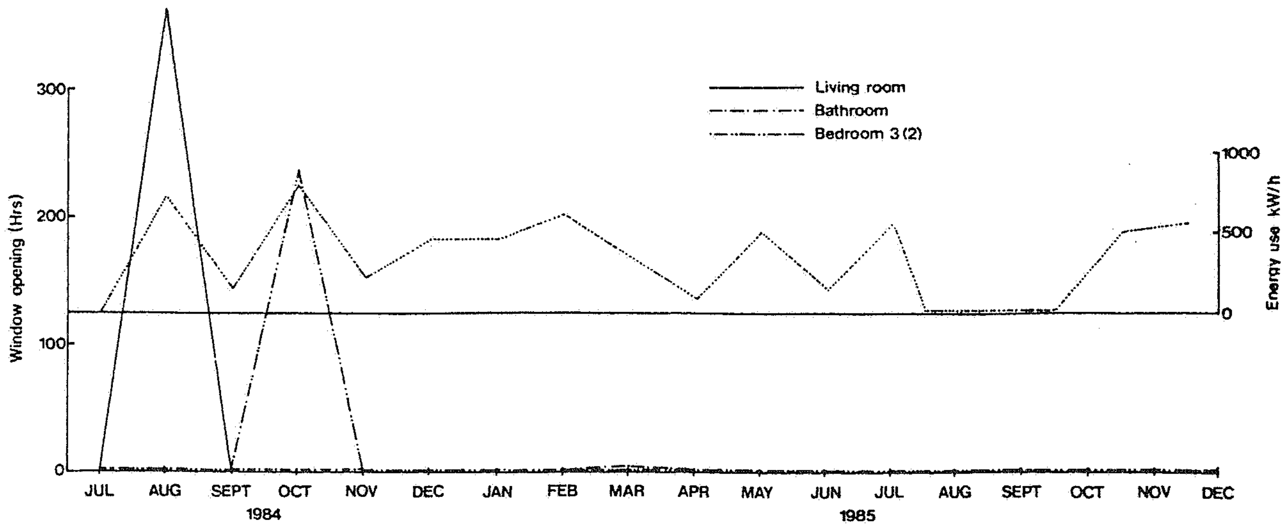


FIG. 6 INDIVIDUAL WINDOW OPENING PATTERNS FOR HOUSE 28

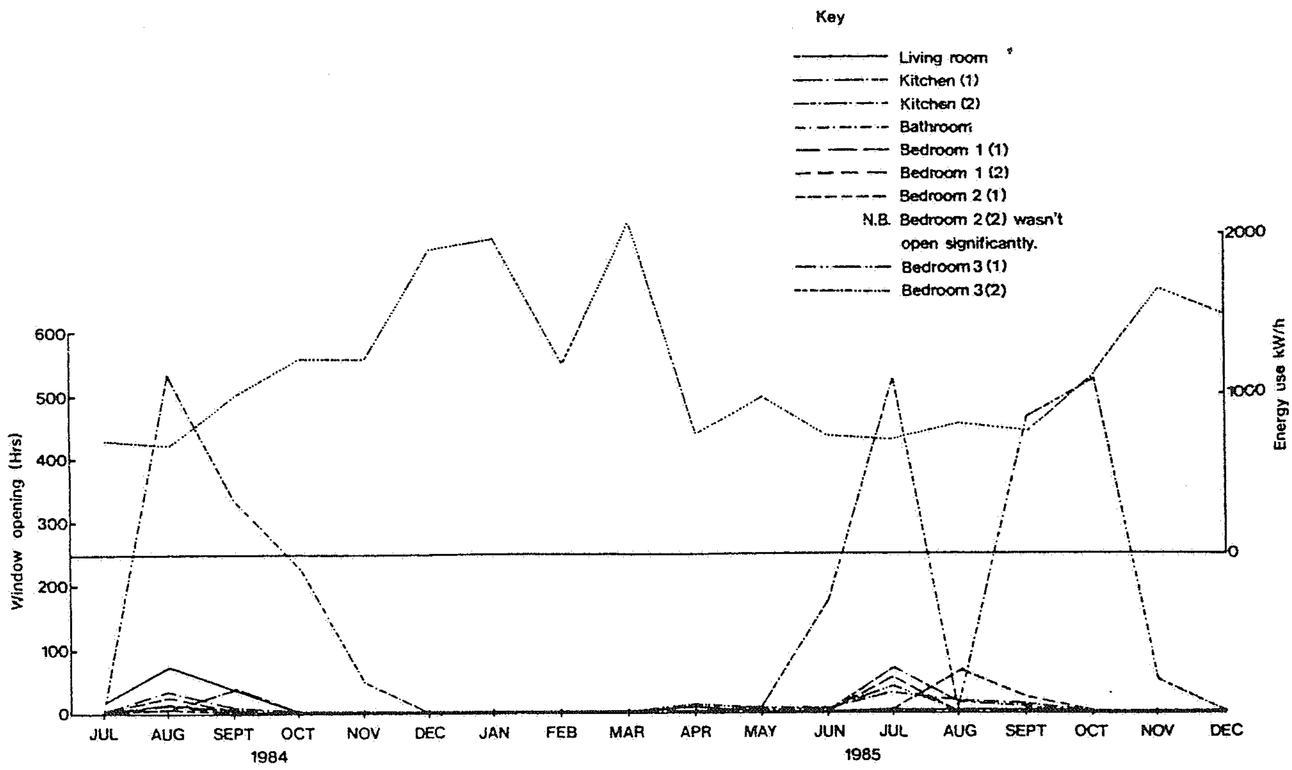


FIG. 7 INDIVIDUAL WINDOW OPENING PATTERNS FOR HOUSE 19

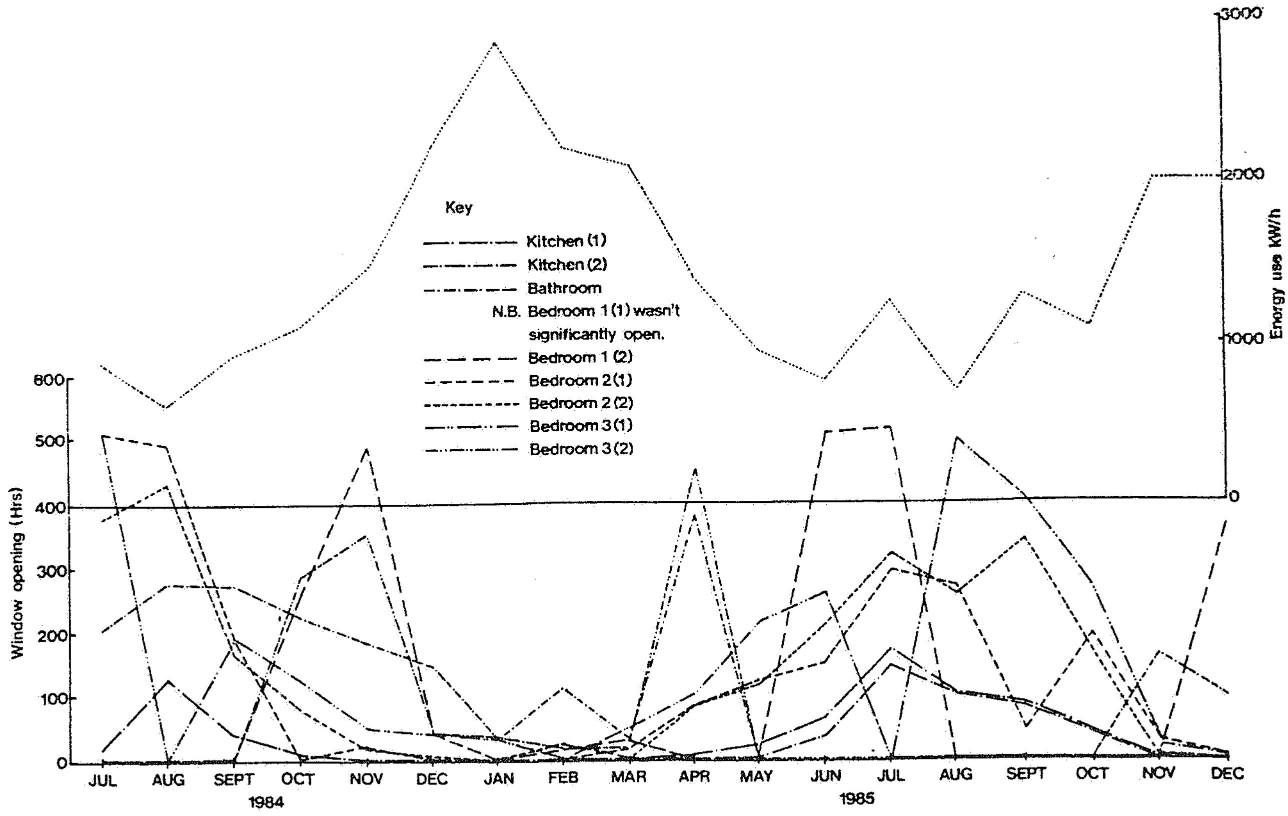


FIG. 8 INDIVIDUAL WINDOW OPENING PATTERNS FOR 25

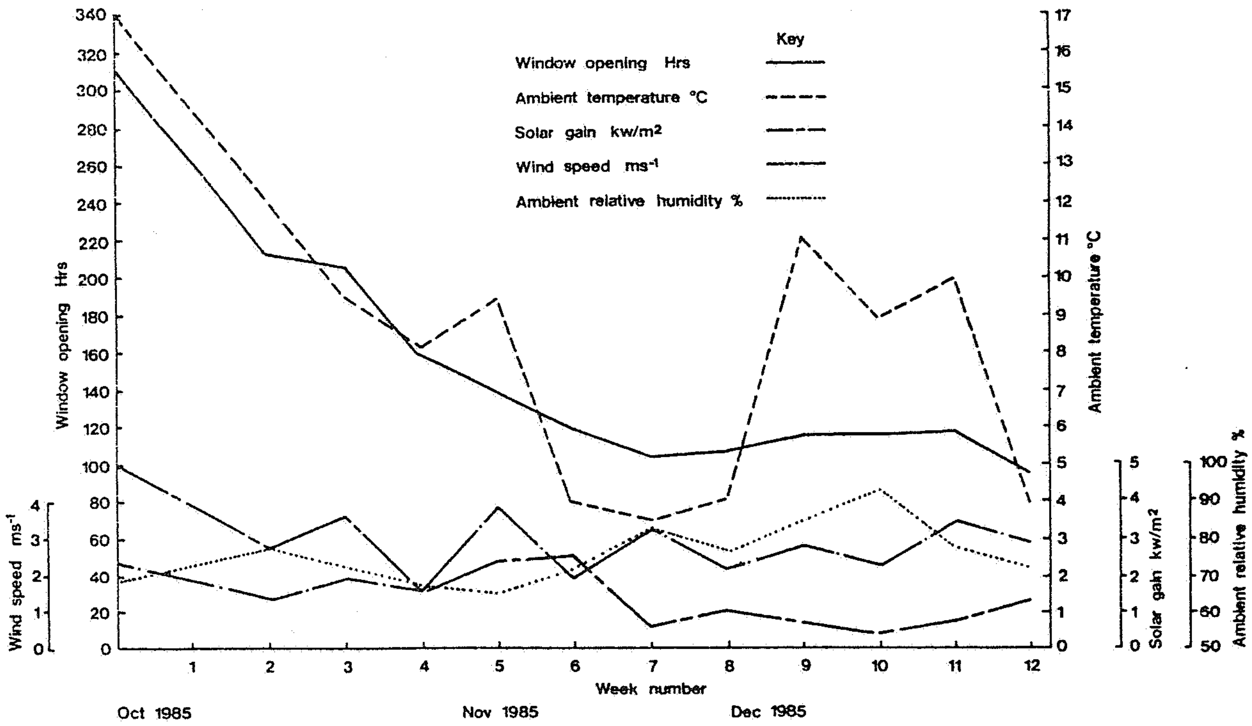


FIG. 9. MEAN AUTUMN WINDOW OPENING 1985 COMPARED WITH AMBIENT TEMPERATURE, RELATIVE HUMIDITY, SOLAR GAIN & WIND SPEED

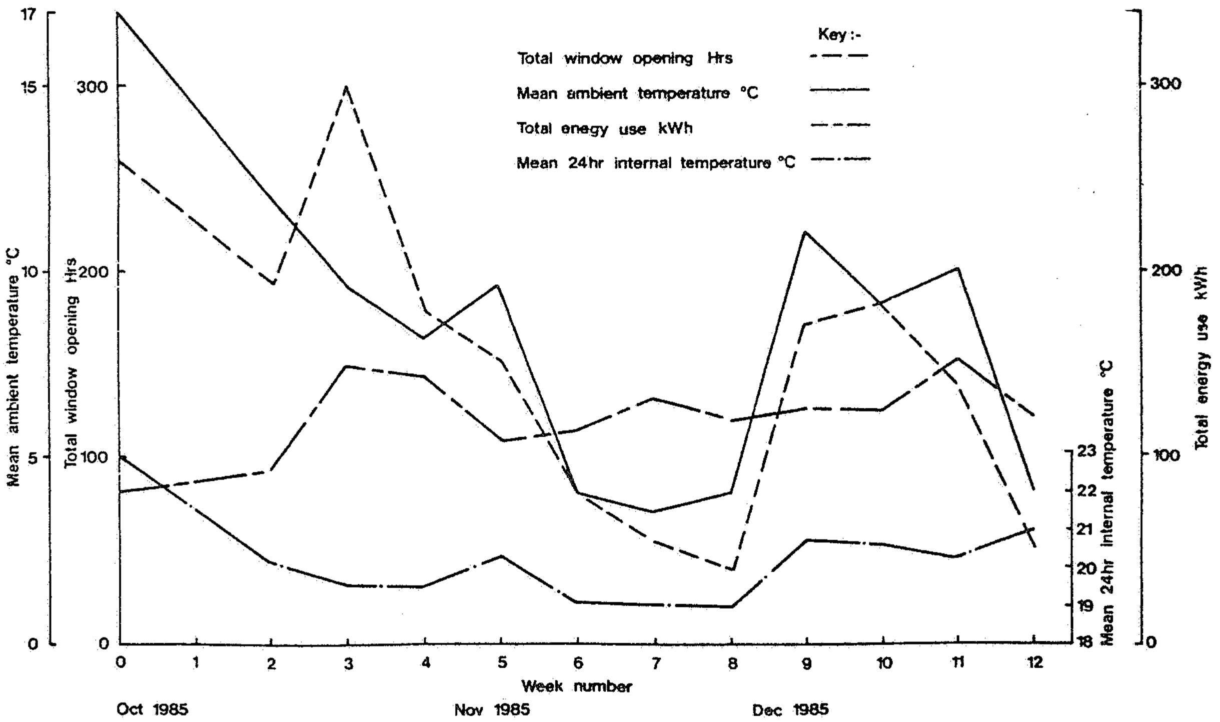


FIG. 10. AUTUMN WINDOW OPENING IN HOUSE 27

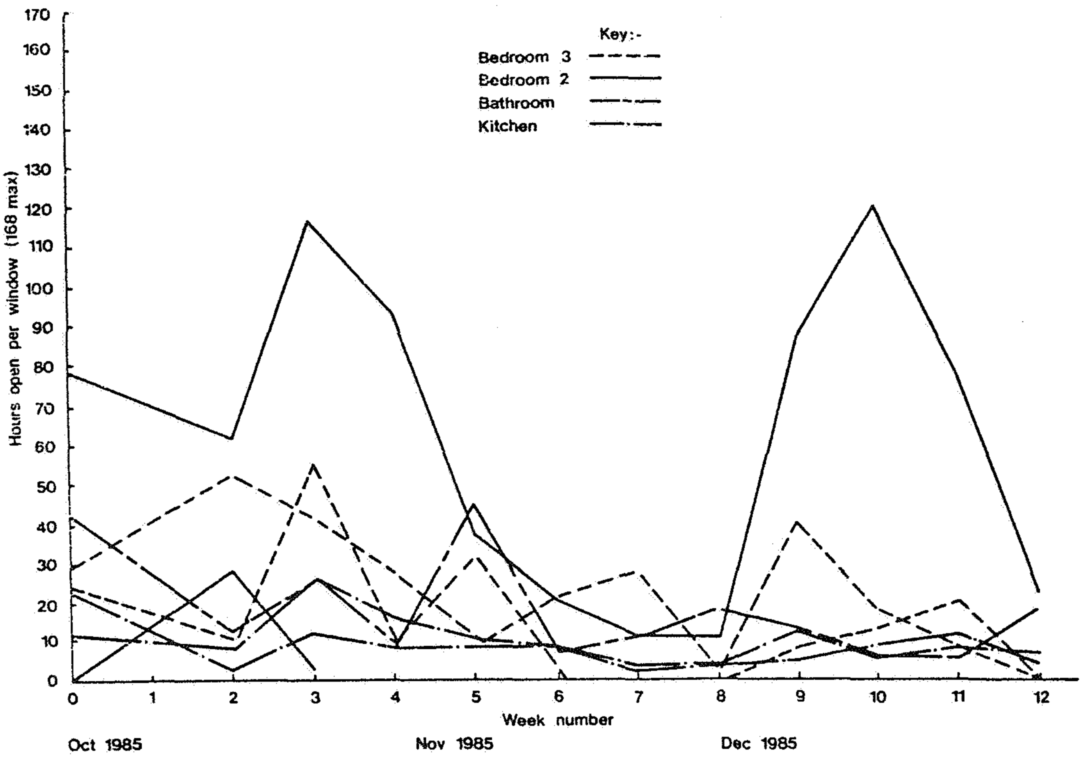


FIG. 11. INDIVIDUAL WINDOW OPENING PATTERN FOR HOUSE 27 (AUTUMN 1985)

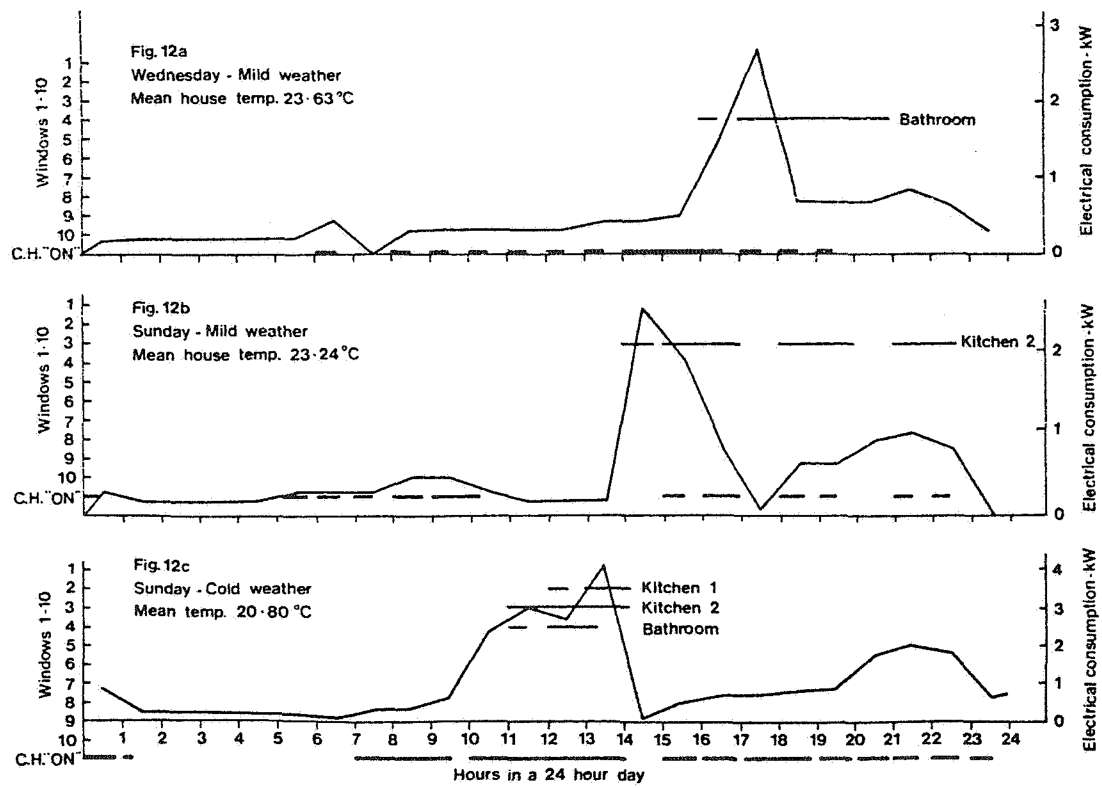


Fig.12 DAILY WINDOW OPENING PATTERNS - HOUSE 27